PETROLEUM:

ITS HISTORY, ORIGIN, OCCURRENCE, PRODUCTION, PHYSICAL
AND CHEMICAL CONSTITUTION, TECHNOLOGY,
EXAMINATION AND USES;

TOGETHER WITH THE

OCCURRENCE AND USES OF NATURAL GAS.

EDITED CHIEFLY FROM THE GERMAN OF

PROF. HANS HOEFER AND DR. ALEXANDER VEITH,

BY

WILLIAM T. BRANNT,

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ILLUSTRATED BY THREE PLATES, [illegible]
ENGRAVINGS.

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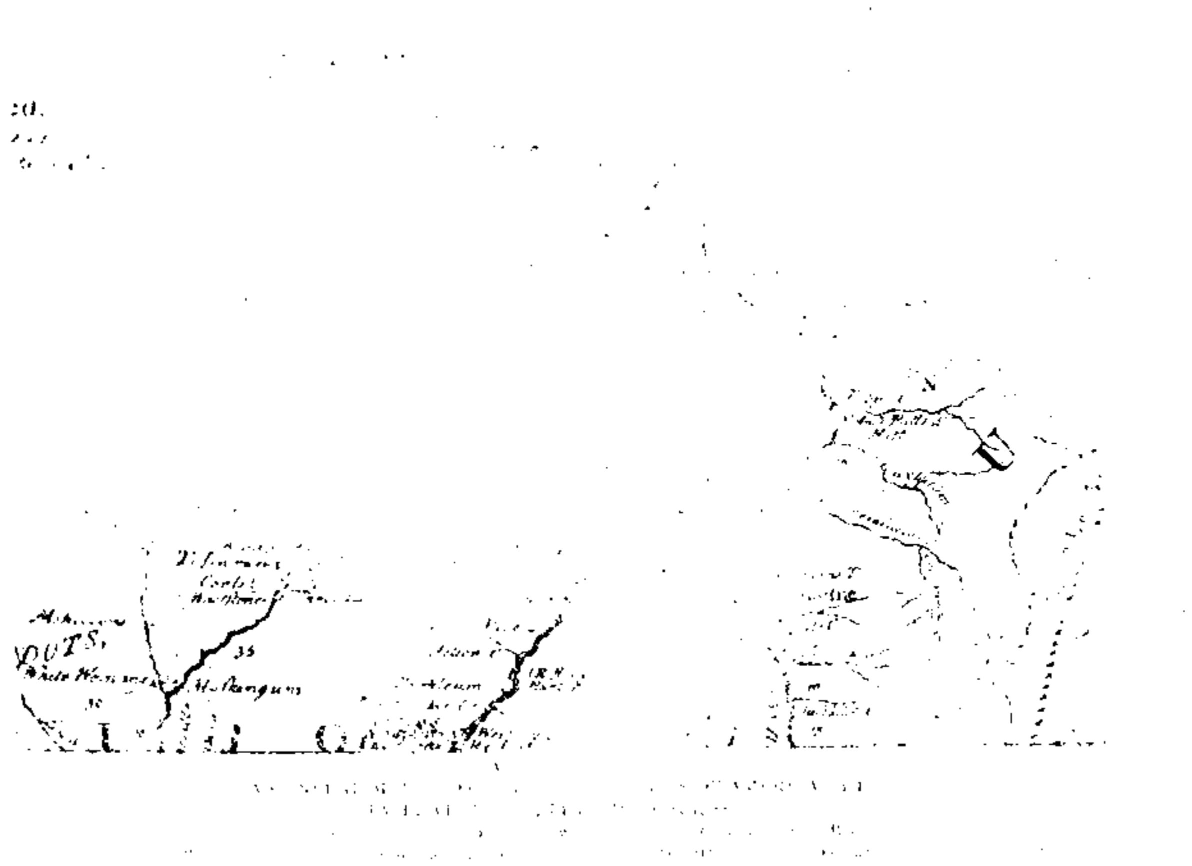
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PROF. HANS HOEFER AND DR. ALEXANDER VEITH,

BY

WILLIAM T. BRANNT.

AUTHOR OF "A PRACTICAL TREATISE ON ANIMAL AND VEGETABLE FATS AND OILS."

ILLUSTRATED BY THREE PLATES AND TWO HUNDRED AND EIGHTY-FOUR ENGRAVINGS.

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PREFACE.

THE purport and scope of the following work are essentially what its title implies. In submitting it to the public it is hardly necessary to enlarge upon the vast importance of the Petroleum Industry of the present day, and it only remains to offer a few observations upon the materials of which the book is composed.

"If we acquire eminence," says Tissot, in the preface to his Essay on Diseases incident to Literary and Sedentary Persons, "by publishing new truths, so, on the other hand, we make ourselves useful by collecting those which are known for the benefit of the persons to whom they are necessary; and surely one is as good as the other."

To make himself useful—to bring together into one comprehensive volume the many valuable researches upon Petroleum scattered through so many publications—has been the aim of the editor in compiling this volume, and for that purpose he has gathered materials from all available sources. It has been a laborious task, and in writing the preface—the portion of a book which the reader as a rule first notices, but which is generally the last written—the editor confesses to a feeling of satisfaction that his work is about accomplished.

The present treatise is mainly based upon the admirable German works, "Das Erdoel (Petroleum) und seine Verwandten," von Prof. Hans Hoefer, and "Das Erdoel (Petroleum) und seine Verarbeitung," von Dr. Alexander Veith. These books have been used with the permission of the authors as well as of the publishers. Both authors are widely and favorably known in the United States, as well as in England, and the recorded researches and experiences of such men must, in the estimation of all educated persons, have value, and cannot fail to be especially welcome to that class of readers who are professionally engaged in this great and growing industry.

Regarding the additions made by the editor, his acknowledgments are due to the "Report on Petroleum," by S. F. Peckham; "A Practical Treatise on Petroleum," by Benjamin J. Crew; Report of the Bureau of Statistics of Pennsylvania, 1892; "A Text-Book of Gas, Oil and Air Engines," by Bryan Donkin; "Liquid Fuel," by E. A. Brayley Hodgetts, and to numerous American and foreign journals and Transactions of Societies, for which due credit has been given whenever possible.

In conclusion, the editor desires to express his thanks to the publishers who, by supplying him with books and journals, and by the lively interest they have taken in the work, have greatly facilitated his labors. As is their general custom, they have caused the volume to be supplied with a copious table of contents, as well as a very full analytical index, which will render reference to any subject in the book prompt and easy.

W. T. B.

PHILADELPHIA, *November 14, 1894.*

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PETROLEUM:

ITS ORIGIN, OCCURRENCE, PRODUCTION AND TECHNOLOGY.

CHAPTER I.

INTRODUCTION.

History of Petroleum—History of the Petroleum Industry in the United States, Galicia, Roumania, Russia, and other Countries.

WITHIN the memory of comparatively young men, petroleum, from being a medicinal curiosity, has advanced to be an almost indispensable article of consumption; and from a few barrels, which, in 1859, were collected by slow and painful processes, the annual production has increased to many millions of barrels, and is still increasing. It may safely be said that no other branch of commerce has ever in so short a time attained such enormous proportions. Forty years ago the value of petroleum was unrecognized, and the vast sources from which it was to be derived, although separated from us only by a thin crust of rock and soil, were unsuspected. With careless and unsuspecting feet we traveled over hidden treasures more valuable and wonderful than the gold mines of California. Now the extraction, refining and transportation of petroleum forms a branch of industry involving the employment of vast amounts of capital and thousands of busy hands. Inventive brains have been set at work and stimulated to contrive appropriate ratus for furnishing by it the most economical and be light. Ships rendered no longer necessary for chasin whale by the introduction of an oil cheaper and more av than whale oil, have been freighted with the rival oil, an with it to the markets of the world. All this has hap since 1859.

Petroleum has been known from the earliest historic pe but was used for different purposes from to-day. The notices of it we find in the Bible, it being stated in the Se Book of the Maccabees, Chap. I., "that when the Jews led into Persia, they found pits in which the priests conc the sacred fire they required for their sacrifices." After r years their grandchildren—contemporaries of the prophet hemiah—searched for the concealed fire and found an oil w when poured upon the hot sacrificial stone, burst into a l flame. The Jews enclosed these pits, and designating t holy, applied to them the term *nephtar* or *nephtoj*—a plac expiation or forgiveness—from which the word naphtha is rived. Höfer[1] states that Herodotus (about 450 B. C.), n tions that "eight days' journey from Babylon stands a called Is, the present Hit, on a small river of the same na which discharges its stream into the Euphrates. Now river brings down with its waters many lumps of bitum which is collected and used in Babylon for building purpos Diodorus, Dio Cassius, Strabo, Plutarchus and Quintus Cur Rufus make similar statements.

Semi-fluid bitumen was used in the construction of Nine and Babylon to cement bricks and slabs of alabaster, and grand mosaic pavements and beautifully inscribed slabs us in the palaces and temples of these ancient cities, many which were of enormous size, were fastened in their places w this material. It was also used to render cisterns, and silos the preservation of grain, water-tight, and some of these stru

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[1] H. Höfer, Das Erdöl, 1888.

ures of unknown antiquity are still found intact in ancient cities of Egypt and Mesopotamia. Asphalt was much used by the Egyptians for embalming corpses, as well as for the manufacture of peculiar black vessels, and as an excellent mortar. While Greece procured its bitumen from the island of Zante, it was found in large quantities in Syria and Mesopotamia.

In 1811 Dr. Nicholas Nugent visited the West Indies, and on his return to England wrote an account of the famous pitch lake of Trinidad, near the mouth of the river Orinoco.[1] From 1820 to 1830 remarkable activity was manifested in the investigation of the nature and occurrence of bituminous substances. The Hon. George Knox read a communication to the Royal Society of Great Britain, in which he noticed the wide distribution of these substances in nature. In 1824 Reichenbach discovered paraffin in the products of the destructive distillation of wood,[2] and in the following year Gay Lussac analyzed it.[3] In 1826 the Hon. John Crawfurd was sent by the British government as ambassador to Ava, and in his journal[4] describes the petroleum wells of Rangoon, furnishing many details regarding the method of their operation and the amount of their product. Boussingault investigated the bitumen of Pechelbronn in Lower Alsace, and compared its peculiarities with those of bitumens from other localities.[5] His work on these substances became very celebrated, and gave rise, in France, to further investigations of both solid and liquid bitumens. Boussingault continued his general researches and, in 1837, published a classical paper on the subject.[6] Virlet d' Oust about the same time propounded the first theory regarding the origin of bitumens;[7] and the asphalts of the Dead Sea,[8] of Pyrmont,[9] and near Havana, Cuba,[10] were examined. Hess wrote on the products of dry distillation, and Reichenbach, in conjunction with Lau-

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[1] Trans. Geol. Soc., London (1), i, 63. [2] Phil. Magazine (2), i, 402. [3] Ann. Chim. et Pharm. (2), i, 78. [4] Journal of Embassy to the Court of Ava, 1834. [5] Constitution of Bitumen, Phil. Jour. (2), ii, 487. [6] Ann. Chim. et Pharm. (2), lxiv, 141. [7] Bull. Soc. Geol. France (1), iv, 372. [8] Journal des Savants, 1855, 596. [9] Rozet. Bull. Soc. Geol. France (1), iv, 372. [10] Taylor & Clemson, Phil. Mag., x, 161.

rent, continued his researches upon paraffin.[1] In 18 Benjamin Silliman described, in the American Jo Science, the oil spring of the Seneca Indians near Cu York.

The decade from 1840 to 1850 was remarkable for t ber of travelers who, in different parts of the world, not occurrence of bitumen, and also for several elaborate re upon the geological occurrence and chemical constituti different varieties. Travelers visited the far East, an China,[2] and gave descriptions of the Naphtha springs of the fire-worshipers of Baku, and the fire-wells of Chi this country, Percival,[5] in Connecticut, and Beck, in Ne called attention to the fact that bitumen was of frequent rence in thin veins traversing the metamorphic and e rocks of Connecticut, New York and New Jersey.

Notwithstanding its wide geological distribution, pet is obtained only in few countries to such an extent as t the basis of a flourishing industry, the United States of ica standing in the front rank in this respect. Of great i ance also are the oil regions of the Caucasus (Baku) Galicia. Considerable quantities of oil are also obtai Roumania as well as in Germany (Alsace).

The Petroleum Industry in the United States.

In the United States the commencement of the in dates from the period between 1850 and 1859, though ously contrived pits lined with roughly-hewn logs, in th producing region of Pennsylvania, indicate that long befo discovery of America by the white race, the existence o oil was known, and that it was gathered in this crude Similar pits or shafts have been found in Ohio (Mecca) a Canada. Höfer[6] attributes these pits to a prehistoric which inhabited those regions before the Indians, and poss

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[1] Jour. f. ökonom. Chemie, viii, 445. [2] Pottinger; W. Robinson: Ains
[3] Kinnier: Persia. [4] Humboldt: Asie Centrale, ii. 519; Cosmos, i, 232.
Jour. Sc. (3) xvi, 130; Am. Jour. Sc. (1) xiv, 335. [6] Das Erdoel, 1888.

a considerable degree of culture. Peckham,[1] however, states that the curbed pits on Oil creek, Pithole creek and other tributaries of the Allegheny have been proved to be of French origin, and that it is not unlikely that the old shaft at Mecca, Ohio, was also made by the French. In 1629, the Franciscan missionary Joseph de la Roche d'Allion wrote a letter in which he mentions the oil springs in what is now the state of New York, and on a map of 1670 a "*Fontaine de Bitume*" is located in the neighborhood of the present village of Cuba, New York.

The early use in this country of the word "petroleum" is shown by "A General Map of the Middle Colonies of America," etc., by Lewis Evans, Philadelphia, 1755, on which by this term the existence of petroleum in the present States of Pennsylvania and Ohio is indicated. The frontispiece exhibits a portion of this map copied from the one in possession of the Historical Society of Pennsylvania. About the middle of the last century, Peter Kalm published in Swedish a book of travels, in which was a map, on which the springs on Oil creek were properly located. This book has been translated into English, and an edition was published in London in 1772.

In 1750, the French commander at Fort Duquesne wrote to General Malcolm that by invitation of the Chief, he had attended the annual religious ceremony of the Senecas, at which the oil covering the surface of a small stream entering the Allegheny was ignited, at a given signal, by the application of a torch, the Indians, at the sight of the flames, giving forth a triumphant shout that made the hills and valleys re-echo again.

George Henry Loskiel, in his "History of the United Brethren among the Indians in North America," 1788, translated by Christian Ignatius La Trobe, London, 1794, speaks of petroleum as follows:

"One of the most favorite medicines used by the Indians is the *fossil oil* (petroleum) exuding from the earth commonly with water. It is said that an Indian in the small-pox lay down in a morass to cool himself, and soon recovered. This led to

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[1] Report on Petroleum.

the discovery of an oil-spring in a morass, and since th many others have been found in the country of the De and Iroquois. They are observed both in running and s water. In the latter the oil swims on the surface, and i skimmed off. But in rivers it is carried away by the Two have been discovered by the missionaries in th Ohio. They are easily found by the strong smell the and even those in rivers and brooks may be smelt at a d of four or five hundred paces. The soil in the neighb of these springs is poor, cold, loamy, or covered with Neither grass nor wood thrives on it, except some sma pled oaks. It does not seem to proceed from a vein of for no coals have as yet been discovered in the neighb of the springs, but strata of sandstone only. And in the borhood of the coal pits on the banks of the Muskingu the least sign of an oil spring has hitherto been disc though the Indians have made a most diligent search.

"The oil is of a brown color, and smells something li When the Indians collect it from a standing water the throw away that which floats on the top, as it smells st than that below it. They then agitate the water violentl a stick; the quantity of oil increases with the motion water, and after it has settled down the oil is skimmed o kettles and completely separated from the water by b They use it chiefly in external complaints, especially in a ache, toothache, swellings, rheumatism, dislocations, etc. bing the part afflicted with it. Some take it inwardly, has not been found to do harm. It will burn in a lamp. Indians sometimes sell it to the white people at five gui quart."

Towards the end of the 18th century, some salt-digger deavored to procure, if possible, a larger supply and l quality of salt, and for this purpose drilled holes in the gr some of which reached a considerable depth. But inste finding, according to their expectations, an abundant s of good brine, the latter was in many cases rendered usele the presence of bitumen. They then endeavored to utilize the bitumen, but without success, except the use of small quantities for lubricating and medicinal purposes. Among the parties actively engaged in the manufacture of salt was a Mr. Kier, who bored a well for brine at Tarentum, on the Allegheny river, and obtained oil that looked like brandy with the water, and this was allowed to flow into the canal leading to Pittsburgh. Mr. Kier's son, Samuel M. Kier, was a druggist in Pittsburgh, and his wife being sick, as was supposed with consumption, her physician prescribed "American oil." It helped her, and her husband was led to compare it with that obtained from his father's well. Concluding, as they possessed the same odor, that they were the same thing, he submitted them to a chemist, who pronounced them identical. Mr. S. M. Kier soon after commenced to bottle American oil for sale, and after a few years, supposed to be about 1855, in company with Mr. McKuen, he first refined petroleum from his father's wells at Tarentum. The oils were treated like the crude oils obtained from coal, and were made into burning oils and heavier oils, that were sold to the woolen factory at Cooperstown for cleansing wool, for which they were found very valuable.[1] It may not be uninteresting to introduce here some notices from the "Oil, Paint and Drug Reporter," regarding the first five gallons of petroleum brought into commerce, such details being of historical interest, because they mark the commencement of the vast petroleum industry, and illustrate its marvelous progress during a period of scarcely thirty years. These five gallons of petroleum were, so to say, the opening wedge, the basis of the great commerce which was to follow.

Although attempts had been made at different times and in various countries to utilize petroleum for illuminating purposes, all efforts in that direction had proved a failure, the oil being everywhere rejected on account of its extremely disagreeable, nauseous odor and the sooty, smoking flame. These almost insurmountable objections had invariably excluded its use, and

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[1] S. F. Peckham, Report on Petroleum.

only after the appearance of the first five gallons of pe
in the New York market the troublesome petroleum, dec
to that time, underwent such alterations that it could t
without danger and became of commercial importance.
1859, the national wealth of the United States was ther
creased more than fifteen hundred millions of dollars.
five gallons of petroleum were distilled in Allegheny, Pen
nia. Nervin, Mackeown & Co., Samuel M. Kier and Dr.
had for some time sold petroleum under the name of *m*
salve and *Seneca oil*, which were used for medicinal pu
When it was found that petroleum would burn in lamps,
later on sent to New York. It was used with some succ
storage cellars and foundries, where its odor and smoke co
some extent, be tolerated. A sample in a tin can was fur
the Hudson Mills; on opening the box it was found, acco
to report, that the can had leaked and the straw in which
packed was thoroughly saturated with petroleum. It di
such a penetrating, nauseous odor that the box had
thrown into the street. This happened in November,
Notwithstanding this failure experiments were continued
the first shipment of oil, consisting of two barrels conta
84¼ gallons, arrived in New York, December 12, 1857.
account of the smell and to prevent the oil from transu
through the wood, the barrels inside were coated with sh
solution, or glue. These precautions, however, proved in
quate, and a special store-house had to be rented in W
street. The second shipment of five barrels, containing 21
gallons, arrived December 18, 1857, and the third shipme
five barrels, containing 210½ gallons, December 23, of
same year. These three shipments constituted the total sal
petroleum in 1857, and appear as the first entries in reports
official statistics of the petroleum commerce.

Of this oil, which was purified in a distilling apparatus
scarcely one barrel capacity, Gessner says: "In 1857 A.
Ferris introduced in the New York market a lamp oil, cal
'carbon oil,' which had previously been distilled, but inc

rectly treated. The oil was recommended as non-explosive—a quality upon which special stress was laid—and as being cheaper than all other illuminating materials. Nevertheless it was difficult for this new product to gain favor. Its unbearable odor and the danger from fire discouraged its use to such an extent that the oil obtained from the distillation of bituminous coal, such as the boghead and bituminous shales, proved a successful rival of it on account of its security from fire."

These events were rapidly succeeded by the discovery of crude oil on Oil creek, and after the construction of suitable burners by E. Miller, of Meriden, Connecticut, and Col. Jones, the use of petroleum also increased. The practical sense of these gentlemen caused them to send out an army of agents, who visited the city and country stores and by a sample lamp explained its advantages, how to lower and raise the flame, and also gave information regarding the occurrence of the oil. While in a few places the introduction of the oil was to some extent successful, many bitter complaints were received from other localities, so that a premature and disastrous end seemed to threaten the enterprise. The complaints were of three kinds: 1. The lamp burnt with success for a short time only; the flame then commenced to get weaker, the wick becoming coated with a carbonaceous crust and the lamp evolving an offensive smell until it went out on its own account, even when still half full of oil. 2. The color of the oil, which, when first distilled, was orange to lemon-yellow, changed in a short time to dirty dark brown, so that the oil was no longer suitable for keeping in glass. 3. The complaints referred to the intense smell which filled the house when burning the oil. But notwithstanding these complaints, curiosity prompted people to buy this new oil of such strange origin. It was discussed by the daily journals, and scientists were invited to visit the newly-opened depot, 184 Water street, New York, to inspect the oil and take samples of it for chemical analysis.

In December 1857, the first barrel of oil was delivered to Messrs. Stout and Hand of Brooklyn at 70 cents per gallon and, hence, this firm may be considered as having sold barrel of *illuminating oil* in the United States. The q oil being limited and the consumption increasing, notv ing the defects of the oil, the price rose to two dollars p before the development of the Oil creek region, this h being at the same time an incentive to search for oi localities. It became now absolutely necessary to im quality of the oil so that the complaints regarding co and incomplete combustion should no longer appear The defect of the flame diminishing and becoming exti was, according to views prevailing at that time, attrib want of volatile substances. Hence it was endeavor move this defect by mixing the petroleum with othe oils. After many experiments a remedy was finall in commercial distilled rosin oil, which when mixed petroleum not only kept the flame at the same height, parted to it greater intensity. The inventor patented t ture for illuminating purposes. It consisted of 40 gall bon oil (petroleum) of 44° to 48° B. and 5 gallons ros 18° B., and had a high burning point which, at a tin almost all other illuminating agents of a similiar natur constant source of danger, was the most important fact introduction. The mixture was at first effected by tal necessary quantity of petroleum from the barrel, adc rosin oil, and stirring with a stick. The mixture effecte manner was, however, incomplete, the heavier rosin oil to the bottom with a change in the temperature, and he mode of mixing had to be changed. Tagliabue, who gaged in the manufacture of apparatus for the oil trac structed an apparatus suitable for the uniform mixing of fluids; but the sale of the product did not increase, t agreeable smell being always the principal impedimen use, and a radical removal of this defect became nec For this purpose a wooden holder lined with zinc pla having a capacity of about 20 barrels was procured and in the cellar of 191 Pearl Street, to which location the b had been removed from Water Street in consequence of complaints of merchants in the neighborhood to whom the stench from the carbon oil business was intolerable. And, indeed, the complaints were well founded, because there was stored not only Oil creek oil, which diffused a terrible smell, but also Canadian petroleum from Enneskillen, which when being transported to New York could for several days be smelled through the entire length of the state. The petroleum to be purified was brought into the above-mentioned holder and a hot solution of caustic soda poured into it. The caustic soda solution was prepared in a "Mott kettle," an apparatus consisting of an iron stove with an open iron kettle on top. The addition of caustic soda solution was continued until no more precipitate formed, the mixing being managed by one workman by means of a pole. The precipitate formed was discharged through a cock. In this petroleum kettle we recognize the first agitator, and hence, the first attempt of refining petroleum. The success of this method was satisfactory in so far that the smell completely disappeared and the color became lighter; but the straw-yellow color of the refined petroleum changed in a short time to brown which gave rise to fresh complaints.

The most productive well, the oil of which contributed most to the development of the petroleum commerce, belonged to Irwin & Peterson and yielded daily from two to ten barrels; according to calculations, the income derived from the well amounted, in 1858, to about $10,000. In order to still further increase the production it was concluded to sink a shaft to the source of the well, it being supposed that about 350 to 400 feet below the surface of the earth a stream of oil would be found which, in order to gain the entire supply, would have to be pumped out and conducted into reservoirs. A steam engine and all other necessary apparatus was procured, and a number of experienced miners were engaged to drive the shaft through the intervening strata and rocks. In carrying on the work they passed through a vein of coal 6 feet thick and a bed of excellent brick clay. At a depth of 200 feet, many difficulties were encountered, which were chiefly caused by water. The sity of constantly pumping out the water and the occurre fire damp rendered the prosecution of the work both exp and dangerous. There being apparently no prospect c cess, it was concluded under these circumstances to stop t work, and the entire tract was sold to the Tarentum Oil and Salt Co., which continued the work, and after through a stratum 6 inches thick, struck, August 29, 185 water and petroleum. From this day dates the actual petr industry of the United States.

About the time when interest in the introduction of Ir Peterson's oil was at its height and the oil brought a high Peterson associated himself with Dale of Allegheny for th pose of building a refinery upon ground belonging to Pet not far from a well yielding salt-water and petroleum. were joined by Dr. Koch, a German chemist, and erec very simple structure, which they fitted up with a plant f distillation and storing of petroleum. The most suitable tion for the refinery was a hill at the foot of which was a sv The latter was utilized for setting up the reservoirs, which constructed by driving, in a circle of about 30 feet in diar staves closely together into the ground and intimately jo the projecting portions by means of iron hoops. The dis apparatus itself consisted of two wrought iron retorts, holding ten barrels. These retorts were connected by r of a conduit with the above mentioned reservoirs, and them the distillate was pumped for further treatment int culiar movable holders, which were perhaps the first an apparatus constructed in this manner. Exactly egg-shap cast iron, about 8 inches thick, each of them weighed se thousand pounds. In order to effect a mixture of their tents, these holders, which were large enough to hold th tillate in the retorts, were set in rapid motion by means of iron bars secured in ears on the exterior. Besides these fying apparatuses, there were others which served for filte They consisted of boxes with perforated bottoms which filled with animal charcoal and placed above the reservoirs. The petroleum thus purified was brought into barrels and stored in pits, to prevent leakage and consequent loss.

In 1857, a company of New Haven stockholders organized under the name of "The Seneca Oil Company." They leased the property of the Pennsylvania Rock Oil Company on Oil creek, and engaged E. L. Drake to go out to Titusville and drill an artesian well for oil. Drake arrived in Titusville about May 1, 1858. He commenced operations by attempting to sink a shaft in one of the old timbered pits, previously mentioned, but water and quicksands continually thwarted him, and he finally resorted to the expedient of driving an iron pipe from the surface to the solid rock. On account of the men he had engaged for drilling securing another job, the work was suspended until the following season, when Mr. William Smith and his two sons were engaged, they having had large experience on salt-wells. These men arrived at Titusville about the middle of June, bringing with them all the necessary tools for drilling. After many vexatious delays, they were fairly under way by the middle of August and had drilled 33 feet, when on the 28th of August, 1859, the drill struck a crevice, into which it fell six inches. The following day being Sunday, Smith visited the well in the afternoon and found the drill-hole full to within a few feet of the top, and on fishing up a small quantity in a tin cup, it was found to be petroleum. Such is the story of the first petroleum well.[1]

After Drake's success, wells were drilled in the valley of Oil creek from Titusville to Oil City, on French creek from Union City to Meadville and Franklin, and on the Allegheny at Tidioute. The production increased far more rapidly than the demand, and the market becoming soon glutted, the price of the oil fell to almost nothing. But the exhaustion of some of the wells led to better prices, and to cover the daily increasing demand, new wells were drilled. During this feverish activity in Pennsylvania, wells were drilled in Ohio and West Virginia.

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[1] S. F. Peckham, Report on Petroleum.

Operations in the latter state were interrupted dur but were resumed in 1864. In 1865, operations w fully undertaken at White Oak, which resulted in the most extensive and best known West Virgin From 1860 to 1865, wells were successfully drilled and at other localities in Washington county, O 1870 to 1880 the region between Tidioute and Oil constantly become of less importance, on account duction decreasing to a considerable extent. Other ever, were discovered in accordance with C. D. An theory." Wells had been put down near the jun Clarion and Allegheny rivers as early as 1863 and very little notice had been taken of them at the ti was not until 1868 that a successful well on the Parker's Landing attracted attention and led to th ment of what is called the "lower country," lying Armstrong and Clarion counties. In studying the r sitions of the most productive wells, Mr. Angell had in the "upper country," that a narrow belt extendi from Scrubgrass, on the Allegheny river, to Petroleu on Oil creek, included many of the best wells in th In the "lower country," he projected a similar belt, direction nearly parallel with the first, and extending Petersburg, in Clarion county, through Parker's La Bear creek, in Butler county. Subsequent developm firmed the correctness of Angell's belt theory. T have shown that the oil rock lies in belts or in long a areas, having a general northeast and southwest extens not more than 30 rods in width, but several miles i that the sand-rock is thickest and most productive axis of the belt, thinning out towards its borders, t surface being level and the under surface curved upw the center; that the present configuration of the surfa relation to the form, extent, or direction of the "belt. facts established, and their successful application ab demonstrated by the remarkable success attending operations, have given a certain degree of accuracy to the development of oil territory that it never possessed before. On the other hand, they have led to very exaggerated views, some enthusiasts affirming their belief that the line north 16° east, upon which Angell achieved his first success, governed the direction and extent of territory containing oil from Canada to Tennessee.[1]

Canada and South America.

The oil territory of Canada lies in the county of Lamberton, in the western part of the province of Ontario, and principally in the township of Enneskillen. Indications of surface oil had there been observed by the earliest settlers, but instead of adding any value to the land in the township, seriously detracted from it. The dark oily liquid with its disagreeable odor was not then a marketable product. The streams of water were polluted with its nauseous taste, and where wells were dug, the same manifestations were observed to such a degree as often to condemn them. In 1857, these surface marks attracted the attention of more skillful and better informed men, and a man by the name of Shaw, who dug an ordinary well, as for water, struck, after several days digging, a tremendous flow of oil, which ran in a stream into the creek. The usual phenomena attending such a discovery followed; land was bought, and more wells were dug, and oil flowed; they gathered what they could and wasted the remainder; fortunes were made and lost, and after a time, in 1864, the town of Oil Springs contained 3,000 inhabitants. The territory in which oil in paying quantities is found contains about 200 square miles, and within this range, Petrolia, Bothwell and Oil Springs have produced nearly all the oil. The latter has the largest wells, though Petrolia now produces more than nine-tenths of the amount at present obtained. The petroleum of Canada contains sulphur, and is difficult to refine; but the refining process has been so much improved, that at present Canadian oil supplies a large demand throughout the British possessions.

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[1] S. F. Peckham, Report on Petroleum.

Argentine Republic.

In this country petroleum springs and bituminous slat long been known to exist in the province Selta, near Me Towards the end of 1889, there were in operation neighborhood five productive wells, and it is intended to large refinery. At the present time, the oil is used for th ufacture of gas. In the province Selta, about 23 miles Mendoza, a field stretches up-hill, which from the v mountains is known as Cachenta. According to Stelzn crude oil found here belongs to the rhetian formation, occurrence, known at the present time only in the Sehnde, Hanover. Four wells were drilled here, and struck at a depth of 656 feet.

The first well yielded little oil, in the last years 5 per day; the second well scarcely anything; the thi barrels per day of a slightly thick oil, at a depth of 25 and the fourth a greater quantity of good oil, with a y 300 barrels per day, at a depth of 377 feet. The oil peculiar, though not disagreeable odor, which may perh due to a small content of combinations of sulphuretted carbon. With the light falling upon it, it shows a slight ish fluorescence, while with transmitted light its color i brown. At 70.25° F. it is viscous. It freezes at 32° quiring the consistency of butter without separating p nor could a separation of paraffin be observed at a temperature. In petroleum ether the oil is soluble w residue; its flashing point lies at 113° F., and its burning at 194° F. Its specific gravity at 62.6° F. is 0.9032. boiling point is the same as the flashing point. Subjecte normal distillation in Engler's apparatus, the oil yielded:

	Per cent. by volume.	Per ce by weig
Essences (up to 302° F.)	6.4	4.0
Illuminating oil (302° to 590° F.)	27.6	21.9
Residuum	66.0	73.9

The fractions boiling at over 590° F. consisted of:

	Calculated to residuum. Per cent.	Calculated to crude oil. Per cent.
Mixed oil (solar and gas oil)	20.00	14.8
Heavy oils, very paraffin-like	70.00	51.8
Residuum	10.00	74.0

The heavy oils showed an ointment-like consistency, the paraffin appearing in crystalline scales in the receivers. As regards the chemical nature of the Argentine oil, Engler and Otten found hydrocarbons of the series C_nH_{2n+2} and C_nH_{2n}.

Refined in the ordinary manner, an illuminating oil equal to the best Pennsylvania oil was obtained. The railroads of the Argentine Republic use the crude oil as fuel.

The petroleum residuum is very rich in paraffin and cannot be worked for lubricating oil.

On the other hand, from the residuum are obtained a soft paraffin with a melting point of 95° F. and a hard paraffin melting between 136° and 139° F. The total content of paraffin, determined by Zaloziecki's method, amounts to 55.75 per cent., calculated to residuum, and to 25.7 per cent. calculated to crude oil.

Bolivia and Peru. The occurrence of petroleum in Peru and Bolivia has been known since the sixties. According to a report by the mining engineer, F. Hurss,[1] in *Bolivia* petroleum occurs in as great an abundance as in Pennsylvania. The three principal wells are at Cuarazuti, Plata and Signiracada (between Oran and Pilcomayo) in a circuit of about 58 miles, and form, it is said, an oil-creek 6 inches deep and 7 feet wide. The mass of oil issuing from these wells is so great that Hurss considers boring superfluous. Besides the three wells above mentioned there are, in the same region, eight others which are claimed to have been just as productive as those of Cuarazuti.

The oil fields of *Peru* are said to have been known for many centuries. They are located in the coast region of the ocean and stretch from Cape Blanco to the Tumbez river, a distance of about 120 miles.

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[1] Wagner's Jahresbericht, 1868, 14, 728.

In the year 1867 oil was for the first time struck near by boring to a depth of 130 feet, and since that time pe has been obtained on a larger scale. According to a the first shipment of 30,000 boxes of petroleum has been made to Japan, and as the export trade is growi eral refineries for the production of illuminating oil ha established.[1]

Venezuela. From the reports of the Consuls of the States the occurrence of considerable petroleum spr Venezuela has for some time been known. The spri located in the neighborhood of the Maracaibo Lake northern part of Venezuela. The occurrence of oil is be very extensive, stretching over a surface of about 60 One of the largest springs recently discovered yields, ac to E. H. Plumacher, the commercial agent of the United 4 gallons per minute, or 240 gallons per hour, or 5,760 during the 24 hours of the day. The petroleum is said very good quality, being of 0.083°, which is the requir sity in the British markets of the petroleum imported fr United States. If such be the case this petroleum find be of great future value, it being located in the im neighborhood of the sea so that it can be directly shipp

The government has granted to the National Pet Company the sole right for twenty-five years of work wells. The Company owns over 100 shafts, and machir boring and refining purposes. The drills are driven by power, and in the refinery 2,500 gallons of petrole month were at first produced.

To assist the domestic industry the Government has a high duty upon importations of Russian and Americ minating oils.

Africa.

In Egypt petroleum occurs, according to Robert Ir the neighborhood of Gemsah and Djabel-Said, a re

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[1] Chemiker- und Techniker-Zeitung, 1891, No. 10.

which the occurrence of oil has for some time been known. The crude oil obtained by boring is of a dark brown color and has an odor evidently due to combinations of sulphuretted hydrocarbon. Its specific gravity at 60° F. is 0.934. The oil is thick, possesses great lubricating power, and remains fluid at a low temperature, from which it may be supposed not to contain any hard paraffin. Mixed with chemicals a product of 0.850 to 0.950 specific gravity is obtained.

The loss from washing with acid amounts to more than 50 per cent. From this fact and the absence of illuminating oil, the purification does not seem to be profitable. On the other hand, the crude oil by itself possesses a high value as a lubricant, and might also be suitable for fuel. Kast and Kunkler[1] have recently subjected the oil to a thorough examination and confirm the fact that, in consequence of its slight content of volatile oil, it is not suitable for the fabrication of illuminating oil, but furnishes an excellent material for lubricating oils. Oil in large quantities is also said to occur in South Africa. L. Campbell Johnston[2] reports having found in the Orange Free State infallible indications of the presence of heavy oils.

Australia.

In the year 1889, the discovery in South Australia of petroleum springs supposed to be of great value created quite a sensation, the wells, according to the *Oil, Paint and Drug Reporter* of May 15, 1889, being located in the neighborhood of Yorktown on the extreme point of the peninsula of York, between the Spencer and St. Vincent Gulf, and were discovered by A. Tocchi, who had for some time examined the region in the hope of finding oil. The Government of South Australia granted him the exclusive right of 90,000 acres of land to search for oil. Nothing more has, however, been heard of these discoveries.

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[1] Dingler's polyt. Jour., 278.

[2] Oil, Paint and Drug Reporter, 1889, April 3.

New Zealand.

In this part of Australia petroleum has been found 1860, in various regions, but researches regarding quanti quality have been made only in recent years. The fi ploration for oil was made at Waiapu, on the East coast province Auckland, and the next at Maunthai, on the Eas Considerable quantities of good oil were found, but on depth of 1000 feet. The oil from the first-mentioned closely resembles Canadian oil. After a few distillatio refining with acid and lye, about 65 to 67 per cent. of g luminating oil with a specific gravity of 0.844 at 59° F. v tained. The crude oil from Maunthai has a slightly color, is almost transparent, and has a specific gravity o at 60° F. It contains very little soluble paraffin, and by c tion a yield of 80 per cent. illuminating oil is obtained, burns quite well in ordinary lamps. A yield of only cent. of illuminating oil gives an excellent product of specific gravity.

Russia and the Caucasus.

Next to the oil regions of North America the petroleur of Russia and the Caucasus are of the most importance.

Although the petroleum industry of Baku in its pres tent and great development belongs to the most modern the working and use of Caucasian naphtha and ga course in their simplest form—have been known from ti memorial. Six hundred years before the Christian era was a resort for the fire-worshipers of Persia and the Ca the inflammable gases issuing from the ground being ma of in their ceremonies, and every year thousands of p traveled to the temples on the peninsula Apsheron to v the holy or eternal fires.

Even at the present time surface-naphtha is found in places in the vicinity of old temples, and it may be su that such occurrences were not unknown to the inhabita pilgrims of that time. The first trustworthy statements ing the occurrence of naphtha in that region are furnished by Masudi, who died in 950, and by Katib-Tschebabi. Interesting is also Marco Polo's report, who visited Baku in the thirteenth century. He describes the use of naphtha for various purposes, and states that it was transported by means of camels to Bagdad. "It is not good to use with food," he says, "but 'tis good to burn, and is also used to anoint camels that have the mange." He further states that "at Baku is a fountain of oil of great abundance, inasmuch as a hundred shiploads might be taken from it at one time." From these statements we learn that the trade in Russian petroleum is not a new thing. Dr. Oscar Schneider states that in an old naphtha pit a stone with an Arabian inscription was found, according to which the respective pit was worked in the year 1003 after the Hedschra (1600 according to our chronology), and was rented for that purpose from the son of Mohammed Nurrs, Allah Jar. Up to the end of the seventeenth century we find no further references to the naphtha wells; but at that time a detailed description of them, as well as of the eternal fire, was given by Kämpfer, who travelled through the Apsheron peninsula. A few years later the same region was visited by Lerche, Gmelin and Hanway. "On July 30, 1737," says Lerche, "I travelled five versts[1] along of the inextinguishable fire of Balakhani to the black oil wells. While this region was under Persian rule there were fifty-two such black oil wells, but now only twenty-six remain uninjured. From these wells the naphtha is poured into large, deep stone-pits, and from there transported in leather bags upon 'arbas' (two-wheeled carts) to Baku."[2] According to Lerche's statements the naphtha was used for fuel, and as a remedy for rheumatism and scurvy. From the statement of Jonas Hanway, 1754, we learn that "the Persians load the naphtha in bulk in their wretched vessels, so that sometimes the sea is covered with it for leagues together. When the weather is thick and hazy the springs boil up the higher, and the naphtha often takes fire on the surface of the earth, and

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[1] 1 verst = 3501 feet.

[2] Victor Ragosin, "Die Naphta und die Naphtaindustrie."

runs in a flame into the sea in great quantities to a almost incredible. In clear weather the springs do not above two or three feet; in boiling over, the oily sı makes so strong a consistency as by degrees almost the mouth of the spring; sometimes it is quite clo: forms hillocks that look as black as pitch, but the sprin is resisted in one place breaks out in another. Som springs which have not been long open form a mouth ten feet in diameter. The people carry the naphtha by into pits or reservoirs, drawing it off from one to anoth ing in the first reservoir the water or the heavier p: which it is mixed when it issues from the spring. It is ı ant to the smell, and is used mostly amongst the pooı of the Persians and other neighboring people, as we us lamps, or to boil their victuals; they find it burns bes mixture of ashes. As they obtain it in great abundanc family is well supplied."

Pallas in describing, in 1793 to 1794, the Kouban sus) naphtha region, says that there, and especially in (i. e., the naphtha valley) the naphtha floating upon water or collecting in pits is used for heating pı Reinipp states that the region about Baku must be ex rich in mineral oil, because Balakhani, a small district, ı from Baku, had 25 open oil springs, the daily yield of which amounted to from 50 to 80 poods.[1] The Khan reserved the entire output for himself, and caused fifteen be dug in a house, into which the oil was poured ar which it was sold. According to Gmelin the price of a (about 17 lbs.) was 5 kopecks,[2] and the yearly incom Khan of Baku from this source amounted to about rubles.[3] The output of naphtha in the Apsheron pe varied very much according to whether the region was possession of Persia, Armenia or Russia; and only iı when Baku and the surrounding district came into the

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[1] 1 pood = 36 pounds avoirdupois. [2] 1 kopeck = about 2/3 of a cent. ble = $0.7779.

sion of Russia, the revenues derived from the naphtha commerce, which formerly belonged to the Khan, were declared imperial property. However, this decree was not immediately enforced, because, up to 1820, no charge was exacted for working the springs.

From 1820 to 1834, the monopoly of working the springs was farmed out every four years to the best, or perhaps the favorite bidder, the government limiting the selling price of the crude oil. From 1834 to 1850 the government itself worked the springs to some extent, the annual income from this source amounting to between 75,000 and 80,000 rubles. From 1850 to 1872 the springs were again farmed out to private parties, the revenue derived from the leases increasing steadily up to 1867 from 111,000 to 162,000 rubles per annum, while from 1867 to 1872 the yearly income amounted to about 136,000 rubles, with an output of, at the utmost, 350,000 poods. During the last term of the lease the selling price of the pood of crude oil was fixed by the government at 45 kopecks. In 1861, Witte & Co. built on Holy Island a factory for working ozocerite, which they procured from the island of Tschelekon. By distillation about 60 per cent. paraffin and 8 per cent. oil were obtained, but, after working for several years, the enterprise was abandoned. In Baku itself, the first refinery was built in 1863, by one Melikoff, but lacking capital for the extension of the plant, he was forced to hand it over to a company in order to save the enterprise. The establishment of other refineries soon followed.

Up to 1872 the development of the industry was, however, hampered by the existing monopoly. In that year, in pursuance of recommendations of a commission appointed by the government, the territory upon which there were surface indications was divided into plats of 25 acres each, and sold to the highest bidder by sealed proposals. By this time the field had attracted much attention, and the parcels were disposed of at, in some cases, enormous prices. For instance, 257 cisterns, 5 pits, 12 natural springs, the bore-hole in the government Baku, 22 cisterns in the Dagestan district, as well as 86 pit natural springs in the government of Tiflis, which were appraised at 552,240 rubles and were sold in 4 brought 2,957,967 rubles, hence more than five t valuation. Some of the parcels were appraised at o each and brought from 2500 to 3450 roubles each, w group in the peninsula of Apsheron the valuation of w 114,562 rubles, 925,000 rubles was paid.

Thus the real birth of the industry may be said to d the year 1872, when the lands passed into private ha its development progressed more rapidly. The produ refineries was, however, so bad, and the market so limi there was not enough energy engaged to bring on a the industry. The government had placed an ex which, under the circumstances, was unbearable, an time, previous to 1878, the operators were upon the ruin. No work was done except to fill contracts pr made. At Nishni-Novgorod there were in store more t and a half millions of poods, almost 200,000 barrels, uns the price had gone down from 3.50 rubles to 1.30 ru pood. The government then removed the excise tax industry commenced largely to develop, so that at pres equal in importance with that of the United States.

Up to 1872 very primitive methods for obtaining the were in use. Pits resembling water-wells were dug, i the naphtha collected, and it was then dipped out by horse-power, and conducted through gutters into subte cisterns. In that year the first well was bored accordin American system, whereby the production was largely in and at the same time the Noble Brothers came forwa their improved system of transportation.

The total extent of the Caucasian naphtha fields is known. According to official statements it is estim about 30,000 square versts, of which, 6,000 square verst the Kouban district and in the peninsula Taman. The oil region in the Caucasian territory is the peninsula of Ap which, together with the neighboring district, comprises about 2,000 to 3,000 square versts, of which only about 12 square versts are worked. The principal field is at Balakhani, 9½ miles north of east of Baku, covering a territory of, say 3½ by 1½ miles. Two miles south of Baku, is a small field at Bēbēābât, on which there are some 25 wells. The cost of sinking wells ranges from $5,000 to $7,500. What can be obtained for such an expenditure may be illustrated by the result of boring the Droobja well, which cost $7,500—the total amount of oil poured forth by this well in six months of 1883 being, according to the lowest estimate, 55,000,000 gallons, and according to the highest, 125,000,000 gallons. Had the oil been in England, it would have realized a million sterling. At Baku the bulk of it was lost. Not only this, however, but this Droobja fountain, which was from 200 to 300 feet high, produced much more sand proportionately than the average Baku well, although all wells there produce immense quantities of sand with the oil. Some one-story buildings, about 15 feet high, within a hundred yards of the well, were completely buried out of sight in sand from the well, and an area of probably 10 acres around the well was covered from 1 to 15 feet with sand. The Mining Company, which owned the well, not only lost their oil, but were ruined by the damages they had to pay the surrounding well-owners for flooding them with sand and oil.

The great Markoff fountain, bored in 1887, spouted oil and sand 400 feet high—a veritable volcano. On windy days the oil spray was carried eight miles away. The Markoff fountain was situated not far off the Droobja, which pessimists had prognosticated erroneously would drain the whole area. On this occasion, the Russian government, which had been angered by the waste of oil from the Tagioff fountain—which spouted 2,700,000 gallons a day the previous year, and endangered the town of Baku by raining oil upon it, although three miles away—gave permission to the other Baku firms to lynch the "gusher" at the owner's expense. Accordingly they sent their best engineers to the spot, and after several unsuccessful attempts the well was finally capped over, and a stop the disgraceful waste of oil. All the same, no law e prevent any foreigner or Russian repeating the same tion to-morrow. Large firms, like Noble Brothers, manage to have good engineers and the best appliance spot to check a "gusher" at the outset, and allow the to flow as they want it. But the native firms bore hee and for want of "caps" at the right moment, all contro over the well, and it belches forth millions of gallon forming rivers that flow away to the Caspian Sea or si the earth again.

According to United States Consul James C. Chamb port,[1] the production of crude petroleum in Russia, i was over 45,000 barrels, of 40 gallons, for every da year; *i. e.*, the amount of crude used was over 45,000 per day—and no one knows how much was lost, but the doubt that the loss was at least 20 per cent., and that t ual amount of crude taken from the ground during tl was nearer 55,000 barrels per day than 45,000. Of 20 per cent. allowance of oil wasted will seem to an An very liberal; but if the manner in which oil is conducted servoirs from wells, the construction of reservoirs, and th number of flowing wells are considered or understood, t timate will not appear so liberal. In 1887, the amo crude oil wasted was undoubtedly much greater than previous year, because of the number of flowing wells a great productiveness of some of them.

In recent years no new territory has been discovere very little effort has been made to find any, notwithst the fact that the theory advanced by some of Baku's e scientists, that the complete exhaustion of the present dev territory is very near at hand, seems to be gaining supp One of these scientific gentlemen now says that the Bala Sabunchi territory will not last more than three years, in opinion, it is said, he is backed by some of the people h

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[1] Reports from the Consuls of the United States. No. 92, April, 1888

the heaviest financial interests in the trade. However, on the other hand, Professor Mendelejeff and Mining Engineer Torokin, assert that, according to their calculations, there is sufficient oil in this region to supply all refineries in Baku for 100 years to come.

Attention has recently been drawn to the Sundhenski naphtha region in the Northern Caucasus. This territory has been known for a long time, and on account of its favorable situation (east from Wladikawkas, between the Sundscha river and the principal direction of the Caucasus) may be destined to replace the disappearing oil-wealth of Baku. No borings have thus far been made, and only four natural wells, not very deep, are worked at Grosenensk, Brahmsk and Benojewsk. In the year 1889, 170,000 poods of naphtha were obtained, while in 1890, after deepening the wells, the output amounted to 350,000 poods. In 1889 the average daily production of a well was 300 poods, and after deepening the well, 600 poods. These conditions are analogous to those found in the Baku industry.

With an apparently unlimited supply of crude oil, a great refining capacity and a profitable market for refined oil, it is clear that the limited transportation facilities of the railway are the chief obstructions to a rapid increase of export. Since December, 1886, railway transportation has entirely governed the price of oil at Batoum. Refined oil for Caspian Sea shipment, during 1886, brought an average price, free on board at Baku, of about $1\frac{3}{10}$ cents per gallon, while the same quality of oil, free on board cars for Batoum, averaged $2\frac{3}{10}$ cents per gallon. At the beginning of 1887 the railway company had 1250 tank cars in service, and there were no private tank cars on the road. The price for refined oil, free on board cars at Baku, then reached $3\frac{1}{8}$ cents per gallon, a premium of almost 2 cents per gallon on tank car capacity. This encouraged refiners to put cars of their own upon the railway, and permission was granted them by the department of the government controlling the railway to place over 4,000 private tank cars upon the road.

But even these measures were insufficient for the ever- ing quantities of refined oil. In 1887 the Batoum t aggregating about 23,000,000 gallons, was about full, monthly receipts were probably 3,000,000 to 4,000,000 in excess of the shipments. A pipe-line for crude oil f Caspian to the Black Sea has been proposed, but it will ever get any further than talk. The advantage of such line is evident, as it would increase not only the carryir city but also the production of oil.

There are a number of tank steamers in the Batou with an annual carrying capacity to ports for which t chartered of about 90,000,000 gallons. About 35,000, lons of oil are shipped in cans and cases, while the railw deliver about 150,000,000 gallons, so that the tankag full, the difference, or 25,000,000 gallons, will have to ported in barrels to keep up with receipts.

The export of petroleum and petroleum products am according to Engler:

	From Baku. Barrels.	From the Uni Barrel
In 1884	6,079,384	12,230,
In 1885	7,622,344	13,681,
In 1886	8,094,283	13,756,
In 1887	8,828,068	14,114,
In 1888	13,091,079	13,770,
In 1889	16,700,000	14,671,

From a recent report of the Executive Committee of troleum Bourse at Baku, it appears that, though the petroleum industry has succeeded in increasing the s Russia in supplying the foreign market at the exp American competition, this success has been more than by the lower prices obtained. In 1891, the share United States in supplying the markets of the world w troleum amounted to 70 per cent., and that of Russia to cent., while at the present time, that of the former is cent., and that of the latter 34 per cent. This increase export trade, however, has not improved the condition Russian petroleum industry. The great decline in the petroleum is shown by the following figures: In 1888, the proceeds of the Baku works for the 32 millions poods exported amounted to 10.2 millions rubles after the deduction of 6.4 millions rubles for freight from Baku to Batoum. In 1892, exportation rose to 51 millions poods, but the proceeds of the Baku works from this entire quantity amounted only to 3.3 millions rubles after the deduction of 12½ millions rubles for freight to Batoum. Hence petroleum brought only about ⅓ of the price paid in 1888. The Russian petroleum companies are now endeavoring to improve their condition, partially by an agreement with the Standard Oil Company, as well as by cheapening the freight by means of a proposed pipe-line from Baku to Batoum, and an understanding with the Trans-Caucasian Railroad Company.

A Belgian journal, the "*Bulletin du Mussée Commercial,*" of January 20, 1894, gives the following statistics regarding the consumption of American and Russian petroleum in various countries:—

Of the total consumption of petroleum there was used,

	Of American		Russian Origin.	
In Germany, Belgium and the Netherlands ..	90	per cent.	10	per cent.
In Austria-Hungary	0	"	100	"
In Turkey	1	"	99	"
In Italy	62	"	38	"
In Spain and Portugal	100	"	0	"
In France	77	"	23	"
In Great Britain and Ireland	69	"	31	"
In India	38	"	62	"
In China	71	"	29	"
In Japan	75	"	25	"

During the last ten years there has also been a considerable reduction in the price of American petroleum, as shown by the following figures from publications of the Bureau of Statistics at Washington. The average price per gallon of refined petroleum of 70° Abel in New York was:

	Cents.		
In 1883	8.14	In 1889	
In 1884	8.28	In 1890	
In 1885	7.86	In 1891	
In 1886	7.07	In 1892	
In 1887	6.75	In 1893	
In 1888	7.50		

According to a report by Special Agent Joseph
the production of petroleum in the United States,
amounted to 48,412,666 barrels, valued at $28,932,
in 1892, to 50,509,136 barrels, valued at $25,901,
largest amount—54,291,980 barrels—was produced
The production in other countries is given as follow
(Baku), 1893, 33,104,126 barrels; Austria-Hungar
816,000; Canada (1891), 755,298; Peru (1890),
India (1891), 146,107; Germany (1892), 103,323
(1891), 70,000; Japan (1890), 48,027; Argentine
(1891), 21,000; Italy (1891), 8085; Great Britain
1526.[1]

Galicia.

As compared with the two immense centres of the p
industry—the United States and Baku—all other co
the globe occupy a more or less subordinate posi
Austria-Hungary the most important deposit of petrol
an industry corresponding to it, occurs in Galicia. Oi
have flowed in this region from time immemorial, an
has been collected and used by the inhabitants of the
Under the name of "mountain balsam" it was used a
edy for rheumatism, etc., and later on it was also empl
lubricating purposes.

The first scientific references regarding the occur
petroleum in Galicia, we find in Hacquet's "Recent Ph
cal Voyages in the years 1788 to 1789." In 1835, the
Zeuschner found reports, two hundred years old, regar
occurrence of petroleum in this region, but in the

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[1] Hamburger Boersen Zeitung.

years, up to 1845, they are only short official reports from the imperial inspectors of mines at Drohobicz and other places. In 1810, Josef Hecker and Johann Mitis obtained petroleum in the Drohobicz district, and made a trial of the distilled and crude oils, which was obtained from dug wells and afterwards treated in stills, but having worn out their still in 1818, their works were closed. According to Heinrich Walter, experiments in illuminating with Boryslav petroleum were successfully made, more than 70 years ago, in Prague. The commencement of an actual petroleum industry in Galicia, however, dates from the year 1848. In that year some Hebrew business men submitted to the druggist Miskolcz, of Lemberg, a sample of a thick oily fluid, which, according to their statement, they had collected from the surface of stagnant water. Professors Ignaz Lukasiewicz and Pzeh analyzed the fluid and found it to be petroleum. They introduced it as a remedy for various diseases. They subjected it to dry distillation, and applying the term *oleum petrae* to the distillate, brought it into commerce under that name. In 1853, A. Schreiner and L. Stiermann, two Hebrew business men of Drohobicz, by boiling petroleum made a superior article of grease. Companies were then formed which were capable of carrying on the business in a more rational manner, by digging wells or shafts, and thus gave impulse to a great industry. In 1860 to 1867 the East Galician wells were the most productive, the region about Kolomea, Peczenyczyn and Sloboda-Rungurska especially being the centre of numerous borings.

In Middle and East Galicia, in the region about Boryslav and Drohobicz, an abundance of crude oil containing paraffin was found in the year 1862, and gave rise to a considerable ozocerite industry. In recent years a remarkable phenomenon has occurred in Galicia: the East Galician wells have gradually failed, while boring experiments in Mariampol, Krosno, Ustrziky, etc., have given results scarcely surpassed at first in Baku or in the United States. The firm of Bergheim and MacGarvey—Canadian borers—have been especially favored by luck, they having struck in their territory several wells which daily produce from 500 to 600 barrels of oil. In recent years modern refineries have been erected, which unfortunately have ruined the smaller establishments.

Considering the difficult conditions which the Galician petroleum industry had to combat, especially the want of capital, the lack of intelligent professional persons, the indolence of the workmen, and last but not least, the overwhelming influence of Russian and American competition, as well as the absence of any kind of protective tariff, it may be said that it has not only gained a secure footing for the present, but that its prospects for the future are still brighter.

Roumania.

Up to a short time ago the petroleum industry of Roumania was of a very subordinate nature. The oil wells occur mostly on the southeast foot of the Carpathians, there being five principal locations where petroleum is obtained. The total yield of petroleum in Wallachia amounts to over 19,800,000 lbs. The oil contains much paraffin and is used for many purposes. The Roumanian oil territory extends through the districts of Prahova, Dimbovitza and Bureu, where petroleum has been known since the commencement of this century, and been used for lubricating purposes. The oil was originally collected, as in other localities, from the water of the springs, with which it flowed from the crevices in rocks. In recent years borings have been made, since the primitive deposits of oil are only found in the older formations. At present the wells are at a depth of from 150 to 375 feet. There are two kinds of crude oil—heavy and light—the latter yielding about 60 to 70 per cent. of illuminating oil.

Glodeni, near Targovesti, may at the present time be considered the richest oil district in Roumania. A pipe line, about 6½ miles long, has been finished to the nearest railway station, thus doing away with the expensive transport by wagons. New discoveries have been made near Campina, and since work is also more energetically carried on in other districts, it may be expected that the Roumanian oil industry will gradually gain in importance. Besides a large refinery has been erected in Bucharest, the product of which, it is supposed, will be almost sufficient for the home demand.

Germany.

In Germany, there are three districts in which petroleum occurs in such quantities as to allow of its being worked on a large scale. One district is in the direction of Hanover to Brunswick (Verden, Wietze, Steinförde, Hänigsen, Edemissen, Oedesse, Sehnde, Oberg and Oelsburg), the second in Alsace (in the Ill valley near Altkirch and in Lower Alsace at Pechelbronn, Lobsan, Schwabweiler, and Hagenau), and the third on the west side of the Tegernsee.

The oil was formerly obtained in a primitive way by digging pits in which it was allowed to collect. In the 18th century shafts were first dug in Alsace. The oil was exclusively used for wagon grease. In Germany, like in all other countries where oil occurs, the rational production of petroleum by boring and its refining for illuminating purposes were commenced only after the attainment of the splendid results, in the United States, in the production and utilization of Pennsylvania petroleum. Borings were first made towards the end of the fifties in Hanover, soon afterwards in Alsace, and later on on the Tegernsee: at present, boring companies are everywhere engaged to open new deposits.

The Alsace oil district is of the most importance in regard to productiveness, the average daily yield being from 150 to 200 barrels, while the Hanoverian fields (Oelheim) produce daily 50 to 60 barrels; the product of the Tegernsee region is very small. According to the very interesting work of Le Bel, "Notices sur les gisements de Pétrole à Pechelbronn," the first deep shaft was caused to be dug, in 1735, by Eyriny d'Eyrinys, a Greek physician, residing at Pechelbronn. In the

year 1785, the family of Le Bel obtained posses
Pechelbronn petroleum fields and erected quite a la

Scotland.

According to a communication by D. K. Stenars i
nal of the Society of Chemical Industry, 1887, in bo
tuminous schist at Broxburn, a thickly-fluid oil of sp
ity 0.842 was brought to the surface from a depth
In the same vicinity, at a depth of 918 feet, a brow
cific gravity 0.830 was found, which congealed
Distilled in the usual manner it yielded:

Light naphtha (0.700 spec. gr.)	5.0 p
Heavy " (0.730 spec. gr.)	5.2
Illuminating oil (0.802 spec. gr.)	34.1
Intermediate oil (0.840 spec. gr.)	10.5
Lubricating oil (0.865 spec. gr.)	16.7
Paraffin (melting point 104° F.)	12.5
Loss	16.0
	100.0

The absorption of bromine being considerably les
ordinary varieties of petroleum, the oil may be con
contain but a small quantity of olefines.

The brine occurring together with the oil has
gravity of 1.095 and contains 14.4 per cent. of non v
stituents, consisting chiefly of sodium, potassium, cal
nesium, and traces of ferric chloride. Many bor
Broxburn emit at intervals considerable quantiti
From one bore-hole gas issued once a month for se
which when ignited formed a bright flame 20 feet h
joint occurrence of petroleum, salt and gas at Bro
interest, since in other localities petroleum comes to
under similar circumstances. The oil district at B
very likely quite extensive and might be worked wi
the crude oil could be raised by means of pumps.
on account of its large content of paraffin, the oil un
becomes solid at a temperature of 60.8° F., which w
the working of the field within a conceivable time.

Italy.

In Italy, near Piacenza, in the valley of the Rhiglio, there are at present three borings yielding an extremely clear and pure oil. There is also a very productive boring at Veleja.

Burmah.

The occurrence of petroleum in Burmah has been known for a long time, but it seems that only lately attention has been directed towards its utilization.

In a letter from Rev. J. N. Cushing, dated Toungoo, September 14, 1881, appears the following in relation to the Burmah oil wells:

"There are only two places in all Burmah where petroleum is produced to any extent, viz.: Arracan and Yenangyoung, in Upper Burmah. The production of the wells in Arracan is very small. Within a few years a company has been formed to work them as an experiment, but I have never seen any statement of the results, and think they must be inconsiderable. Yenangyoung (Earth-oil river) is a large town on the Irrawaddy about 400 miles north of Rangoon, and the oil-wells lie about 3 miles east of the town among some low and very barren hills, the chief vegetation of the unproductive soil being several varieties of cactus. There seemed to be a good deal of light, soft sandstone, through which here and there ran layers of dark rock resembling granite. The roads were in some places worn into the hills to a depth of 10 feet, the fierce torrents formed during the rain washing out all loose soil.

"When I visited the wells they were about 200 in number, although some were not yielding oil. These were upon ground as highly elevated as any, and occupied an area of about 100 acres. They were of various depths, the deepest being about 160 cubits (240 feet). I do not think that the number of wells has greatly increased since my visit, for before that petroleum had been found only in that locality, although search had been made for it in adjacent localities."

As regards the future of the Burmah oil fields, it depends, according to Fritz Noetling's report,[1] on the method of working and the geological nature of the country. The prevailing mode of digging shafts by hand is of little use, since the oil-carrying stratum lies too deep, and at present can only be superficially utilized.

To increase the yield it will be absolutely necessary to go deeper, which considering the quite considerable depth of the stratum, can only be accomplished by boring according to the American or European method.

Japan.

The knowledge of petroleum in Japan is of great antiquity. In more recent times wells have been bored for obtaining it, but the yield appears to have been small, since, in a very elaborate report made by United States Consul-General Van Buren, in 1880, no mention is made of any domestic production of petroleum, although Consul Stahel of Hiogo shows that the imports of American refined petroleum into Japan have increased from about 1,000,000 gallons in 1872, to nearly 18,000,000 gallons in 1880.

The techno-chemical industries of Japan are still in their infancy. As regards the petroleum industry, Japan is still dependent on imported oil. American boring experiments have thus far not succeeded. In tertiary districts borings, sometimes yield water containing petroleum, but the content of the latter is so small as to be of no value. Prof. Fesca, for instance, found in 1888, in Mabara (province Kazusa), such water which had an odor of petroleum and even burned on the well, but it was impossible to distil the oil off in the laboratory. Petroleum is at present obtained in five provinces. The crude petroleum is subjected to a very primitive refining process, and is consumed in the district where it is obtained. The principal supply is imported from the United States, though since 1888, a considerable quantity of Russian petroleum refined in Baku is brought to Japan *via* Batoum.

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[1] Supplement to the Burmah Gazette.

CHAPTER II.

DIVISION AND NOMENCLATURE OF BITUMEN.

THE bituminous bodies occurring in nature may be gaseous, liquid, or solid. They consist mostly of carbon and hydrogen, oxygen in larger quantity entering only occasionally into the combination.

All bituminous bodies belong to the same process of formation; the heavier bodies—the last-named members of the series mentioned below—are mostly formed partly by partial evaporation and partly by chemical conversion from the lighter bodies.

The fluid and solid bitumens are distinguished from mineral coal by their solubility in oil of turpentine, benzol, ether, etc.

Petroleum (earth oil) also dissolves solid bitumens; when the first evaporates, the latter are again separated, a process which has also taken place in nature.

The bituminous bodies may be divided as follows:

I. Gases............	1. Earth gas (natural burning gases).
II. Fluids (earth oils).	2. Rock oil (Steinoel) and naphtha (very mobile, very volatile, water-clear).
	3. Earth oil and petroleum (fluid, quite volatile, colored).
	4. Earth-tar, mineral tar and maltha (viscous, brown-black).
III. Solid bodies......	5. Mineral wax (Erdwachs) (kneadable, yellow to brown).
	6. Mineral pitch (kneadable, black, in very thin layers, brown).
	7. Asphalt (brittle, black).

The fluid bitumens, to which the general term "earth oils" may be applied, will here be chiefly discussed, but they are so closely connected with the other forms that the latter will have to be taken into consideration, particularly when their connection with the occurrence of petroleum can be established.

Mixtures with mineral coal. a. With brown coal (lignite). Dysodile, jet. *b. With black coal.* Cannel coal, bog-head coal, foliated coal, torbanite.

Mixtures with inorganic masses (rocks). a. Oil rocks, for instance, oil schist, oil sandstone (with petroleum or maltha). *b.* Asphalt rocks, for instance, asphaltic limestone, asphaltic sandstone (with asphalt, partially also maltha). From these mixtures the bituminous portion can frequently be extracted by the previously-mentioned solvents, and determined by evaporating the latter.

Nomenclature. The term *earth oil* may be applied either to the entire group of fluid bitumens, or only to the colored varieties which occur most frequently and possess the ordinary degree of mobility, while the viscous varieties may be designated *maltha* or *mineral tar*, and the very mobile ones *rock oil.*

To distinguish it from refined oils, the natural earth oil is also called *crude oil.*

The term *petroleum*, which means rock oil, is in many languages used as a synonym for earth oil; it is, however, also generally employed to designate a certain distillate (illuminating oil or kerosene) obtained from the crude oil, and, therefore, it would seem advisable to use the term only in the latter sense.

Naphtha (of Persian or, more correctly, Median origin, derived from *nafata* = to exude) is locally used, for instance in Galicia and Russia, in the same sense as earth oil or petroleum, while the term was originally applied to water-clear and very volatile derivatives. In the United States, and partially also in Europe, very volatile distillates of petroleum are also called naphtha.

Naphtha was long since mentioned by Dioscorides and Strabo, and Pliny speaks of it as *bitumen liquidum candidum*, while Agricola, in the middle of the sixteenth century, mentions *naphtha flos bituminis* and *liquidum bitumen, nunc vocatur petroleum.*

Other designations for earth oil or petroleum are: *Ropa*, *ropianka* (Slavonian, used in Galicia); *pekureti* (Roumanian); *mineral oil, crude oil* (English); *bitume liquide, huile de naphte, pétrole* (French); *Erdoel* (German—within a few years the Germans have also used the word "petroleum"); *yenan* (Burmah); *sekinoyn* (Japanese)—the rock oil is called *seki-schitza; shi-yu* (Chinese).

In the literature of the Greeks and Romans, maltha or mineral tar is mentioned by Dioscorides as *pittolium* (πιττα=pitch), by Pliny as *pissaphaltus*, and as *maltha* (from μαλθη=soft wax). In French it is called *bitume visqueux, bitume glutineux, poix mineral, mineral graisse.*

In Galicia, especially in Boryslaw, the transition of maltha to mineral wax is called *kendebal.*

Mineralogically the mineral wax is chiefly represented by *ozocerite;* the mineral wax is called *naphtgil, neftgil,* on the shores of the Caspian Sea, especially at Baku; *gumbed* in America; *goudron mineral* (French); *brea* (Spanish.)

The various synomyms for asphalt are, according to Zincken, as follows: *Judenpech* (German); *bitume compacte* (French); *smola* (Slavonian); *hemâr* and *kofer* of the ancient Hebrews; *chumal* (*humar*) of the ancient Arabs, and *elhumar* of the modern Arabs; *kupru* also *amâru* and *ididu* of the Assyrians; *mur* also *aschir*—burning water—of the oldest Babylonian people; *abu thâbun*—the asphalt of the Syrians, which was contaminated with sand, and dug on the shores of the Dead Sea; *dore—kioei—teire—kisa* of the Japanese. Some of these terms refer partially also to mineral pitch.

In the neighborhood of Baku occurs an earthy asphalt, called kirr, kar, katrau, kitrau, katirau, which contains some mineral wax.

The minerals called *albertite* and *grahamite* belong to the group of asphalts.

CHAPTER III.

PHYSICAL AND PHYSIOLOGICAL PROPERTIES OF PETROLEUM.

PETROLEUM is oily, thinly- to thickly-fluid, seldom water-clear (rock oil, naphtha) or yellow, mostly brown to black, and, according to its color, more or less transparent.

Mineral tar or maltha is viscous, gummy, black or brown-black, and can be drawn into threads.

Both have an unctuous feel and a fatty lustre.

Density. While mineral tar has a density of 0.9 to 1.0, that of petroleum varies between 0.73 and 0.97 (from Terra di Lavore). As a rule light-colored oils are specifically lighter than dark oils.

B. Redwood has made a series of determinations of densities, which he gives in his pamphlet[1] in chronological order. By grouping, however, the figures of his table according to the density, the connection between the latter and the color will be immediately recognized, though the samples are derived from the remotest regions. The following table shows that, generally speaking, the density is less the lighter the oil is.

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[1] Cantor Lectures on Petroleum and its Products, 1886.

Density.	Color.	Odor, etc.	Place of Derivation.
0.777,	Straw-yellow.	Strong, disagreeable.	Persia.
0.787,	Straw-yellow,	Agreeable.	Near Milan (Italy).
0.810,	Reddish-brown.	——	Bradford (Pennsylvania).
0.818,	Reddish-brown.	Slight, agreeable.	Mud volcano Kyouk Phyon (Burmah).
0.828,	Brownish.	Slight.	New Zealand.
0.829,	Amber-color.	Agreeable.	India.
0.835,	Dark brown.	Slight, agreeable.	East Borongo (Arakan).
0.836,	Dark reddish-brown.	Slight, agreeable.	Russia.
0.843,	Dark brown.	Slight, agreeable.	Hanover.
0.852,	Dark red brown.	Slight.	South America.
0.865,	Dark brown.	Acrid.	Canada.
0.866,	Dark brown.	Slight, agreeable.	Minbyin (Burmah).
0.888,	Chestnut-brown.	Slight, agreeable.	West Baranga (Burmah)
0.900,	Dark brown.	Scarcely perceptible, somewhat viscous.	South America.
0.910,	Black.	Disagreeable.	Wyoming (U. S).
0.913,	Brownish-black.	Disagreeable.	Oelheim (Hanover).
0.933,	Dark brown.	Slight, agreeable, viscous.	Assam (India).
0.935,	Deep dark brown.	Viscous.	India.
0.942,	Brownish black.	Very slight, viscous.	Russia.
0.945,	Black.	Disagreeable.	Wyoming (U. S).
0.957,	Black.	Tarry.	Barbados (Central America).

In the different petroleum regions the density varies as follows:

Region.	Density.			Author.
	From	To	Average.	
Galicia,	0.779 (Klenczany).	0.902 (Harklowa).	——	Nawratil.
West Galicia,	0.762 (Klenczany).	0.910 (Harklowa).	——	Strippelmann.
East Galicia,	0.750 (Ropianka).	0.950 (Plowce).	——	
Wallachia,	0.80	0.82	0.81.	Olszewski.
Moldavia,	0.84	0.86	0.85.	
Hanover,	——	0.940 (Wietze).	——	Kraemer.
Baku,	0.780	0.890	0.868.	Gulischambaroff.
Canada,	0.8484	0.8750	0.8617.	——
Pennsylvania,	0.757	0.875	0.8045.	Sadtler.

The density of petroleum sometimes varies considerably in in the same region within narrow limits. Thus Dr. Kraemer mentions that at Oelheim (Hanover) two borings of nearly the same depth and at a distance of only 65 feet from each other yielded petroleum of 0.88 and 0.905. One and the same bed nearly always gives in the neighborhood of the outcrop an inferior oil of greater density than deeper down. In Pennsylvania, where there are three oil beds, one below the other, the oil also becomes specifically lighter with an increasing depth.

Thus:—

1st oil sand (upper) 0.8750 to 0.8484.

2d oil sand (middle) 0.8235.

3d oil sand (lower) 0.800 to 0.7777.

The vertical distance from the first to the third oil sand is about 250 feet.

As a rule the specifically lighter oils furnish a greater yield of illuminating oil, though exceptions have been known. Thus Nawratil's investigations of Galician oils proved that the quantity of illuminating oil (distillate of from 302° to 572° F.) is greatest (50.4 per cent.) with a density of 0.83, and decreases with specifically heavier as well as specifically lighter crude oils; with a density of 0.90 it amounts to 28 or 29 per cent., and with a density of 0.78 to 34 per cent. However from this decrease no constant relation between density and yield of illuminating oil can be recognized.

The density of petroleum also does not furnish a sure clue to its content of paraffin, though, as a rule, the latter increases with the density.

In the practice the density of petroleum is generally determined by means of the aerometer, and indicated by degrees Baumé (°B.).

The following table of equivalence may be acceptable to the reader:—

Table of the Specific Gravity corresponding to each degree of Baumé's hydrometer, also the number of Pounds contained in one United States Gallon at 60° F.

Baumé	Specific gravity.	In one gallon.	Baumé	Specific gravity.	In one gallon.	Baumé	Specific gravity.	In one gallon.
Deg.	Deg.	Pounds.	Deg.	Deg.	Pounds.	Deg.	Deg.	Pounds.
10	1.0000	8.83	32	0.8641	7.20	54	0.7608	6.34
11	0.9929	8.27	33	0.8588	7.15	55	0.7567	6.30
12	0.9859	8.21	34	0.8536	7.11	56	0.7526	6.27
13	0.9790	8.16	35	0.8484	7.07	57	0.7486	6.24
14	0.9722	8.10	36	0.8433	7.03	58	0.7446	6.20
15	0.9655	8.04	37	0.8383	6.98	59	0.7407	6.17
16	0.9589	7.99	38	0.8333	6.94	60	0.7368	6.14
17	0.9523	7.93	39	0.8284	6.90	61	0.7329	6.11
18	0.9459	7.88	40	0.8235	6.86	62	0.7290	6.07
19	0.9395	7.83	41	0.8187	6.82	63	0.7253	6.04
20	0.9333	7.78	42	0.8139	6.78	64	0.7216	6.01
21	0.9271	7.72	43	0.8092	6.74	65	0.7179	5.98
22	0.9210	7.67	44	0.8045	6.70	66	0.7142	5.95
23	0.9150	7.62	45	0.8000	6.66	67	0.7106	5.92
24	0.9090	7.57	46	0.7954	6.63	68	0.7070	5.89
25	0.9032	7.53	47	0.7909	6.59	69	0.7035	5.86
26	0.8974	7.48	48	0.7865	6.55	70	0.7000	5.83
27	0.8917	7.43	49	0.7821	6.52	75	0.6829	5.69
28	0.8860	7.38	50	0.7777	6.48	80	0.6666	5.55
29	0.8805	7.34	51	0.7734	6.44	85	0.6511	5.42
30	0.8750	7.29	52	0.7692	6.41	90	0.6363	5.30
31	0.8695	7.24	53	0.7650	6.37	95	0.6222	5.18

Memoranda.

One United States gallon of pure water=231 cubic inches, contains 58,318 grains (or 3779.031 grammes)=8.331 pounds avoirdupois.

One imperial gallon of pure water=277.276 cubic inches, contains 70,000 grains (or 4536.029 grammes)=10 pounds avoirdupois.

One cubic foot of pure water at 60° F. contains 1,000 ounces=62.5 pounds avoirdupois.

To reduce imperial gallons to United States gallons, divide by 1.2.

To reduce United States gallons to imperial gallons, multiply by 1.2.

To reduce United States gallons to cubic feet, divide by 7.5.

To reduce cubic feet to United States gallons, multiply by 7.5.

To find the number of pounds avoirdupois in one cubic foot of any substance, multiply its specific gravity by 62.5.

To find the degree Baumé corresponding to any specific gravity:

$$\frac{140}{\text{sp. gr.}} - 130 = B^{\circ}$$

To find the specific gravity corresponding to any degree Baumé:

$$\frac{140}{130 + B^{\circ}} = \text{sp. gr.}$$

Since the volume changes according to the temperature, the temperature at which the density has been found should be placed alongside the density-figure. With the assistance of the expansion coefficient the density-figures for other temperatures can then also be determined. The densities are generally referred to 14° R.=17.5° C. For the practice sufficiently accurate results are obtained by taking 0.001 change of density for 1° R., the correction being added with oil of a temperature over 14° R., and subtracted with oil below 14° R. Thus for instance the density of a crude oil of 20° R. has been found as 42° B.=0.8139, which corrected would be (6×0.001=0.006) 0.8145.

These corrections are of importance, especially in the refining process, for the accurate determination of the commencement and ending of the kerosene fraction.

The expansion coefficient varies, according to investigations by W. Markownikoff and W. Ogloblin, with petroleum from different regions, it being in an inverse ratio to the density. This agrees also with experiments made with North American oils, which gave the following results:

Density at 15° C. (59° F.)	Expansion coefficient for every 1° C.
Below 0.700	0.00090
0.700 to 0.750	0.00085
0.750 to 0.800	0.00080
0.800 to 0.815	0.00070
Above 0.815	0.00065

In Pennsylvania the oils of various densities run into one tank, the result being an average oil; hence it is customary to allow an expansion coefficient of 0.00072 for 1° C. (0.004 for 10° F.)

From the subjoined table, compiled by Dr. H. Gintl, the above-mentioned relation between the expansion coefficient and the density may also be recognized:

REGION.	Density.		Expansion coefficient.
	0° C.	50° C.	
West Virginia (White Oak)	0.873	0.853	0.00046
“ (Burning Spring)	0.841	0.808	0.00081
Pennsylvania (Oil Creek)	0.816	0.784	0.00082
Canada (de Vest)	0.870	0.851	0.00044
Burmah (Rangoon)	0.892	0.861	0.00072
Russia (Baku)	0.954	0.920	0.00071
East Galicia	0.870	0.836	0.00081
West Galicia	0.855	0.852	0.00077
Roumania (Plojesti I.)	0.862	0.829	0.00080
“ (Plojesti II.)	0.901	0.869	0.00073
Italy (Parma, Neviano de Rossi)	0.809	0.772	0.00096
Hanover (Oberg)	0.944	0.914	0.00066
Alsace (Pechelbronn)	0.912	0.880	0.00073
France (St. Gabian)	0.894	0.861	0.00069
Zante	0.952	0.921	0.00067

A detailed table of expansion of West Virginia Natural Oils has been calculated by J. Schubert.[1]

For practical purposes a knowledge of the expansion coefficient is of importance, especially for calculating the so-called expansion—spaces in the packages in which the oil is shipped.

Optical properties. Color, transparency and lustre have previously been mentioned. It remains only to be stated that water-clear petroleum is of rare occurrence, for instance, in Persia and at Smith's Ferry, Pennsylvania. Transparent oils are distinguished by strong refraction of light and possess a blue flourescence, and the dark varieties a green fluorescence, which is frequently quite intense.

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[1] S. F. Peckham, Report on Petroleum, p. 111.

As far as at present known, petroleum does not turn the plane of polarization of a ray of light.

The action of light upon the color of petroleum deserves also to be mentioned, that of white, blue, and green light being strongest, and that of yellow, red and black, weakest. By the action of light ozone is formed, which frequently appears by an exposure of a few hours only. By this change the illuminating power of the oil is reduced.

Volatilization. By exposure to the air petroleum volatilizes partially, whereby it becomes denser, less mobile, finally viscous or solid. This explains the fact previously mentioned that petroleum from a greater depth is specifically lighter, and also that in the neighborhood of the outcrop it is frequently so viscous that it can be directly used as wagon grease, maltha or mineral tar having formerly been frequently employed for that purpose. Hence the only sure conclusion which can be drawn from the quality of the outcrop is that at a greater depth oil specifically lighter and, as a rule, richer in illuminating oil, may be found.

The volatility of petroleum renders its storage in tight and well-closed vessels necessary, and to avoid losses it should not be stored for a long time. In regard to this Nawratil has made some interesting experiments with a thinly-fluid crude oil from Blich near Gorlice, West Galicia, the specific gravity of which, fresh from the well, was 0.800. Kept in an open porcelain dish at the ordinary temperature for one month, its specific gravity was 0.895, and it was thickly-fluid. The fresh oil contained 9.3 per cent. light oils (distillate up to 212° F.,) while after several days' transport in a tight oak barrel it contained only 0.5 per cent., of these constituents. Hence there was a considerable loss, especially for the producer of the crude oil.

The gases evolving first from petroleum are very inflammable and mixed with air form an explosive combination. Hence great precaution against fire has to be used near the wells as well as in the store-rooms.

The great volatility of certain constituents of petroleum also explains the difference in chemical analyses of petroleum from the same well, if the greatest care has not been exercised in taking and preserving the samples.

According to experiments by Dr. H. Gintl regarding the volatility of crude oil at the ordinary temperature of a room (61° F.,) the evaporation amounted:

In 1 week to	25 per cent.
" 2 weeks "	30.6 "
" 3 " "	33.6 "
" 4 " "	34.3 "
" 5 " "	34.7 "
" 6 " "	35.0 "
" 7 " "	— "

Petroleum volatilizes the more readily the richer in hydrogen and the poorer in carbon it is.

Boiling point. With an increasing temperature vaporization becomes of course greater, until at a certain temperature gas bubbles appear, and at a still higher temperature the oil commences to boil. This boiling point varies and for most American crude oils lies, according to N. Tate, between 104° and 122° F. On the other hand, according to Balley and Schwarzenbach, Pennsylvania crude oil evolves gas bubbles at 89.6° F., and commences to boil at 134.6° F., while for Canadian crude oil these values are about 4° higher. With both varieties of oil, the difference in the two above-mentioned temperatures is 77° F.

Crude oil from	Boiling point at ° F.	Specific gravity at 62.6° F.
Pennsylvania I.	179.6	0.8175
" II.	165.2	0.8010
Sloboda (Galicia)	194.0	0.8235
Bibicybat (Baku)	195.8	0.8590
Balachani (Baku)	221.0	0.8710
Pechelbronn (Alsace)	275.0	0.9075
Oelheim (Hanover)	338.0	0.8990

However, according to Engler, the boiling points of Pennsylvania crude oils are much higher, and are given together with those of other varieties of petroleum in the table on preceding page.

The boiling point rises with the progress of vaporization, and hence is in a reverse ratio to the density. After storing there will, therefore, be considerable variations in such determinations of a petroleum from the same origin.

Physiological properties. Petroleum has an aromatic odor disagreeable to many persons. Some varieties, for instance, Canadian, South American and West Indian crude oils, have, however, an offensive odor which appears to be due to a small content of sulphur.

Water shaken with crude oil acquires the odor of the latter.

The vapors arising from petroleum are in some regions, for instance in Pennsylvania, considered beneficial for persons suffering from lung troubles, but, according to Poincaré, workmen employed in distilling crude oil complain frequently of irritation of the mucous membrane of the nose. Investigations by Poincaré showed that guinea-pigs kept in such an atmosphere died in one or two years, and rabbits suffered from somnolence and loss of appetite.

CHAPTER IV.

CHEMICAL CONSTITUTION OF PETROLEUM.

PETROLEUM consists essentially of various hydrocarbons belonging mostly to the methane series ($C_nH_{2n} + 2$) or also corresponding to the type C_nH_{2n}, both groups being indifferent to mineral acids. In the oils of one region there is a decided preponderance of the members of the one or other type, in addition to which there frequently occur in very small quantities members of the aromatic series, and here and there combinations of nitrogen and oxygen. The inorganic portion is also exceedingly small.

Petroleum has been frequently subjected to analysis. It has been stated that gold in small quantities has been found in the ashes of crude petroleum and in the residuum of petroleum stills. Sulphur exists in small and varying proportions in almost every variety. It is frequently noticed in the exit pipe conveying the gas from the stills in refineries, in such quantities as sometimes to effectually close the pipe. Metallic arsenic also, it is said, has been noticed to condense in the goosenecks of the retorts in which the bituminous limestones of Lobsan are distilled.

In the subjoined table most of the elementary analyses known are given, for which we are chiefly indebted to St. Claire-Deville (D.), Boussingault (Bo.), Baumhauer (B.), Gintl (G.), S. F. Peckham (P.), Gulischambaroff (Gn.), Markownikoff and Oglobin (M. O.)

Wells of the same region in close vicinity to one another frequently yield entirely different oils.

The subjoined table shows that Peckham and Markownikoff and Oglobin could not establish a content of oxygen, while the former found nitrogen.

Locality.	Specific gravity at 0° C.	C.	H.	O.	N.	Analyst.	Remarks.
Galicia, West	0.855	85.3	12.6	2.1	—	D.	
" East	0.870	82.2	12.1	5.7	—	D.	
Hanover, Odesse	0.892	80.4	12.7	6.9	—	D.	
" Oberg	0.944	84.4	11.5	4.1	—	D.	From a depth of 39 feet: gummy, transparent.
" Wietze	0.955	86.2	11.4	2.4	—	D.	
Alsace, Pechelbronn	0.892	86.1	12.7	1.2	—	D.	Black, gummy, liquid.
" "	0.968	85.6	9.6	4.6	—	D.	
" "	0.892	85.7	12.0	2.3	—	D.	
" "	—	88.3	11.1	1.1	—	D.	
" Schwabweiler	0.829	79.5	13.6	6.9	—	Bo.	
" "	0.820	85.5	14.2	0.3	—	G.	
" "	0.861	86.2	13.3	0.5	—	D.	
" "	—	88.7	12.6	0.4	—	D.	Bluish, fluorescent.
" †	0.912	86.9	11.8	1.3	—	D.	
France, St. Gabian	0.894	86.1	12.7	1.2	—	D.	Black, gummy.
Italy, Neviano de Rossi	0.809	81.9	12.5	5.6	—	D.	Amber color, very fluid: from pliocene clay.
" Sala	0.790	84.0	13.4	1.8	—	D.	Fluid, pale, fluorescent.
" Piedmont	0.919	86.4	12.2	1.4	—	D.	
Zante	0.952	82.6	11.8	5.6	—	D.	Black, fluid.
Roumania, Plojesti	0.770	82.6	12.5	4.9	—	D.	Black, gummy.
" "	0.901	83.0	12.2	4.8	—	D.	
Russia, Baku	0.954	85.3	11.6	3.1	—	G.	
" "	—	86.0	13.0	1.0	—	Gn.	Average of Baku oil.
" " Benkendorff's wells	—	80.5	13.35	—	—	MO.	Further: 0.064 Sand, 0.09 ash. O was established in distilling.
" "	—	87.1	13.22	—	—	MO.	
" "	—	86.89	13.18	—	—	MO.	
Circassia	0.950	85.3	11.6	3.1	—	D.	Black, gummy.
Burmah, Yenanyoung	0.874	83.8	12.7	3.5	—	D.	
Giava, Tjibodos Fanggah	0.770	83.6	14.0	2.4	—	D.	
Java, Rembang	0.923	87.1	12.0	0.9	—	B.	
China, Fu-chu-fu	0.860	83.5	12.9	3.6	—	D.	Fluid, slightly colored, fluorescent.
Canada, Bothwell	0.857	84.3	13.4	2.3	—	D.	From a depth of 606 feet.
" Petrolea	0.870	84.5	13.5	2.0	—	D.	" " 554 "
Pennsylvania, Oil Creek	0.730	82.0	14.8	3.2	—	D.	" " 656 "
"	0.880	84.9	13.7	1.4	—	D.	From Devonian sandstone.
Ohio	0.887	84.2	13.1	2.7	—	D.	Black, gummy.
" Mecca	—	86.316	13.071	—	0.2300	P.	
West Virginia	0.840	84.3	14.1	1.6	—	D.	From Devonian sandstone at a depth of 835 feet.
" "	0.857	83.2	13.2	3.6	—	D.	From a depth of 114 feet.
" "	0.897	83.6	12.9	3.5	—	D.	Greenish.
" " Scotia well	—	86.622	12.929	—	—	P.	
" " Cumberland	—	85.200	13.359	—	0.5400	P.	
California, Hayward Petroleum Co.	—	86.934	11.817	—	1.1095	P.	

Nitrogen.

This constituent was established by Peckham[1] not only in the oils mentioned in the table, but also in other California crude oils. He found in oils from

Pico Springs	1.0165 per cent.
Canada Lago	1.0855 "
Maltha Ojai Ranch	0.5645 "

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[1] Report Geol. Surv. California. Geology 2, 89.

That nitrogen does not exclusively occur in American oils, but also in other oils, and may have escaped the notice of some analysts, is proved by the fact that, according to Dr. Feodorwicz petroleum from Siary, West Galicia, contains ammonia, and St. Claire-Deville[1] established the presence of nitrogen in maltha from Pechelbronn, Alsace. Delesse[2] found 0.154 per cent. of this constituent in elaterite, and 0.256 per cent., in maltha from the Trinidad pitch lake. In elaterite from the Odin pit in Derbyshire and from Montrelais, Henry[3] found 0.15 and 0.10 per cent., nitrogen, and Strohmeyer[4] 0.66 per cent., in asphalt from Bentheim. Mr. Carnegie[5] reports that a gas well near Pittsburgh, Pennsylvania, immediately after being opened, threw out crystals of ammonium carbonate. Hence conclusions drawn as to the genesis of petroleum from the absence of nitrogen in it are no longer tenable, and the less so since the presence of nitrogen will probably be established in other crude oils as well as in American. Kraemer and Böttcher[6] have, however, failed to find it in German crude oils. In what combination nitrogen occurs in crude oil is not yet known, but it would seem that, together with carbon and hydrogen, it forms nitrophenols.

Oxygen and its Combinations.

(*Acids of petroleum.* $C_nH_{2n-2}O_2$, *and phenols.*)

The elementary analyses given above show a content of oxygen as high as 6.9 per cent. The correctness of such high figures is, however doubted by some, for instance, by Dr. Kraemer. But on the other hand, it may be said that petroleum, especially when heated, gradually absorbs oxygen from the air, and the high percentage may be due to the fact that the sample had for some time been exposed to the air and no longer corresponded with the fresh material, which was perhaps entirely free from oxygen. That petroleum as well as dif-

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[1] Comp. rend. 66, 442; 68, 485. [2] De l' Azote et des Matieres dans l'Ecorce Terrestre, pp. 172, 173. [3] Jour. d. Chim. med., 1825. [4] Neues Jahrb. f. M., 1862 833. [5] Iron and Steel Inst., 1885. [6] Ber. deutsch.-chem. Ges., 20, 595.

ferent distillates from mineral coal etc., readily absorb oxygen and then form the so-called acids of petroleum has been demonstrated, among others, by the investigations of E. Schaal, who proposed to use this property for technical purposes.[1]

It has been shown by experiments—among others also by Dr. Kraemer—that in petroleum in which the acid has been neutralized, acids are again formed by the absorption of oxygen, and, therefore, samples fresh from the wells intended for analysis should be well protected from the air.

The oxygen occurs especially in the acid and phenol-like combinations. The former ($C_{11}H_{20}O_2$) were first thoroughly investigated, particularly in the Roumanian oils, by Hell and Medinger who, however, did not succeed in definitely determining their constitution. For the establishment of the phenol, we are indebted to Markownikoff. The latter, with the assistance of Oglobin, established the presence of quite considerable quantities of oxygen in the distillates, as well as in the light and heavy crude oils of Baku. Generally speaking, they found that this constituent quantitatively increases with the specific gravity and the boiling point, so that in benzine it amounts only to about 0.79 per cent., but in the fractions of from 428° to 446° F. to 5.21 per cent. The oxygenated product obtained from the crude oil or its distillates, which were decomposed by the sulphuric acid, however without the possibility of establishing oxygenated sulpho-derivatives, are chiefly neutral, though of an acid character. Of the previously mentioned acids of petroleum, these investigators determined undecanaphthene acid ($C_9H_{19}CO_2H$) and dodecanaphthene acid ($C_{10}H_{21}CO_2H$), the latter being identical with that prepared by Hell and Medinger.

The Baku oil, which, on the whole contains only 0.2 per cent. acid (fatty and acetic acids) seemed to be poorer in this constituent than Roumanian and Galician crude oils.

Dr. Kraemer,[2] who especially investigated the German earth oils, found the content of acid in 1,000 cubic centimeters of

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[1] German patent No. 32,705.

[2] Sitzber. Ver. z. Bef. des Gewerbefleisses, 1885, 296.

crude oil expressed in cubic centimeters of normal acid, as follows:

From Tegernsee	5.20
From Alsace	14.20
From Oelheim	22.04

The latter quantity, based upon Hell's formula, would correspond to 0.5 per cent. of the crude oil. According to later researches, the content of acid in oil from Alsace amounts to 0.136 per cent. and in oil from Oelheim to 0.081 per cent. From a fraction boiling at a lower temperature an acid of the formula $C_{13}H_{24}O_2$ was separated, and from one boiling at a higher temperature an acid of the formula $C_{16}H_{28}O_2$.[1] The separated acids are colorless oily fluids boiling at about 572° F. and without doubt are identical with those examined by Hell and Medinger, and Markownikoff and Oglobin. Dr. Kraemer arrives at the conclusion that they belong to the ordinary fatty acids, and are not poorer by 2H, as was supposed by the other investigators named. Besides acids and phenols, Dr. Kraemer also succeeded in determining other oxygen combinations in German crude oil.

The absorption of oxygen by the distillates of crude oil also explain the well-known fact that an illuminating oil loses burning power by being for some time exposed to the air.

Although the acids of petroleum have the same composition as the fatty acids, they vary very much in their properties. According to Dr. Kraemer, the former are carbonic acids of the naphthenes.

Oxygen has also been established in some mineral waxes belonging to the paraffins, Johnston having found in an elaterite up to 3.8 per cent.

Pebal and Freund[2] determined phenols in Galician crude oil, Markownikoff and Oglobin[3] in Caucasian, and Kraemer and Böttcher[4] in German crude oils.

The solvent action exerted by petroleum upon metals is

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[1] Sitzb. Ver. z. Bef. d. Gewerbefleisses, 1886, 553.

[2] Annal. d. Chem. u. Pharm., 115, 21.

[3] Ver. deutsch. Chem. Ges., 19, 349.

[4] Ibid., 20, 596.

dependent on the presence of free acids. Dr. Stevenson Macadam[1] concludes that paraffin oil dissolves considerable quantities of lead and zinc. Engler refers to Dr. Macadam's experiments, and maintains that lead, tin, zinc, copper, magnesium and sodium, are attacked by petroleum only under the influence of air or oxygen, when acid compounds are formed. Petroleum washed in caustic alkalies and distilled in carbonic acid has no solvent action on metals.

Sulphur.

In the table of elementary analyses, it has been mentioned that Markownikoff and Oglobin found 0.064 per cent. of sulphur in the crude oil from the Benkendorff well near Baku. O. Hesse has shown the presence of sulphur in Syrian and American asphalt to the amount of 8.78 and 10.85 per cent. respectively, and one sample of California petroleum examined by F. S. Peckham contained a sufficient amount of sulphur to form a deposit in the neck of the retort.[2] An oil from the Kirghish steppe is said to contain 1.87 per cent. of sulphur and to be purified with great difficulty. It is well known that Canadian oil contains sulphur. Nawratil[3] found sulphuretted hydrogen in crude oil from Pagorzyn, Galicia, while Dr. Kraemer established its presence in German crude oils with the exception of Tegernsee oil, and supposes that it is contained in the oil in the form of thiophene-like combination. The petroleum of Terra di Lavore (Italy)[4] contains as much as 1.30 per cent. sulphur. The Pennsylvania and West Virginia oils are remarkably free from sulphur. Böttger separated from a distillate of Pennsylvania crude oil, boiling between 131° and 149° F., a white body of the composition $C_5H_{10}SO_3$.

Even very small quantities of sulphur, for instance, like those contained in the German crude oils, impart to the oil a very disagreeable odor, which can be removed from the distillates only with great difficulty. From this the conclusion may be

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[1] Stowell's Petroleum Report, 1878, No. I. [2] Report on Petroleum. [3] Dingl. pol. Jour., 246, 423. [4] Engler, Dingler pol. Jour., 250, 316.

drawn that the sulphur is not fixed by gypsum, as has been supposed by some, but by volatile combinations.

Inorganic Admixtures.

These are always present, but only in very minute quantities. N. Tate[1] has shown the presence of phosphorus and arsenic in various crude oils. Arsenic is also said to be present in bitumen from Lobsan, Alsace.[2] Markownikoff and Oglobin[3] determined the average content of ash of Benkendorff petroleum (Baku) as 0.09 per cent., and found lime and iron predominating in it; further, alumina and copper, as well as traces of silver. Generally speaking, these results agree with those of Lidow,[4] according to whom the content of ash of petroleum amounts to 0.11 per cent. The analysis of the ash gave

Ferric oxide	76.71	per cent.
Lime	5.48	"
Insoluble matter	16.07	"
	——	"
	98.26	"

The large content of iron leads to the conclusion that it was not present originally but is formed later on—perhaps during storage in iron vessels—by solution in the acids formed by the action of the air.

According to Mr. John Tunbridge, gold may be found in the ashes of crude oil and in the refuse of petroleum stills.

The Hydrocarbons.

It may here be mentioned that a complete quantitative analysis of petroleum has thus far not been made, and therefore only the series of hydrocarbons present can be given, as well as those which predominate and, qualitatively, the separate members of each series.

The following series may be designated as occurring in petroleum, the most predominant being indicated by larger type:

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[1] Hirzel. Steinoel und seine Producte. p. 52.
[2] Ann. d. Mines (4) 19, 669.
[3] Chem. Centrabl. 1881, 609.
[4] Jour. Russ. phys. chem. Ges., 1882, 323.

1. $C_nH_{2n} - 2$.
2. C_nH_{2n}.
3. C_nH_{2n-2}
4. C_nH_{2n-4}
5. C_nH_{2n-6}.

$C_nH_{2n}-8$.
C_nH_{2n-10}.
C_nH_{2n-12}.

I. *Methane (Marsh Gas or Paraffin).*

Series: $C_nH_{2n}-2$.

(Saturated Hydrocarbons.)

In many crude oils, for instance in those of Galicia, Germany, Pennsylvania, Canada, Zarskiji Kolodzi (Government Tiflis), the members of this series form the most essential part. Schorlemmer,[1] in England, Pelouze and Cabours,[2] in France, C. M. Warren,[3] F. H. Storer[3] and C. F. Chandler,[4] in this country, Lackowicz,[5] in Austria, and others, have published researches on this series, especially as regards its importance for the constitution of crude oil.

At the ordinary temperature the methane series is represented in the crude oil by gaseous, fluid and solid members, the former as well as the latter being capable of dissolving in the fluid. The gaseous members separate from this solution when the temperature is somewhat increased, or the pressure decreased, and the solid members when the temperature is decreased.

With the molecular attraction, the value for *n* in the general formula $C_nH_{2n}+2$ rises as well as the boiling point; hence they are smallest in the gaseous, and greatest in the solid members.

According to Schorlemmer and Chandler, the following com-

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[1] Proc. Manchester Phil. Soc., March 11, 1863, etc.; Jour. Chem. Soc. of London, 28, 3011, etc.; London Chem. News, 11, 225; Trans. Royal Soc., (5) 14, 168; Ann. d. Chemie u. Pharm., 127, 311. [2] Ann. Chim. et Phys. (4) 1, 5, Compt. rend., liv. 1, 56, 124; 54, 505; 57, 62. [3] Mem. Am. Acad. of Arts and Sciences (N. S.) 9, 10; Am. Jour. of Science (2) 39, 327; 40; 41; 45, 262; 46. [4] Am. Chemist, 1872, No. 11; 1876, No. 77. [5] Ber. deutsch. chem. Ges., 14, 1620.

binations of the methane series have thus far been determined in Pennsylvania crude oil.

Name.	Formula ($C_nH_{2n}+2$).	C.	H.	Boiling point °C.	Specific gravity.
Gaseous:					
Methane	CH_4	75.00	25.00	gas	0.559
Ethane[1]	C_2H_6	80.00	20.00	"	1.036
Propane[1]	C_3H_8	81.81	18.19	"	
Butane	C_4H_{10}	82.80	17.20	1	0.600
Fluid:					
Pentane	C_5H_{12}	83.33	16.67	30	0.628
Hexane	C_6H_{14}	83.72	16.28	69	0.664
Heptane[2]	C_7H_{16}	84.00	16.00	97.5	0.669
Octane	C_8H_{18}	84.21	15.79	125	0.703
Nonane	C_9H_{20}	84.38	15.62	136	0.741
Decane	$C_{10}H_{22}$	84.51	15.49	158	0.757
Endecane	$C_{11}H_{24}$	84.61	15.39	182	0.765
Dodecane	$C_{12}H_{26}$	84.70	15.30	198	0.776
Tridecane	$C_{13}H_{28}$	84.78	15.22	216	0.792
Tetradecane	$C_{14}H_{30}$	84.85	15.15	238	—
Pentadecane	$C_{15}H_{32}$	84.90	15.10	258	—
Hekdecane	$C_{16}H_{34}$	84.94	15.06	280	—
Octodecane	$C_{18}H_{38}$	85.04	14.96	—	—
?	$C_{20}H_{42}$	85.11	14.89	—	—
?	$C_{23}H_{48}$	85.18	14.82	—	—
?	$C_{25}H_{52}$	85.23	14.77	—	—
Solid:					
Paraffin (myricyl)	$C_{27}H_{56}$	85.26	14.74	—	—
Paraffin (ceryl)	$C_{30}H_{62}$	85.31	14.69	370	—

From the normal members given in the above table, Schorlemmer succeeded in isolating from American crude oil the following isomerides, which, with the same composition and specific gravity as the former, show a slight difference in the boiling point:

	Formula.	Boiling point °C.
Isopentane	C_5H_{12}	30
Isohextane	C_6H_{14}	61
Isoheptane	C_7H_{16}	91
Isooctane	C_8H_{18}	118

It may be mentioned that in American illuminating oil, the

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[1] First discovered by Ronalds. [2] The heptanes of Pennsylvania oil were thoroughly investigated by Morgan. Ann. d. Chem. u. Pharm., 117, 304.

members C_7H_{16} to $C_{12}H_{26}$ inclusive are present, and, according to Biel, also $C_{14}H_{30}$ and $C_{16}H_{34}$.

In Galician crude oil the members of the methane series predominate, according to Lackowicz; he isolated pentane and isopentane (present in the proportion of 1 : 3) normal and secondary hexanes, heptane, nonane and decane. Beilstein and Kurbatoff showed the presence of pentane, hexane and heptane in the readily liquefying portions of the crude oil from Zarskiji Kolodzi (Government Tiflis), the oil, unlike the Baku oil, consisting chiefly of members of the methane series. According to Dr. Kraemer, the distillates of German crude oil up to 302° F. belong chiefly to the methane series, which series, according to C. F. Chandler, is entirely absent in Italian oil.

Warren also succeeded in isolating isomerides of the methane series in Pennsylvania crude oils. The results of these very careful investigations are given below, the specific gravities referring to 0°C.

I. NAPHTHA GROUP.				II. BETA-NAPHTHA GROUP.			
Formula.	Boiling Point °C.	Specific Gravity.	Vapor Density.	Formula.	Boiling Point °C.	Specific Gravity.	Vapor Density.
C_4H_{10}	?	0.600[1]	2.110[1]	C_4H_{10}	8 to 9	0.611	
C_5H_{12}	30.2	0.640	2.538	C_5H_{12}	37.0	0.645	2.514
C_6H_{14}	61.3	0.676	3.053	C_6H_{14}	68.5	0.689	3.038
C_7H_{16}	90.4	0.718	3.547	C_7H_{16}	98.1	0.730	3.551
C_8H_{18}	119.5	0.737	3.992	C_8H_{18}	127.6	0.752	3.990
C_9H_{20}	150.8	0.756	4.600				

This table shows the boiling points of the analogous members of the II group to be 7° to 8° C. higher than those of I, and, that in the one as well in the other, with one atom of carbon the boiling point is increased 30° C. This law has been par-

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[1] According to Ronalds, Jour. Chem. Soc. of London (2), 3, 54.—Bull. Soc. Chim., 1866, 135; formerly also established by Pelouze and Cahours, who gave the boiling point somewhat above 0° C.—Ann. Chim. et. Phys. (4), 1, 5.

tially confirmed only as regards the isomeric members by the above-mentioned investigations of Schorlemmer. Nevertheless Warren's careful investigations deserve due credit.

The determinations by Pelouze and Cahours, of the boiling points, specific gravities and vapor densities, are, according to Warren, not to be relied on, the methods used by them having not been sufficiently accurate.

The presence of paraffins in petroleum has long been known. For a time there existed a doubt whether they should not be classed with the ethyl series (C_nH_{2n}), whose content of carbon and hydrogen they closely approach in consequence of the high value for *n*, and it has only in recent times been finally decided to place them in the methane series.

Reichenbach, after having discovered, in 1824, paraffin in coal tar, established its presence ten years later in petroleum.[1] Buchner separated it in 1820 from the petroleum of Tegernsee, but its identity was first established later on (1835), by V. Kobell. Further investigations also showed its presence in the petroleum of Baku and Amiano (Parma). Rangoon oil (Burmah), which is of the consistency of goose-grease, and possesses a slight, not disagreeable odor, and a greenish brown color, contains according to Gregory, Warren de la Rue and H. Müller[2] up to 11 per cent. paraffin, and Java oil, according to Bleckrode,[3] even up to 40 per cent. Paraffin, according to Perutz,[4] occurs also in the petroleum from Taiakeiana (District Porbolingo, East India), but the latter determinations require further confirmation. Galician oil contains generally 3 to 5 and up to 11 per cent. paraffin, Alsace oil, according to Kraemer, 0.5 per cent., but Oelheim (Hanover) oil only inconsiderable quantities of it. On the other hand, the Sehnde oil (Hanover) contains, according to Bussenius and Eisenstueck, considerable quantities of it, as well as the oil from Turcomania and Central Africa, according to Livingstone.

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[1] Schweiger's Jour., 9, 133.

[2] Vohl found 6.071 per cent. paraffin and 4.605 per cent. asphalt.

[3] Wagner, Hand-buch der Chem. Technologie, 12 Aufl., 970.

[4] Industrie der Min. Oele, 88.

Dr. H. Gintl[1] gives the content of paraffin in the following oils: Bukowina, 12.4 per cent.; Boryslaw (Galicia), 6.07; Red Sea, 5.2; Baku, up to 5.06;[2] Canada, according to N. Tate, 3.0; Roumania, 2.23. In Galicia, it is claimed, the eocene oils have been found free from paraffin, which is present only in oils from cretaceous and miocene strata.

For some time it was questioned whether paraffin was a constituent of American oils, but Zuirek found up to 2 per cent., in it, N. Tate between 2 and 3 per cent., and Bolley and Schwarzenbach 0.7 per cent., in Pennsylvania crude oil, while according to Kerl[3] some New York oils contain as much as 2.5 per cent. American paraffins have also been studied by Goldstein,[4] Stenhouse,[5] Odling,[6] Herman,[7] Morgan,[8] Schorlemmer[9] and others.

Notwithstanding that paraffin has been known for a long time, its manufacture on a large scale was commenced only in 1856. The product thus obtained does not possess a constant composition, it being a mixture of various solid and highest members of the methane series. For this reason the melting point of paraffin varies very much; the higher the melting point, the more valuable the paraffin is. Melting point and specific gravity stand in direct, approximately arithmetical proportion to one another.

Schorlemmer considers paraffin a mixture of primary and secondary hydrocarbons, while Morgan discusses the possibility of the presence of even a tertiary series. In consequence of this extraordinary diversity, the separate paraffin-individuals are difficult to separate by fractional distillation.

Solid paraffins are white, waxy, crystalline fatty substances, without odor or taste. Their specific gravities vary between 0.869 and 0.943, and their melting points between 100.4° and 141.8° F., the latter, according to Anderson, being that of

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[1] Kick-Gintl. Techn. Wörterbuch, 6, 618. [2] According to Rossmässler, most Baku oils contain little or no paraffin. [3] Kerl-Muspratt, Techn. Chemie, 3. Aufl. 5. 987. [4] Ber. deutsch. Chem. Ges. 12. 689. Jour. Chem. Soc. of London, 36. 765. [5] Bull. Soc. Chim. de Paris, 1878, 189. [6] Proc. Royal Inst., 8, 16. [7] Rep. B. A. A. S., 1875. [8] Ann. Chem. Pharm., 177. 312. [9] Jour. Chem. Soc. of London, 28. 3011.

Rangoon paraffins. When heated for several days the paraffins absorb oxygen and turn brown. They are insoluble in water, but readily soluble in ether, petroleum, oils of turpentine and olive, photogen, benzol, chloroform and disulphide of carbon; boiling absolute alcohol dissolves about 3 per cent. From some solutions they separate in the form of a jelly and from others in a crystalline state. At the ordinary temperature they are not attacked by alkalies, acids and chlorine; the latter, however, attacks them after acting upon them for some time at a higher temperature; bromine and sulphur act in a similar manner. The paraffins cannot be saponified like the fats; when melted with them they separate on cooling. However, when melted together with wax, stearic and palmitic acids and resins, intimate mixtures are formed.

For some time it was questioned whether the paraffins were originally present in the crude oil or whether they were formed during distillation, since the latter, considering the high temperature at which the paraffins pass over, might be destructive. However, Sadtler[1] several years ago called attention to semi-solid mixtures rich in paraffin which deposited in the derricks, pipes, etc., these observations having been confirmed and augmented by S. F. Peckham, especially in the Bradford district, so that at present there can be no doubt of the paraffins being originally present in the crude oil. Such observations may be further augmented by every one having to do with petroleum, as may be shown by the following example. If the amber-colored petroleum of Klenczany (Galicia), which is rich in vaseline, be allowed to stand a few months at the ordinary temperature, a solid mass remains behind, which consists chiefly of paraffin closely resembling the mineral wax of Boryslaw (Galicia).

Even within recent times the assertion has been made that the paraffins are originally present in an amorphous state in crude oils, and acquire a crystalline structure only by distillation. However, most investigators do not agree with this opinion, and as a proof to the contrary a nearly white, partially

[1] Am. Chem. Jour., 1, 30.

transparent paraffin may be mentioned which was found in a fine-grained sandstone, together with petroleum, near Soszmezo, (Transylvania), and in a polarized light plainly shows the twin-striation. The gray to greenish-gray sandstone does not show the slightest action of a higher temperature, and for geological reasons, the action of a heat of about 698° F. (the boiling point of $C_{30}H_{62}$) cannot be supposed.

Paraffins are also found fossil, there being an entire series of organic compounds which consist either exclusively of them or chiefly of mixtures of them. Their melting points, which in the subjoined enumeration are added in brackets, vary according to the predominating paraffin-individual or according to the other admixtures. Of these organic compounds may be mentioned: Urphelite (melting point 102.2° F.); hatchetine (114.8° to 116.6° F.); ozocerite (132.8° to 149° F.); chrismatite (131° to 140° F.); zietrisikite (179° to 194° F.); scheererite (nearly 212° C.) Of these the ozocerite or fossil wax is of considerable technical importance, it being obtained from several thousand shafts in Boryslaw (Galicia). It also occurs in this country in the Sanpete valley in Utah.

2. *Ethylene (Olefine) Type:* C_nH_{2n}. *(Constant quantities of* $C = 87.51$, $H = 14.29$.)

A. *Actual Ethylenes (Olefines).*

It has previously been mentioned that many crude oils consist chiefly of methanes, and that the presence of the latter can be established with absolute certainty. Such, however, is not the case as regards our knowledge of the presence of the ethylenes. To be sure where C_nH_2 preponderates in petroleum, as in the Baku region, the composition agrees with the members of the ethylene series; but not the chemical behavior, and, therefore, the ethylenes will have to be separately considered.

Although in several crude oils the presence of ethylenes has been established, it seems that quantitatively they become chiefly of importance in the heavier oils only. In small quantities they were found by Tuttschew[1] in Galician oil, by Beil-

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[1] Jour. f. prakt. Chem., 93, 394.

stein and Kurbatoff in oil from Zarskiji Kolodzi (Government Tiflis), and by Warren[1] and Chandler in Pennsylvania crude oil; in larger quantities by C. F. Chandler, S. F. Peckham in California crude oil, and by Warren de la Rue and H. Müller, especially in maltha from Rangoon, they preponderating in the latter.

According to Lackowicz the ethylenes are wanting in Galician petroleum, and he conjectures that where found they are formed by distillation. Dr. Kraemer also points out that by pressure and heat the components of petroleum, especially those boiling at a high temperature, are decomposed to aromatic bodies, and that by gasification, hydrocarbons of the ethylene series may be formed. Schorlemmer, and partially also C. F. Chandler, have shown in American crude oil the presence of the following members of the ethylene series, which may be gaseous, fluid or solid at the ordinary temperature:

NAME.	Formula C_nH_{2n}.	Boiling Point °C.	Specific Gravity.
Gaseous:			
Ethylene	C_2H_4	Gas	0.978
Propylene	C_3H_6	−18	—
Butylene	C_4H_8	+3	—
Fluid:			
Amylene	C_5H_{10}	35	0.663
Hexylene.	C_6H_{12}	69	—
Heptylene	C_7H_{14}	95	—
Octylene	C_8H_{16}	104	—
Nonylene	C_9H_{18}	140	—
Decatylene	$C_{10}H_{20}$	160	—
Endecatylene	$C_{11}H_{22}$	195	0.782
Dodecatylene	$C_{12}H_{24}$	216	—
Decatritylene	$C_{13}H_{26}$	235	0.791
Cetene	$C_{16}H_{32}$	275	—
....	$C_{20}H_{40}$	—	—
Solid:			
Cerotene	$C_{27}H_{54}$	—	—
Melene	$C_{30}H_{60}$	375	—

Warren has also shown the presence of two isomeric groups in North American crude oil; the one comprising the fluid members he called the pittolium group and the other the par-

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[1] Mem. Am. Ac. 9. Am. Jour. Science (2) 40.

affin group. Of the former he established the four members given below; the paraffin group comprises mostly solid bodies of the methane series, and, therefore, need not be considered under the ethylenes.

Formula.	Boiling point ° C.
$C_{10}H_{20}$	174.9
$C_{11}H_{22}$	195.8
$C_{12}H_{24}$	216.2
$C_{13}H_{26}$	235.0

Hence for one atom of carbon the boiling points rise about 20°, while in Schorlemmer's series no conformity can be observed.

B. *Naphthene Group* (*Hexahydroaromatic Hydrocarbons.*)

Hydrocarbons of the type C_nH_{2n} were first found in Baku crude oils by Beilstein and Kurbatoff,[1] and later on by Schuetzenberger and Jonine.[2] These hydrocarbons, however, do not belong to the ethylene series, since they do not add bromine and are indifferent toward concentrated mineral acids, showing in this respect great similarity to the paraffin members. The authors mentioned above considered them hydrogenized hydrocarbons of the aromatic series ($C_nH_{2n}—6$), and according to that would correspond to ($C_2H_n—6 + H_6$).

Benzole	C_6H_6	Hexahydro-benzole	C_6H_{12}
Toluole	C_7H_8	Hexahydro-toluole	C_7H_{14}
Isoxylole	C_8H_{10}	Hexahydro-isoxylole	C_8H_{16}

Recently Le Bel[3] has also accepted this opinion.

Markownikoff and Oglobin continued these investigations, but at first considered them entirely new combinations, which they called naphthenes, and established the presence of the members mentioned below, of which the first two were more closely investigated by them. Of the naphthenes, derivatives analogous in many respects with those of the fat series might be produced. The chlorine derivatives were especially used by the last-mentioned chemists for further determinations.

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[1] Ber. deutsch. chem. Ges., 13, 1818, 2025.

[2] Ber. deutsch. chem. Ges., 1880, 2428; Bull. Soc. Chim., 1880, 673.

[3] Engineering, 42, 579.

NAME.	Formula.	Boiling Point at °C.	Specific Gravity at °C.
Octanaphthene	C_8H_{16}	118 to 120	—
Nonanaphthene	C_9H_{18}	135 to 136	—
Decanaphthene	$C_{10}H_{20}$	160 to 162	0.795
Endecanaphthene	$C_{11}H_{22}$	180 to 195	0.849
Dodecanaphthene	$C_{12}H_{24}$	196.5 to 197	0.8655 (at 40)
Tetradenaphthene	$C_{14}H_{28}$	240 to 241	0.8390
Pentadenaphthene	$C_{15}H_{30}$	246 to 248	0.8294

The boiling points, which vary essentially from those of the ethylene series with the same composition, do not rise so rapidly as in the latter, their course being not regular either in one or the other. Markownikoff has recently abandoned his standpoint, since further investigations, especially of the so-called octanaphthene, which he made with the assistance of J. Spady, proved it actually to be a hexahydroxylole.[1] This view is also supported by the results obtained by M. Konowaloff[2] in bromizing nonanaphthene.

According to Markownikoff and Oglobin, the portion of the so-called naphthenes in Baku oils amounts to at least 80 per cent. They further showed that American oils also do not consist exclusively of saturated hydrocarbons—which, however, has never been maintained—but contain small quantities of naphthene and naphthylene.[3] They also found naphthene in Hanover oil. Lachowicz established the presence of hydrogenized hydrocarbons, especially of hydrotoluole, in Galician petroleum, and, according to him, Galician crude oil, as regards the content of naphthene, stands between Baku and Pennsylvania oils.

According to Le Bel[4] the crude oils of Becherelli and Tschungnelek (Crimea, Russia) closely resemble the Baku oils.

Dr. G. Kraemer[5] was at first inclined to consider the

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[1] Ber. d. Deutsch. Chem. Gesel., 1887, 20, 1850. [2] Jour. der Russ. Phys.-Chem. Ges., 1887 (1), pp. 255 to 257. [3] Schuetzenberger and Jonine established the $C_n H_{2n}$ combinations in question in American oils. [4] Engineering, 42, 579. [5] Sitzbr. Ver. zur Beförderung des Gewerbefleisses, 1885, 292.

naphthenes a mixture of methanes with aromatic bodies, but in one of his most recent articles published jointly with W. Böttcher,[1] he acknowledges the existence and independence of the hexahydrides of the aromatic series. The two authors mentioned above found that in the more strongly resinified, denser Oelheim oil, most of the naphthenes occur in the portion indifferent towards mineral acids (methane and naphthene), while in the lighter oils from Tegernsee and Pechelbronn, there is a decided preponderance of methanes.

In the crude oils of the Pechelbronn flowing wells, of Schwabweiler, of Oelheim and of Tegernsee, Engler showed the presence of mesitylene and pseudocumol in the form of nitro-derivatives and bromo-derivatives. He did not search for the other members of the benzole series, his object being to establish the presence of such aromatic bodies in German oils, as their presence proves that petroleum must have been formed by dry distillation.

All chemists who have investigated the naphthenes, now declare them to be hexahydrides of the aromatic series ($C_nH_{2n}-6+H_6$).

3. *Benzole Series:* $C_nH_{2n}+6$. (*To the group of the aromatic Hydrocarbons.*)

The specific gravity of the members of this series is about 0.86; the most important are:

NAME.	Formula.	C.	H.	Boiling Point °C.
Benzole.	C_6H_6	92.3	7.7	82
Toluole	C_7H_8	91.3	8.7	111
Xylole	C_8H_{10}	90.6	9.4	139
Cumole	C_9H_{12}	90.0	10.0	148
Cymole	$C_{10}H_{14}$	89.5	10.5	175

The benzoles are quite widely diffused in petroleum, though

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[1] Ber. deutsch. Chem. Ges., 20, 590 to 598.

they are always present only in very small qnantities. Thus, for instance, Pawlesky found in the benzine obtained from Galician petroleum about 4 per cent. benzoles and paraxylol. Since, however, the yield of benzine from Galician oil is at the utmost about 10 per cent., the content of benzoles referred to crude oils is about 0.4 per cent. Engler determined the content of pseudocumol and mesitylene in American petroleum as 0.2 per cent.

Besides these normal series, isomeric bodies are also found in petroleum or its distillates. Of these combinations the following have thus far been established:

Benzole was found in Galician distillates by Palewsky[1] and Lachowicz; in Baku crude oil, by Markownikoff; in crude oil from Zarskiji Kolodzi (Goverment Tiflis), by Beilstein and Kurbatoff; in Rangoon oil, by Warren de la Rue and H.. Müller, and in Pennsylvania oil, by Schorlemmer.

Toluole was found in all oils given under benzole by the investigators mentioned there.

Xylole was prepared from Rangoon oil by Warren de la Rue and Müller, and from Pennsylvania crude oil by Schorlemmer. *Isoxylole* (boiling point 141° C) was established in the distillates of Galician crude oils by Palewsky and by Lachowicz, in Caucasian crude oil by Dr. Kraemer, and in Baku crude oil by Markownikoff. *Paraxylol* (boiling point 137° C.) was obtained by Palewsky from Galician distillates.

Cumol was found by Warren de la Rue and H. Müller in Rangoon oil, S. F. Peckham also mentioning *isocumol*. Pseudocumol (boiling point 166° C.) was found in Caucasian oil by Markownikoff and Oglobin, and in oils from America (very likely Pennsylvania), Alsace, Hanover, Galicia and Italy (Terra de Lavore) by Engler.[2] Mesitylene (C_9H_{12}, boiling point 163° C.) was established in Galician crude oil by Lachowicz, and in crude oils from America, Alsace, Hanover, Galicia and Italy by Engler. Markownikoff found it in Baku oil. The above mentioned benzoles also occur, according to Schultz and others, in coal tar.

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[1] Ber. deutsch. chem. Ges. 18, 1915.

[2] Ber. deutsch. Chem. Ges. 18, 2234.

Besides the above-mentioned aromatic combinations, there are also found in the fractions of Caucasian petroleum, boiling between 248° and 420.8° F., *durole*, *isodurole*, *diethyltoluole*, *isocambylbenzole* and other combinations after the type $C_{11}H_{16}$.

According to Beilstein and Kurbatoff, aromatic hydrocarbons are also said to be present in the Hanover crude oil and, according to Schorlemmer,[1] also in Candian oils. Pelouze, Warren, N. Tate, M. Murphy, C. F. Chandler, Bolley and Schwarzenbach searched in vain for benzoles in Pennsylvania crude oils.

4. *Other Series of Hydrocarbons.*

Besides the previously-mentioned hydrocarbons, the presence of others in the fractions boiling at a high temperature has been partially established, and partially conjectured for more or less good reasons. They are of no special importance, on account of their rarity and the extraordinarily small quantities in which they occur.

A. *Acetylene Series:* C_nH_{2n-2}.

From the behavior of some fractions of the Baku oil towards certain reagents (potassium permanganate, nitric acid, mercuric iodide), Mendelejeff inferred the presence of hydrocarbons of this series. Later on they were also found in very small quantities by Markownikoff and Oglobin.[2]

B. *Camphene Series:* $(C_nH_{2n-4}.)$

According to investigations by the two last-named chemists, this series is present in very small quantity in Baku oil. Boussingault[3] produced from the maltha and asphalt of Pechelbronn, at 572° F., fractions which he called petrolene, and considered as the fluid part of all asphalts (the solid part he called asphaltine). He gave it the formula $C_{10}H_{16}$, whereby he placed

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[1] London Chem. News, 11, 255; Trans. Royal Soc. (5) 14, 186.

[2] Chem. Centr. Blatt, 1881, 609; Ber. deutsch. chem. Ges. 18, 2234; Chem. Industrie, 1882, 5, 189.

[3] Ann. Chim. Phys., 61, 141; 73, 442.

this body in the camphene series, especially amongst the terpenes. He determined the boiling point=536° F., and the vapor-density=9.415. Warren in a private communication to Prof. Dana[1] points out that the vapor-density could only be 8.49, and that petrolene is a mixture consisting chiefly of ethylenes.

Völkel[2] subjected tough bitumen from Travers (Switzerland) to distillation in iron cylinders, and obtained six fractions whose contents of carbon and hydrogen were nearly the same, but whose boiling points were between 194° and 482° F., and the densities (at 59° F.) between 0.784 and 0.867.[3] The temperature and volume weights rose gradually. He arrived at the common formula C_6H_{10}, and considered the fractions as polymeric bodies of $C_{12}H_{20}$, for which reason they would have to be placed in the camphene series. In this case also we have very likely to do with mixtures.

Nendtwich[4] claims to have found solid petrolene in maltha from Pecklenicza near Murakoz (Hungary). Kraemer conjectures that small quantities of terpenes or polyterpenes must be present in heavy petroleum, since the viscous condition of the fractions of heavy oils boiling at high temperatures can only be thus satisfactorily explained. They may partially be originally present in the petroleum and partially be formed during distillation.

The above-mentioned investigations allow of the conjecture that the camphenes may be present in greater abundance in maltha and asphalt. Further careful investigation is, however, necessary to definitely settle this question.

C. *Combinations rich in Carbon.*

Markownikoff and Oglobin have separated in the fractions boiling at over 410° F., very small quantities of hydrocarbons

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[1] Dana, System of Mineralogy, 730.
[2] Annal. Chim. Phys., 87, 143, 1862.
[3] The densities are throughout greater than those of the members of the ethylene series of the same boiling point, nor do they correspond with the napthalene series.
[4] Haidinger's Berichte, 3, 271; Jahrb. geol. Reichs-Anst. 7, 743.

of the type $C_nH_{2n}-8$. In the fractions boiling at 464° to 482° F., they obtained, however, not only C_nH_{14}—a member of that series—but also combinations of new series: $C_nH_{2n}-10$ ($C_{11}H_{12}$ and $C_{12}H_{14}$), and $C_nH_{2n}-12$ ($C_{13}H_{14}$). All these hydrocarbons belonging to the isologous series of $C_nH_{2n}-6$, do not directly combine with the halogens, and for this reason cannot be classed with the benzole series, but must be put in new series.

Kraemer[1] also separated in the distillates of 392° to 572° F., from petroleum of Tegernsee and Oelheim very small quantities of naphthalene ($C_{10}H_8$) in crystals, which must be classed with the last-mentioned type $C_nH_{2n}-12$. Whether this naphthalene was originally present, which is very likely, or has been formed by the action of various reagents, has to be decided by further investigation. The volume-weight of the fractions between 482° and 500° F. was=0.92 and that of those at 572° F., even so much as 1.016.

Warren de la Rue and H. Müller[2] a considerable time ago established the presence of naphthalene in maltha from Rangoon.

In distilling residuum obtained from Pennsylvania crude oil in red-hot iron retorts, a yellowish-brown, viscous substance passes finally over which congeals on passing out from the retort-pipe and, prior to 1873, was used as a lubricant for the necks of rolls in rolling mills. From these substances Professor Henry Morton[3] has separated very small, acicular, greenish-yellow crystals, which he called *thallene* (*viridine*) and which might be isomeric with anthracene.

According to Truax, however, it does not exist ready formed in the petroleum, but is formed by destructive distillation. According to Hamilton[4] this substance is called petrocene and corresponds to the formula $C_{32}H_{22}$. According to H. W. Tweddle, petrocene is, however, at the same time the raw

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[1] Sitzb. Ver. z. Bef. des Gewerbefleisses, 1885, 299.

[2] Mem. Am. Acad., 9.

[3] Am. Chem., 3, 106, 162; 7, 88.

[4] Jour. Chem. Soc., London, 32, 867; Zeitschr. f. Paraffin, 1878, 59.

material from which the thallene has been separated. According to Graebe and Walter[1] petrocene is identical with the picene ($C_{22}H_{14}$) of brown coal (lignite) tar, which has been examined by Burg. L. Prunier and R. David,[2] also examined the distillate first observed by Prof. Morton, and independent of paraffins with uncommonly high melting points (up to 185° F.), separated from it a considerable number of other combinations rich in carbon—*anthracene*, *phenanthrene*, *chrysene*, *chrysocene* and *pyrene*—whose content of carbon varies between 88 and 96 per cent. All these substances appear, however, to be formed by destructive distillation.

Divers and Nakamura isolated a solid body with a melting point between 536° and 545° F., and of the composition $(C_4H_3)_n$. Le Bel and A. Munz[3] examined the black coloring matter of the semi-liquid asphalt of Pechelbronn. They gave it the name asphaltine. It is obtained in brittle black scales from solution in carbon disulphide, and its coloring power compares with aniline. It is not volatile.

Solubility and Solvent Powers of Petroleum.

These have been thoroughly investigated in Baku oil by Markownikoff and Oglobin. Petroleum dissolves slightly in water, but also absorbs the latter, the quantity absorbed being the greater, the lower the temperature of the distillates is. In alcohol the greater portion of the oil dissolves, the resinous parts remaining behind; ether dissolves all. Salts and metallic oxides are also absorbed by the oil, but after boiling for some time with sodium, it is no longer colored by the oxides of iron and copper. Petroleum is also capable of dissolving iodine and sulphur. The solvent power of petroleum as regards metals has previously been mentioned (p. 53) and explained.

Changes in Petroleum by Exposure to the Air.

The changes petroleum experiences by exposure to the air,

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[1] Ber. deutsch. Chem. Ges., 14, 175.

[2] Bull. Soc. Chim., Paris, 31, 158, 293; Ber. deutsch. Chem. Ges., 12, 366, 843.

[3] Bull. Soc. Chim., Paris, 17, 156.

and which may be accelerated by a higher temperature, may consist partially in evaporation and partially in the absorption of oxygen.

The most essential facts relating to *volatilization* have been given on p. 46. By this process the oil, in consequence of the escape of volatile hydrocarbons, becomes constantly denser and changes to maltha. The latter occurs either as an accumulation on the surface of the ground, or in sand or porous sandstone.

If the oil contains paraffins, the latter will finally remain behind as a solid mass, mineral wax (ozocerite) having thus been formed. It can accumulate in considerable quantities only under the above-mentioned conditions, namely, volatilization without oxidation, and a considerable content of paraffin. Mineral wax becomes the more solid, the more chances the fluid constituents have to escape. The kendebal of Boryslaw is the transition-stage between petroleum and mineral wax; if exposed to the air for some time it loses weight and is converted into mineral wax.

In the absorption of oxygen, two different processes may take place:

a. The absorption of oxygen takes place with splitting off of water, which is promoted by pressure and heat. A portion of the hydrogen of the oil combines with the oxygen of the air to water, which escapes, while the hydrocarbons become richer in carbon, and the methanes may be converted into ethylenes, or generally into combinations of the type C_nH_{2n}, and also into aromatic bodies.

b. The oxygen forms new combinations with the hydrocarbons, which may be present partially as phenols and partially as acids. This process is called resinification of petroleum.

These processes of oxidation, either by themselves or in connection with volatilization, increase the density of petroleum, and contribute towards the formation and separation of solid bodies. Asphalt, a viscous or solid and brittle body, consisting of carbon, hydrogen and oxygen, is the final product of all these processes, which have locally contributed in various degrees to its formation, and for that reason its composition varies, the content of oxygen being, for instance, between 23 and scarcely 1 per cent.

Techno-Chemical Examination of Petroleum.

The technical examination of petroleum extends only to the determination of the quantity of the separate distillates passing over at different temperatures, without further entering into their chemical nature. In the practice it is customary to distinguish among the distillates three different groups, viz.:

I. Light oils[1] distilling over up to 302° F.

II. Illuminating oils distilling at 302° to 572° F.

III. Residuum.

The quantities of these fractions vary very much; in working on a large scale they are, according to Engler, as follows:

	Pennsylvania.	Galicia.	Roumania.	Alsace.	Baku.
	Per Cent.				
Light oils	10 to 20	3 to 6	4	....	5 to 10.6
Illuminating oil	60 to 75	55 to 65	60 to 70	35 to 40	32 to 53.5
Residuum	5 to 10	30 to 40	25 to 35	55 to 60	36 to 60

For a more complete table we are indebted to the investigations of Dr. H. Gintl:

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[1] American light oils comprise chiefly the members C_5H_{12} to C_8H_{18}, and the illuminating oil C_7H_{14} to $C_{16}H_{34}$ of the methane series.

PRODUCTS OF DISTILLATION.	Grade oil from								
	Pennsylvania.	Canada.	Rangoon (E. India).	Red Sea (Africa).	Slary (W. Galicia)	Boryslaw (E. Galicia)	Bukowina.	Roumania.	Baku (Russia).
	Specific Gravity								
	0.824	0.845	0.885	0.912	0.827	0.842	0.84	0.846	0.865
	100 Parts Yield								
Light oils	15.00	20.0	4.01	2.5	8.50	9.38	10.00	10.00	8.5
Illuminating oil, I. quality	47.00	50.0	40.70	30.0	44.85	52.49	25.7	61.28	40.7
Illuminating oil, II. quality	20.00	19.0	36.99	57.0	24.22	12.57	18.3	20.60	18.3
Paraffin	....	3.0	6.07	5.2	....	11.40	12.4	2.23	5.0
Tar	12.00	5.0	4.61	3.7	13.25	2.48	23.6	....	15.0
Coke and loss	6.00	2.0	7.62	1.6	9.18	11.10	10.0	5.89	12.5

The supposition that the yield of illuminating oil decreases with an increase in the specific gravity is, generally speaking, correct only as regards the manufacture on a large scale in one region.

I. *Light Oils.* These are variously subdivided and named according to their boiling points. In some places the terms "ether" and "benzene" are also used without the fractions corresponding with these bodies, they being only partially used for the same purposes. The term naphtha is also used, but in some regions this term is employed as a synonym for petroleum. To avoid confusion it is advisable to prefix the word "petroleum," which may, however, be omitted in business circles. The light oils are divided as follows:

1. *Petroleum ether* (*keroseline, rhigolene, Sherwood oil*). *Boiling point:* 104° to 158° F. *Density:* 0.65 to 0.66. *Use:* Solvent for resins, caoutchouc and oil; as a local anaesthetic in surgical operations, and for the production of cold.

2. *Gasoline* (*canadol*). *Boiling point:* 158° to 176° F. *Density:* 0.64 to 0.667. *Use:* For the extraction of oils from acids etc., freeing wood from fat, for air-gas machines and as an illuminant in lamps of special construction.

3. *C-petroleum-naphtha* (*petroleum-benzine, safety oil, Danforth oil*). *Boiling point:* 176° to 212° F. *Density:* 0.667 to 0.707. *Use:* For the removal of stains, for the adulteration of petroleum, in large quantities for firing purposes, and as an illuminant in lamps of special construction.

4. *B-petroleum-naphtha* (*ligroine*). *Boiling point:* 176° to 248° F. *Density:* 0.707 to 0.722. *Use:* For burning in lamps of special construction, in the preparation of illuminating gas, in painting in place of oil of turpentine, it drying more rapidly than the latter.

5. *A-petroleum-naphtha* (*Putzoel, polishing oil*). *Boiling point:* 258° to 302° F. *Density:* 0.722 to 0.737. *Use:* For cleaning parts of machinery, as a substitute for oil of turpentine, for thinning oil-paints, varnishes, etc.

The fractions mentioned under 3, 4, and 5 are sometimes comprised under the term petroleum-spirit. *Density:* 0.667 to 0.737. *Boiling point:* 176° F. to 302° F.

The division given above is a modification of that originally complied by R. Wagner, in order to make it more generally acceptable by taking into consideration the division into gasolene, C-, B- andA-naphthas customary in Pennsylvania. Besides the boiling points are at nearly equal graduations.

II. *Illuminating oil* (*petroleum, kerosene*). *Boiling point:* 302° to 572° F. *Density:* 0.753 to 0.864. To make it a commercial article, it is treated with sulphuric acid and an excess of the latter neutralized with soda. Its use is well known.

III. *Residuum* (*tar*). *Boiling point:* 572° F. or above: *Density:* varying, over 0.83. By a further increase in the temperature are obtained:

1. *Heavy oils*, which pass over with continued distillation, and, according to their density, are divided into

a. Lubricating oil. Density: 0.7446 to 0.8588.

b. Paraffin oil. Density: 0.8588 to 0.959.

Paraffin is separated in scales from the heavy oils, especially from the last named. It is used for candles, as an insulating material, etc. The use of lubricating oil is indicated by the word.

2. *Coke.* This remains as a solid body in the still, and is used for firing.

In consideration of its technical importance, the salve-like product known as cosmoline, vaseline, petrolina, etc., which may be separated from the residuum of some oils, may here be mentioned. R. Wagner[1] declared it a mixture of paraffins with the fluid member heptane, while Moss[2] considered it a mixture of readily fusible paraffins. Miller[3] agrees with Wagner, he having shown it to be a mixture of paraffin with volatile oils. Engler and M. Böhm[4] arrive at the same conclusion in regard to the Galician and American products.

Cosmoline serves as a vehicle for salves, for the preparation of pomades, rouges, etc., as well as for a protection against rust and oxidation for all metals and their alloys, for oiling machines, etc.

The relative proportions of the separate fractions vary according to the different localities, even oil of the same well yielding different results, according to whether fresh oil or oil stored for some time has been used for analysis. The result of the latter is also influenced by the manner in which it is executed, and especially by heating.

It remains to be mentioned that the density of distillates of the same temperature from different crude oils may vary; those, for instance, of Baku oil being throughout specifically heavier than those from Pennsylvania oil, because in the one there is a preponderance of hydrocarbons of entirely different series from the other. Generally speaking, the Pennsylvania petroleum is the generic type, the Baku oil forming an exception.

According to S. F. Peckham,[5] the average percentage of commercial products obtained from crude petroleum (specific gravity = 0.800) from Pennsylvania, New York, Ohio and West Virginia is a follows:

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[1] Dingl. pol. Jour., 233, 515. [2] Jahrb. f. reine Chemie, 1876, 471. [3] Deutsch. Ind. Ztg., 1875, 18. [4] Dingl. pol. Jour., 262, 468. [5] Report on Petroleum, p. 165.

Gasoline	1.5	per cent.
C-naphtha	10.0	"
B-naphtha	2.5	"
A-naphtha	2.5	"
Illuminating oil	54.0	"
Lubricating oil	17.5	"
Paraffin	2.0	"
Coke and loss	10.0	"
	100.0	

To avoid confusion, it may here be mentioned that in working on a large scale the yield of illuminating oil from Pennsylvania crude oil amounts to about 75 per cent.

To Dr. Kraemer we are indebted for an examination of the petroleum of most regions, whereby the fractions above 482° F. passed over under a decreased air-pressure. The results of the analyses were as follows:

Crude oil from	Density of the crude oil.	Fractions obtained up to ° F.								Residue and Loss.
		302°		482°		572°		Over 572°		
		Per cent.	Density.	Per cent.	Density.	Per cent.	Density.	Per cent.	Density.	Per cent.
Tegernsee	0.812	20.04	0.726	26.12	0.782	14.02	0.825	35.91	0.856	3.07
Alsace	0.888	1.30	0.720	16.37	0.778	17.07	0.824	47.88	0.903	16.28
Oelheim	0.885	0.74	0.750	11.05	0.805	9.75	0.852	73.91	0.910	3.92
Pennsylvania	0.814	14.34	0.725	25.35	0.811	13.75	0.820	40.99	0.850	5.57
West Galicia	0.842	14.21	.....	16.93	.....	13.30	.....	47.58	.....	8.95
Wallachia	0.857	14.32	.....	22.59	.....	13.86	.....	39.51	.....	9.72
Baku	0.880	0.63	0.762	21.73	0.811	15.55	0.825	57.97	0.903	4.12
Kuban	0.930	2.30	.....	10.60	.....	3.20	.....	64.40	.....	9.50

In the lighter oils, like those from Tegernsee and Pennsylvania, considerable quantities of dissolved non-condensed gases of the methane series were established.

In more recent times, Engler also examined various varieties of oil; a few of his analyses are given below:

Crude Oil From	Density at 62.6 °F.	Quantity in …	Distillates up to °F.										
			266	302	338	374	410	446	482	518	554	572	Over 572
Sloboda (Galicia)	0.8235	c.c.	16.0	10.5	10.25	6.5	6.5	7.0	6.75	6.0	3.5	0.5	26.5
		g.	11.3	7.6	7.6	5.2	5.3	5.6	5.5	5.6	2.8	0.45	
Bibicybat (Baku)	0.8590	c.c.	16.0	7.0	6.5	6.5	5.0	5.0	5.0	5.5	3.5	1.0	39.0
		g.	11.0	5.7	4.9	5.1	4.1	4.2	4.2	4.7	3.1	0.9	
Balachani (Baku)	0.8710	c.c.	3.75	4.75	5.5	4.75	5.25	5.0	7.0	4.75	5.5	1.75	52.0
		g.	2.7	3.4	4.3	4.0	4.3	4.1	5.6	4.1	4.6	1.6	
Pechelbronn (Alsace)	0.9075	c.c.	.....	3.0	4.4	5.4	4.5	6.6	7.3	7.0	10.3	4.5	47.0
		g.	.....	2.2	3.3	4.1	3.5	5.3	5.9	5.8	9.7	4.0	
Oelheim (Hanover)	0.8990	c.c.	.....	.....	.....	4.75	5.25	6.0	4.0	5.0	5.0	2.0	68.0
		g.	.....	.....	.....	3.2	2.6	4.8	3.4	4.3	4.3	1.8	

c.c.=Cubic Centimetres. g.=Grammes.

A. Nawratil has rendered great service in making us acquainted with the crude oils of West Galicia, he having determined, commencing with 104° F., the fractions of 18 different samples comprising most localities of this region. From this valuable series of investigations, the two crude oils differing most in specific gravity and the limits of value found will here be given:

Crude Oil from	Specific gravity		Fractions up to ° F.										
			212	302	392	482	572	662	752	Over 752	Gum.	Coke.	Loss.
Kleczany	[illegible]	p. c.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0	0.05	0.05	0.1
		Sp. gr.	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—
Harklowa	[illegible]	p. c.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.1	5.5	2.0
		Sp. gr.	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—
Limits of value Min.	[illegible]	p. c.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.05	0.05	0.1
		Sp. gr.	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—
Limits of value Max.	[illegible]	p. c.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.1	5.5	2.0
		Sp. gr.	—	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	—	—

p. c.=per cent.

Hence the differences in the specific gravities of the fractions at the same temperature of the two most extreme varieties of Galician oil vary as much as the fractions of Baku oil compared with those of Pennsylvania oil. These comparisons lead to the following proposition, which is valid, however, in a general way only: The denser the crude oil the denser its fractions.

Calorific Value of Petroleum.

Dr. H. Gintl gives for various districts the calorific values (the absolute heating effects) of petroleum. Since the quantitative composition of the oils, even of one and the same region, varies, these calorific values give only a general idea, which is, however, of some importance, as the values quite agree. For a better comparison the combustion-heat of methane and ethylene, which has been determined by the calorimetric method, is added:

Petroleum from	Units of heat.
West Virginia	10.180
Pennsylvania	9.963
Java	10.831
Baku	11.640
East Galicia	10.085
West Galicia	10.231
Roumania	10.005
Methane (CH_4)	13.065
Ethylene (C_2H_4)	11.850

The calorific value of crude oils is, therefore, nearly three times as large as that of dry wood substance, about four times as large as that of air-dry pine, or nearly 1.5 times as large as that of excellent Moravian coal (with 8.28 per cent. ash). Massive coal being, however, about 1.5 times denser than crude oil, both fuels occupy about the same volume, but in consequence of comminution, coal requires more space than crude oil, which might be of importance as regards steamships, etc.

The steamers running on the Caspian Sea and the Volga, as well as the refineries of Baku and the railroad from Baku to Batoum, have for some time used for firing the very cheap residuum remaining in the distillation of crude oil. Its calorific value is given as nearly twice that of good coal.

Gases accompanying Petroleum.

Gases which burn when ignited always occur together with petroleum, and hence, special precautions against the dangers of explosion and fire have to be taken in the immediate neighborhood of the wells. In the oil regions and their vicinities of North America and Baku, the gases issue from the ground, frequently without petroleum, in such quantities that they can be used for technical purposes, and hence deserve special consideration.

The natural earth gases issuing from the petroleum wells of Pennsylvania have been examined by Fouqué, Ronalds, Lefèbre, Sadtler, Ford, Hay, Fulton and others, those of New York by Wurtz, of the peninsula Apscheron (Baku), which, according to Abich, have a temperature of 69° F., by Schmidt, and those of the peninsulas Kertsch and Taman (Asow Sea) by Bunsen. All these investigators found a decided preponderance of methane and its nearest homologues in them. Further details are given in the following table, which might be still more enlarged:

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	From Apscheron.		From Kertsch and Taman.					From North America.												
	According to Schmidt.		According to Bunsen.					According to Sadtler.				Hay.	According to Ford.						Fulton.	Wurtz.
								Burns.	Loechburg.	Harvey.	Cherry-tree.	Pittsburgh.	Near Pittsburgh.				East Liberty.		Grapeville, Pa.	W. Bloomfield, N. Y.
	Per Cent.																			
Methane CH_4	92.49	93.09	92.24	95.39	97.51	95.56	97.89	75.44	89.65	80.11	60.27	95.20	72.18	65.25	60.40	49.58	57.85	75.16	35.08	82.41
Ethane C_2H_6	......	......	......	......	......	......	......	......	......	......	......	......	3.60	5.50	7.92	12.30	5.20	4.80	28.87	2.94(?)
Ethylene C_2H_4	4.11	3.26	4.26	......	......	......	......	18.12	4.39	5.72	......	0.50	0.70	0.80	0.98	0.60	0.80	0.60	0.17	
Hydrogen	0.34	0.98	......	......	......	......	......	6.10	4.79	13.50	22.50	2.00	20.02	26.16	29.03	35.92	9.64	14.45	7.05	
Carbonic oxide	......	......	0.00	0.00	0.00	0.00	0.00	trace	0.26	......	......	1.00	1.00	0.80	0.58	0.40	1.00	0.60	0.22	
Carbonic acid	0.93	2.18	3.50	4.61	2.49	4.44	2.11	0.34	0.35	0.66	2.21	0.00	0.80	0.60	0.00	0.40	0.00	0.30	0.58	10.11
Oxygen	......	......	......	......	......	......	......	......	......	......	0.83	1.30	1.00	0.80	0.58	0.40	1.00	0.60	0.16	0.28
Nitrogen	2.13	0.49	......	......	......	......	......	......	......	......	7.32	0.00	0.00	0.00	0.00	0.00	23.41	2.89	27.87	4.31
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.44	99.99	93.13	100.00	99.30	99.91	99.49	99.60	98.90	99.40	100.00	100.00

The analyses 13 to 16 refer to the same gas well, but the samples were taken at different periods (October 28 and 29, November 24, and December 4, 1884). Analyses 17 and 18 also refer to the same well at different periods (October 18 and 25, 1884). These analyses, showing remarkable changes in the composition of the gases, are in many respects of great interest; while the one series (13 to 16) shows in the course of time with a steady decrease in methane, a steady increase in ethane and hydrogen, in the other series the reverse is partially the case, the only agreement which can be recognized being that the quantities of methane and ethane are in a reverse ratio.

The natural gases from Murraysville, Speechley, and Fredonia II have recently been analyzed by C. Phillips[1], who took the samples directly from the wells he examined—

1. Gas of the Fredonia Co.
2. " " Sheffield Co.
3. " " Wilcox well.
4. " " Kane well.
5. " from Speechley.
6. " of the Murraysville well.

—and found:

	1.	2.	3.	4.	5.	6.
N.	9.54	9.06	9.41	9.79	4.51	2.02
CO_2	0.41	0.30	0.21	0.20	0.05	0.28
O.	....	trace	trace	trace	trace	trace
H	....	....	....	....	0.02	....
$C_n H_m$.	90.05	90.64	90.38	90.01	95.02	97.70

The hydrocarbons C_nH_m contained:

	1.	2.	3.	4.	5.	6.
C.	21.83	23.36	23.48	23.18	22.93	25.06
H	78.17	76.64	76.52	76.82	77.07	74.94

Ammonia as well as carbonic oxide could not be established.

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[1] Annual Report of the Geological Survey of Penna.

Whether nitrogen was present in a free or fixed state was not closly examined into. Its determination was effected by conducting the gas over red-hot copper oxide. That the large amount of nitrogen cannot be referred to atmospheric air (somewhat decomposed) is proved by the small quantities of carbonic oxide and by the presence of oxygen in traces only. With this agree also analyses 1, 11, 16 and 19 of the table previously given. Phillips mentions expressly that ammonia is not present in the natural gases examined by him.

Engler examined the following natural gases of Pechelbronn (Alsace). I. The salt-water gas No. 1., which continuously issues from the ground together with salt water and is used for heating purposes in the laboratory; II. the salt water gas No. 2, and III. the gas which issues together with the oil from the wells.

Constituents.	I.			II.	III.	
	1.	2.	3.	4.	5.	6.
	Per cent. by volume.					
Marsh gas	73.6	74.2	73.4	68.2	77.3	77.3
Oil-forming gas and olefine	4.0	4.1	4.0	3.4	4.8	4.8
Carbonic acid	2.2	2.0	2.2	2.9	3.6	3.6
Carbonic oxide	3.0	3.0	3.2	3.7	3.5	3.4
Oxygen	......	......	......	4.3	1.8	2.0
Nitrogen (residue)	17.2	16.7	17.2	16.9	8.9	9.0

In the salt water gas No. 1 (I) free oxygen and hydrogen were searched for in vain. Engler supposes that the oxygen is derived from the air, which was originally in contact with the oil and gradually yielded its oxygen to the latter, so that only nitrogen remained behind. In II. and III. the oxygen and nitrogen were referred directly to atmospheric air.

The high content of carbonic oxide in the Pechelbronn natural gas is remarkable, and, according to Engler, supports the hypothesis according to which petroleum has been formed by dry distillation, and is opposed to the supposition of a process of fermentation. Natural gas has for a long time been used in various localities for technical purposes; for the longest time perhaps in the district Tsien-Luon-Tsing, China, where, according to Imbert, it issues together with the brine from wells up to 3000 feet deep, in such quantities that it is used not only for illuminating purposes, but also for evaporating the brine. Baron von Richthofen states that in the province Sz'-tschwan the gas is at the present time used for the same purposes. Such exhalations of gas have been frequently observed to accompany the occurrence of salt; thus as early as 1786 the gas was used for illuminating the salt-mine Ludovica at Szlatina (Hungary).

The gas is, however, most extensively used in the eastern parts of this country, especially in Pittsburgh, where it issues in enormous quantities from many wells. It is chiefly used for fuel and but seldom for illuminating purposes, its illuminating power being somewhat less than that of ordinary illuminating gas.

By experiments on a large scale it was found that in firing boilers 83 per cent. of the theoretical heating effect is utilized (of the best Pittsburgh coal 64 per cent.), 100 liters of gas weigh 64.86 grammes and possess about 790,000 units of heat, hence about seven times as many as the Siemens gas.

A committee of the "Engineers' Society West Pennsylvania" determined by direct boiler experiments the evaporating power of best Pittsburgh coal as 9 kilogrammes (19.8 lbs.) of water, and that of natural gas as 20.31 kilogrammes (44.68 lbs.) referred to 1 kilogramme (2.2 lbs.) of fuel. Hence the calorific value of natural gas is 3.36 times greater than that of coal.

CHAPTER V.

OCCURRENCE OF PETROLEUM.

Primary and Secondary Deposits.

A GREATER natural accumulation of petroleum in the crust of the earth or on its surface is called a *deposit,* and may be either *primary* or original, or *secondary* or shifted.

Petroleum, as will be shown later on, is of organic origin, and hence could only be formed where organisms were present. For this reason it cannot have originated in the massive or eruptive rocks, just as little as in the oldest azoic (archæan) strata. The seat of the formation of petroleum can, therefore, be located only in strata more recent than the archæan, which also agrees with all assured facts known at the present time.

The *primary* or *original* deposits of petroleum may, therefore, belong to the strata of the Silurian age up to those of the present time. It is a remarkable fact that they are wanting, or are of no technical importance, in the strata carrying larger coal measures.

In the primary deposit the organisms accumulated, and conditions prevailed which promoted the process of transformation and permitted an accumulation of the product of transformation —the petroleum. It could, therefore, be only a *sedimentary* deposit. Besides the organisms, inorganic masses, such as debris, sand, mud, or the hard portions of animals, were separated, so that the oil formed later on exuded through this collection of strata, which in time might also have hardened and been partially transformed. The primary deposit is, therefore, an impregnated stratum or deposit, according to whether it retains the plate-form or the latter passes over into the lenticular form. Both types, which differ geometrically only, are found in nature.

Sand, debris, coarse-grained sandstone, conglomerate, especially when poor in cementing material, porous limestone, and, in general, rock with many and large pores or many cracks and fissures, will absorb the oil in greater quantities and, when opened, yield it more rapidly than compact varieties of rock.

H. Römer some time ago showed the presence of up to 17 per cent. of lime in the oil-bearing sandstone of Oedesse (Hanover). Br. Walter also points out that the oil-bearing Ropianka sandstones are rich in lime, and supposes that the number of pores is increased by the lixiviation of calcium carbonate. These strata are in fact rich in calcite veins. These indications deserve further consideration, since they may possibly be of advantage for the practice.

J. F. Carll's investigations prove that the oil-sand of Pennsylvania contains $\frac{1}{10}$ of its bulk of crude oil, and he supposes that under pressure this capacity may increase to $\frac{1}{8}$.

The occurrence of oil in the Carpathian menilite schists must be considered an original deposit, as well as a great portion of the North German finds in the Jura and Wealden strata (according to H. Credner).

In these original deposits the oil frequently stands under a higher pressure, especially in consequence of included gases formed during the processes of transformation, so that in drilling the heavy string of tools may be ejected from a deep bore-hole. In consequence of this internal pressure the oil endeavors to escape in all directions. If the vicinity of the original deposit consists of porous rock, the oil will penetrate the latter, and the size of the deposit will thus be increased. By this process it may, however, happen that the oil is distributed over such large masses of rock that its flow in a shaft or bore-hole decreases to such an extent as to render the working unprofitable. The gases penetrate the rock with more ease and for a greater distance, and in nearly every oil region are therefore considered a good indication of the speedy opening of an oil deposit.

By the above-mentioned wandering or migration the oil is afforded more chances to evaporate, so that in consequence of these processes a formerly productive deposit may become simply bituminous rock. The formation of the latter, however, may also have been due to the fact that but few organisms capable of forming oil were deposited in it, or that the processes on which transformation depends were not favorable. This explains partially why the same group of strata may be only locally oil-bearing.

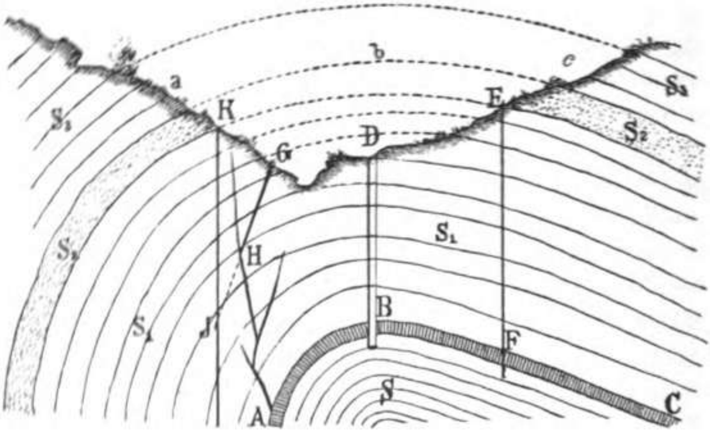
The processes by which the original extent of a primary deposit of petroleum may be enlarged have been mentioned above; in such a case it will frequently be impossible to determine the original limits of the deposit. However, the enlarged, as well as the original, deposits must show the type of a sedimentary deposit, the surrounding porous rocks being also deposited in strata.

However, the pores of solid rocks alone do not afford much opportunity for migration to the oil, and the less so the smaller they are, this view being justified by experiments with rocks into which water was forced by means of high pressure. If we take into consideration that the pores of rocks are frequently closed by the specifically heavier water—the so-called rock-moisture—and further that the entering oil experiences considerable loss of pressure in consequence of capillarity and friction, which have to be overcome, an enormously high pressure would have to be supposed to make the further migration of the oil in the pores of the rock possible.

The conditions are, however, more favorable in loose masses, sand, debris, etc., the interspaces being larger than in the more compact rocks, and therefore readily penetrable.

The escape of the oil standing under internal pressure from its primary deposit through fissures communicating with the latter is very possible, and the more so the wider these fissures are and the greater their number. The oil enters these fissures, fills them, and according to the pressure, ascends frequently to the surface, forming there an oil well. This occurrence in fissures, as, for instance in some localities in Ohio and West Virginia, constitutes a *secondary* or *shifted* deposit; it fills the clefts, and is, therefore, a structure corresponding to veins and lodes. The veins frequently change in size and direction; they divide and unite again, and, in short, their geometrical proportions are subject to more frequent changes than those of the beds (primary oil deposits) which lie concordant to the surrounding strata. For this reason turns, bendings and similar disturbances of the oil bed may be recognized from those of the adjoining strata running in an analogous manner, which for the practice, particularly in drilling, is of special importance. With such an occurrence the risk in searching for oil is much smaller, and the possible success, after the expenditure of time, labor and capital, can be calculated with greater certainty than with the vein-like occurrence of oil, as may be seen from the accompanying sketch, Fig. 1.

FIG. 1.



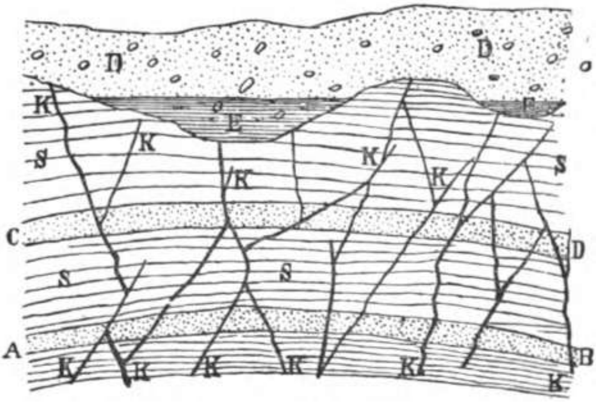
The original deposit *A B C* is concordant with the dead rock-strata S S_1 S_2 accompanying it. From the outcrop of the latter a picture of the trend or bearing of the deposit after it has been found, may be made, for instance, at *B*, through the shaft *D B*, since its trend must be parallel to *a b c*. If then at *E* a bore-hole be commenced, its depth *E F* can be quite accurately determined. This depth is not only a guide for the preliminaries of time and money, but under certain conditions also determines the mode of working, etc. Besides, when the deposit is not found after the bore-hole has reached a certain depth, and a study of the geological conditions shows that there is a disturbance, for instance a fault, between *B* and *F*, it is then known that the deposit does not extend thus far, but has previously dwindled away.

With a vein-like occurrence of the oil the technical questions are quite different. At *G* an oil well corresponding to a cleft has been discovered, and the latter has been exposed. Hence a bore-hole is commenced at *K* in the hope of reaching the oil-cleft (the oil-vein) at *J*. The latter, however, at a certain depth turns round, a change which could not be foreseen even by the most thorough geological investigation. The bore-hole misses the cleft, and no result is attained if the primary deposit is at such a depth that it cannot be reached with the drill. If such unfortunate incidents happen in searching for oil, a territory is frequently abandoned as unprofitable, although it may contain considerable quantities of oil.

From the foregoing explanations the importance of correctly deciding the question whether the oil occurs in a primary or secondary deposit will be understood.

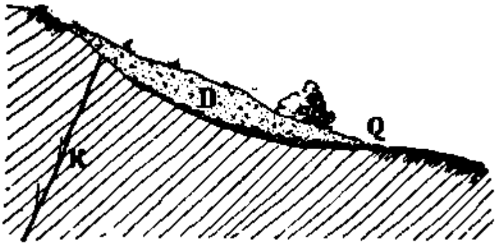
In the fissures the oil, if there be sufficient pressure, may rise to the surface, where it can be determined, and, under suitable conditions, extensive accumulations may be formed on the surface near the oil wells, as, for instance, the pitch lake of the island of Trinidad. If, however, the outcrop of these fissures *K*, Fig. 2, is covered with loose masses of rock (debris, sand, etc.,) the oil spreads out in the latter and forms accumulations like water undrground. In Canada such accumulations are called *surface wells*. If, however, the oil passes out from the rock-fissure *K* in a declivity covered with conglomerate *D*, Fig. 3, it will run down along the bottom of this covering, and, on the foot of it, as an oil-spring *Q*, such occurrence having to be taken into consideration in searching for oil. These accumulations of oil near the surface thus form a secondary deposit, which, however, differs essentially from the vein-like type previously discussed as being similar to a bed.

FIG. 2.



When the fissures *K*, Fig. 2, cross a bench or a group of strata of very porous rock *C D*, the oil may accumulate in it. Such secondary deposit shows the bed-like type of the rock-bench, and frequently cannot be distinguished from an original deposit. Thus, for instance, the rich Pennsylvania oil deposits which belong to the sandstones and conglomerates imbedded concordant to the schist are by many supposed to be not primary, but secondary deposits.

FIG. 3.



Petroleum occurs also in small hollow spaces in the eruptive rocks. But this occurrence being of a very subordinate nature is only of scientific interest. Thus, small quantities of oil have been found in the diorite of Gaspé, Canada, in the melaphyres and similar eruptive rocks of Central Scotland, in the basalts at the foot of the Etna, and in Auvergne. The content of bitumen of many northern granite boulders which were found near Kiel (Dorfgarden, Pappenberg,) is well known. Small quantities of bitumen are carried here and there by granite in Cornwall (Poldice) and in Auvergne (Chamalier, Clermont); by the greenstone trachyte of Parad (Hungary), the melaphyre of Bohemia (Rybnik, Semil), and of the Palatinate of the Rhine (Oberstein).

The massive rock, during its eruption either traversed an oil-bearing or bituminous rock, or crossed a coal measure, which, by reason of the high temperature and consequent destructive distillation, yielded petroleum-like products. Such occurrences must also be classed as secondary deposits.

Deposits of petroleum may, therefore, be:—

I. Primary (impregnated beds and strata).

II. Secondary
  1. In fissures.
  2. Superficial.
  3. Bed-like.
  4. In eruptive rocks.

Every secondary deposit presupposes the existence of a primary deposit; the yield of one, however, cannot be judged by that of the other. If the primary deposit was, for instance, located in slate-clay, which is capable of absorbing and maintaining large quantities of oil, and this slate-clay was later on crossed by fissures, the superfluous oil might pass into them and accumulate, so as to form productive secondary deposits, while in the primary deposits but small quantities of oil are yielded by strongly bituminous schist.

There are many erroneous ideas regarding petroleum deposits. The expression "subterranean oil reservoirs" is explained to mean that in the crust of the earth there are large caverns filled entirely or partially with crude oil, and even in literature is frequently found nearly the same sketch of such a lenticular cavern, which is said to be filled on the bottom with water, in the centre with petroleum, and on top with gases. Such caverns may exist, but their existence has never been established, and it is about time that this "hereditary wood-cut" should disappear from literature.

Oil Lines.

It is a fact recurring in various regions that the productive oil wells are disposed in a certain direction, and that the productive territory lies in long narrow areas. Thus, for instance, the lower oil territory of Pennsylvania, south of Franklin, is 2 miles wide and 35 miles long. This peculiarity as regards the above-mentioned region was first observed, in 1867, by C. D. Angell. While investigating the occurrence of petroleum, he studied the relative positions of the most productive wells, and upon this basis erected the so-called "belt-theory," which rapidly reduced the risk in searching for oil from about 25 per cent. mis-drills to from 3 to 5 per cent.—certainly an extraordinary success.

A line laid in the centre of such a productive oil territory, stretching in the main in one direction, is called an *oil-line*; it indicates the way in which later bore-holes or shafts have to be disposed in order to secure the greatest probability of success.

In the United States the oil-lines were first drawn upon the basis of simple experience. In many other regions it might also be advisable to see whether the most productive wells do not correspond to a line, and in such case to arrange the next borings in the continuation of this line. In a region not yet opened the oil-line—in case the existence of one can be supposed—will have to be drawn upon a theoretical or hypothetical basis; the better founded the latter is, the greater the probability of success.

To connect two or several points where oil has been found by a straight line, and declare that to be the oil-line, as has unfortunately been repeatedly done, is not only useless, but may divert attention from the proper way and bring a territory into discredit.

The extension in definite directions, which can be accurately shown in several oil regions, may be connected, 1st, with the extension of the oil-bearing stratum; 2d, with an anticlinal, and 3d, with a displacement.

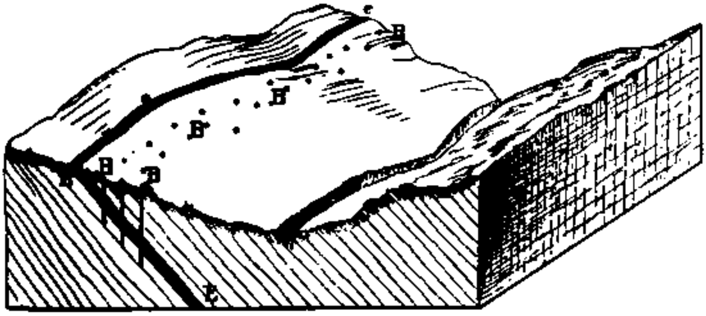
These cases will here be discussed in detail.

1. *Oil-line corresponding to the oil-bearing stratum.*

a. *The deposit belonging to a stratum stretches in the form of a plate in courses and dips.*

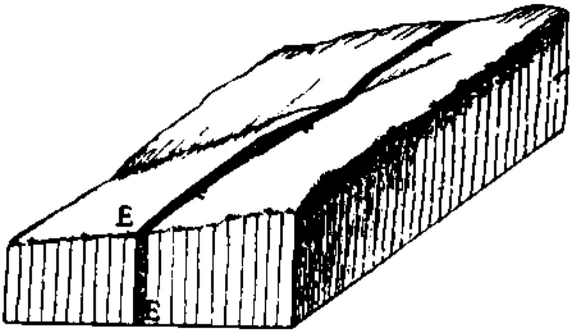
If an oil-bearing group of strata *E*, Fig. 4, which crops out on the surface at *e*, stands quite steep, the borings will rapidly assume great depths the further they are from *e e*. The operations will, therefore, be chiefly carried on in courses of the oil deposit *E e*, as indicated in the sketch by dots which mark the borings. If this is sketched in a map an oil-field stretching in length corresponding to the courses of the strata is obtained without an actual oil-line being in this case present, because this arrangement of the working has nothing to do with the distribution of oil, it depending only on the slighter difficulties and expense of labor and money.

FIG. 4.



This linear arrangement of the workings will be the more pronounced the steeper the strata, and the deposit imbedded concordant with them, stand. If the latter assume a vertical position, Fig. 5, the oil may be found in a very narrow tract corresponding to the size of the deposit in the direction of the bearing of the stratum. If the latter is a straight line, the oil-line sketched in the map will also be a straight line, no matter how undulating the surface of the ground may be. Any bends in the bearing of the deposit, which have to be considered in sinking the bore-hole or shaft, will be recognized from the conformable bends of the strata accompanying it, so that in this case a thorough study of the stratum will be of great advantage in the working.

FIG. 5.



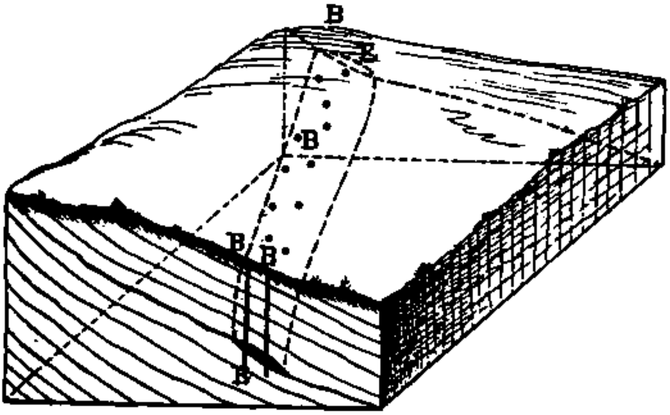
E. Oil-deposit. *e*. Its outcrop.

As regards the oil-line and the working, the conditions remain the same as explained above; in case with a vertical position of the deposit the strata incline towards right and left and become more level, thus forming an inverted fan. In this case a pronounced oil-line is also present.

b. *The deposit corresponding to a stratum possesses a linear extension*. Beds of sandstone and conglomerate need not always show the form of a plate, but with a comparatively small width and thickness may stretch to a considerable length in one direction. Thus, for instance along rivers, the beds of sand and debris, by the cementation of which the abovementioned rocks are formed, can frequently be traced, with slight interruptions, for many miles. Many geologists of the United States are inclined towards explaining in this manner the Pennsylvania oil-lines.

If *E*, Fig. 6, be such linear deposit, the workings above ground must be arranged in the same direction, otherwise they will be without result; they must follow the oil-lines, which in this case do not always coincide with the bearings of the strata.

FIG. 6.



E. Oil-deposit. *B*. Bore-holes.

Such accumulations of debris and sand may also have been formed along a coast, and in them, as well as in analogous formations along running waters, the oil may also appear in secondary deposits, because, like the conglomerates and coarse-grained sandstones formed from them, they possess between the separate fragments apertures readily penetrable by the oil. In fact, as previously suggested, the secondary deposits resembling beds can only be formed in such rocks containing many fissure-joints. Hence the expression "*without sand* (which also includes sandstone and conglomerate), *no oil*," is justified for many regions; the more so since these rocks, when opened, allow the oil to ooze out or flow out more readily and more rapidly, as, for instance, clay-slate. In the latter it may also be frequently observed that the oil contained in them in a primary deposit is obtained in more abundant and profitable quantities only from the imbedded sandstone seams.

2. Oil-lines corresponding to anticlinals and folds.

It has previously been mentioned that C. D. Angell in his belt-theory pointed out the occurrence of oil-lines in Pennsylvania. It became then necessary to explain them; some, and amongst them especially members of the Geological Survey of Pennsylvania, for instance, Lesley, Carll and Wrigley, suppose that the oil-lines correspond to ancient coast lines or river beds, after which, during the Devonian period, the oil-sands were deposited (Fig. 6). H. Höfer,[1] in 1876, pointed out that in Canada, Ohio and West Virginia the principal quantity of oil has without doubt accumulated on the anticlinals, and that, since the principal direction of the strike of the upper, as well as of the lower, oil regions of Pennsylvania runs with almost mathematical accuracy parallel with the anticlinals of the Chestnut and Laurel Ridges, these occurrences might also belong to gentle anticlinals.

Later on J. Carll and C. Ashburner, members of the Pennsylvania Geological Survey, admitted the favorable influence of the anticlinals in many cases, but in comparison with the more prominent importance of the petrographical character of the oil strata, considered them only of secondary consequence.

The anticlinal theory was first taken up and advocated by practical men, but later on was vigorously defended by Prof. J. C. White, Dr. H. M. Chance, and others. It was also quite successfully applied to the occurrence of natural gas, especially by Prof. White, who by reason of his investigations of the location of the most prominent gas-wells in Pennsylvania, as well as in West Virginia, comes to the conclusion that every one of them is located immediately on, or in close vicinity to, an anticlinal axis, and that the gas zones are only about 1300 feet

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[1] Die Petroleumindustrie Nordamerika's.

wide; further, that all borings in the synclinals yielded little or no gas, and in many cases large quantities of saline water.

On the other hand, C. Ashburner states "a great many wells have been drilled in the synclines which have found gas."[1]

Prof. E. Orton, Director of the Geological Survey of Ohio, has recently entered into the discussion, so to say, in an impartial manner.[2] He is not only thoroughly versed as regards the occurrence of petroleum and natural gas in Ohio, but has also repeatedly studied the Pennsylvania districts. He sees in the disturbed structure of the rock-strata a paramount and predominating influence upon the formation of oil and gas deposits, and lays stress upon the fact that in this respect he is opposed to Carll and Ashburner. In the supplement to the report above mentional he proves by a series of examples that the largest quantities of oil and gas in Ohio stand in close relation to the monaclinal fold, summit-like saddles and anticlinals. He finds coincident proofs, especially in all the gas and oil wells of Northwestern Ohio. In correspondence with these disturbances the productive gas and oil wells arrange themselves in so-called gas and oil lines, of which the Findlay monoclinal may at present claim to be of the greatest importance. In the head of this monoclinal the productive gas wells are found, while the oil wells correspond to the steep leg of the fold. Upon the basis of this Findlay Lima fold, a very productive gas-well, was opened at St. Henry, while in the same region (Mercer county) bore-holes had been sunk without success in several places outside the extent of this fold. In this case the anticlinal theory, therefore, achieved a decidedly practical success in showing the prospector after many unsuccessful attempts the productive territory.

Orton[3] also refers to the gas and oil-bearing Berea grit, which cannot be connected with the petrographic composition of the strata, otherwise the entire region over which these homogeneous strata are distributed would have to be productive, while,

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[1] Geology of Natural Gas. [2] Preliminary Report upon Petroleum and Inflammable Gas. [3] Preliminary Report upon Petroleum, etc.

in fact, oil and gas have been found only where a disturbanc in the natural bed of the strata could be shown. This is evidently a proof of the predominant influence of disturbances o the strata upon the greater content of oil and gas in the sam series of strata, and for this reason Orton recognizes this facto as especially favorable, in which he differs from the Pennsylvania Geological Survey.

In the occurrence of oil in Pennsylvania the following fact deserves special attention. In the lower oil region (Butler and Clarion counties) the linear extension appears most plainly; in its most southwestern part it corresponds to the bearing 1,70 (N. 22° E) and curves gradually towards N E to 4_h (N 60° E). To this comparatively rapid and sharp curve also corresponds in the same degree the curve running between Ebensburg and Williamsport, which on the west slope of the Alleghanies divides the Devonian from the Carboniferous and runs parallel with the Silurian lying somewhat to the east—hence a considerable anticlinal (Plate I). By inclosing all the more important oil occurrences in Pennsylvania inclusive of the adjoining Alleghany district of New York in two lines, the result will be an oil-zone about 15 miles wide, which runs in conformity with the previously mentioned boundary between Ebensburg and Williamsport, and generally speaking also with the elevations of the Alleghanies.

If we are not satisfied to accept these facts as a mere coincidence constantly recurring, they certainly prove a connection between rock-structure and oil-bearing, and in addition it may be remarked that in Pennsylvania the folds of the strata actually run parallel with the previously mentioned boundary curve, and further they do not lie horizontal, but flat, inclined towards southwest.

Under otherwise equal circumstances the oil will be present in greater abundance in rock, and flow more abundantly from it, the more hollow spaces the rock possesses and the larger the latter are. Coarse-grained sandstone and coarse conglomerates are certainly an excellent oil-sponge, especially when the cementing

material quantitatively recedes. If such rocks further contain many small fissures, their absorbing and yielding capacities are considerably increased. Such fissures, however, were formed by the flexures of the strata at their turning points, on the axes of the anticlinal and synclinal, while the connecting legs were least bent and broken.

When a complex of strata consisting of alternate beds of more elastic and of more brittle, less solid rocks are thrown into folds, it may a thousand times be proved in nature that the brittle rock strata, for instance limestone and conglomerate, are split asunder on the turning points of the folds, while the tougher strata, for instance shales, can follow these turnings without splitting. If, however, the bending exceeds a certain limit, whereby the duration of deformation is of essential importance, the tougher upcast strata—in Pennsylvania the schists and shales—are also broken and the oil can then ascend in the cracks extending to the surface and flow out, whereby large quantities of it are withdrawn from the conglomerate reservoir.

Hence there must exist a definite belt of anticlinals and synclinals, inside of which the flexures of the strata have been so great that on their turning points the conglomerate strata were split asunder as much as possible without fissures extending to the surface having been formed in the schists and shales; in consequence of which the absorbing and yielding capacities of the conglomerates were increased to the maximum though the oil could not escape. If the flexures were too small, *i. e.* if the strata were folded not at all or too little, no cracks were formed in the oil-rock, and the latter when opened by boring would yield less oil. If, on the other hand, the flexures were too large, the greater part of the oil had run out before the deposit was opened by man.

That gas occurs chiefly in the anticlinals and more seldom in the synclinals is explained by H. H. Chance[1] by the collection of water in the latter, they being the deeper portions of the

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[1] The Anticlinal Theory of Natural Gas. Trans. Am. Inst. of Mining Engineers, 1886.

porous strata, and the consequent displacement of the gas; but where water is absent the synclinals may also carry gas. Mr. Chance will no doubt permit the application of his view to the distribution of oil inside of a folded complex of strata.

Let us briefly sum up these discussions. By itself the dip of a stratum whether anticlinal or synclinal cannot be declared to be oil-bearing, there being necessary also a porous rock that absorbs and yields the oil. Where such rock is bent to a certain degree it will be richest in oil. Generally speaking the anticlinals of porous rocks are richer in oil than the synclinals.

The explanations given above refer to the conditions in Pennsylvania and adjoining districts. That elsewhere the structure of the strata may also be of essential importance, is shown by the investigations of the occurrence of petroleum in the Carpathian mountains by C. M. Paul and E. Tietze.[1] They arrive at the final conclusion that "one thing seems to be certain in the latter respect (in regard to special kinds of complication in the position of strata or disturbance) that the prospects of striking oil by boring are better on the elevation of strata-saddles than in the depth of strata-basins, the conditions prevailing, among others, at Boryslaw, Bóbrka, Mrasznica, Orów and Ropianka, being at least favorable to this view."

The conclusions of these investigators are confirmed by a fact in the Galician territory. At Pokar near Skole, Galicia, the oil occurs in the menilite slate, which dips 40° to 50° S W and in separate strata is rich in fish remains, and in higher strata in imbedded hornstone or chert. The productive shafts are throughout put down to the above-mentioned slate, but only those gave satisfactory results and have been productive for several years which are located in a secondary anticlinal which runs towards S W, hence crossways to the principal bearing of the strata—and in this direction also dips down. The principal saddle of melinite slate is destroyed, this occurring frequently in the Carpathian mountains.

Special attention may here be called to such small lateral

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[1] Jahrb. Geol. Reichs-Anst., 1879, 302.

saddles, which are placed more or less crossways to the principal bearing of the strata and which are plainly perceptible only in detailed maps.

The facts previously mentioned confirm an actual concentration of oil along the anticlinal ridges; related to this, but not identical with it, is the phenomenon recurring in many regions that the natural oil-springs issue forth along the anticlinals, which, however, does not prove an actual concentration of oil in the latter, because the outflow of oil may be due to the fact that the anticlinal fissures extend to the surface, while the synclinal may be closed on top, thus preventing the oil from reaching the surface.

A few cases of this kind may here be mentioned.

In Ohio and West Virginia the oil issues from fissures corresponding to the anticlinal axes. The occurrence of oil in Kentucky and Tennessee corresponds to the anticlinal parallel to the Alleghanies, which divides the carboniferous formation into two coal fields.

As regards the North German occurrence of oil, Bunsen,[1] as far back as 1839, has shown that the most important localities of oil and maltha lie in a nearly straight line, which running from southeast to northwest connects the localities, Wietze, Haenigsen and Oedesse.

The Carpathian mountains in the Bukowina, which form the continuation of those in Galicia, have been investigated by Bruno Walter. He showed that all natural oil springs in that country belong to the lower chalk strata, especially to the Ropianka strata, and lie in three lines parallel to the Carpathian mountains, which correspond to anticlinals.

The favorable influence of the anticlinals as regard the Roumanian oil regions has been shown by Paul and Olezewski.

The favorable influence of the saddles of the folds upon the oil-bearing strata of Apscheron (neighborhood of Baku) is also well known, and we will here quote H. Abich's[2] remarks re-

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[1] 3. Jahresber. Verein f. Naturkunde in Cassel. S. 12.

[2] Jahrb. geol. Reichs-Anst., 1879.

garding this region: "Wherever at Apscheron naphtha in a fluid or inspissated form spontaneously issues forth immediately from the old tertiary formation, and the presence of larger accumulations of bitumen at a greater depth is, according to experience, probable, the stratification is in the form of an elliptical, mostly flat arch, which is either closed or anticlinally opened in the direction of its longitudinal axis."

On the northern declivity of the Caucasus the anticlinals also exert an extremely favorable influence. From a Russian official document[1] we quote as follows: "With the distance from the mouth of the Kuban the effects of the upheaving forces become more and more apparent. Oil springs appear on the elevated points in the anticlinal dips, as well as mud volcanoes, bitter springs and sulphur springs. This relation between oil springs and mud volcanoes is so constant that the latter may be used in searching for the former. The springs on the elevated lines yield a far more fluid product than those of the monoclinal dips. The general distribution of the springs in this region is closely connected with the direction of the upheaval of the sedimentary strata."

In regard to the trans-Caspian oil region Dr. Hj. Sjögren[2] has recently shown that both of the larger oil localities—Neftjanaja gora and Buja-Dagh (with up to 130° F. hot brine springs)—visited by him, lie upon the ridges of two anticlinals, the structure of one of which is symmetrical and of the other unsymmetrical.

According to Zincken, petroleum occurs about 29 miles SSW of Chokand, Russian Turkestan, on the anticlinal axis of upheaved chalk strata. At Khatan, Bellouchistan, oil occurs, according to R. Townsend[3] on the summit of an anticlinal, as can be readily recognized from the profile of this region given by him.

H. B. Medlicott[4] repeatedly refers to the fact that not only in

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[1] Apercu des Mines du Ministere du Domains de l'etat, 1879. [2] Jahrb. geol. Reichs-Anst., 1887, S. 47. [3] Report on the Petr. Expl. at Khstan; Rec. Geol. Surv. of India, 1886, 19. 204. [4] Note on the occurrence of Petroleum in India; Rec. Geol. Surv. of India, 1886.

Khatan, but also in the Punjab, Assam, Arakan and Burmah, the occurrence of petroleum coincides with disturbances in the structure of strata, without, however, indicating them more closely for the different regions. C. Zincken,[1] on the other hand, expressly characterizes this disturbance, at least for the Punjab, as an anticlinal, this connection being also shown by B. S. Lyman[2] for many oil-wells of Japan.

We have seen that along the strata-saddles there is either a considerable concentration of oil that is especially productive when mined, or that many natural oil springs correspond with these saddles, which is of great interest to the prospector. Without denying that in some instances the basins may carry oil, in most cases the anticlinals will offer the most promising field to the prospector.

3. *Oil-Lines corresponding to a Displacement.*

That petroleum occurs also in fissures as a secondary deposit has previously been mentioned. The course of many fissures runs to a considerable extent in a definite direction, in which case the oil-finds will also extend in the same way. Instead of a fissure along which displacements of the two portions of rock divided by it have taken place, there may also be an entire tract of fissures which, with a narrow width, frequently runs a considerable distance. Since moreover, such fissures or tracts of fissures stand very steep to vertical, there can for technical reasons be only a very narrow width for striking oil. The borings or shafts must, therefore, arrange themselves in the bearing of the fissure, and thus mark an oil-line.

Strongly arched anticlinals will also give rise to the formation of tracts of fissures, in which case the oil-line has to be referred to the one or the other.

An illustration of what has been said above is obtained if, in Fig. 5, p. 94, *EE* represents with any position of the strata, a fissure or tract of fissures.

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[1] Geol. Horiz. Foss. Kohlen, etc., S. 114.

[2] Geol. Survey of the Oil Lands of Japan, Tokio, 1877 and 1878.

An example of the linear arrangement along displacements, which has been discussed above, is given by the occurrence of various bitumens, especially of asphalt, along the Jordan fissure, which for many miles stretches from *N* to *S*.

Brine with Petroleum.

Much stress has been laid by some upon the fact that brine and petroleum frequently occur together. From such occurrences it has, on the one hand, been attempted to draw conclusions as to the genesis of petroleum, and, on the other, brine springs have been considered guides in searching for oil. While it is true that brine springs frequently issue from fissures along which oil may also circulate, it has to be taken into consideration that these two fluids do not always occur together, and that the brine would prevent the egress of the oil into the fissure of the spring. Hence, brine springs are, as a rule, of no importance for the prospector, except that, under certain local conditions, they may draw attention to a zone of disturbance in which petroleum may also ascend.

It may further be pointed out that an influx of brine is frequently met with in coal-fields, for instance, in England and Scotland, without any theoretical conclusions or rules for prospecting being drawn therefrom.

In Pennsylvania also brine is generally met with only in the carboniferous strata, especially in the sub-carboniferous overlying the oil-bearing Chemung strata, though sometimes also in the conglomerates of the Devonian strata. Hence, since the original sources of brine and oil are frequently completely separated one from another, it is plain that these two fluids cannot be brought into close genetic relation.

An analysis of such brines, if they are not connected with a rock-salt bearing group of strata, might be of scientific interest. It would show in many cases that though there is a preponderance of sodium chloride, the sulphates, which are present in considerable quantities in brines derived from rock-salt bearing strata, are frequently entirely absent. Hence such brines cannot be referred to the occurrence of rock salt.

Since petroleum is found in many localities without water, or with water of ordinary composition, it is plain that the speculations which would connect the occurrance of oil with deposits of rock salt, must be supported by further proof. Moreover there are brine springs, like those in the vicinity of the Palatinate melaphyre region (Nauheim, etc.,) which are not connected with deposits of salt.

Natural Gases and Petroleum.—Flowing Oil Wells.

Petroleum is always accompanied by natural gases, and where the latter appear in larger quantities oil also is frequently found, so that in many localities the striking of gas is considered a good indication of finding oil in the near future. In such case the gases result from the same process as the petroleum, they being the lowest members of the series of hydrocarbons which constitute crude oil. Since the gases penetrate the pores of the partition-rock with greater ease than the oil, they are found in the level strata of the oil deposit as forerunners of the latter, and are also more widely distributed than the oil. Hence in sinking a shaft or in drilling, the use of a safety-lamp is recommended, and may, in many cases, be absolutely necessary.

The natural gases are absorbed or dissolved by the oil, and to a greater degree the greater the pressure is. When a deposit of oil rich in gas is opened the pressure prevailing in it suddenly falls, and the gases in endeavoring to escape force the oil upwards in the bore-hole in accordance with the over-pressure of the gas, so that it rises even to the surface where it overflows or ascends into the air as a flowing well or oil fountain.

Descriptions of such flowing wells have previously been given. They have been drilled in every larger oil region, and generally increased the eagerness for prospecting in the vicinity, though sometimes they have proved fatal to the lucky finder, as exemplified in the case of the Droobja well mentioned on p. 25.

If the pressure under which the oil issues forth were dependent on water, oil wells would have to be supposed to act in a similar manner to artesian wells, and that after an oil region is exhausted water would finally break through. Both of these propositions, however, are contradicted by facts.

Since hydrostatic over-pressure does not constitute, as, for instance, in the case of artesian wells, the impelling force of such wells, but the over-pressure of gas, and the latter is emptied together with the oil, in consequence of which the gas-pressure in the deposit itself decreases, the life of such flowing wells is very short, it lasting perhaps a few hours or a few days. The oil then flows quietly from the mouth of the bore-hole, but later on does not reach up to the latter and has to be pumped.

Sometimes the overflows of oil are intermittent, they taking place in pauses of several minutes or hours. When the deposit is opened by the drill, a jet of oil shoots up into the air, which, however, becomes constantly less in height until the oil reaches up only to the mouth of the bore-hole. The weight of the column of oil in the bore-hole is now equal to or smaller than the momentary gas-pressure at the lower end; if the latter be the case the column of oil gradually sinks in the bore-hole until the equilibrium is restored. During the eruption of oil, the oil deposit had been emptied, especially in close vicinity to the bore-hole. The hollow-spaces which have thus been emptied are gradually filled by portions of oil standing under still greater pressure and exerting a lateral force, whereby the pressure is again increased, and finally becomes greater than the weight of the column of oil in the bore-hole, so that the persistent capacity of the latter and its friction on the sides of the bore-hole are finally overcome, and a fresh eruption takes place. Thus the intermission between two overflows will mainly depend on the pressure under which the oil stands in the deposit, on the resistance which the oil meets with in its movement inside the deposit (size and number of the small hollow-spaces) on the depth and tubing of the bore-hole, and on the density of the oil.

Eruptions of gas without oil or accompanied by only a small quantity of it may also take place. The eternal fires at Baku have been known for a long time. In Pennsylvania natural gas is extensively used for heating and illuminating purposes, especially in the large manufacturing establishments and in the households of Pittsburgh. Such an occurrence is always closely connected with that of petroleum, a porous rock being required as a reservoir, and the anticlinals and synclinals, especially the former, also exert a favorable influence. The productiveness increases with the size of the reservoir and the pressure prevailing therein, the geology of petroleum being, in this case, also that of natural gas. In Pennsylvania, as well as in all other regions, the gas-bearing strata are the same as the oil-bearing (conglomerate and coarse-grained sandstone).

Of interest as regards general geology is the Sheffield well, which lies in an anticlinal axis 2½ miles east of Sheffield, and, since 1875, supplies that city with light and heat. In drilling a crevice with brine was crossed at a depth of 418 feet, but the flow was not stopped. The "gas-sand" (conglomerate) 45 feet thick was reached at a depth of 1350 feet. The flow of gas which was quite considerable at first decreased rapidly and finally stopped entirely—the bore-hole was frozen up.

This phenomenon is explained by the well-known fact that by the increase in the volume of a certain quantity of gas the temperature is lowered in consequence of the very high pressure being diminished. In the conglomerate the gases stood under very high pressure which suddenly was considerably diminished, so that in consequence of the rapid lowering of the temperature of the surroundings—the brine—connected therewith, heat was withdrawn to such an extent that the brine froze.

The gas sometimes occurs in its deposit together with water. The gas is absorbed by the water and, as is the case with petroleum, flowing wells, which later on become intermittent, may be formed. The absorbing capacity is much assisted by salt in solution. Hence if 20 cubic feet of salt water absorb 1 cubic foot of marsh gas at atmospheric pressure, the same quantity of salt water would, according to Henry's law, absorb at 150 pounds or 10 atmospheres 10 cubic feet, or 50 per cent.; and at 450 pounds or 30 atmospheres 30 cubic feet or 150 per cent. If the bore hole is 500 meters (546.81 yards) deep a pressure of about 50 atmospheres would correspond to such a column of water, and, in case brine is present, the absorbing capacity would be 50 cubic meters, *i. e.*, 1 cubic meter brine contains 2.5 cubic meters gas. That such or a similar condition will soon prevail in the bore-hole may be reasonably supposed, and hence considerable subterranean reservoirs and a large flow of brine would be required for the escape of sufficient gas at the mouth of the bore-hole to supply a smaller manufacturing town for several years with light and heat. If, however, instead of brine, water is present which absorbs marsh gas to a far less degree, the yield of gas will be considerably less.

The conditions will be more favorable when the deposit—the reservoir—is filled by gas alone. The gas is as a rule confined in the reservoir under greater pressure, which, among others, is dependent also on the possibility of escape, even if in small quantity. Although no direct measurements of the tension of gas recently unlocked have been made, other observations lead to the conclusion that it must be very great. Thus it has been repeatedly reported that in striking a gas deposit the heavy tools have been hurled even from very deep bore-holes, and a conclusion as to the magnitude of the gas-tension may also be drawn from the considerable height attained by oil and water fountains.

The pressure under which the gas escapes from bore-holes already in use has been directly and accurately measured in but few cases. The most carefully observed pressures and productions have been made in Ohio.[1] In the Findlay field the actual product of wells varies from 80,000 cubic feet, at the Adams well, to 12,080,000 cubic feet, at the Karg well. The closed pressure at the wells of this district is about 375 pounds to the square inch. In the first wells it registered 450 pounds.

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[1] Jos. D. Weeks. Natural Gas. Abstract from "Mineral Resources of the United States, Calendar Year 1885."

In none does the limit now exceed 400. It has been found that all wells of a district, great and small, attain finally the same pressure, some reaching the maximum or average pressure sooner than others. The Karg well in the Findlay district reaches it in 1½ minutes; the smaller ones may require hours. The actually observed productions of four wells in this district, as given by Professor Orton, are as follows:

	Cubic feet.
Karg well	12,080,000
Cory well	3,318,000
Briggs well	2,565,000
Jones well	1,159,200

No accurate statements of production and pressure of Pennsylvania gas wells have been obtained. The estimated production of some of the "gassers" of the Murraysville district is 30,000,000 cubic feet a day. The partially open pressure in this district is from 150 to 200 pounds. In the Wilcox district the closed pressure reaches 575 pounds and there remains stationary. In some parts of Butler county it is 250 pounds.

In Allegany county, New York, the closed pressure is 450 pounds. In Illinois a pressure of 400 to 450 pounds was reported at the Litchfield well when first drilled, but this has been reduced to 125 pounds. At Urbana the pressure at one well is but 10 pounds; at a second, 25 pounds.

When the pressure exceeds a certain limit, the gases will be liquefied. Hence the question has been frequently raised whether the natural gases are not accumulated in this state in their deposits. If such were the case it would be possible for a single comparatively small subterranean reservoir to yield for many years immense quantities of gas. That with the answer to this question the hopes regarding the duration of this modern fuel are closely connected requires no further explanation.

To solve this question, which is also of great scientific interest, it will be necessary to subject the various natural gases directly to compressing experiments. Although marsh gas (CH_4) constitutes the principal portion (60 to 80 per cent.,) of natural gases, the experiments made with it by Faraday, Dewar, Cailletet and K. Olszewski furnish only a basis for conjectures that in mixtures of gases the proportions may be considerably changed. Thus, for instance, natural gas contains ethane (C_2H_6) and propane (C_3H_8), the former up to 28.9 per cent., and the latter up to 2.0 per cent. Ethane is liquefied at 35° C. (95° F.) under a pressure of 42.5 atmospheres. In a Pennsylvania deposit of gas at a depth of 500 meters (546.81 yards) the temperature cannot be above 25° C. (77° F.), the waters discovered at such depths showing, as a rule, a somewhat lower temperature. Hence considerable less pressure would suffice for the liquefaction of the ethane. Since a pressure of 50 atmospheres corresponds to a column of water 500 meters high, and one of 40 atmospheres to a column of petroleum of the same height, it may be accepted as a fact that ethane and propane also exist as liquids, the latter being liquefied at atmospheric pressure at a temperature of —25° C. to —30° C. (—13° to —22° F.,) and at a normal temperature at quite moderate pressure. There are, however, no results of experiments to what degree these liquid hydrocarbons and any accompanying petroleum are capable of dissolving the methane (CH_4), especially with regard to the high pressure.

To liquify methane at about 25° C. (77° F.) in the gas-deposit, an enormous pressure would be required, because K. Olszewski's most recent researches show that at 54.9 atmospheres and a temperature of—81.8° C. this gas reaches the critical point and liquefies at 49.0 atmospheres and a temperature of —85.4° C. From these low temperatures it may be supposed that at a temperature of 25° C. (77° F.) at least several hundred atmospheres would be required for the liquefaction of methane, in case it were present by itself.

Independent of water, which may contain salt, and of petroleum, natural gas may occasionally be accompanied by other interesting substances. Thus S. A. Ford observed in the outlet-pipe of a gas well in Pennsylvania a soft gray-white substance consisting of calcium chloride, which almost obstructed the pipe. Another gas-well threw out, immediately after being opened, crystals of ammonium carbonate.

In loose and plastic ground the outbreaks of gas cause eruptions by which mounds resembling volcanoes are formed, from the craters of which the gases at first issue with great vehemence. A spark caused by two rock fragments knocking against one another during the eruption may ignite the gas and the column of fire thus originated increases the external resemblance to an actual volcano. Such *mud volcanoes* or *salses* are frequently found in the vicinity of and in oil territories, several of them occurring in Trinidad, also in the Caucasus, especially on its western and eastern ends.

A more detailed description of these mud volcanoes or salses would be out of place here, they being not related to actual volcanoes.

Some Peculiarities in the Occurrence of Petroleum.

The fact that the oil of a deposit is denser and of less value near the outcrop has been previously mentioned and explained. Hence, we have here to deal, as in the case of many ore deposits, with a region of oxidation in the vicinity of the outcrop. This also agrees with the observation that heavy oils contain, as a rule, no gases, and light oils many of them. Thus, for instance, large quantities of gas escape from the light oils of Schwabweiler and but little from the maltha (mineral tar) of Pechelbronn (Alsace), which belongs to the same geological horizon.

It has further been pointed out that several deposits—in Pennsylvania frequently three—may be below one another, and that the lowest deposit generally carries the best and lightest oil. With a nearly horizontal position of the strata, as in America, several such deposits may be opened by one boring. If, however, the separating intermediate layers are of great thickness, or the strata are very much tilted up, opening the deposits by means of one bore-hole will have to be given up. This is, for instance, the case in the Austrian Carpathian mountains, where several—three or four—levels of petroleum are known, which belong to different formations, viz.: 1. Chalk (Ropianka strata). 2. Eocene (upper hieroglyphic strata). 3. Oligocene (melinite slate) and 4. Neogene (saliferous clay.)

The oil sandstones and conglomerates generally are, on their fresh fracture, of a brown color—in the most different shades according to the quantity and quality of the oil contained in them—and darker than the same kinds of rocks free from oil. On exposure for some time to the air they acquire a lighter color in consequence of the volatilization of the oil, though occasionally small dark dots and stains of resinified oil may be recognized.

As regards the dependence of the productiveness of a deposit on *meteorological factors*, especially pressure of air and quantity of rain, we have no results of direct observations. In the Caucasus and at Apscheron the summer season, it is claimed, has been found more productive than the winter season. In Galicia the productiveness of the wells is said to be less in dry seasons. In Oelheim, on the other hand, the assertion is made that the production of the wells decreases with an increase of surface water, and as regards the occurrence of maltha near Wietze (Hanover) the most productive months are, according to Eck,[1] August, September and October. However, all these experiences require more careful, controlling observations, embracing a longer period of time, before they can be introduced into science and conclusions drawn from them.

The temperature of the crude oil from a newly opened deposit is throughout such as may be expected with due regard to the depth of the deposit and the geothermal grade.

Distribution of Bitumen in the various Strata of the Geological Formations.

The summary given below is not claimed to be complete, and, hence, no far-reaching conclusions should be drawn from it in regard to strata perhaps poor in petroleum.

In many regions the determinations of the age of bitumen-

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[1] Zeitschr. f. Berg-, Hütten- u. Sal.-Wesen im preuss. Staate, 14, 349.

bearing strata are either entirely wanting or doubtful. In the summary are many gaps, which it would be desirable to have filled up as soon as possible; but even in its present form it shows that petroleum and other bitumens closely allied to it are not confined to certain formations. Even the richest occurrences which have up to this time been worked on a large scale, do not belong to the same formations. Thus, for instance, in the miocene strata are found the rich oil-strata of Apscheron (Baku), Taman, Roumania and partly of Galicia (Boryslaw), while the eocene carries oil in Galicia, Hungary, Roumania (partly), Italy, Koordistan, in Hit (Bagdad), which was celebrated 500 years B. C., in Belloochistan, and especially in the East Indies. On the other hand, the richest oil horizon in Galicia and Bukowina belongs to the chalk formation. The oil occurrences in Brunswick and Hanover belong to the various formations of the mesozoic group. The principal oil deposits of Eastern North America, especially of Pennsylvania, belong to the paleozoic group, the Devonian system.

I. CENOZOIC.

1. *Alluvium.*

Exudations and effusions of petroleum are found in alluvial strata, but such occurrences are in secondary deposits. However, the exudations of oil in the coral reef of Djebel Zeit in the Red Sea belong to a primary deposit.

2. *Diluvium.*

Germany: Hanover: Petroleum at Wietze, Steinförde, Weenzen, Verden; maltha at Haenigsen, on the Fissenberg; petroleum at Linden.—Petroleum between Heide, Mehldorf and Hemming (Sleswick-Holstein).—*Austria-Hungary:* Petroleum at Raczsindol (Slavonia).—*Canada:* Enneskillen. In diluvium also the oil occurs almost exclusively in secondary deposit.

3. *Tertiary.*

France: Unimportant occurrence of petroleum and asphalt in sand and clay at Dak in the Landes (Pyrenees).—At Dallet not far from Clermont Ferrand (in crevices), maltha and asphalt; also a few miles east of Clermont (Department Auvergne) in basalt trap. Maltha in basalt trap near Pont du Chateau (Dept. Est).—Asphaltic limestone at Barjă Bagnols Arr. Alais (Dept. Gard).—*Italy:* Petroleum in the Emilia (from St. Colombaro to Faenza).—Several of the occurrences of petroleum and gas in *Japan* may belong to the tertiary period.—*Dutch India:* All occurrences of petroleum belong to the tertiary formation.—*New Zealand:* At Waipawa (Auckland) petroleum in crevices of brecciated trachyte.—*California:* In many places petroleum and asphalt, the most important locality being the coast range from Santa Clara to San Diego.

a. Pliocene.

Roumania: According to Pilide and also to Olszewski all occurrences of oil in Wallachia belong to the pliocene formation; the most important localities being: Colibasi, Plojesti, Buzeu, Baicoiu, Tintea, Campina, Telega, Droganese, Pekuretzi; chiefly in sandstone.—*Turkey:* Asphalt in masses up to 10 feet thick at Selenitza (Albany), in sandstone accompanied by maltha and soft asphalt.—*European Russia:* Petroleum and mineral wax on the island Tscheleken (Caspian Sea) in sandy-clayey strata (according to Sjögren perhaps miocene).

b. Miocene.

Switzerland: Asphalt of the Canton Waadt in strata of sandstone and lime.—*Italy:* Petroleum on the north declivity of the Apennines between Padua and Bologna (partly pliocene) in clay and sandy marl. Asphaltic limestone from Ragusa at Niszemi, Sicily (Province Syracuse).—*Germany:* Petroleum, asphalt and maltha in Alsace (Hirzbach, Hirsingen, St. Croix, Echery, St. Bilt, Roderen, Mutzig, Mohlsheim, Biblisheim, Pechelbronn, Schwabweiler, Lobsann, etc.), chiefly in sand and sandstone.—Asphalt and maltha at Ehingen (Würtemberg).—*Austria-Hungary:* Galicia: Mineral wax and petroleum at Boryslaw, Dzwiniacz and Starunia. Asphalt in small quantity is found on the west and south foot of Monte Promina (Dalmatia).—*Hungary:* Petroleum at Recz, Kowac, Garbonac, Dragomer, Soósmezö.—*Roumania:* Petroleum at Moinesti, Campeni, Taslau, Comonesti, Majonesti, Ohna, Solanti, Pocura; mineral wax at Slanik, Zietrisikit on the mountain Zietrisika (Moldavia).—*European Russia:* Petroleum, earthy asphaltum, kirr and earth gases in large quantities in the peninsula Apscheron (at Baku) and upon the Holy Island (Caspian Sea); at Umachan-Jurt (north foot of the Katsch-Kalykowsky chain); Peninsula Taman (Asow Sea).—*Transcaspia:* In larger quantity at Neftjanaga-gora and Buja-Dagh in sand strata.—*East Indies:* Petroleum at Padouk-Beny (District Thayetmyo) in sandstone and schists.—*Venezuela:* Petroleum at Maracaibo and Punto D'Acaja in shale, limestone and sandstone.—*Trinidad:* Petroleum and asphalt in shale, limestone and sandstone, besides the well-known pitch lake in which the bitumens collect.

c. Eogene.

Italy: Asphalt at Rocca d' Arce, Roccasecca, etc. (Province Caserta) in limestone and sandstone.—Petroleum at Roccamorice and Albataggio (Province Abbruzzo ulterio) in limestone.—*Germany:* Petroleum at Tegernsee (Bavaria), derived, according to v. Gümbel, from the nummulitic strata. Asphalt in nummulitic strata at Sonthofen, on the Kressenberg, at Reichenhall, Frechenwand on the Eibsee, at Grunten.

a. Upper-Eocene (Oligocene.)

Italy: Petroleum at Vergato, Pietra Mala (Province Piacenza).—*Austria-Hungary:* Galicia (mostly shales); Petroleum at Schodnica, Koziowa, Pohar, Bóbrka.—*Hungary:* Petroleum at Smilno, Szinna, Maramaros, Jód, Dragomer.—*Roumania:* According to Cobalcescu, the oil-bearing strata of Moldavia belong to this formation.

β. *Lower-Eocene.*

Austria-Hungary: Galicia: Petroleum in sandstone at Schodnica, Bóbrka, Sloboda rungurska.—*Hungary:* Earth oil in sandstone at Konyha, Saczal, Maramaros, Zibo, Udvarhely, Soózmezö.—*Roumania:* Petroleum at Moinesti (Moldavia), according to Olszewski.[1]—*Koordistan:* Petroleum in several localities.—*Turkey in Asia:* Petroleum at Hit (Bagdad).—*East Indies:* Mineral pitch at Sulgi (District Ihilam) in sand; Petroleum at Panoba (District Kohat) in crevices of nummulitic limestone; asphalt and petroleum, sometimes in considerable quantities in the nummulitic limestone of the district Rawalpineli, viz., at Dulla, Boari, Churhut, Gunda, Lundigar and Ruta Otur; Petroleum and natural gas at Yenan Douny (District Prome) and Toungboje.—Petroleum in Khatan (Belloochistan).—Petroleum in larger quantities in Arakan, Assam and Upper Burmah (for instance, Rangoon). According to H. B. Medlicott,[2] these three territories may be middle-tertiary.

II. MESOZOIC GROUP.

4. *Chalk.*

Spain: Asphaltic sandstone in the Province Santander, District Escudo.—Asphalt in the province Soria, at St. Leonardo and Casarejos.—Asphalt in the province Saragossa at Torrelapaja.—*Italy:* Petroleum in the Neapolitan district (Tocco, Manopello, Guardagreli, Chieti, Rionero di Molise, Tirriolo, Squillace, Gerace, Zacarise). *Austria-Hungary:* Galicia: Petroleum in sandstone at Ropianka, Mrasznica.—*Bukowina:* Petroleum at Kimpolung, Dichtenitz, Putna, Krasna and other localities.—*Hungary:* Arva, Liptau, Komarnik, Mikowa, Luch, Przolina, Soóamezö.—*European Russia:* Petroleum at Telaw and Douchette (southern slope of the Caucasus).—*Russian Turkestan:* Petroleum in the district of Namangan, further at Chokand.

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[1] According to Paul, miocene.

[2] Record. geol. Survey of India, 1886, 19, 202.

a. Senonian.

Germany: Petroleum at Darfeld (District Münster); clay containing maltha at Badenstedt (Hanover).—Petroleum in the chalk between Heide, Mehldorf and Hemming (Sleswick-Holstein.)

b. Cenomanian.

Syria: Petroleum and asphaltum in sandy marl under cenomanian limestone on the eastern slope of Djebel el Dahr.—*Palestine:* Petroleum and asphalt in limestone on the shore of the Dead Sea; asphaltic limestone in Antilebanon, at the sources of the Jordan, and at Hasbeya.

c. Gault.

Switzerland: Asphalt in Val de Travers and other localities in the Canton Neufchatel (in secondary deposit).

d. Neocomian (including Wealden).

Portugal: Oil sandstone asphaltic sandstone in the Province Estremadura.—France: Asphaltic sand- and limestone at Pyrimont, Volant and Challonge near Seyssel on the Rhone, Department d' Ain (content of bitumen 8 to 9 per cent.)—*Austria-Hungary:* Silesia: Asphalt and petroleum in very small quantities in small cavities of the limestone in the vicinity of Skotschau, Grodischt and Bielitz.—*Galicia:* In the Ropianka strata at Ropianka, Mrasznica. All occurrences of oil in Bukowina.—*Germany:* Petroleum in small quantity at Hordorf (Brunswick) in black clay.—*Hanover:* Petroleum at Klein-Oedesse in limestone and sandstone with coal and bituminous shale; petroleum at Hoheneggelsen, Linden, Oelheim; petroleum and maltha between Oelheim and Badenstedt in clay, at Ahlfeld and Delligsen.—The occurrences of oil in the Argentine Republic (Selta, Jujuy) and in Bolivia belong partially to this formation.

5. *Jura.*

a. Upper-Jura.

Portugal: Asphalt at Torres Vadeas, Serra de Cabeco in schistose limestones.—*France:* Asphaltic limestone at Orbagnoux, Diablerets, Chavaroche, Pyrimont (Department l'Ain).—*Germany*: Asphaltic limestone near Vorwohle in the Wintjenberg and in the Waltersberg near Eschershausen (Brunswick). Petroleum at Haenigsen (Hanover) in marl. Petroleum at Linden. Maltha and asphalt at Limmer in limestone, marl and marly limestone.

b. Middle Jura.

Germany: Petroleum at Reitling (Brunswick) in gray sandy clay.—Petroleum at Wietze, Steinfoerde, Weenzen, Verden, in dark grenish clay; at Linden (Hanover).

c. Lower Jura.

Germany: Petroleum at Klein-Schöppenstedt and Schöningen (Brunswick), in dark clay.—Petroleum at Weitze, Steinförde, Weenzen, Verden (Hanover), in dark greenish clay.—*Austria-Hungary:* Black petroleum occurs sporadically in the Grestner strata of Lower Austria.

6. *Rhaetic.*

Germany: Petroleum and asphalt at Sehnde (Hanover), in clay.—*Austria-Hungary:* Asphalt in schistose beds of the chief dolomite at Seefeld (Tyrol).—*Argentine Republic:* Petroleum in bituminous schist at Mendoza (Province Selta), according to Dr. Stelzner.

7. *Trias (Upper).*

Austria-Hungary: Insignificant exudations of asphalt and maltha in the vicinity of the Raibler strata at Bleeberg and Raibl (Carinthia).

III. Paleozoic Group.

8. *Dyas.*

European Russia: Petroleum at Sukkowo (Zechstein, Government Kasan), at Michailowka, Kamischli, Schugorowa, Sarabilkowa, Jakuschkino, Nowo-Semekino (Government Samara).

9. *Carboniferous.*

France: Petroleum at Gabian (Department Hérault).—*Germany*: Petroleum in very small quantities in the coal measure of Wettin on the Saale (Province Saxony).—*England:* Petroleum in the coal measure of Derbyshire, in sandstone at Shropshire, at Dawley and Dingle, at Coalbrookdale near Newcastle.—*European Russia:* Asphaltic limestone in the peninsula of Samara and at Ssyrau, both on the Volga.—*Pennsylvania:* Gas wells at Pittsburgh.—*Ohio* (East): Gas at East Liverpool, Neff, Wellsburg. Oil at Macksburg—*Kansas:* Considerable gas wells in the eastern part of the State, for instance at Iola, Fort Scott, Kansas City, Rosdale.

10. *Devonian.*

European Russia: Petroleum in larger quantity on the Uchta (Government Archangel).

a. Upper Devonian.

Pennsylvania and New York: The most productive oil and gas wells of North America (Counties: Allegheny, McKean, Warren, Venango, Clarion, Lawrence, Beaver, Armstrong, Butler).—*Ohio* and *West Virginia:* (Counties: Noble, Washington) Petroleum.

b. Middle Devonian.

Larger quantities of natural gas in *Western Pennsylvania* and *Ohio*. Earth oil in *Tennessee* and *Kentucky*.—*Indiana:* Occurrences of oil of slight importance.

c. Lower Devonian.

Canada: Petroleum at Enniskillen in considerable quantities, and at Gaspé in small quantities.—*Indiana:* Occurrences of oil of slight importance.

11. *Silurian.*

European Russia: Asphalt at Baltischport (Esthland).

a. Upper Silurian.

Austria-Hungary: Petroleum, maltha, and asphalt in trifling quantities in small cavities of the lime-stone of Central Bohemia (for instance, at Slimenetz, Kuchelbad).—*Illinois:* Unimportant occurrences near Chicago.—*Ohio:* Natural gas at Fremont.

b. Lower Silurian.

New York: Petroleum at Gulderland, near Albany; Watertown.—*Ohio:* Larger occurrences of oil and gas at Findlay, Bowling Green, Lima, Corey; gas wells in Hancock and Wood counties.—*Kentucky* and *Tennessee:* Larger occurrences of oil in the Cumberland territory.—*Canada:* Petroleum on the island of Grand Manitouline; at Packenham; at Riviére à la Rose.—*Missouri:* Petroleum and asphalt in the lead and zinc region (Oronogo, Joplin, Ratis, Newton County).

CHAPTER VI.

ORIGIN OF PETROLEUM.

THE opinions of scientists, geologists, and chemists regarding the origin of petroleum, and the bitumens related to it, differ very much, not taking into consideration the views of many laymen. Of the latter only one, that of a Pennsylvania "oil-man," may be mentioned on account of its originality, according to which the American petroleum is the urine of whales which has found its way from the polar circle through subterranean passages to Pennsylvania.

In discussing the interesting question regarding the origin of petroleum, the subject naturally divides itself into several details, the question thus resolving into several, viz.:

1. From what; and
2. By which process has petroleum been formed?
3. How did the petroleum deposits originate?

Formation of Petroleum (*Original Material*).

The opinions prevailing up to the present time, which embrace nearly everything feasible, presume for the formation of petroleum, either

A. Inorganic substances, or
B. Organic substances, and in the latter case:
  a. Carburetted hydrogen gases.
  b. Plants.
  c. Animals.
  d. Plants and animals.

A. *Emanation Hypothesis; Inorganic Origin.*

The origin of petroleum from inorganic combinations has chiefly been advocated by chemists, who have also described the processes they claim to have taken place therein. The argument for a purely chemical origin of petroleum was first brought to the serious attention of scientific men in 1866 by the French chemist, Berthelot. He supposed that by the reciprocal action of carbonic acid and alkali metals in the interior of the earth acetylides are formed which, in the presence of hydrogen, are converted into acetylene (C_2H_2), from which petroleum and tar-like products are formed. Later on (1869) he endeavored to strengthen his hypothesis by experiments.

H. Byasson (1871) supposes that aqueous vapor and sulphuretted hydrogen, carbonic acid and iron at a white heat, have reacted upon each other, and in this manner he has obtained in his laboratory a liquid combination, resembling petroleum. He provides the requisite conditions in nature by assuming that sea water penetrates the terrestrial crust, carrying along substances containing carbonic acid, especially marine lime, and at a great depth comes in contact with metallic iron at a white heat, or also with pyrites.

M. Mendelejeff (1877), one of the most prominent chemists of modern times, proceeds from the supposition that the fiery liquid in the interior of the earth contains metals, especially iron, combined with carbon. Through fissures water reaches these metallic carbides whereby metallic oxides and hydrocarbons are formed. This opinion was shared by the geologist Abick, who studied only the Caucasus oil regions, which apparently furnish many vouchers for the correctness of this emanation hypothesis. Mendelejeff, it is said, has recently succeeded in producing in this manner hydrocarbons resembling petroleum.

Cloez, in 1877, succeeded in obtaining hydrocarbons resembling certain constituents of petroleum as the result of the action of dilute sulphuric acid on the carbides of iron and manganese such as occur in spiegeleisen. In 1878 he produced similar combinations by the reaction of boiling water upon a carbide richer in manganese, and he regards his results as a sufficient basis for an hypothesis by which to account for the origin of petroleum.

A. von Humboldt (1804) also advocated the emanation theory, without however expressing an opinion of "how" petroleum is formed. He observed a petroleum well issuing from metamorphic rocks in the bay of Cumana and remarked: "If it may be supposed correct that further eastward near Cariaco, the hot and submarine waters are sufficiently abundant to change the temperature of the gulf at its surface, we cannot doubt that petroleum is the product of distillation at an immense depth, issuing from those primitive rocks beneath which lie the forces of volcanic commotion."

Rozet (1835) also supposes that the asphalt in Pyrmont emanates from a great depth from which it has reached its present deposit by sublimation. He connects this process with basaltic eruptions at a distance (Java, Burgundy, in the Vosges).

S. W. Prott (1846) connects the occurrence of petroleum at Bastények, a village in the south of France, with the ophite eruptions of the Pyrenees. Parran (1854) also asserts "that during the Tertiary period an asphaltic epoch took place to which it is convenient to recall the numerous eruptions of trachytes and basalts which characterize that period, and have probably acted by distillation upon the masses of combustibles hidden in the bosom of the earth." He deduces the occurrence of asphalt between Mons and Auzon from the distillation of deeper strata, the inferior cretaceous, or perhaps the carboniferous, formation, which contain combustible substances.

Thoré, in 1872, published a paper on the occurrence of petroleum in the water of St. Boés (Basses-Pyrénées) and arrived at a similar conclusion to Prott. He asserts that the greater part of the deposits of petroleum is related to the eruptive rocks (ophite), which may be considered the principal cause of its formation, or, at least, of the appearance of mineral oil.

The investigators above mentioned supposed that the oil-forming process takes place at a great depth, partially in the pyrosphere, that the hydrocarbons formed are forced upwards through deep-reaching fissures where they condense to fluids and remain either as an accumulation in the fissures, or spread out in the porous rocks they met with in ascending. We have thus to deal here with *emanation hypotheses.* The occurrence of petroleum together with cavities and hot springs might be referred to as an apparent confirmation of these hypotheses. However, this process would have to take place at the present time also, if the requisite agents have not been exhausted. Hence, according to the emanation hypotheses, it might be expected that an oil territory cannot be exhausted, since it would constantly receive a new influx from a great depth. These sanguine expectations are unfortunately contradicted by experience in many localities, especially in the hitherto most important oil regions, namely those of Pennsylvania.

That, independent of the above-mentioned reason, the emanation and similar hypotheses are untenable, is proved by the following statement:

The oil derived from a very great depth would have to show a higher temperature than can be supposed from the increase in the heat of the earth, which, however, is not the case. On the contrary it might be said that the petroleum, having been imbedded for a long time in the strata traversed by the supply-fissures, has acquired their temperature. But, when this old supply is exhausted, fresh quantities of oil would gush from the deep in consequence of the pressure which forced the oil upward from an extraordinarily great depth, and these fresh quantities of oil would possess a much higher temperature, which, however, does not agree with experience.

To quote the hot springs in proof of the correctness of these hypotheses, as was repeatedly done in the discussion of the conditions prevailing in the Caucasus, is inadmissible in consideration of the low temperature of the petroleum opened up, which scarcely exceeds that of the soil by 2° or 3°. These facts rather prove that the seat of the petroleum formation must be located at a slighter depth. Moreover, the thermal and oil springs of that region are not genetically connected.

According to these emanation hypotheses, petroleum might be expected to occur wherever deep-reaching fissures are shown to exist, the more so since there is no reason to suppose that metallic carbides are evolved locally only in the interior of the earth. However, this supposition is not correct, the Alps, for instance, being traversed by extraordinarily deep-reaching fissures without petroleum occurring in them.

One of the greatest known faults in Europe, outside the Alps, is the Eifel fissure, which is, however, destitute of oil. C. M. Paul and E. Tietze have also referred to the fact that though the petroleum of the Carpathians may occur in fissures, the most important faults are totally destitute of oil. They further lay special stress upon the fact that " in the Caucasus also it is not the region of the great downcast in the south of the mountains which appears to be exclusively distinguished by the occurrence of petroleum, but that, independent of the larger and better known occurrences on both ends of the chain (Baku, Taman), petroleum is frequently found on the northern slope of the same."

In Pennsylvania the petroleum does not occur in the Apallachians, where the disturbances are greatest and consequently reach most deeply into the interior of the earth, but west of them, where the anticlinals are extraordinarily shallow.

Another objection to these emanation hypotheses is that petroleum very frequently occurs in sedimentary regions destitute of any kind of volcanic action. It may only be mentioned that eruptive rocks are entirely wanting in the oil regions of Pennsylvania, New York, Canada, Galicia, etc. On the other hand considerable quantities of petroleum or exhalations of carburetted hydrogen gases are scarcely ever found in the neighborhood of volcanoes active at the present time. The occurrence of petroleum in eruptive rocks has, on account of its rarity and the small quantities found, been of scientific, but never of industrial interest.

In the Carpathians, the most productive oil regions are situated on the north side—in Galicia—which is free from eruptive rocks, while on the south side, where extensive eruptions have taken place, petroleum does not occur in the neighborhood of the eruptive rocks, or at least only in very small quantities.

The erroneousness of the proposition that the origin of petroleum is due to processes which have taken place at a great depth by the reaction of inorganic substances, is also proved by the fact, that up to the present time, petroleum has nowhere been found in the Archean strata,[1] which were formed at a period when no living being inhabited the earth, although they are also suitable for the reception of this fluid and are frequently traversed by faults. However, this fact supports those hypotheses which deduce the petroleum from organisms.

It has been endeavored to strengthen the emanation hypothesis by the fact of the association of mud-volcanoes (salses) with the occurrence of petroleum. These mud-volcanoes, however, are in no way connected with genuine volcanoes, the material thrown out by them being taken only from the underlying, mostly loose strata, as has been shown by thorough microscopical examinations of organic remains by M. von Gümbel.

In the Carpathians one of the occurrences of petroleum is fixed on shale (fish-shale), while the porous sandstones directly beneath it are destitute of oil. If the petroleum had actually sprung from the deep, it would have very likely impregnated the porous sandstone, and not the shale, difficult to penetrate, lying above. Moreover, there is a series of occurrences of petroleum and other bitumens whfch forces us to the conclusion that these hydrocarbons also have been formed within fixed strata, which will be referred to later on, so that as far as they are concerned the supposition of emanation is inadmissible.

J. L. Piedboeuf points out that the condensing points of the separate combinations of petroleum lie between 0° and 300° C. (32° and 572° F.). Now, if they had ascended in the form of vapors from the deep, they would have been condensed at va-

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[1] Older observations from two points in South America are very doubtful, especially also whether the oil, even if it occurs in the Archean strata, is a primary deposit.

rious temperatures prevailing there, and hence could not occur as a mixture within one stratum.

Moreover, the absence of carbonic oxide in the gases accompanying petroleum, as shown in several localities, speaks against the supposition of a higher temperature in the evolution of petroleum. The above-mentioned facts regarding the occurrence of petroleum in nature speak so decidedly against its origin from inorganic substances, and against the emanation hypothesis connected therewith, that these suppositions have no ground to stand on.

Closely related to the previously discussed views are those which, though they acknowledge condensed carburetted hydrogen gases in petroleum, do not touch the mode of origin of the latter, and hence do not express themselves either for or against the inorganic origin. Thus only half an explanation is given.

The most conspicuous representative of this theory is M. Coquand, who has so fully written upon the occurrence of bitumen in Roumania and Albania. He is of the opinion that in consequence of chemical reaction, petroleum, mineral tar and asphalt have been formed from marsh gas (CH_4). He found mud volcanoes associated with the occurrence of petroleum in Sicily, the Apennines, the peninsula of Taman and the plains of Roumania, and concluded that mud volcanoes produced petroleum and other forms of bitumen by converting marsh gas into more condensed hydrocarbons.

Grabowski in an article on the origin of ozocerite advances similar opinions. He says: "Very little is known about the mode of its formation. It appears to me very probable that it is a product of the oxidation and condensation of the petroleum hydrocarbons. * * * By this hypothesis the formation of petroleum may be reduced to an oxidation of marsh gas, and thus the close connection between ozocerite, petroleum and coal may be explained in the most simple manner."

C. H. Hitchcock has supported similar views.

That mineral tar, ozocerite and asphalt may be formed from petroleum by evaporation and oxidation has been previously explained, but this fact has nothing in common with the origin of petroleum from marsh gas, the latter connection being an unproved supposition. The occurrence of marsh gas together with petroleum, as shown partially by mud volcanoes, does not prove the formation of the latter from the former, just as little as it proves the formation of coal from marsh gas, which also frequently occur together. Since the methane series is represented in petroleum by so many, and even the lowest, members, it should not be strange to a chemist that the first member—marsh gas—also occurs in it, which, however, immediately escapes when the great pressure under which it stood in the interior of the earth's crust ceases.

As far as these attempts at explanation presuppose the emanation hypothesis, the objections made to the latter also apply partially to them.

Many authors refer to the frequent association of brine with the occurrence of petroleum, and to hydrocarbon inclusions in many varieties of rock salt, for instance, in the salt of Wieliczka. They quote Dumas, H. Rose and G. Bischof as having, based upon their investigations, laid down a hypothesis that the petroleum was or might have been formed from these gas-inclusions. This supposition is based upon an error, and to remove it a brief resumé of what these three prominent chemists have published on these questions may here be given.

J. Dumas,[1] who first examined the gas-inclusions in the Wieliczka salt, simply confirms the presence of an inflammable gas which must be included in a strongly compressed state in the clouded rock salt. He, as well as J. C. Poggendorf, calls attention to the frequent occurrence of such inflammable gases together with deposits of rock salt or brine springs, without, however, drawing any conclusions as to the genetic relations between them, and far less as to those between rock salt and petroleum. H. Rose[2] refers to Dumas' investigations of the

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[1] Ann. chim. phys., 43, 316, through Poggendorff's Ann., (1830) g. F., 94, 600.

[2] Poggendorff's Ann., (1839) 48, 353.

Wieliczka salt, and continues them, without, however, arriving at a final result as to the composition of this gas. It very probably consists of hydrogen and carbonic oxide, but it cannot be with certainty determined whether an olefiant gas or a similar hydrocarbon is present. He is of the opinion that the included gas is condensed, and either in a liquid or solid state. Not a word is mentioned regarding the origin of petroleum or of its deposits.

G. Bischof[1] gives Bunsen's analysis of the gas included in the Wieliczka salt, which shows it to consist chiefly (84.6 per cent.) of hydrocarbon, and points out that it must be included in a strongly compressed state. He does not draw any genetic conclusion, nor does he mention a word about a connection of these gas inclusions with petroleum.

Hence there is no reason for ascribing to J. Dumas, H. Rose and G. Bischof, a hypothesis according to which petroleum is formed from inclusions of hydrocarbon in rock salt.

Ochsenius and Dr. E. Pfeiffer have endeavored to explain the relations between the formation of petroleum and the simultaneous occurrence of brine. Dr. Pfeiffer[2] refers to the thorough and long-continued preservation of timbering in salt-mines, and is of the opinion that trunks of trees and similar organic remains have been covered by a flood of salty mud, whereby entirely abnormal conditions of decomposition have been created. The formation of a petroleum free from oxygen may be explained by combinations of iron absorbing oxygen present in the mud.

K. Ochsenius[3] who claims priority for a similar hypothesis, is of the opinion that in an isolated basin of the beach, the sea-water might have been concentrated to the strength of mother-lye, and then broken through the bar. If this mother-lye reached parts of the sea with a luxuriant fauna and flora, all life was destroyed at one stroke, and the dead bodies, especially of innumerable large and small animals, becoming covered by the

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[1] Lehrb. chem. physik. Geologie 2, Aufl. 1, 742. [2] Nature, 1882, S. 246. [3] Nature, 1882, S. 350.

clay and debris carried along, became subject to a peculiar process of putrefaction, which finally yielded the hydrocarbons of petroleum.

Petroleum deposits are known to occur in the neighborhood of, and in the same geological, horizon as salt deposits, for instance on the northern foot of the Carpathians (Boryslaw). For such occurrences these hypotheses deserve further attention and examination. But even where such simultaneous existence of the two different occurrences cannot at present be established, it is nevertheless conceivable that the salt-deposit, not being sufficiently protected against destruction by dissolution, later on disappeared.

Both hypotheses last mentioned and here inserted, which attempt an explanation of the relations between deposits of petroleum and salt, also abstain from any admission which bases emanation upon marsh gas.

B. Organic Origin.

In regard to the origin of petroleum from inorganic combinations, there are so many and essential doubts that all such hypotheses need no further be considered. The larger number of geologists, who have been occupied in studying the question of the origin of petroleum, have arrived at the conclusion that it has to be referred to organic substances; though opinions differ as to whether vegetable or animal remains have yielded petroleum by their decomposition.

a. From plants and mineral coal.

Those who presuppose a vegetable origin consider petroleum as derived partly from marine plants (algae), partly from bog plants (peat deposits), partly from land plants, and partly also from mineral coal, which essentially is nothing but changed vegetable remains.

In the east of North America, in the principal petroleum regions, only *marine* formations are found under the carboniferous strata, which also carry the oil, and hence the derivation of the latter from land plants or coal measures is excluded.

According to L. Lesquereux, the Pennsylvania petroleum has been formed from marine algae. He is of the opinion "that petroleum is the result of the decomposition of marine plants, as coal is the result of terrestrial vegetation."

This Devonian fucoid slate which is predominantly found on the shores of Lake Erie lies between the corniferous limestone and the actual oil zone (Chemung group).

Independent of the fact that in modern times many remains which were formerly considered fucoids have been found to be tracts of mollusks, it may be mentioned that genuine fucoids have been found not only in the oil-bearing strata of Pennsylvania, but also in those of the Carpathians. While, however, in America, the fucoids occur frequently in certain strata, in the Carpathians they are present only in certain oil-levels, and at the same time in such small quantities that it is inconceivable to accept them as the source of the petroleum. Similar fucoid remains are found as frequently in the same strata of the Vienna sandstone on the north foot of the Alps, for instance at Waidhofen on the Ybbs, without the slate being bituminous, and still less oil-bearing. This proves without doubt that the fucoids have nothing to do with the formation of petroleum. As far as known, there is not a rock in Europe carrying, of organic remains, *only* fucoids, which is bituminous or oil-bearing.

Such hypotheses have frequently been supported by reference to the immense accumulation of sea-weeds in the Atlantic and Pacific oceans, known as the Sargasso Sea. However, it has been shown by the investigation of the S. S. "Talisman" (1883), that these so-called accumulations do not exist, and that only isolated fragments of dead seaweeds already in a state of decay, and brought together by the winds and currents, are found, which has also been confirmed by O. Kunze.[1] The dredgings by the above-mentioned vessel showed the bottom of the Sargasso Sea to consist of a very fine mud of a pumice-

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[1] Zincken, Geol. Horiz. foss. Kohlen, etc., p. 119.

like nature, with pumice debris, and of volcanic rock, so that the decaying sea-weeds appear not to have reached the bottom of the sea.

It is well known that Mohr and others have sought to deduce the formation of coal measures also from such accumulations of seaweeds sunk in the water. Although this hypothesis has been abandoned as untenable, and needs no further to be considered, it must be acknowledged that algae, by a gradual change under the exclusion of air, hence a sort of dry distillation, may be converted into coal. For the formation of petroleum from algae an analogous process would have to be supposed, and hence petroleum and coal would have been formed. However, in Pennsylvania, coal deposits, which in consideration of the immense quantities of oil, should be quite extensive, are found neither in nor below the oil-bearing strata. Neither Lesquereux nor other geological observers reports the occurrence of accumulations of coal in the Devonian fucoid strata. T. Sterry Hunt, to be sure, mentions a certain black band met with here and there on the base of the Hamilton formation in Ontario, but the so-called bituminous slates are entirely wanting.

It has also been claimed that petroleum has been formed by the decomposition of peat plants. The principal advocate of this hypothesis is E. W. Binney, who observed in an English peat-bog that the lower layers of the peat were compacted into a sort of bituminized mass. This has been described by Mr. Binney as follows: "The only remarkable feature connected with the upper bed of peat at Down Holland Moss is the western portion of it being covered up with a bed of sand, and being probably sometimes subject to an infiltration of sea water. * * * These circumstances, added to the fact of petroleum being found most plentifully at the edge of the sand, led to the conclusion that it is produced by the decomposition of the upper bed of peat under the sand." Binney supposes that petroleum is the result of slow combustion in the peat, and has been produced by a process partly analogous to that which takes place in the distillation of wood in closed vessels, when, owing to a total absence of oxygen, the combination of hydrogen and carbon in the form of hydrocarbons is effected.

It is singular that this formation of petroleum has been observed only where sand occurs, and where Binney presumes the action of sea water. Deposits of sand have been shown to exist in many continental peat-bogs without petroleum being formed. Thus it would appear that the actual cause must have been the infiltration of sea water, which, however, might also have carried along animal organisms, so that the formation of petroleum might be referred to them.

The process of the gradual change of the peat supposed by Binney takes place in every bog, as in Down Holland Moss, without any petroleum worth mentioning being found. And even if these facts, which are opposed to Binney's hypothesis, did not exist, lignite, and from it other mineral coal, would have to be formed by the same process, and these are not found in, or better under, the oil regions of Pennsylvania, Galicia, Hanover, Alsace or Baku. Hence Binney's supposition is inadmissible.

G. P. Wall and Krüger[1] (1860) also claim the formation of petroleum to be due to the decomposition of woody fibre, and refer to their observations of the occurrence of asphalt in Trinidad, which Wall describes as follows: "The asphalt is almost invariably disseminated in the upper group of the 'New Parian' (a South American tertiary group). When *in situ* it is confined to particular strata, which were originally shales containing a certain proportion of vegetable debris. The organic matter has undergone a special mineralization, producing bituminous, in place of ordinary anthraciferous, substances. This operation is not attributable to heat, nor to the nature of distillation, but is due to chemical reaction at the ordinary temperature and under the normal conditions of the climate. The proofs that this is the true generation of the asphalt repose not only on the partial manner in which it is distributed in the

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[1] Proceedings Geol. Soc. of London, May, 1860.

strata, but also on numerous specimens of the vegetable matter in process of transformation, and with the organic structure more or less obliterated. After removal by solution of the bituminous material, under the microscope a remarkable alteration and corrosion of the vegetable cells becomes apparent, which is not presented in any other form of the mineralization of wood. A peculiarity attending the formation of asphalt results from the assumption of a plastic condition, to which property its frequent delivery at the surface is partly referable; where the latter is hollow or basin-shaped the bitumen accumulates, forming deposits such as the well known Pitch lake."

The change of the wood structure in a tertiary stratum is not astonishing, since it is well known that analogous changes take place in the transformation of woody fibre into mineral coal. But from these changes it cannot be concluded that petroleum or asphalt has been formed from woody fibre.

Reference may here be made to the investigations of T. Rupert Jones. He examined the asphaltic sand or rock of Trinidad and found that when it is boiled several times in spirits of turpentine it loses its bitumen and resolves itself into loose orbitoides and nummulinæ, with a few other foraminifera. On treating this residue consisting of animal remains with acids, a small proportion of green-black sand and a very few rounded grains of quartz remained behind. According to these investigations the bitumen of Trinidad is accompanied almost exclusively by *animal remains*.

So long as we are not in the possession of further detailed observations in that locality, it is preferable not to consider it any further, since with our present knowledge the question whether the asphalt occurring there is of vegetable or animal origin cannot be accurately answered.

J. P. Lesley[1] (1865) expresses the opinion that the oil appearing together with many vegetable remains in the subcarboniferous conglomerate of Kentucky is of vegetable origin,

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[1] The Existence of Petroleum in the Eastern Coal-field of Kentucky, Am. Philos. Soc., 1865.

though in the same article he admits that petroleum may also have been formed from animal remains.

Peckham is also inclined to deduce many petroleums, especially those free from nitrogen, for instance, Pennsylvania petroleum, from the decomposition of plants (fucoids).

A number of investigators are of the opinion that the formation of petroleum is closely connected with that of mineral coal, or that the former originated from the latter. Kobell also shared this opinion, but presumed that the coal must have lost all its bitumen, so that anthracite is to be considered the residue of distillation. This view was opposed by Reichenbach[1] by him pointing out that the distillate obtained from coal is entirely different from that of petroleum, and referring to the absence of paraffin and eupione in the latter—an objection which lost its force by the discovery of these substances in Rangoon tar. As is well known, the presence of paraffin in most petroleums was later on established. Reichenbach, in 1834, obtained by destructive distillation of coal, with a very small quantity of water ($\frac{1}{3200}$ per cent.) an oil resembling oil of turpentine and the petroleum of Amiano, Italy. He therefore supposed that our mineral oil is nothing but turpentine oil of the pines of former ages, existing in a finished state in the coal, and separated from it by the action of subterranean heat.

Daubrée submitted fragments of wood to the action of superheated steam, and changed them into lignite, coal or anthracite, according to the temperature. He also obtained thereby liquid and volatile products resembling natural bitumens and possessing the characteristic odor of the petroleum of Pechelbronn, Alsace. He remarks, bitumens are probably derived from vegetable substances; as they appear not to be a simple product of dry distillation, but to have been formed with concurrent action of water, and perhaps under pressure, graphite being the final product of these substances.

It may be here mentioned that bitumens related more or less to petroleum have been observed, though only in rare cases, to

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[1] Neues Jahrb. der Phys. u. Chem., 1833, S. 19.

be inclosed in and dripping from coal measures. The best known instance is found in the coal measures of Shropshire, England. It is said that in the commencement of the 18th century three barrels of petroleum were collected daily at Wombridge, near Broseley, and that in the pits of Dawley and The Dingle, the miners had to be protected from the dripping petroleum by boards. It may be remarked that the petroleum did not always drip, as is generally stated, from the coal measure, but from cracks in a coarse-grained sandstone inside of the coal formation; this applies especially to the frequently quoted Wombridge (Coalport) instance. Cases are known, as, for instance, in Flintshire (Buckley mountain) where a fluid, resembling petroleum, drips from cannel coal; but bituminous shales full of innumerable fish remains occur directly with the coal, so that not only the dripping oil, but also the bitumen of the cannel coal, are referable to animal remains.[1] In the lignitic brown coal of Koflach (Styria) a small quantity of dark brown liquid bitumen has also been recently collected by M. Karner.

Dr. E. Röhrig mentions a similar find at Fissenberg near Oedesse, where petroleum was found in the coal of the weald clay. Strombeck has also deduced the petroleum of the North German plain from this occurrence of coal.

If petroleum is actually a product of distillation of coal, it is very strange that it occurs very seldom in and together with coal measures, and then almost invariably in minute quantities only. Productive oil finds are entirely wanting where coal measures occur.

In Pennsylvania the coal fields are at a distance of several miles from the oil regions, and lie above the latter. Now since products of distillation do not descend but ascend, these two organic substances cannot be brought into genetic connection. The existence of a coal measure below the Devonian oil strata of Pennsylvania and New York has never been proved, every indication of the occurrence of it in these deep strata being wanting. These facts may probably be the reason why the

[1] Davies, Earthy and Other Minerals, 1884, p. 209.

derivation of petroleum from coal has not been advocated by any American geologist or chemist.

On the other hand, no petroleum, or at least not in quantities worth mentioning, is found in the anthracite and bituminous coal fields of North America, so that as far as the United States and Canada are concerned the conclusion has been arrived at that coal and petroleum almost entirely preclude one another. Moreover, this proposition has not been directly contradicted by observations made in other parts of the globe.

Thus, for instance, von Hochstetter,[1] whose opinion is also shared by Castendyk[2] and Windikiewicz,[3] deduces the petroleum of the Carpathians from dipping coal measures. C. M. Paul and E. Tietze[4] who have contributed largely to our knowledge of the entire geology of the Carpathians, give overwhelming reasons for opposing this view.

East Galicia produces at the present time most of the oil. North of the Carpathian zone the cretaceous strata directly over the Silurian and Devonian strata have been denuded by the deep beds of the Dniester and its tributaries. On the north side of this portion of the Carpathians, in the Bukowina and the territory of the river Vissos, dyas and trias strata destitute of coal measures are imbedded directly over the mica schist, so that there is no just reason for supposing the existence of coal formations or of coal measures below the East Carpathians.

Neither has there been found a trace of carboniferous strata in the northwestern upheaval of the older sedimentary rocks. On the other hand, the strata of productive coal measures are opened up in the spurs of the western portion of the Silesian-Galician Carpathians, in the region of Karwin and Moravian-Ostrau, and the supposition that they dip below the Carpathian sandstone cannot be excluded. But here no oil is found, the nearest place, Klenczany, where it occurs being 20 miles to the east of Karwin.

[1] Jahrb geol. Reichs-Anst., 1865, S. 206.

[2] Oesterr. zeitschr. f. Berg-Hüttenw., 1873, S. 365.

[3] Jahrb. fürB ergakad. 1875, S. 1.

[4] Jahrb. geol. Reichs-Anst., 1879, S. 300.

Hence in the Carpathians also mineral coal in the lower, and petroleum in the higher strata are entirely precluded. The North German occurrence of oil has also been deduced by various authors from the coal measures of the underlying carboniferous formation. Independent of the fact that it is doubtful whether the carboniferous formation below the occurrence of oil carries coal measures, a source, a material being consequently presupposed the existence of which has not been proved, it is incomprehensible that the products of distillation in ascending did not condense in the thick dyas, trias, and still more recent sandstones, though they are even better oil-sponges than the shales and similar rocks in which petroleum and asphalt frequently occur. Independent of its occurrence in seams and reservoirs connected with them, bitumen, in Germany, is imbedded in several primary deposits lying one above the other, as shown by the investigations of H. Credner and Erb. The fact that these deposits mostly belong to the shale and similar strata, which hold the oil firmly fixed, explains the slight productiveness, notwithstanding the fact of the first indications being favorable.

It may further be mentioned that neither the coal measures in Austrian Silesia nor those in the west of North Germany carry oil.

The supposition of petroleum being derived from coal is also opposed by some of the reasons advanced against the emanation hypothesis, with which in many respects it has to be classed. Since oil does not occur in coal measures, but in rocks, especially in sandstone, at a great distance from them, it could be there only in secondary deposit. However, this supposition is opposed, as regards some occurrences, by many doubts, which will be explained later on.

All arguments being against the supposition that petroleum has been formed from coal, the term "coal oil" frequently applied in American literature to the crude oil cannot be approved.

Another objection against the formation of petroleum from coal, which formerly was frequently advanced, consists in that the oil produced by dry distillation of coal or bituminous shale contains, besides saturated, many non-saturated, hydrocarbons, members of the benzol series, acids (phenol, cresol, etc.), ammoniacal combinations, anthracene, etc., which are wanting in petroleum. However, B. Kerl in discussing this question referred to the investigations of J. A. Le Bel, according to which the non-saturated hydrocarbons are slowly changed in contact with water, so that the supposition that the same was later on the case with the non-saturated hydrocarbons of the distillates is justified.

This remark of B. Kerl applies to all non-saturated hydrocarbons, independent of their origin.

b. From Animals.[1]

This hypothesis, according to which petroleum is derived from the decomposition of animal remains, gains constantly more advocates with the increase in our knowledge of the geological relations of petroleum.

Leopold von Buch, in the thirties, deduced the considerable content of bitumen of the Suabia upper lias slate from the abundance of animal remains enclosed in it.

Bertels was the first to advance the opinion that the petroleum of the Caucasus has been formed by the decomposition of mollusks.

Müller is of the opinion that innumerable remains of animals collected on the bottom of the former sea, and covered by mud, gradually decomposed, and thus formed the petroleum, which collected on the bottom of the sea and penetrated the overlying strata.

Prof. J. D. Whitney refers to the extensive marine infusorial rocks of the Pacific coast, especially of California, and suggests that the remains of infusioria which are so abundant in them are the source of the California liquid and solid bitumens.

T. Sterry Hunt in discussing the question of the genesis of petroleum ascribes also great importance to animal remains.

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[1] Höfer. Petroleumindustrie Nordamerikas, 1877, S. 83.

He points out that at Packenham, Canada, the Trenton limestone contains large orthoceratites, the chambers of which are sometimes filled with several ounces of petroleum. Petroleum runs from the fossil corals of the bird's eye limestone at Rivière á la Pose, Montmorency county, Canada. In the sub-Devonian corniferous limestone, the most productive oil level of Canada, the cells of the corniform fossil corals (zaphrentis) are frequently filled with petroleum, as well as the cells of heliophyllum and favosites in certain strata at Bertie, opposite Buffalo. The same author mentions several other occurrences in limestones containing animal but no vegetable remains, in which, according to his explanations, petroleum has originated. Although Hunt only speaks of petroleum as having been formed from *organic* matter buried in the rocks of the earth's crust, in view of the fact that only animal remains are present in the above quoted cases, there can be no doubt about their nature.

C. Knar, in 1866, published an article on "The theory of the formation of asphalt in the Val de Travers, Switzerland," in which he expressed a decided opinion in regard to the animal origin of nearly all bitumens. His conclusions are:

"1. Asphalt (limestone impregnated with bitumen) is due to the decomposition in a deep sea of beds of mollusks, the decomposition taking place under a strong pressure and at a high temperature.

"2. The free bitumen is also formed by the decomposition of certain mollusks or crustaceans in a sea of little depth, and at a high temperature, but under an insufficient pressure to make this bitumen impregnate the shells.

"3. Petroleum is due to the decomposition under water of mollusks, a decomposition which has taken place at a temperature too low to transform it into bitumen (asphalt), but under pressure more or less considerable.

"4. The beds of white limestone formed also by the accumulation of fossil shells, and which contain neither asphalt nor petroleum, have been formed under such conditions that the products of the decomposition of the animal organic matter have been evaporated.

"5. Finally, combustibles only, or pyroschists (*bitumes fixes*), have been formed by the decomposition of plants, while all of the preceding are of animal origin."

Peckham supposes that the petroleum of California, Texas, West Virginia, etc., in which the presence of nitrogenous combinations has been established, are of animal origin.

C. Zincken,[1] in 1883, in his general observations regarding the origin of petroleum, arrived at the result "that in most cases its origin has to be ascribed to animal remains." He says: "The bituminous shales, limestones, and marls, which have to be considered the seat of the petroleum production, contain, besides the remains of fishes and mollusks, the fats of non-fossilizable animal organisms, in which the present sea is so rich, and of which the former may have carried still greater quantities.

"According to a communication from the geologist R. Leuckart, among the non-fossilizable animal forms, leaving behind such fat may be classed: Infusoria, including noctilucines, actinia, soft polyps, medusæ; worms, including gephyreæ, naked snails, cephalopods without shell; possibly also minute crustaceans with soft shells, such as daphnia, cyclops, immense quantities of which inhabit the sea. The remains of fat-yielding animals, immense quantities of which accumulated for thousand of years upon the bottom of the sea, were covered and preserved by a deposit of masses of clay and lime-mud carried along by floods; a process which, according to circumstances, may have been frequently repeated.

"The calcareous shells of many mollusks, etc., were probably dissolved by the carbonic acid of the water, so that only the soft animal body remained behind, and contributed to the deposit of fat-yielding animal substance, by the decomposition of which petroleum has been formed. The content of carbonic acid in former seas might have been still larger than that of the present sea."

According to O. Fraas the bituminous deposits (asphalt,

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[1] Geol. Horiz. d. foss. Kohlen, etc., S. 121.

etc.,) occurring in Syria are derived from the animal world of the cretaceous sea. To this investigator we are also indebted for a very interesting observation of a petroleum occurrence in an older coral reef on the shores of the Red Sea, which projects above the present level of the water. He writes:[1]

"It did not occur to me to think of any other origin of the oil than from the decomposed organic bodies in the reef itself and in the lagoon. The reef next to the sea seems to be permeated with bitumen; the oil runs out drop by drop, and being specifically lighter than the sea water floats upon it. Only a portion of the gases evolved by the decay of the innumerable animals living in the lagoon escapes into the air, the other being condensed to the so-called heavy hydrocarbons which deposit themselves in the dead reef, where they experience furthur condensation and coagulate to drops which collect in the pits of the reef. The occurrence of sodium chloride together with the bitumen is a further proof of the common origin of both from the lagoon immensely rich in salted and at the same time organic substances."

This description reminds one involuntarily of the occurrence of petroleum in the corniferous limestone of Enniskillen, the most productive territory in Canada.

Paul, Tietze, V. Uhlig[2] and several others advocate the animal origin of the petroleum of the Carpathians, and H. Credner[3] that of the petroleum of North Germany, the latter locating the place of its origin in the strata of the white jura which are rich in marine shells, but destitute of plants.

J. L. Piedbœuf[4] has recently declared himself also in favor of the formation of petroleum from animals. The latter were inhabitants of slowly drying-up seas (Dead sea), and dying on account of the increasing content of salt, their excrements and dead bodies were covered by substances sinking to the bottom. In their transformation the organic masses yielded ammonium carbonate, carbonic acid and hydrocarbons, the first being con-

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[1] Aus dem Orient. [2] Vorkommen u. Entstehung des Erdöls. [3] Zeitschr. deutsch. Geol. Ges., 1864, S. 214. [4] Petroleum Central Europas. Düsseldorf, 1883, S. 45.

verted by the action of calcium and magnesium chlorides, as well as of calcium sulphate, into readily soluble ammonium chloride and sulphate with the formation of lime and dolomite.

It may here be mentioned that in some localities, for instance in the Carpathians, petroleum may occur in a primary deposit without the accompaniment of limestone or dolomite; in the above mentioned oil territory these rocks are entirely wanting, and there is no reason to suppose that they have been carried away later on.

The hypotheses of Ochsenius and Pfeiffer, which actually belong here, have already been mentioned.

The formation of petroleum from animal remains acquires greater probability from the forcible arguments presented above in favor of its organic, though not of its vegetable, origin. As a solid support for this hypothesis a series of facts may be mentioned.

1. Petroleum is found in primary deposit with remains of animals, without, or only with insignificant, remains of plants: in the fish-shales of the Carpathians, and in various limestones of the boundary region of Canada and the United States, which have been studied by T. Sterry Hunt.

2. Shales, which on account of their great content of bitumen are, or have been, used for the production of oil and paraffin, are also rich in animal remains, but poor in vegetable remains or entirely destitute of them; for instance, the lias oil shales of Suabia and Steierdorf.

Many other shales rich in bitumen, for instance the copper slate of Mansfield, whose content of bitumen amounts to up to 22 per cent., also bear an abundance of animal remains, but no vegetable remains, or only very rarely so.

3. Rocks rich in vegetable remains are, as a rule, not bituminous; the reverse is, however, the case when the vegetable remains are accompanied by animal remains.

4. By the transformation of animal remains hydrocarbons analogous to those of petroleum may be formed.

5. O. Fraas observed petroleum running from a coral reef

on the shores of the Red Sea, which can be of animal origin only.

That petroleum may have been formed from animal organisms has not been directly denied by chemists, but it has frequently been stated by them that in that case the oil would have to show the presence of nitrogen combinations. Now nitrogen has, on the one hand, been actually found in the petroleum, mineral tar and asphalt of several localities, and, on the other, it may be permissible to suppose that the small quantities of ammoniacal or general nitrogenous combinations formed might have readily escaped into the air or been dissolved in water. This proposition is fully confirmed also by a series of analyses of gases accompanying petroleum, so that this objection to the animal origin of petroleum, which has been a favorite one of chemists, may be considered dismissed. Peckham found nitrogenous combinations in all North American oils, and ascribes their origin to animal remains; however, he did not succeed in establishing the presence of such combinations in Pennsylvania oil, and therefore supposes it to be of vegetable origin. But many recent analyses of the natural gases of this region have shown an extraordinarily high content of nitrogen (up to 27.87 per cent.), which considering the small quantities of free or fixed oxygen cannot be referred to atmospheric air.

Hence, it would appear that during the very gradual decomposition of the animal remains, the greater portion or even the entire quantity of nitrogen might have escaped either in a free state or in a gaseous form as $C_xH_yN_z$ combination. Thus far nothing is known regarding the progress of analogous processes of decomposition which have taken place in nature at a comparatively low temperature.

The objection might be made that it is strange petroleum is found only in certain regions, although strata with animal remains are of such frequent occurrence. To explain this fact one is forced to assume that as a rule—for the animal as well as the vegetable origin—the conditions for the formation or accumulation and preservation of the petroleum were unfavorable, these resulting only under the most favorable conditions. Nature had to make provision that the hydrocarbons formed could not escape, and if they did so later on their accumulation had to be rendered possible.

Experience has shown that animal remains, as far as they are of an organic nature, when transformed in the strata of the earth, leave behind no carbon or at the best only very small residues of it. It may, for instance be mentioned that in the separate layer of the Riabl strata, the inorganic frame of the trias cuttle fish (Acanthoteutis) can be frequently recognized, while a piece in which the bag, head and arms are indicated is seldom found. In the vicinity fishes and crustuceans are found of which the hard portions alone are preserved, while of plants (Voltzia, Pterophyllum) clear black—consequently carbonaceous—impressions are preserved. This shale is bituminous and therefore permeated with petroleum. Equivalent shales in the northern limestone Alps—the Lunz strata—contain only impressions of plants in an analogous state of preservation as in the Raibl strata, but are not bituminous. It is therefore obvious that in this case the bitumen has to be ascribed to the animal remains and not to the vegetable remains, since to suppose the contrary would be against nature.

Since plants by their decomposition in the strata of the earth leave behind either a carbonaceous residue or only their impression, but in the latter case also no bitumen, as shown by the testimony of many slates and fine-grained sandstones, cases analogous to the Raibl strata may be abundantly augmented by any geologist.

Plants leave behind either a carbon skeleton or this may be entirely wanting, the plant bearing strata being in the latter case non-bituminous. If it is supposed that plants leaving behind a carbonaceous residue can be converted into petroleum, the hypothesis connecting the occurrence of the latter with coal deposits would be entitled to consideration; but, as above-mentioned, it is opposed by observations. If, however, such a decomposition of the vegetable substance takes place without a carbonaceous residue remaining behind, but simply an impression, bitumen is always wanting. Empirically, animal remains, as a rule, leave behind no or only slight carbonaceous parts they may under favorable conditions result in an accumulation of bitumen, but as a rule, the hydrocarbons formed will escape without locally concentrating.

A peculiar phenomenon remains to be mentioned, namely, the occurrence of cannel coal, which is in great demand as a gas coal by reason of its large content of bitumen. It is almost invariably found accompanied by animal remains (especially fishes) so that its large content of bitumen has to be ascribed to them and not to the vegetable remains of the coal.

Thus Newberry[1] reports that the Ohio cannel coal frequently contains an abundance of remains of aquatic animals, such as mollusks, fishes, amphibia and crustaceans, and he is forced to assume that the cannel coal is a lagoon formation in which, besides animal remains, macerated parts of plants were deposited.

On pp. 174 and 175 of the same report he again refers to cannel coal and bituminous shales as carrying an abundance of bivalves and crustaceans, but especially estheria.

The gas shale of Nürschau, which received its name from its large content of bitumen, and which has become universally known through the thorough investigations of Dr. A. Fric,[2] contains an extraordinarily rich fauna of reptiles, amphibia and fishes, of crustaceans, insects, etc.

Davies[3] who especially studied the occurrence of cannel coal in Flintshire and neighboring districts of England, in his conclusions regarding the characteristics of cannel coal, lays particular stress upon the fact of its always appearing with fishes.

C. Zincken[4] points out as a characteristic of paper-coal or papyraceous lignite (Dysodil) that it contains remains of insects, fishes, frogs and other animals "to which is due the *content of fat* frequently found."

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[1] Report of the Geological Survey of Ohio, Part I., p. 125.

[2] Ueber die Wirbelthierfauna in der Vorzeit Böhmens.

[3] Earthly and other Minerals, p. 229.

[4] Physiographie der Braunkohle, 179.

Many more examples proving the appearance of bitumen in coal and lignite and in bituminous shales being due to the presence of animal remains might be quoted.

Hence the supposition that bitumen has been formed by the decomposition of animal, and not of vegetable substances, is the only one in accordance with nature.

In conclusion Engler's[1] recent investigations of this subject may be given. After several experiments on a small scale which referred to the investigation of the products of decomposition of fats when heated under pressure, Engler proceeded to the execution of these experiments on a large scale.

In the Riebeck mineral oil factory at Webau, 492 kilogrmmes (1082.4 lbs.,) of menhaden oil were subjected in a Krey apparatus to distillation under pressure. Distillation commenced with a pressure of 10 atmospheres and a temperature of 608° F., and ended with a pressure of 4 atmospheres and a temperature of 752° F. About 60 per cent., of distillate of specific gravity 0.8105 was obtained. It had a brownish color with greenish fluorescence and a disagreeable odor reminding one of acrolein. Of saponifiable parts about 5 per cent., remained behind. The determination of the quantities of the separate fractions resulted as follows:

	Up to 257° F.	257° to 302°.	302° to 347°.	347° to 392°.	392° to 437°.
Cubic centimeters..	21.5	8.0	10	6	9.5
Grammes.........	15.5	5.5	7.5	5	8

	437° to 482°.	482° to 527°.	527° to 572°.	Over 572°.	
Cubic centimeters.	10.5	11	10.5	13	residue.
Grammes........	9	9	8.5	13	loss.

Hence principal fractions:

	below 302°.	302 to 572°.	over 572°.
Per cent. by volume...............	29.5	57.5	13
Per cent. by weight...............	25.9	58.0	16.1
Specific gravity..................	0.712	0.817	—

Since the determination of the gases could not be made in Krey's apparatus, distillation for this purpose was effected in

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[1] C. Engler and S. Seidner: "Ueber die Zersetzung der Fettstoffe beim Erhitzen unter Drunck." Compare, Dingl. Polyt. Jour. 1889, 271.

closed tubes, the result, by determining the loss being 8.9 per cent. gases. After washing with water and purifying with acid to remove the non-saturated and aromatic hydrocarbons and other admixtures, the distillate obtained from the menhaden oil was subjected to several distillations and in the separate fractions pentane, hexane, normal and secondary heptane, normal octane and normal nonane were established according to their characteristic properties.

The loss in distillate by treatment with ordinary and fuming sulphuric acid amounted to about 37 per cent., and from this it could be inferred that it contained olefines and aromatic hydrocarbons.

If from a mixture containing paraffin hydrocarbons, olefines and naphthenes the olefines are removed by ordinary sulphuric acid, the specific gravity, refractive power and refractive exponent of the remaining oil will decrease; but if the naphthenes present are then taken out with fuming sulphuric acid, the first two quantities decrease, but the specific refractive power increases. In the absence of naphthalene the latter remains unchanged or decreases. This being presupposed, Engler and Seidner obtained results from which the presence of naphthenes, thoughonly in small quantities, in the distillate of menhaden oil appeared probable.

To prepare an illuminating oil from the distillate, the latter was first subjected to distillation, and the fractions between 284° and 572° F. caught. After refining this fraction in the ordinary manner a product was obtained which could not be distinguished from ordinary commercial petroleum, and possessed all the properties of a good illuminating oil. Its specific gravity was 0.8025, its flashing point 80° F., and its medium intensity of light 13.2.

Since it is known that fish oil consists chiefly of triolein, the latter, for controlling purposes, was synthetically prepared and subjected to a similar distillation, the results obtained corresponding with those of menhaden oil.

To obtain an idea of the behavior of not only the fat, but of the entire animal substance, when distilled under super-pressure, Engler had formerly subjected in Oehlrich's refinery marine animals, dried fishes and mollusks to distillation at a pressure of 16 atmospheres.

The distillates obtained, however, differ in their entire composition so much from petroleum that there can be no doubt that petroleum could be formed only by accumulated masses of animal bodies having passed first through a process of putrefaction, whereby the nitrogenous substances were destroyed and removed, the fat alone remaining behind, which was in later epochs converted into petroleum by pressure and heat, and perhaps by the first alone. That petroleum is not of vegetable origin is proved by the absence of carbonaceous residue in the localities where petroleum occurs, which would absolutely be the case if its origin were due to vegetable remains. Because if we take cellulose ($C_6H_{10}O_5$) as the representative of the crude materials of petroleum, then with its composition of 44.4 per cent. carbon, 6.2 per cent. hydrogen, and 49.4 per cent. oxygen, a residue would remain after parting only with a small portion of the elementary substances under the formation of water, which would be so poor in hydrogen and so rich in carbon that *without a separation of carbon* a formation of saturated hydrocarbons, or even of hydrocarbons of the series C_nH_{2n} could no longer be considered possible. It is, however, entirely different with animal fats or fatty acids formed by the splitting off of glycerin. By eliminating from the latter the total oxygen with the hydrogen belonging to it as water, carbon and hydrogen still remain behind in a proportion (87 per cent. carbon and 13 per cent. hydrogen), which comes remarkably close to the total composition of our crude petroleum.

Proceeding from his classical experiments, Engler shows that the formation of petroleum may be due to the fact that after the putrefaction of the bodies of marine animals all the nitrogenous organic substances, etc., were destroyed, whereby the nitrogen was carried away as ammonia or ammoniacal salts, and the fatty substances consisting chiefly of trioleate, tristearate, and tripalmitate of glycerin remained behind. By the pressure of deposits of sedimentary strata and perhaps also by the gases formed during putrefaction and by heat, this fat suffered an initial splitting into the acids (oleic, stearic and palmitic acids), and into glycerin, the latter being washed away as such or converted into acreolin. The fatty acids, under the same pressure and heat, were finally decomposed, hydrocarbons and water being formed. The appearance of carbonic acid and carbonic oxide in his experiments, Engler considers only an incidental phenomenon (because only slight traces of these gases occur in petroleum and the gases accompanying it), but the appearance of water as the principal phenomenon. The less carbonic acid and carbonic oxide are formed, the more regularly, according to Engler, the process of the conversion of fatty acids into petroleum progresses.

Based upon the results of Engler's experiments, the hydrocarburetting process from the fatty acids may also be explained in a different form. The transformation of the glycerides of the fatty acids into the hydrocarbons of petroleum might also have taken place by the fats suffering decomposition under pressure into glycerin and fatty acids. The glycerin was next decomposed into acreolin and water. The acreolin condensed to benzol, water being simultaneously split off, a reaction characteristic of the aldehydes and ketones. The fatty acids, on the other hand, underwent far-reaching splitting into hydrocarbons and carbonic acid, the former being dissociated under the prevailing pressure and heat, whereby the hydrocarbons characteristic of petroleum were formed. The second product of the splitting of the fatty acids—the carbonic acid—was reduced by the hydrogen molecules, which were in a nascent state during the dissociation of the hydrocarbons, and by the most volatile hydrocarbons, carbonic oxide being formed, so that the appearance of carbonic acid and of carbonic oxide in nature, as well as in Engler's experiments, may be considered an absolute factor in the formation of petroleum from fats. The partial or entire absence of these gases in natural gas may be due to their absorb-tion and convertion into carbonates by masses of earths, earthy alkalies, etc., surrounding the petroleum.

c. From plants and animals.

Several geologists and chemists consider petroleum of both animal and vegetable origin. A few of them may here be mentioned. Prof. Lesley connects the formation of Pennsylvania petroleum with the "vastly abundant accumulations of Paleozoic sea weeds, the marks of which are so infinitely numerous in the rocks, and with the infinitude of coralloid sea animals, the skeletons of which make up a large part of the limestone formations which lie several thousand feet beneath the Venango oil-sand group." Ashburner also ascribes a vegetable and animal origin to petroleum. Newberry (1859) asserts that the oil has been separated from vegetable and animal remains at the transitory stage of the organisms which is called bitumization. Prof. E. B. Andrews, however, calls attention to the fact "that if the oil were formed with the bitumen of the coal, we should expect that wherever there is bituminous coal there would be corresponding quantities of oil, which is not the case."

N. S. Shaler[1] supposes animal as well as vegetable origin, and regarding the first refers to certain Devonian limestones, and the latter to the Devonian black shale of Eastern America.

E. Orton[1] is also of the opinion that petroleum occurring in shale and sandstone is of vegetable origin and that occurring in limestone of animal origin.

Peckham endeavors to prove that the quality of petroleum varies according to its origin; thus bitumen which forms asphalt but contains no paraffin is of animal origin, while that which does not form asphalt, but contains paraffin, is of vegetable origin.

Harper ascribes the formation of the Hanover petroleum to the decomposition of large masses of organic bodies of the animal and vegetable kingdoms, especially to those of the Devonian and carboniferous formations. Strippelmann holds a

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[1] Stowell. Petr. Rep., 1877. No. 7, p. 6.

similiar opinion. He considers "that the formation of petroleum is without doubt connected with the Silurian, Devonian and carboniferous formations and the decomposition of masses of vegetable and animal substances accumulated in unknown depths is still in progress under the coöperation of greater heat. From this seat of production and its collecting spaces, the latter of which belong chiefly to the more recent formations, the productive oil regions have been filled and are still filled partially by condensations of gas and partially by capillary attraction."

According to Dr. Kraemer petroleum is the product of dry distillation of organisms of pre-carboniferous epochs. The process of transformation has taken place (and perhaps takes place to-day), where folds and piling up of the earth's crust gave rise to mountains.

2. *Process of Formation.*

As will be seen from the explanation given in the preceding sections, there can be no doubt of the organic origin of petroleum. It has been frequently suggested that the process of transformation has been effected by distillation, but in this respect also, opinions are diametrically opposed to one another. Some suppose for this distillation temperatures similar to those employed in the destructive distillation of coal; others consider the presupposition of a high temperature either unnecessary or as being in conflict with the chemical composition; while others again combine high and lower degrees of heat.

Daubrée's experiments with fragments of wood exposed to the action of superheated steam showed the possibility of the formation of volatile and liquid products resembling natural bitumen at a relatively low temperature, though above 202° F.

Those who presuppose a high temperature for the formation of petroleum, refer either to the neighborhood of volcanoes, which, however, can be but very seldom established, or to the terrestrial heat at great depth. In either case it becomes neccessary to suppose, besides the seat of formation exposed to a high temperature, a considerably cooler condensing sphere located nearer to the surface of the earth. As previously mentioned, Piedboeuf advances reasons deserving attention for objecting to the separation during the formation of petroleum.

Dr. Krämer is of the opinion that this process cannot be identical with the processes of distillation employed by us (distillation of coal, manufacture of gas). "Certain differences in the petroleum and the distillates of fossils presuppose a different process. It is remarkable that the oxygenous constituents; especially the phenols, which are essentially components of coal tar, are either entirely wanting in petroleum or present only in very small quantities, and that nitrogenous constituents cannot be established with certainty. Of still greater force is the fact that in all pyrogenous decompositions there is obtained besides the distillates a residue-coke remaining in the retort, while petroleum must have formed without such a residue, coal in no form having been found in localities where oil occurs." (The doubt about the absence of nitrogenous combinations has already been refuted.)

"Regarding the question of temperature at which the final transformation into petroleum has been effected, the well known experiences in dry distillation may also be referred to. We have seen that the light oils—photogen and solar oil—of brown coal tar, which is obtained at a comparatively low temperature, although much richer in aromatic hydrocarbons than even the specifically heaviest petroleum, are in this respect far behind the light oils of stone-coal tar, which chiefly consist of aromatic hydrocarbons. Now since stone-coal tar is obtained at a much higher temperature than brown coal tar, it follows that the formation of petroleum must have been effected at a still lower temperature than is required for the production of brown coal tar. However, the lower the specific gravity of petroleum the poorer in aromatic hydrocarbons it has been found to be, and the lower it may be supposed the temperature of the formation must have been, if not, what is very likely possible, the concentration of heavy hydrocarbons took place later on. Since petroleum at a higher temperature, or when its vapors are conducted through red-hot pipes, is decomposed to gaseous hydrocarbons, the causes of the observed differences in its composition may be reasonably attributed to a time later than its formation."

If from a chemical standpoint Dr. Krämer lays stress upon the fact that the temperature at which petroleum has been formed must have been lower than that at which brown coal distillates are produced, we have to agree with him from a geological standpoint also, though his observations are based upon the behavior of vegetable remains. Since no traces of the action of a former red heat have been found in any petroleum region, even where the oil is still in primary deposit, nor where shales which are readily reddened by heat and otherwise changed, for instance by the disappearance of the few black remains of fish scales, etc., carry or accompany oil, we are forced to the conclusion that petroleum must have been formed at a decidedly lower temperature than even the most moderate red heat. The possibility of such process of transformation at a quite low temperature is proved by O. Fraas' observations at the coral reef at Djebel Zeit, in the Red Sea. An analysis of this petroleum would be of great scientific interest.

Since the petroleum of the Carpathian fish-shale contains paraffin, though only in small quantities, and since it occurs in primary deposit which shows no sign of the action of a red heat, it follows that the formation of paraffin is also possible at a lower temperature than red heat.

The above mentioned oil, bearing fish-shale, is like the coral reef of Djebel Zeit, a proof of the possibility of petroleum being formed from animal remains at a relatively low temperature. It is also very probable that the same factors have been active in all other oil regions, the only exception being the sporadic inclusions of oil in eruptive rocks which are of no technical importance, and which may have been formed by destructive distillation of broken through coal strata.

E. Orton[1] also arrives at the result that the transformation

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[1] Preliminary Report on Petroleum and Inflammable Gas, 1887, p. 11.

has taken place at a relatively lower temperature—at all events below 392° F.—and he therefore calls the process spontaneous, instead of destructive distillation.

Whether in the formation of petroleum from organisms *water* has co-operated is still an insolved question, which has scarcely ever been discussed.

Daubrée alone presupposes its presence necessary, his synthetic experiments having been made with the use of superheated steam. In view of the general distribution of water, especially in organisms also, its presence in the transformation of the latter into petroleum can scarcely be doubted.

Another point in question is to what extent is it necessary to presuppose an *increased* pressure in the transformation of the organisms. In view of the overlying sedimentary rocks it may be supposed that the oil-bearing strata stood formerly under a greater pressure than at present. That chemical action is also augmented by this greater pressure is well known and, hence, the formation of petroleum could be the more readily effected at a comparatively low temperature.

In the primary deposits the spheres of formation and condensation were situated in the same locality. Hence the light hydrocarbons formed could not be condensed by a lower temperature than that of their formation, their becoming liquefied being rendered possible only by standing under greater pressure, which is conditional on the degree of resistance the gases met with in their endeavor to escape, hence is dependent on the primary oil deposit being tightly closed on all sides. That petroleum in its deposits frequently stands under a high pressure has been confirmed in many localities.

G. Kraemer and W. Böttcher[1] also have recently arrived at the conclusion that the formation of petroleum must have taken place under great pressure.

These few observations may suffice to justify the assumption of a higher pressure in the formation of petroleum.

It is well known that *the various petroleum regions yield dif-*

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[1] Ver. deutsch. chem. Ges., 1887, S. 595.

ferent crude oils, this being best illustrated by the fact that the crude oil of Pennsylvania yields 70 per cent. of illuminating oil, while that of Baku yields only about 30 per cent.

That in the same oil deposit the density of the oil decreases to a certain limit at a greater depth has been observed in many localities, and can, as previously mentioned, be explained only by the fact, that the petroleum nearer to the earth's surface has been changed and become denser by evaporation and oxidation, this also being very probably the reason why the first oil sand of Pennsylvania yields a denser crude oil than the second, and this again a denser than the third, the lowest oil sand.

In Klenczany (West Galicia) yellow petroleum, rich in paraffin, and dark petroleum, poor in paraffin and of little value, occur at a slight distance (about 3280 feet) from each other.

The difference in the oils of the various states of North America, for instance, Pennsylvania, New York, California, etc., caused Peckham to suppose for some a vegetable, and for others an animal origin, though the proofs given are not sufficient.

Dr. Kraemer[1] says: "The evaporation and the superheating of the petroleum, together with a resinification taking place later on under the influence of the oxygen of the air and sulphur, are the causes of the great differences in petroleum observed at the present time. The more recent the formation of the petroleum, and the less its deposit has been changed, the more insignificant these differences appear." The latter proposition might be objected to, while the first, independent of the presupposed volcanism during these processes, mentions, in many respects, important factors of the transformation.

While Peckham seeks the difference in the material of origin, Kraemer finds it in processes acting upon the finished oil.

There is no doubt that a difference in the petroleum had to be conditional on the fact whether, for instance, remains of saurians, or of fishes, or of coralloid animals, were employed in its formation. These differences can, therefore, be sufficiently

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[1] Sitzb. d. Ver. z. Bef. d. Gewerbefl., 1885, S. 311.

explained by animal remains alone, without supposing, like Peckham does, entirely different materials of origin.

However, the difference in the quality of crude oil can be explained not only by the difference in the raw material and the variety of processes which have subsequently acted on the petroleum. There are other self-acting factors, such as temperature, duration of the process and the pressure prevailing thereby, the rock material which was encountered by the oil in a state of formation as already formed, which may also have co-operated in bringing about this difference in quality, as is well known to every chemist who has studied, for instance, the chemistry of coal tar. To decide in a given case to which of the above-mentioned factors the differences in quality are due, will frequently be a fruitless effort.

It may be mentioned here that coals of the same geological age and alike in nearly all other respects, for instance the coal of Wigan and of Newcastle, yield different tars, that of the first locality being rich in phenol and benzol, and that from the latter, in naphthalene and anthracene.[1]

3. *Origin of oil deposits.*

Having discussed the formation of petroleum, the next question refers to the formation of its deposits, those local accumulations by which it becomes of technical importance.

It is a fact established in various petroleum regions that petroleum may also occur in fissures. That the oil has not been formed in them, but occurs in a secondary deposit, needs no further explanation.

If the mouth of such a fissure, in which the oil ascends, is covered with debris or sand, the latter are actually filled with petroleum.

If such a fissure crosses a porous stratum, the pores of the latter will be filled with petroleum. The accumulation of oil extends with this stratum and has the appearance as if, in this

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[1] Dr. G. Schultz. Chemie des Steinkohlentheers, 2. Aufl., S. 22.

case, we had to deal with a primary accumulation resembling a deposit.

The above mentioned deposits as well as those previously described are only *secondary*. They are found, as well as both kinds combined, in several localities, for instance, in Canada.

Regarding the question of the formation of petroleum these secondary deposits are, however, of as little importance as oil reservoirs above ground; they suggest only a seat of origin. Those investigators who locate the seat of origin in the red-hot depths of the earth moreover deny the presence of a primary deposit, since according to that opinion no accumulation can take place in the retort—in the seat of origin—but only in the cooled receiver, namely in the fissures leading to the surface and the porous rock strata connected with them.

Hence, independent of the practical importance, it is of theoretical interest to inquire whether primary oil deposits exist. This can only be decided by observation. Since the origin of petroleum, like that of coal, from organic remains has to be accepted as settled, it has first to be determined by observation whether an accumulation of petroleum corresponds to a deposit, i. e., to a concordantly imbedded layer of strata. It must further be shown that the oil (or bitumen in general) occurring therein has not been transported from the exterior, but has been formed in this deposit.

A few localities may here be mentioned in which primary petroleum deposits have been established: In the same localities secondary deposits may, of course, have been formed, as soon as the oil had a chance to escape from the original deposit.

Peckham says in regard to the petroleum of California and Tennessee that it has without doubt been formed in the shales from which it issues.

T. Sterry Hunt is of the opinion that the oil-bearing Niagara limestone, especially at Chicago, Illinois, is a primary deposit. To the same author we are indebted for a very interesting observation in the township of Bertie, which is on the Niagara River opposite Buffalo. He says: "Here in a quarry are seen massive beds, slightly inclined, composed of a solid, crystalline encrinal limestone, which appears not only destitute of petroleum, but, from the water by which it is impregnated, to be impermeable to it. In some of the beds are large corals of genus Heliophyllum, the pores of which are open but contain no oil. Two beds, however, one of 3 and one of 8 inches, which are interstratified with these, are in a great part made up of species of *Heliophyllum* and *Favosites*, the cells of which are full of petroleum. The layer of 3 inches was seen to be twice interrupted in an exposure of a few feet, thus presenting lenticular beds of the oil-bearing rocks." These facts prove without doubt that the petroleum occurs here in primary deposit, since the presence of a fissure along which the oil could have been transported, could not be established.

Hunt arrives at the same result in regard to the limestones carrying corals and oil of Canada. He says: "The absence of oil from the unfilled cells of corals in the adjacent and interstratified beds forbids the idea of its introduction into these strata either by distillation or infiltration." The same observations apply to the Trenton limestone of which he gives examples in Ontario.

The occurrence of oil in Kentucky, which appears in a conglomerate and sandstone filled with broken and already macerated vegetable remains (?) on the base of the coal formation is, according to J. P. Lesley, also in primary deposit.

According to E. Orton the oil in northwestern Ohio is also deposited in its original seat of formation.

The asphalt of Trinidad is, according to G. P. Wall, *in situ* in certain strata of the upper Newer Parian group.

Bright and Prestwich consider the petroleum of England as formed in the limestones and shales. Concerning the origin of the petroleum of Shropshire, Arthur Aiken says: "The thirty-first and thirty-second strata are coarse-grained sandstone entirely penetrated by petroleum, are, both together, 15½ feet thick, and have a sandy bed of shale-clay about 4 feet thick interposed between them. By certain geologists this reservoir of petroleum has been supposed to be sublimed from beds of coal that lie below, a hypothesis not easily reconciled to present appearances, especially as it omits to explain how petroleum in the upper of these beds could have passed through the interposed bed of clay so entirely as to leave no trace behind. It is also worthy of remark that the nearest coal is only 6 inches thick, and is separated from the above beds by a mass 96 feet in thickness, consisting of sandstone and clay strata without any mixture of petroleum." Moreover, these facts do not allow of the assumption that the oil has been forced upwards either in the form of gas or in liquid drops. There is but one explanation, and that is, the oil is in primary deposit.

A. Andreæ, by reason of his thorough study of the occurrence of petroleum in tertiary strata, arrives at the conclusion that the oil of Upper as well as Lower Alsace is in primary deposit. The brackish water petrifactions, as well as the other geological conditions, point towards the accumulation of the organic material in a lagoon or a delta; the transformation of the organisms into petroleum has been effected under the exclusion of air and great pressure.

Concerning the occurrence of bitumen at Seyssel on the Rhone, France, D. C. Davies says: "The chalk formation contains three beds of bituminous chalk 10 to 13 feet thick, and have interposed between them deposits of white chalk not impregnated with bitumen, 3 to 50 feet thick. The impregnated beds are in some places highly crystalline and consist in others of the remains of shells accompanied by some fish teeth. The bitumen occurs in geodes, cavities, and in beds, and forms 8 to 10 per cent. of the entire mass."

Now, since some limestone beds are bituminous, and others free from bitumen, and the occurrence of a fissure for the conveyance of the bitumen has not been observed, the oily substance can, in this case, be only in primary deposit.

Regarding the occurrence of mineral tar at Limmer, Hanover, H. Credner is of the opinion that it is of animal origin as well as in the original deposit. Regarding the North German finds, Eck says: "We have every reason to believe the mineral tar occurring in the clays of the lias and of the brown Jura, and in the rocks of the Wealden formation, to belong originally to these strata."

In the Carpathian zone an oil level belongs to the fish-shale, which, as indicated by its name, carries remains of fishes. Below and above it is sandstone which contains no oil, notwithstanding it is a porous rock, while the fish-shale is difficult to penetrate by fluids. In this case the introduction of petroleum from the exterior is, therefore, entirely excluded, and it must have been formed in the shale bed. The fact of the frequent occurrence of fish remains in this shale and the entire absence of vegetable remains furnishes another proof of the animal origin of petroleum.

In Galicia it may also be frequently observed that in a fish-shale group the oil is preponderantly fixed in one or more beds. There may be two causes for this phenomenon, which have to be determined for each particular case; such interstratified oil beds correspond either to a special concentration of fish remains, or to the interstratification of a porous rock, for instance, sandstone.

H. B. Medlicott[1] refers to the fact that all occurrences of petroleum in the Punjab belong to the eocene and only to one geological horizon in this group of strata, and he, therefore, recognizes it as a primary deposit. The occurrences of petroleum in Khatan (Belloochistan) show, according to R. Townsand,[2] the same genetic character.

The occurrence of oil, gas and bituminous shales (pyroschists according to T. S. Hunt), by the distillation of which considerable quantities of oil may be obtained, also proves the formation of bitumen in a primary deposit, because these shales are not readily permeated by fluids and have above and below them more permeable and more porous rocks, such as sandstone, limestone or dolomite, which would have more readily

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[1] Note on the Occurrence of Petroleum in India (Record Geol. Surv. of India) 19, 201. [2] Rep. Petr. Expl. at Khatan, Record of Geol. Surv. of India, 19, 204.

absorbed the oil. If some bitumen is found in the more porous rocks—generally in fissures—it is mostly in such close vicinity to the shales that it can be traced to them.

The bituminous shale can be concordantly interstratified in a shale free from bitumen, and in this case also the bitumen can be only in primary deposit.

The oil shales contain either animal remains only or besides them also vegetable remains. That the latter is only of passive importance in the formation of bitumen has previously been mentioned.

Of shales especially rich in oil may only be mentioned: Those of the Lothians in the British coal formation, with ostracodes, fishes, coprolites, etc.; the shales of the upper lias of Suabia and Franconia, which are extraordinarily rich in animal remains, among them the well-known saurians, fishes, and cuttle fishes (ink-bag and frame of *loligo*); the oil slate 78 to 98 feet thick, which at Steierdorf is concordantly interstratified in a tract of shale overlying the upper vein.

The bitumen of the Ohio shale, which in the eastern part of Ohio attains a thickness of up to 650 feet, being uniformly distributed through the entire group of strata, can only be of primary naturc. The same applies to the Heldenberg, Clinton, Niagara, corniferous and other limestones of the Eastern portion of North America. Hunt has made a calculation showing the amount of petroleum which the oil-bearing dolomite of Chicago holds to the square mile for every foot of thickness in the stratum. "If we apply," says E. Orton, "a like calculation to the rocks of the Ohio shale, we shall find the total amount of oil enormously large. We may take, for example, the Waterlime stratum, which is notably and almost universally petroliferous. Estimating its petroleum content at one-tenth of one per cent., and the thickness of the stratum at 500 feet, both of which figures are probably within the limits, we find the petroleum contained in it more than 2,500,000 barrels to the square mile. The total production of the great oil field of Pennsylvania and New York to January, 1885, is 261,000,000 barrels. It would require only three ordinary townships, or a little more than 100 square miles, to duplicate this enormous stock from the Water-lime alone. But if the rate of one-tenth of 1 per cent. should be maintained through a descent of 1,500 feet at any point in the State, each square mile would, in that case, yield 7,500,000 barrels, or nearly one-thirtieth of the total product of the entire oil field. These figures pass at once beyond clear comprehension, but they serve to give us some idea of the vast stock of petroleum contained in the earth's crust. If petroleum is genally distributed through a considerable series of rocks in *any* appreciable percentage, it is easy to see that the aggregate amount must be immense. Even $\frac{1}{1000}$ of 1 per cent. would yield 75,000 barrels to the square mile in a series of rocks 1,500 feet deep, but this amount is nearly one-tenth of the greatest actual production per square mile of any of the leading Pennsylvania fields.

"It is obvious that the total amount of petroleum in the rocks underlying the surface of Ohio is large beyond computation, but in its diffused and distributed state, it is entirely without value."

The facts given above prove that bitumen, and especially petroleum, occurs also in primary deposits.

We thus arrive at the following conclusions:

1. Petroleum is of animal origin; saurians, fishes, cuttlefishes, coralloid animals, etc., especially have authentically contributed to its formation, though soft animals without solid frame, of which no authentic, determinable remains are left behind, may also have co-operated.

While coal has been formed by the transformation of vegetable substances, petroleum and the allied bitumens originated from animal substances.

2. It is still an unsolved problem whether petroleum could be formed from animal remains only under special conditions; neither is the nature of these conditions known.

3. Petroleum has been formed in all ages of the earth's history of which animal remains exist. The Archean strata are free from petroleum.

4. Petroleum could accumulate and be preserved in the original deposit only, if during its formation it was shut off from escape.

5. The formation of petroleum has been effected without the co-operation of an uncommonly high temperature, and.

6. It has taken place under higher pressure, the influence of which upon the chemical process is not known.

7. The deposits of petroleum are partially original (primary) and partially secondary; the latter may be or were connected with the former.

Concerning the formation of natural gas the same materials and similar processes as for the formation of petroleum may be presupposed. The accumulation of both also took place in the same spaces, frequently in such a manner that the gas occupied the higher, and the oil the lower sections of the same rock stratum. No process being known by which petroleum can be formed from natural gas, while the separation of the latter from the former—even at the ordinary temperature—is a well-known fact, it is very probable that petroleum is the primary, and gas the secondary product.

That ozocerite, maltha and asphalt have been formed partially by vaporization and partially by oxidation of petroleum has been previously explained.

CHAPTER VII.

BORING—CONVEYANCE—TRANSPORTATION.

WHEN the use of petroleum was limited and before its great value was recognized, very primitive methods for obtaining it were in vogue. At first the oil collecting on the surface of the water was skimmed off and purified by heating and straining. Later on, especially in regions where natural segregation took place to a limited extent, shallow pits were dug in which the oil issuing from the lower rock strata collected, and was kept for use. The North American Indians and the Persians of the Caucasus were in the habit of laying cloths in the pits which, when soaked full of oil, were wrung out, or they dipped the oil out with earthen pots.

With the increasing consumption of the oil the shallow pits were gradually changed to deep wells (30 to 100 feet), from which the oil was ladled by hand or animal power. After Drake's success in Titusville, Pennsylvania, the digging of wells was replaced by boring, which has now been almost everywhere introduced where petroleum occurs.

The oldest traces of obtaining oil by mining are found in Japan, where from a very remote period wells have been dug and tunnels have been run into hillsides for oil. Some of these abandoned drifts have caved in and large trees are growing upon them. In relation to the manner of working these wells, B. S. Lyman in his *Reports on the Geology of Japan*, 1877, says: "The present mode of working is very simple, a method that has probably grown into its present form in the course of centuries of experience, and is now apparently practiced in all the oil regions with little or no variation. The digging is all done by two men, one of whom digs in the morning from nine o'clock in the morning until noon, and the other from noon until three. The one who is not digging works the large blowing machine or bellows that continually sends fresh air to the bottom of the well. The well is timbered with larger pieces at the corners and light cross pieces, which serve also as a ladder for going up or down. The oil is skimmed from the surface of the water and drawn up in buckets."

In Galicia, wells were dug as for water, and, in some instances, such wells were united at the bottom by galleries into which the petroleum filtered from the rock.

In the United States several different methods for obtaining oil were employed before wells were drilled. In the Ohio oil districts shafts were found, of the sinking of which there are various traditions; but since the curbed pits on Oil creek, Pithole creek, and other tributaries of the Allegheny have been proved to be of French origin, it is not unlikely that these old shafts in Ohio were also made by the French. An unsuccessful attempt to obtain oil in this way was made at Mecca, Ohio, about 1864, and another attempt to sink a shaft to the Venango oil sand was made in 1865 in the bend of the Allegheny river, on the east side, below Tidioute.

Prof. Silliman, in 1833, thus described the method for obtaining Seneca oil at the famous spring at Cuba: "A broad, flat board, made thin at one edge, like a knife, is moved flat upon, and just under the surface of the water, and is soon covered by a coating of petroleum, which is so thick and adhesive that it does not fall off, but is removed by scraping the instrument upon the lip of a cup."

J. D. Angler, of Titusville, worked the springs on Oil Creek for some years prior to 1859. He found the springs logged up 6 to 8 feet square, and as many feet deep. He arranged a sort of sluice box with bars that held the oil while the water flowed on beneath. In this way he obtained 8 to 10 gallons of oil per day, which he sold at Titusville for medicine and for lighting saw mills and derricks of salt wells.[1]

In Germany, like everywhere else, oil was obtained in a very

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[1] S. F. Peckham, Report on Petroleum.

primitive manner. Pits about 3½ to 10 feet long, 3 to 3½ feet wide, and 10 to 20 feet deep were dug, and the upper portion timbered. The oil collecting on the surface of the water was skimmed off and kept in wooden vessels. In Alsace the oleiferous sand was brought into pits containing water, and after thorough stirring the oil collecting on the surface was skimmed off.

In Roumania the mode of obtaining oil is still very primitive. Shafts from 164 to 550 feet deep are sunk, and the oil is hauled up in wooden buckets. The ventilation of the shafts, which lie quite close together, is effected by means of large bellows. The average yield per 24 hours of each shaft is from 300 to 1000 viadra,[1] this quantity keeping up for years. By rational drilling a considerable increase in the yield of oil might be obtained. At present only Theiler Brothers drill successfully in some localities according to the Canadian system. It is said that a short time ago they had obtained a daily yield of 25 to 30 barrels from three borings 520 to 575 feet deep, in a territory in which formerly more than 100 shafts were worked with but slight success.

The inhabitants of the Caucasus, the Persians and Tartars, formerly obtained the oil by digging pits about 10 feet deep, and protecting the sides from falling in by wicker-work. The naphtha collecting on the bottom was ladled out with earthen pots or bottles of sheepskin, the latter serving also for keeping and transporting the oil. Later on a better method was adopted. Funnel-shaped cisterns from 7 to 65 feet deep were dug. The sides of these cisterns were in the form of steps to facilitate the throwing up of the earth. When an oil-bearing stratum was struck, a cavity was made in the bottom of the cistern, which served as a collecting basin for the naphtha. In 1830, 82 such pits or cisterns were in use in the peninsula Apscheron; in 1862, 220, and in 1872, 415. They were emptied by means of leather bottles (burdjuk) secured to ropes. The cisterns had to be frequently emptied, otherwise

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[1] 1 viadra = 3.7434 gallons.

the influx of oil would be injured, and had to be occasionally cleansed from the accumulation of mud. In the twenties, the daily yield of the separate cisterns varied between 8 and 140 pud, but according to Abich's statement, 70 pits at Balakhani produced in 1856, 250,000 pud. When the news of Drake's success penetrated to the Caucasus, Colonel Norvosiljoff caused borings to be made in the Kubany district near Kudako. The experiment showed such good results that Mirsojeff, a rich Armenian, who rented the crown pits in the Apscheron peninsula, also made drilling experiments, the success of which forms the basis of the present large Russian petroleum industry.

Artesian Wells.

In the petroleum industry artesian wells form the transition to the present deep borings. Although they have not been especially employed for obtaining oil, their use is as old as the primitive methods previously mentioned. In China the Jesuit missionaries found artesian wells in full operation. These wells were drilled for brine and natural gas, the latter being frequently accompanied by petroleum. It may be interesting to give an extract from Abbe Huc's work on China, describing the Chinese method of drilling wells:

"The wells are usually from 1500 to 1800 feet deep, and only 5 or 6 inches in diameter. The mode of proceeding is as follows: If there be a depth of 3 or 4 feet of soil on the surface, they plant in this a tube of wood surmounted by a stone, in which an orifice of the desired size of 4 or 5 inches has been cut. Upon this they bring to work in the tube a rammer of 300 or 400 pounds weight, which is notched and made a little concave above and convex below. A strong man, very lightly dressed, then mounts a scaffolding, and dances all the morning on a kind of lever that raises this rammer about 2 feet and then lets it fall by its own weight. From time to time a few pails of water are thrown into the hole, to soften the material of the rock and reduce it to pulp. The rammer is suspended to a rattan cord not thicker than your finger, but as strong as our ropes of catgut. This cord is fixed to the lever, and a triangular piece of wood is attached to it, by which another man, sitting near, gives it a half turn, so as to make the rammer fall in another direction. At noon this man mounts on the scaffold and relieves his comrade till the evening, and at night these two are replaced by another pair of workmen. When they have bored 3 inches they draw up the tube, with all the matter it is loaded with, by means of a great cylinder which serves to roll the cord on. In this manner these little wells or tubes are made quite perpendicular and as polished as glass. When the rock is good the work advances at the rate of two feet in 24 hours, so that about 3 years are required to dig a well."[1]

In Europe the first artesian well was drilled in 1126, at Lillers, in the department Pas de Calais, France. However, on a more extensive scale, artesian wells appear to have first been drilled in Modena and in Austria. The term artesian well is derived from the county Artois, the soil of which is especially suitable for drilling such wells.

In the United States the first artesian well was drilled in 1809, and furnished, besides a very large volume of gases, a great quantity of oil. Prior to 1858, a great many wells had been drilled for brine in the valley of the Ohio and its tributaries, with such additional improvements as rendered them very effective for this purpose. Steam, horse and hand power had been employed in drilling with equal success, the tools and general manipulations of the well being essentially the same. The drilling of wells with hand-power was accomplished by means of a spring-pole. For this purpose a straight tree, 40 or 50 feet in length, was selected. After the branches were removed, the butt was secured in the ground in such a position that the pole extended at an angle of about 30°over the spot at which the well was to be bored. To the smaller end the tools were attached, and by the elasticity of the pole, as it was alternately pulled down and allowed to spring back, they were lifted and made to strike at the bottom of the well.[2]

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[1] **Travels in the Chinese Empire, 1300. Harper's ed., 1855.**

[2] **S. F. Peckham, Report on Petroleum.**

The success which attended the drilling of artesian wells gave, indirectly, rise to the drill. The drilling of the first petroleum well by Colonel Drake has already been described.

Drilling for Petroleum.

Prior to drilling it is absolutely necessary to acquire as thorough a knowledge as possible of the geology of the soil, in order to determine, on the one hand, the point where to sink the drill, and, on the other, to what depth drilling might have to be done to attain the desired result. These two factors serve as the basis for the choice of one or the other of the customary drilling systems, it not being the same whether by a drilling system chosen at will a slighter or greater depth is to be attained in a soft, for instance, a slimy or sandy soil. A drill which may be very suitable for a soft soil and a slight depth would perform but poor work in drilling through a hard soil and to a greater depth. The principal drilling systems in use are the rotatory, percussive and free-fall systems. There is more or less difference in the drilling and auxiliary tools, as well as in the execution of the drilling operation itself.

I. DRILLING TOOLS.

A. For the Rotatory Method.

The screw auger, Fig. 7, is used for slight depths; the diameter does not exceed 4 inches, while the diameter of the stem should be at least 1 inch.

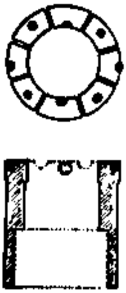
The common earth or clay auger, Fig. 8, may be used for slight depths and for penetrating soft rock, clay and sand. A stout stem is required.

The drill with diamond or steel crown consists of a hollow rod through which a continuous supply of water is forced down to keep the crown cool and to carry off the *débris* formed by the erosion of the strata by the crown. The water flows through channels cut in the face of the crown, rises on the outside of the core-tube to the surface, and is collected in settling ponds where the sediment is deposited. For soft rock steel crowns are used, while for harder rock the crown is provided with black diamonds (Fig. 9.).

FIG. 7.

FIG. 8.

FIG. 9.



The method of cutting hard rocks employed by the ancient Egyptians remained a mystery for a long time. However, a solution of this question seems to have been found by the researches of Flinders,[1] who through various finds at Gizeh came to the conclusion that the Egyptians used precious-stone drills. He states that granite broken from a drill-hole at Gizeh showed marks which can be explained only by the use of solid points of precious stones. Hence the diamond drill can no longer be considered a modern tool, and Fauck's statement that it was employed in the stone and bronze ages seems plausible.

For deep drilling the diamond drill was first employed in the United States, but it was improved by Captain Beaumont, an Englishman. However, this improvement embraces only the

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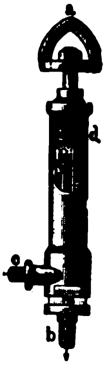
[1] Flinders, "The Pyramids and Temples of Gizeh."

machinery of the drilling operation, the drill itself remaining essentially the same as employed for a long time by Leschot in Switzerland. The boring rods are tubes of drawn steel, 2 inches outside diameter and ⅜ inch in thickness, in lengths of 5 feet. To the lower end of the rods is screwed the core-tube, 15 feet long, the diameter of which corresponds to that of the drill-hole (2½ to 3 inches). The drilling crown is screwed to the core-tube and contains eight or more black diamonds. Only a small portion of the diamonds projects above the edge of the crown in which they are imbedded, otherwise they might readily break out. Fig. 9 shows the arrangement of the diamonds, as well as the channels between them for the passage of the rinsing water and for carrying away the debris.

By utilizing the inventions of Koebrich, Olaf Terp and others, the Well Works Co. of Aurora, Ill., has succeeded in arranging the boring machinery so that the drill alternately exerts a rotatory and percussive effect. The advantage of this invention consists in the use of a feed-cylinder, Fig. 10, suspended to the stirrup *a*, which for drilling with the use of water serves for regulating the feed for the hollow stem. The water enters at *c* and is discharged at *b*, or with the valve closed, by lifting the piston *d*, through the apertures *f*.

FIG. 10.



The great cost of the diamond drill has thus far been a hindrance to its general introduction, though in some cases it cannot be employed on account of local conditions. However, by comparing the rapidity and quantity of effect of a diamond drill with that of a free-fall drill worked by steam-power, it will readily be seen that the cost of the former is completely compensated by its advantages. Thus the average daily performance of a free-fall drill with steam-power is about 5 feet, and if a hole 1800 feet deep has to be drilled, 360 working days would be required for the purpose. The average performance of a diamond drill is about 30 feet per day, so that for a depth of 1800 feet only 60 working days are required. By now taking the operating expenses at $20.00 per day, it will be seen that with the use of the diamond drill the expenses will be $6,000 less.

Olaf Terp's emery core-tube method, which has been patented in every country, is essentially nothing but a diamond drill. In place of the diamond crown the drilling crown consists of a copper cylinder encircled by a layer of corundum 5¾ inches high. The upper portion of the copper drilling crown is provided with a core-catcher, while the lower part is furnished with coarse-grained emery so firmly fixed that it will stand strong friction and high pressure. Since corumdum is but one degree less hard than the diamond, it will be readily comprehended that such a drill is capable of penetrating all softer rocks.

B. Percussive Drills.

The ordinary percussive drill is in the form of a chisel, Fig. 11, and serves only for slight depths. By using a screw-auger or clay-auger for drilling through solid strata, a depth of 600 feet may be reached. When using the chisel-auger it is necessary to clear the bore-hole of debris by means of the instrument shown in Fig. 12. For the chisel as well as for the clay-auger, the same kind of boring rods are used. They are of different degrees of strength, according to the depth of the hole for which they are required. At one end is a male screw and at the other end a female screw, for the purpose of connecting them together. To impart to the rods a rotary motion the instrument shown in Fig. 13 is used. It is so arranged that it can be conveniently taken hold of and secured at any height to the rods. The lifting and lowering of the rods is effected by means of an ordinary crane having a lifting capacity of about 10,000 lbs.

To reduce the stoppages for the withdrawal of *débris* the system of Fauvelle was introduced, but it is now very little practiced. The system answered tolerably well when applied to shallow borings, but was found to be attended with great disadvantages when applied on a large scale. The chief prin-

Fig. 11.

Fig. 12.

Fig. 13.

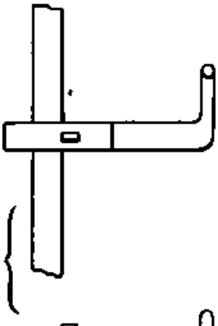


Fig. 14.

Fig. 15.

Fig. 16.

Fig. 17.

ciple upon which it was founded was the injection of a current of water which by descending through a central tube should wash out the *débris* created by the cutting tool at the bottom.

To the series of percussive drills belong also the system with jars, Figs. 14, 15, 16, and 17, on iron or wooden rods (Canadian system) or on a cable (American or Pennsylvanian system). The jars are two peculiarly constructed pieces of metal so formed that, as indicated by their name, a sudden jar will be imparted to the tools at every upward and downward motion as the drilling progresses, serving to loosen the centre bit if by chance it should become wedged in the hard rock. Fig. 14 shows them closed, or with the upper wing resting upon the lower one, the improved rounded wing in front concealing the central slot from view; and Fig. 15 shows another pair, where both wings are made alike and the links are open. The two sets are precisely alike in principle, and vary only in details of construction, Figs. 16 and 17 represent sections of the jars shown in Fig. 14. The jars form the transition from the percussive drill with solid rods to the free-fall drill, the system permitting greater rapidity for the percussive weight than is possible with a solid connection.

C. American or Pennsylvanian and Canadian Systems.

The first step of an oil miner, after having located his well and made the necessary arrangements by purchase, lease, or royalty, for the territory on which the venture is to be made, is to make his contracts for what is termed the "carpenter's rig." This part of the expense comprises all the wood work over the mouth of the well, affording shelter for the workmen, and the appliances necessary to the convenient handling of the well-driller's tools.

The illustration, Plate II,[1] will enable a mechanic to con-

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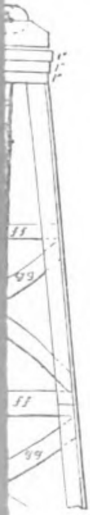
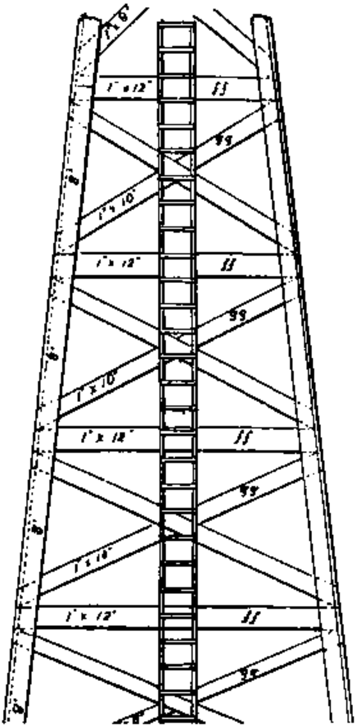
[1] This plate forms one of the illustrations of the Geology of the Oil Regions of Warren, Venango, Clarion, and Butler Counties, Pa., etc., by John F. Carll, of the Second Geological Survey of Pennsylvania, and is here republished in reduced size through the courtesy of the Board of Commissioners of the Geological Survey. The description of the details with illustrations are from the same volume.

struct a first class rig, although he may never have see
well. Fig. 1 (Plate II) shows the side elevation,
(Plate II) the end elevation, and Fig. 3 (Plate II) the h
tal projection. The most conspicuous part of the arran
is the derrick, Fig. 1 (Plate II), a feature in the landscap
out of sight in the oil regions. This is a tall pyramida
structure about 75 feet in height and 12 feet square at th
Fig. 4 (Plate II) shows a plan of the foundation timbers
rig. The dimensions of the timber depend very much
cumstances. While the illustration is drawn for sawed t
it is generally cheaper to hew it from timber felled ne
well, in which case it will necessarily vary somewhat in
The mud sills, *a*, which are generally sunk in trenches,
gains cut into them for the reception of the main sill *d*
sub-sills *e* and *e′*; *f* represents the derrick sills and *f′* the
rick floor sills. After all the timbers have been placed in
proper positions and levelled up, the whole foundation is fi
locked together by driving in the keys or wedges *h*.

The derrick stiles are connected by the girths *ff*, and br
by the diagonals *gg* at frequent intervals; *hh* is a ladder re
ing from the base to the top of the structure; *g* represents
derrick floor, and *j* the corner stones or blocks. The san
post *k* and the jack posts *l* and *o* and knuckle post *r* are d
tailed into the sills and held by keys *h*. The braces *k′* are
in gains and keyed up, no mortices or tenons being used
the structure. The derrick contains the bull wheel *bb*,
crown pulley *jj*, and crown pulley block *jj′*, for hoisting
lowering the drilling implements; also the walking beam *y*,
band wheel *m*, and the sand pump pulley *ii*.

The engine *b′* is bolted to the engine block *b*, which re
upon the cross sills *a′*, and is braced by the brace *c*. The stea
pipe *kk* connects the engine with the boiler. By means of th
driving pulley, which carries the belt *oo*, motion is commun
cated to the band wheel *m*, and through it to all parts of th
machinery. The throttle valve *ll* is operated by a groove
vertical pulley, from which an endless cord or wire *mm*, calle


ff
gg
ff
gg


1"x 8"
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gg
8"
1" x 10"
1" x 12"
ff
gg
8"

the telegraph, extends to the derrick and passes around a similar pulley *nn* fixed upon the headache post *s*, also called a "life preserver." As its name indicates, the headache post is designed to save the driller a headache, or perhaps his life, in case the wrist-pin should break or the pitman fly off of it while drilling, thus causing the derrick end of the walking beam to drop under the great weight of the suspended drilling tools, and endangering the safety of all within reach. This post is set upon the main sill immediately under the walking beam, so that if such an accident occurs the walking beam can fall but a few inches and do no harm. The pulley *nn* and that fixed upon the headache post being thus connected, the movement of one communicates a like motion to the other, and the driller by placing his hand upon the derrick-pulley can operate the throttle valve and start or stop the engine, and decrease or increase its speed at pleasure, without leaving his position. The reverse link *pp* is also operated from the derrick by the cord *qq*, which passes over two pulleys, one fixed in the engine house and the other in the derrick. The band wheel *m* receives its motion direct from the driving pulley of the engine, to which it is connected by the belt *oo*. On, or near, the end of its shaft *o*, is the bull-rope pulley *n*, and to its other end is fastened the arm or crank *o'*. In this arm a number of holes are drilled for the reception of the adjustable wrist-pin *p*, which thus may be easily moved from one hole to another to regulate the length of the stroke required in drilling or pumping.

As the band wheel communicates motion through the pitman *q* to the walking beam while drilling, to the bull wheels *bb*, by the bull rope *rr*, while running up the tools, and to the sand-pump reel by the friction pulley *w*, while sand-pumping, and as these movements are all used separately and at different times, it is necessary that the machinery be so constructed in its different parts that connection may be quickly made or broken, and one kind of motion substituted for another at pleasure.

The sand-pump reel *w* is put in motion by pressing on the lever *v*, which is joined by the connecting bar *u* to the upright lever *t*. This brings the face of the bevelled pulley *w* into contact with the face of the band wheel. It is simply a friction pulley, and can be thrown in or out of gear, no matter at what speed the band wheel may be revolving.

For a fuller illustration and explanation of the details of Figs. 1 to 3 (Plate II) we annex figures representing a complete set of irons belonging to a carpenter's rig.

Fig. 18.—Walking-beam stirrup.

FIG. 18.

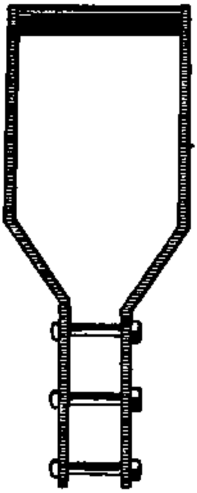


FIG. 19.

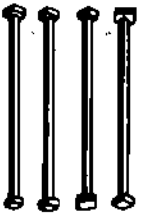


FIG. 20.

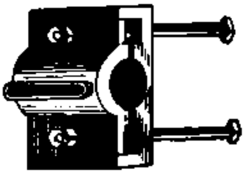


FIG. 20a.

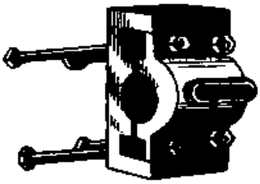


Fig. 19.—Bolts for securing this by a wooden cap to walking beam.

Fig. 20 and Fig. 20a.—Boxes for band wheel shaft.

Fig. 21.—Band-wheel shaft, arm and flanges.

Fig. 22.—Centre irons for walking beam and samson posts.

Fig. 23 and Fig. 23a.—Bolts for securing the saddle to walking-beam.

Fig. 24.—Derrick or crown pulley.

Fig. 25.—Walking-beam hook, to hold temper screw.

With the rig built, and the boiler and engine set up, the sinking of the bore hole or well proper can be commenced. In the early days a wooden box called a conductor (*i*, Fig. 1,

FIG. 21.

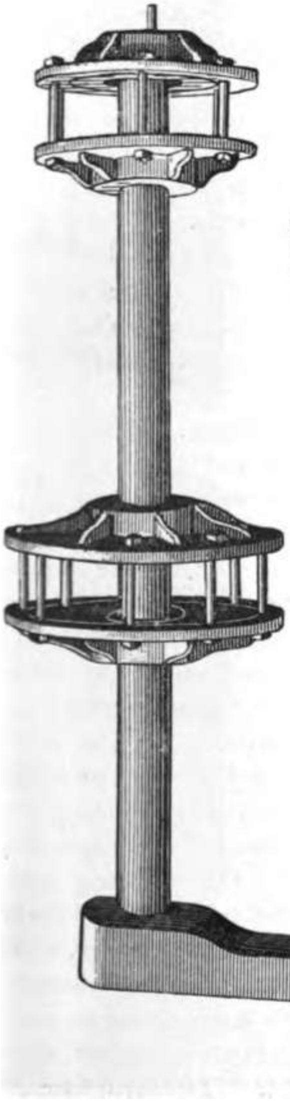


FIG. 22.

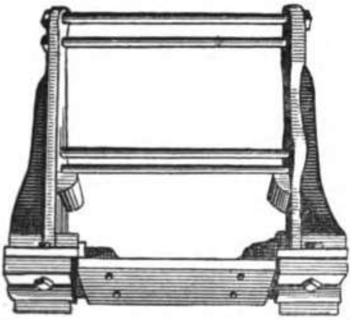


FIG. 23.

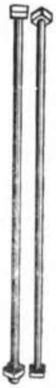


FIG. 23a.

FIG. 24.

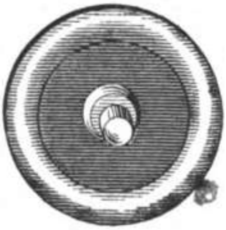


FIG. 25.

Plate II) was first put down to the bed rock, through the surface clay or gravel constituting the unconsolidated deposit of drift lying above the upper stratum of rock. Where it became necessary to go down several hundred, instead of several feet before the rock was reached, as is often the case in valleys, a pipe was driven down through the soft formation. This is the general practice now; the first section of a well from the surface of the ground to the first solid rock consisting of a driven pipe eight inches in diameter or larger. This is necessary to keep the earth from caving and choking the well, or the surface water from *seeping* into it and giving trouble. The drive pipe is put down in exactly the same way as piles are driven; the derrick serving as support for the pipe, and as a guide for the heavy maul as it goes down. This pipe has to be cleared out in the same manner as the bore that is afterwards carried down through the rock.

The hole through the rock is now begun. If the driven pipe is long enough, the work is started and carried on regularly; but frequently there is not room to start off with a full string of tools, as they require at least 60 feet before they can begin their work. In such cases the upper part of the bore has to be made by "spudding;" the auger or drill being suspended on a rope running up over the pulley at the top of the derrick, and raised and lowered by the skillful manipulation of the end of the rope in the hands of the driller, it having first been carried around the bull wheel, which is kept in motion by the engine. This is continued until the regular string of drilling tools can be used. There are four principal tools, properly so called, used in the process, viz., the centre bit, the auger stem, the jars and the sinker bar. In a well that is being drilled these tools hang in the order named, the centre bit being the lowest. This is a bar of iron, Fig. 26, a few feet long, with a sharp steel cutting edge on the lower end. To this is attached the auger stem, Fig. 27, which is simply a round bar of 4-inch iron from 28 to 40 feet in length. Then come the jars, which have already been described on p. 175. The fourth piece, to

FIG. 26.

FIG. 27.

FIG. 28.

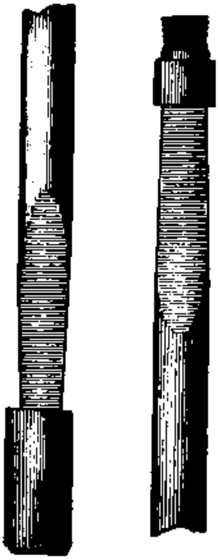
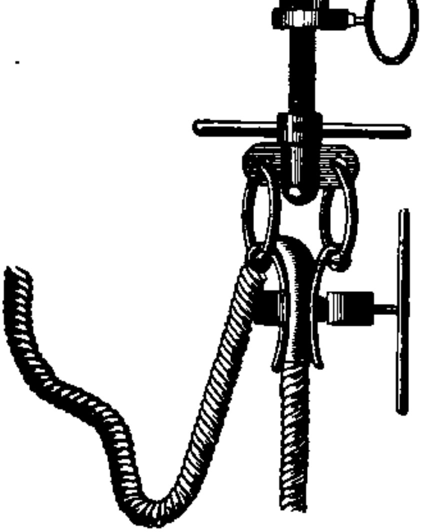


FIG. 29.

FIG. 29a.



which is attached a long cable reaching up to the surface, is the sinker bar, Fig. 28, resembling the auger stem, but only from 14 to 16 feet long, and used simply to give additional weight to the other tools.

The jars form very important parts of the drilling tools, they being the connection between the drill at the bottom and the cable above. Carll's explanation of the manner in which the jars perform their work will, perhaps, help to an understanding of their function:

"Suppose the tools have been just run to the botton of the well—the jars are closed—the cable is slack. The men now take hold of the bull wheels and draw up the slack until the sinker-bar rises, the play of the jars allowing it to come up thirteen inches without disturbing the auger-stem. They watch for the coming together of the cross-heads, which will be plainly indicated by a tremulous motion communicated to the cable and by the additional weight of the auger-stem. When the jars come together they slack back about four inches, and the cable is in position to be clamped in the temper-screw.

"If now the vertical movement of the walking beam be twenty-four inches, when it starts on the up stroke the sinker-bar first moves; it rises four inches, the cross-heads come together with a sharp blow, and the auger-stem is picked up and lifted twenty inches. On the down stroke the auger-stem falls twenty inches, while the sinker-bar goes down twenty-four inches to telescope the jars for the next blow coming up. This is the theory of the movement, but, of course, in practice the spring of the cable in deep wells and the weight of tools may make many modifications necessary."

The string of tools—the bit, the auger-stem and jars, with the sinker-bar—are more than sixty feet long and weigh very nearly a ton. The cable holding the string of tools runs up over the pulley at the top of the derrick down to the large wheel at its foot. Upon this wheel it can be coiled to draw the tools out of the well, whenever it is found necessary to sharpen or replace the bit, or clean the bore of the pulverized rock at the bottom. This cable is fastened at the end of the walking-beam already described. By the upward and downward swing of this walking-beam, amounting to two feet or more, the tools are lifted and dropped at the bottom of the hole. The connecting link between the walking-beam and the cable is the *temper-screw*, Fig. 29. It lowers the tools a little at every stroke. With the old fashioned temper-screw a great deal of time was spent in readjustment, for it had to be screwed up thread-by-thread by tedious revolutions of the clamps. But

FIG. 30.

FIG. 31.

FIG. 32.

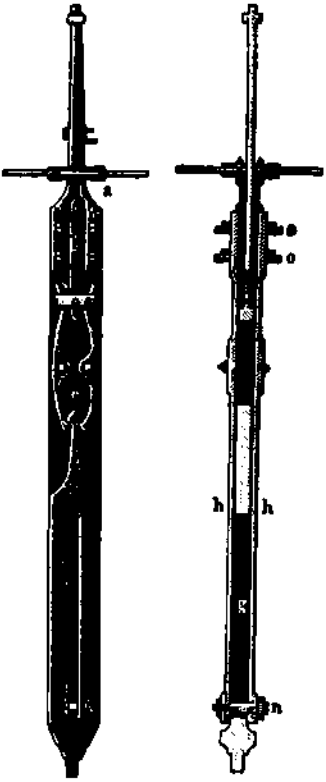


FIG. 30a.

this delay is now obviated. The nut through which the screw passes is cut in halves, one-half being attached to the left wing of the screw frame, the other half to the right wing. An elliptical band holding the set screw (Fig. 29a) passes around the nut. It is riveted securely to one of the halves, and the set screw presses against the other half to keep the nut closed. The wings are so adjusted that they spring outward and open the nut whenever the set-screw is loosened. To "run up" the screw the driller clasps the wings in his left hand and loosens the set-screw; he then seizes the head of the temper-screw in his right hand, and, relaxing his grip upon the wings, the nut opens, when he quickly shoves the screw up to its place, and again grips the wings and tightens the set-screw, the whole performance occupying less time than it has taken to describe it.

The *débris* resulting from the drilling operation is held in suspension at the bottom of the well, water being poured into the well for that purpose. When a considerable quantity of broken rock has accumulated, the tools are withdrawn, and a "sand pump" inserted which removes the liquid mud and sand from the well. The sand pump descends into the well by its own gravity, and to prevent it from attaining a too great speed, it is checked by pressing the lever *v*, Fig. 1 (Plate II), backward, so as to throw the friction pulley *w* against a post or curved piece of sheet iron set behind it in proper position to act as a brake when the wheel is pressed against it. The sand-pump line is coiled upon the shaft *x*, Fig. 1 (Plate II). It passes direct from the shaft over the pulley *ii*, and thence down inside the derrick to the well mouth, where it is secured to the bail of the sand pump.

Sometimes a tool called a *reamer* is inserted in place of the centre-bit, which reams out the hole and removes any irregularities. The tool is shown in Fig. 30, and a bottom view of the same in Fig. 30a.

The Canadian system of drilling differs from the American chiefly in that rods are used instead of a cable.

D. Free-fall Drill.

The most simple and successful free-fall drill is Fabian's, Fig. 31, as it can be used in all cases, it being suitable for bore-holes with the smallest as well as the largest diameter. However, Kind's boring instrument, Fig. 32, with self-acting free-fall tool, is older and historically of greater importance than Fabian's drill. Since the drill can be liberated by a peculiar self-acting contrivance, Kind's apparatus does good service in boring at great depths. The disk *a* is lifted by the resistance of the water in the bore-hole and the fangs *d* are pressed together by the ring *c*, allowing the tool to fall down free. The disk *a* is connected by means of the guides *b*, and the screws *oo*, with the ring *c* and the wedge *s*. In lifting the tool, the water presses from above against the disk *a*, thus preventing the opening of the fangs *d*. When the highest stroke is reached, i. e., the moment the bore-rod strikes the spring-pole, the water in going down presses below the disk, the forcible stroke and back-stroke of the spring-pole increasing the rapidity of the movement of the tool. At the same time the impact of the standing water against the disk *a* becomes more violent, whereby, at the commencement of the descent, the fangs *d* are opened, allowing the tool *g* to fall down free. Since during the further descent of the upper portion of the tool the water pressure from below continues, the fangs remain open. At the lowest stroke they catch the head *e*, and close immediately when the ascent begins, because the water pressure now acts from above. The guide-wedge *n* is carried in a slit. The broad guides *hh* are held together by the guide-wedge *n*. The wedge *s*, which is also connected with the rods *b*, is pressed during the ascent between the fangs thus preventing the premature release of the tool.

The rods for the suspension of the tool, and for the transmission of blows to it, were of oak; and this alone would constitute one of the most characteristic differences between the system of tools introduced by Kind and those made by the majority of well-borers. However, like the disengagement of the tool intended to comminute the rock, it depends for its success upon the bore-hole being filled with water. The presence of a column of water is, however, not always to be commended, especially when the borings have to be executed in the carboniferous strata.

E. Fauck's Boring System with Free-fall Drill.

The principal constituents of this system are as follows: The drilling chisels, Figs. 33 and 34, which are made of best cast steel in numbers of from 2.4 to 24.4 inches cutting width. The side edges are curved towards the centre of the bore-hole. The double keying, *b*, serves for connecting the drill with the upper

FIG. 33.

FIG. 34.

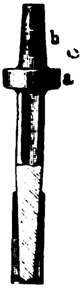
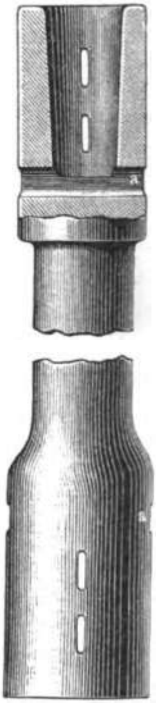


FIG. 35.



portion of the disengaging rod. The connection is rapidly broken by means of special wedges, which are driven in the holes, *a*, Fig. 35. The collar, *a*, Figs. 33 and 34, serves for conveniently taking hold of the drill in case of breakage. The boring rod, Fig. 35, serves to increase the weight of the drop-tool, thus giving greater effect to the stroke.

The reamer, Figs. 36, 37 and 38, is inserted between the boring rod and the drill when the tubing is to be carried below the drill-hole by enlarging the latter. The body is of wrought iron, and is provided above with a spindle, *a*, and below with a socket, *b*, for a double key joint. In the centre are two cutting jaws, *c*, of best crucible steel, which can be readily replaced by others of different dimensions. When introducing the tool in the bore-hole, the cutting jaws are tied together with wire (Fig. 37), which is carried over the edge of the drill. The latter on striking the bottom of the bore-hole cuts the wire, and the cutting jaws separate below the tubes. The contrivance for holding the cutting jaws lies protected in the interior of the apparatus, and will be understood from Fig. 38.

FIG. 36.

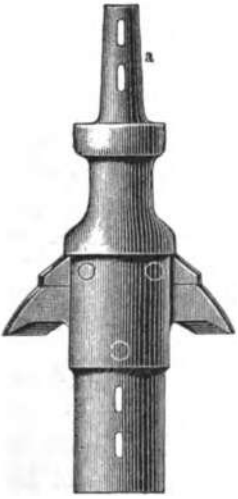


FIG. 37.

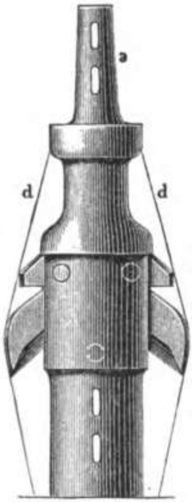
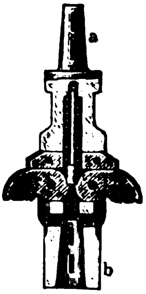


FIG. 38.



The free-fall tool consists of two parts, viz., the drop-tool and the socket. The so-called catch-wedge, *c*, Fig. 39, slides up and down in the two longitudinal slits of the socket. It connects the wrought-iron drop-tool, *a*, with the socket, *b*. The catch-wedge, *c*, Fig. 40, is held below by another wedge, c_1, which, in its turn, is secured by a conical pin, c_2. On the lower end the drop-tool is provided with a collar, *e*, and spindle, *f*, for joining it to the boring rod by means of a double key joint. The collar, *g*, serves for taking hold of the tool in case of breakage.

The wrought-iron socket is connected with the boring rod by means of a ferrule on the screw-bolt *h* and collar *i*. The slits *d* are enlarged to wedge-points *k*, the cushions of which are formed of inserted steel segments *l*, Fig. 41. Below the slits widen to the so-called safety-lock *m*, Fig. 39. When letting down the boring tools in the bore-hole, the catch-wedge rests in this safety lock, and in case the drill, on its way down, sticks fast, strikes the upper grooving, whereby the drop-tool is prevented from being caught on the wedge-cushion above, and from causing damage by suddenly dropping down.

F. Fauck's Self-acting Free-fall Drill.

The self-acting free-fall drill, Fig. 42, is arranged for diameters of from 11.81 to 19.37 inches, and for depths of over 1,000 feet. The apparatus consists of the chisel *a*, free-fall tool *e*, and frame *d*. Instead of one, the free-fall tool has two catch-wedges. The lower one, *f*, of these catch-wedges is immovable and intended for guidance and suspension in the safety-lock, while the upper one, *g*, the actual catch-wedge, turns in steel bands. The catching of the drop-tool is effected in the ordinary manner, and the self-acting detachment by the pressure of the lower oblique plane of the rail *h* against the catch-wedge. The upper continuation of the socket of the free-fall tool forms a longer rod *i* of square cross section. It is guided in the upper portion *d'* of the frame and takes the latter along when the boring rod is turned round. On top it is

FIG. 39.

FIG. 40.

FIG. 41.

FIG. 43.

FIG. 42.

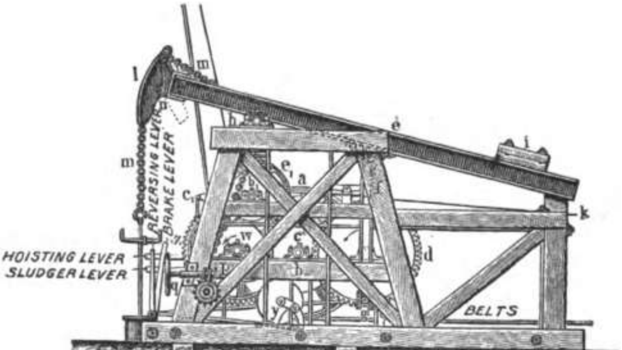
provided with the screw *k*, which serves for connecting it with the boring rods. The frame, which consists of four round iron rods *c* and the connecting pieces *d* and *d'*, is slightly raised during the descent of the instrument, the turning of the boring rod being also effected during this time.

The boring rods, Fig. 43, of square wrought iron, are each 16 feet 4 inches long, and are screwed together by conical male screws *a* and female screws *b*. The upper collar *c* below the male screw *a* serves for the lift-pulley, while the key catches under the lower collar *d*. A diameter of ¾ inch gives the rods sufficient solidity for attaining a considerable depth and spring, as well as for the transmission of the turning of the boring rod to the free-fall tool. For exceptionally great depths it is better to give the rods a diameter of about 1 inch.

The boring transmission, Figs. 44 and 45, is arranged in accordance with the following points:

1. Good spring of the beam as principal condition.

FIG. 44.



2. As high a stroke as possible, from 3 to 4½ feet.

3. High position of the stirrup of the beam for emptying the bore-shaft.

4. A beam stirrup which can be laid back without moving back the entire beam.

5. Such an arrangement of the parts, that all drilling operations can be effected one after the other by the driller from a convenient point.

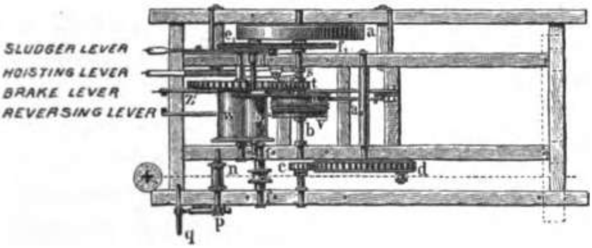
6. Use of a simple steam engine without reversing gear for all contrivances.

According to Fauck, these requirements may be fulfilled by the following arrangement:

The pulley *a* is set in motion by the steam engine and drives the principal shaft, upon which it is keyed, in the indicated direction. From this shaft the power for the different boring operations is obtained by pulling various levers.

When drilling is to commence the cog-wheel *c* is engaged by means of a lever with the wheel *d*. The latter serves also as a crank pulley, and at different distances from the axle has four holes so that the stroke of the boring beam can be changed at will from 3 to 1½ feet. The transmission to the beam *e*, Fig. 44, is effected by the iron connecting rod *f*. The point of application of the latter, however, is not rigid, but is formed by a bearing shiftable in a frame *g*. The beam consists of stout T-irons joined together, and no pushing back being required, is firmly fixed at *h*. A counterbalance *i* is placed on the rear part of the beam and can be shifted at will. By means of this counterbalance the boring tools are not only balanced but even forced upward, the effect being that the tail end of the beam strikes forcibly upon the spring-post, thus causing a rebound. The boring chain *m* (Fig. 44) running over the beam-head *l* is

FIG. 45.



secured to the drum *n* (Fig. 45), and during drilling is gradually slackened by means of a self-acting temper-screw consisting of the worm-wheel and worm *p*, and by turning the handwheel *q*. The beam-head has the form of the segment of a circle, the effect of this being that the boring chain always remains exactly in the centre of the bore-hole. If the chain is to be used for other operations, the bolt is taken out, the segment of a circle turned back, and the bolt again inserted.

To withdraw the drill, the socket *s* (Fig. 45) which sits loose upon the principal shaft *b*, upon which are keyed the cog-wheel *t* and the brake *n* provided with a friction cone, is pushed by means of a lever against the friction socket *v*, which is fast upon the axle, whereby the cable of the hoisting drum *w* is moved in the direction of the arrow.

To lower the drilling tools the reversing lever is pushed forward. The lever lifts the movable bearing (Fig. 44) of the short shaft *g* which carries the cog-wheel *t* engaged with the large cog-wheel *z* (Fig. 45), and the wheel *u*. The latter is pressed against the grooves of the friction socket *v* and the hoisting drum *w* is moved in the opposite direction of the arrow. The lowering of the drilling tools is effected with still greater rapidity than withdrawing them, and the tools can be stopped at any moment by the brake *a*, Fig. 45.

The movement of the cable of the sludger drum *b* is effected by pressing down the sludger lever, whereby the movable bearing *d* (Fig. 45) of the sludger drum, which is connected with the lever *c* (Fig. 44) is lowered, and the wheel *e* is pressed against the wheel *f* (Fig. 45), which sits upon the principal shaft. In lowering the sludger, and while it is in operation, the friction serves at the same time as a brake.

Figs. 46 and 47 show Fauck's self-acting free-fall jars with and without the use of water for rinsing. The boring rod *a* (Fig. 46) with the drill *b* is connected by means of a double key *a'* with the drop-tool *c* which is movable in the socket *d*. Guides serve the head of the frame *f* with screw *e* and frame *kk*, as well as the rails *gg* and the ring *i*. The key *c'* of the drop-tool can be turned in the bearing hh, which can be stopped by the pins $h'h'$. In descending, c' is turned by the portion d' of the slit d'', and in ascending c'' is caught by the slit d''' of the socket. In Fig. 47 the wing a encloses the boring tools and is connected with the rod c by b and b'. S is the bore-hole. The jar d is connected with the shaft l; it has two grooves for the reception of the slides ee, which are connected with the coupling-box g, and pass through the guide h. The spring o presses g and h together.

FIG. 46.

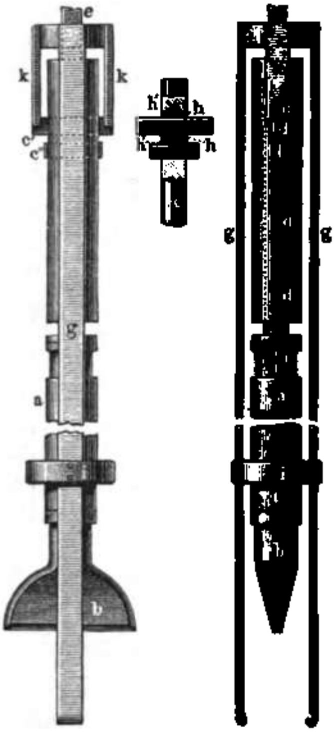
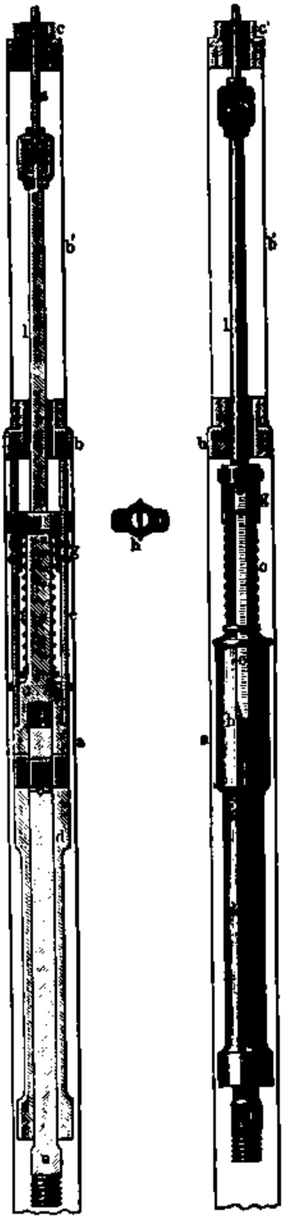


Fig. 47.



II. Auxiliary Tools.

Tubing of Bore-holes.

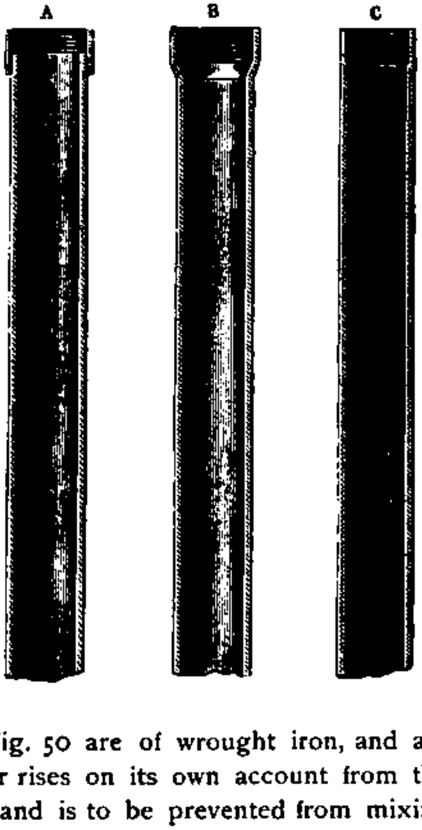
The tubes, Fig. 48, serve for the simplest kind of tubing. They are somewhat wider on the upper end than on the lower, so that one piece of tubing can be readily pushed into the other. The joints are then riveted.

The tubes with conical ends shown in Fig. 49 are of stout sheet iron, and may be recommended when the tubes are to be forced down with great pressure from above.

FIG. 48.

FIG. 49.

FIG. 50.



The tubes shown in Fig. 50 are of wrought iron, and are only used when the water rises on its own account from the bottom of the bore-hole, and is to be prevented from mixing with the upper water, as is frequently the case in drilling for oil. There are three kinds of these tubes. Fig. 50, A, is similar to ordinary gas-pipes, one end being sufficiently widened to serve as a socket-joint, Fig. 50, B. The tubing shown in Fig. 50, C, is contracted on one end so that it can be screwed into the next tube.

Sinking the Tubes.

This is effected as follows: A crib is constructed of wood, cast iron or wrought iron, which also serves for the first tubing of the bore-hole. When made of wood it is either round or hexagonal or octagonal; often a square box suffices. If made of cast or wrought iron, it is simply a stout pipe. A shaft about 18 feet deep is first dug, in which the crib, Fig. 51, is placed perpendicularly, if possible upon solid rock, so that it is exactly beneath the point of application of the beam. But, if in consequence of water-bearing strata, the condition of the soil is such as to render the digging of a shaft impossible, the crib, when a water-bearing stratum is reached, is placed in position and driven. If in the drilling operation, which now begins, the crib has not reached a more solid stratum, the first tubing is placed in position. For this purpose several lengths of tubing are riveted together and suspended in the bore-hole. The upper end is held by a pair of pipe-clamps projecting sufficiently above them to permit the convenient riveting of the next length of tubing. The pipe-hanger, by means of which the first section of tubing has been lowered into the bore-hole, is now removed and screwed on to the fresh length of tubing. The whole length of tubing is then raised a few inches whilst the clamps are removed from the lower part. When the tubing has been sufficiently lowered, the clamps are reapplied, and the operation of riveting another length of tubing is repeated.

While being lowered the tubing is turned, and this turning should be continued as long as the tubing will move before resorting to driving. Wrought iron tubes when driven must be handled carefully by means of a ring made of wrought iron

FIG. 51.

FIG. 54.

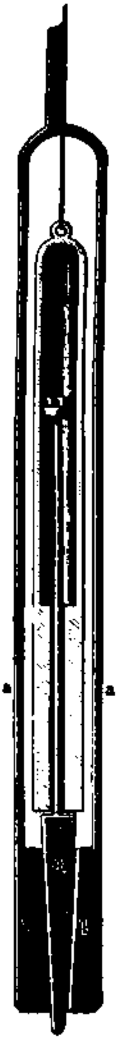


FIG. 52.

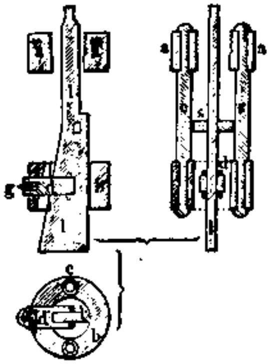


FIG. 53.

from 1½ to 2 inches in height and ¾ inch thick, or driven with a pipe-dolly. The ring or the dolly is screwed into the lowermost boring rod, and worked at the same rate and in a similar manner to the chisel, due regard being had to the depth at which the driving is being done, as the weight of the boring rods will materially affect the strength of the blow delivered. Cast-iron tubing may be driven hard with a monkey, or forced down by screw-jacks or hydraulic pressure.

If after the boring operation is finished the tubing is to be recovered, it will be necessary to have recourse to cutting in case the lower end of the tubing sits so fast that it is impossible to remove the whole without tearing. For this purpose various tools have been constructed, but only the simplest and most suitable shall here be described.

The stout annular pieces *a* and *b*, Fig. 52, are connected by the bolts *c*, *c*; *d* shifts into a corresponding opening of the annular piece *b* by the raising of the key *l*, whereby the cutting wheel *g* is pressed against the wall of the tubing. The pin *s* carries the key *l*. The upper annular piece *a* is provided inside with a gas pipe thread for 2-inch tubing, but the key *l* with a thread for correspondingly slighter rods. In cutting, the rods are screwed in with a female screw, the tubing being turned at the same time until cut through.

The withdrawal of the tubing is best effected by wedging a riveting clamp in the upper end of the tubing and lifting the latter by it. If the tubing sticks fast the lower portion is first cut off and lifting is then continued. If still unsuccessful, stout boring rods are brought into requisition. The lower end of the rods is provided with a screw with left-handed thread. A wooden cylinder, Fig. 53, wider in the centre, is stuck upon the lower round end of the rods, and the latter screwed in the female screw *s* inserted in the wood. If now the wooden cylinder reaches a certain point in the tubing, the rods are fastened and coarse sand and gravel poured into the tubing. On raising the rods the conical cylinder is firmly squeezed against the tubing, and in this manner the latter is withdrawn without damage.

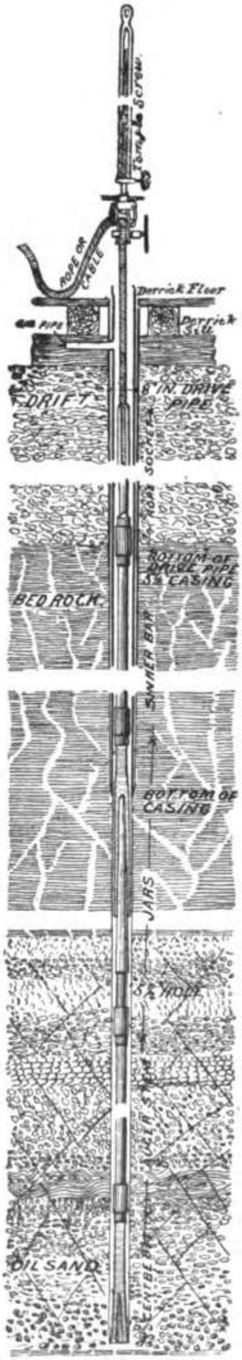
In case the tubing does not stick too fast, its withdrawal may also be effected by means of the instrument shown in Fig. 54. The two legs *a a* are connected below with the hooks *b b*, and above with the boring rods. The wedge *d* is provided on the upper end with jars which can be brought into activity by means of the sludger cable. The legs are of sufficient length for the jars to find room between them. After inserting the instrument in the tubing to be raised the wedge is keyed by means of a wedge and the jars.

In the United States lining tubes are cut out as follows: An expanding cutter-head, in which the circular cutter-heads are first tightened, is lowered into the bore-hole and then put into action by turning the boring rods at the surface.

Among the auxiliary tools may also be mentioned the instruments used to withdraw broken or defective tools. They are of all kinds and devices, from the delicate grap designed to pick up a small piece of valve leather, or a broken sucker-rod rivet from the pump chamber, to the ponderous string of pole tools containing tons of iron, which, at a depth of 1,500 feet or more, can unscrew a set of stuck tools, and bring them up piece by piece, or cut a thread upon the broken end of a sinker bar, or an auger stem, so that it can be screwed fast to and loosened by the use of "whiskey jacks" at the surface.

In conclusion we furnish to our readers a diagram, Fig. 55, of the drilling operation, which exhibits also the different strata through which the drill passes. These may be classified under three general heads: 1. What may be termed the surface drift, composed of alluvial soil, beds of gravel, sand of loose texture. This division may have a depth of only a few feet in some places; in others, in the valleys, it may be two or three hundred feet thick. 2. The water-bearing rocks, at the bottom of which, where the drill has reached this point, a "seed-bag" packing is placed to prevent the inflow of water into the well. 3. The rocky strata in which little or no water is found. These comprise one thousand or fifteen hundred feet of the whole depth of the well. A well was dug at Titusville through

FIG. 55.


Temper Screw
ROPE OR CABLE
Derrick Floor
GAS PIPE
Derrick Sill
DRIFT
8" IN. DRIVE PIPE
ROPE SOCKET
BOTTOM OF DRIVE PIPE 5⅝ CASING
BED ROCK
SINKER BAR
BOTTOM OF CASING
JARS
5⅝ HOLE
AUGER STEM
CENTRE BIT
OIL SAND

3300 feet of rock, where water had to be poured in at the top to moisten the drilling and allow of the working of the sand pump.

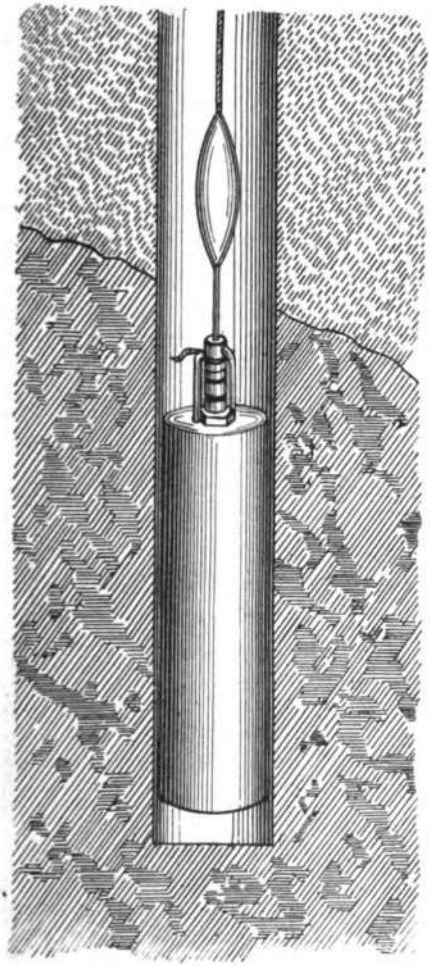
Use of Torpedoes.

In 1862, Colonel E. A. L. Roberts conceived the idea of exploding torpedoes in oil wells, for the purpose of increasing the production. Having applied for a patent, in the fall of 1864 he constructed six torpedoes, and early in 1865 he visited Titusville to try his first experiment. The risk of damaging the wells prevented their owners from allowing the tests to be made, but Colonel Roberts finally persuaded Captain Mills to allow him to operate on the Ladies' well, on the Watson flats, near Titusville. The explosion of two torpedoes caused this well to flow oil and paraffine. This result produced great excitement and led to the filing of several applications for patents and as many law suits for infringement, which were all finally decided in favor of Roberts. The complete success of the torpedo was not established, however, until December, 1866, when Colonel Roberts exploded one in the Woodin well, on the Blood farm. This well was a "dry hole," and had never produced any oil. The result of the operation was to secure the production of twenty barrels a day, and in the following month a second torpedo was tried, which brought up the production to eighty barrels. These results established beyond a doubt the usefulness of the invention, and immediately a demand for it sprang up throughout the oil region. The mode of operation in adding to the yield of oil is probably to be explained by the complete disintegration of the oil-bearing strata in the vicinity reached by the terribly explosive force of the nitroglycerine employed, by which the petroleum is set free from the thousand small cavities in which it has been confined. According to Prof. S. F. Peckham's opinion, the crushing effect of the explosion of a torpedo in such rock as the Bradford oil sand is comparatively limited. He says: "The generation of such an enormous volume of gas in a limited area, the walls of which are already under a very high gas pressure, and which is held down by a motionless column of air of 2000 feet (the use of water tamping has been abandoned) must be followed by an expansion into the porous rock that drives both oil and gas before it until a point of maximum tension is reached. The resistance then becomes greatest within the rock, and reaction taking place, oil and gas are driven out of the rock and out of the well, until the expansive forces originally generated by the explosion are expended. By this reaction the pores of the rock are completly cleared of obstructions, and the pressure of the gas within the oil rock continues to force the oil to the surface until it is no longer sufficient for the purpose."

The value of torpedoes in individual cases is unquestioned, but as a whole their value to the oil interest is doubtful, as shown by numerous cases, the yield of one well being frequently increased at the expense of another. The use of torpedoes is at best a destructive method which yields rapid results, but often accompanied by great losses. In close sand torpedoes are of very little use; such at least being the opinion of those whose long experience well qualifies them to judge.

The explosion of the torpedoes is effected either by percussion or electricity. The usual method of employing them in the Pennsylvania oil regions is thus described: "When a well is ready to be 'shot,' word is sent to the Torpedo Company, and the canisters are prepared in sections of about 10 feet in length and five inches in diameter. These sections are made conical at the bottom, so that they will rest securely on top of each other. The nitroglycerine is carried in cans, that are placed in padded compartments, in a light spring wagon, which is often driven over the roughest mountain roads with great recklessness. Arrived at the well, one of the sections is suspended by a cord that passes over a pulley and is wound upon a reel. The nitroglycerine is poured into the canister, until it is filled, and then it is lowered by the cord to the bottom of the well. Another section is filled and lowered in like manner, until the proper amount is put in place. A charge of 100 lbs. of nitroglycerine will do the work of a ton of gunpowder. A cap is adjusted to the top of the last section, and upon it a

FIG. 56.



weight is dropped down through the well after the cord lowering the nitrogylycerine has been withdrawn. A few seconds after the explosion a fountain of oil, water, mud and pebbles shoots up through the well mouth to the top of the derrick and above it, saturating it with oil, and scattering a shower of broken stones in every direction."

Fig. 56 represents the torpedo in position.

Generally speaking, the cost of drilling wells can never be determined with perfect accuracy. The expenses vary not only with the system used, but the geological formation, the question of wages, etc., have also to be taken into consideration. Much of the work is done by contract, and the contractors are, of course, reticent about disclosing the actual expense. Carll, in his report for 1880, gives detailed figures, which he says were furnished him by a large producer in the Bradford field, as representing the cost of a well drilled in December, 1878:

Carpenter's rig complete	$350 00
Belt, bull rope, engine, "telegraph," steam pipes and fittings to connect boiler and engine	100 00
Boiler (20-horse power), engine (15-horse power), on ground	750 00
Contract for drilling, contractor to furnish fuel, tools, cable, sand pump, line, etc., at 65 cents per foot, say 1500 feet	975 00
Casing, say 300 feet, at 80 cents per foot	240 00
Tubing, say 1600 feet, at 20 cents per foot	320 00
Torpedo (almost universally used before tubing)	100 00
Packer	25 00
Working barrel	8 00
Casing head	3 00
Tees and elbows to make tank connections	5 00
One twenty-five barrel tank	25 00
One two hundred and fifty barrel tank	110 00
Tank house	25 00
Expense of tubing and packing well	20 00
Expense for hauling, tubing materials, etc., etc., say	50 00
Total cost of well, flowing	$3,106 00

In the above well no "drive pipe" was used, a short wooden conductor, set by the rig builder, being all that was required. In localities where from 100 feet to 280 feet of drive pipe casing, costing $1.80 per foot, is required, the cost of a well is increased accordingly.

If the well is to be pumped, the following items are to be added:

Fifteen hundred feet of sucker rods, at 5½ cents per foot	$82 50
Valves for working barrel	7 00
Polished rod	2 50
Stuffing box	1 50
Adjuster	5 00
Tees, elbows, etc., say	2 00
	$100 50

The necessary tools and implements for handling the tubing and sucker rods are:

Large pulley block	$11 00
Tubing elevators	9 00
Three pairs of tubing tongs	10 00
Tubing cable	25 00
Sucker rod rope	11 00
Sucker rod wrenches and elevators	3 00
	$69 00

For the United States Census of 1880, and again for that of 1890, careful statistics were laboriously collected at considerable expense on this and other features of the petroleum industry. For the census of 1890 the records were made for 1889. The cost would seem to have been for rigs about $300 per week; labor drilling about $500; boiler and engine about $500; pulleys, ropes, etc., about $75; casing and tubing about $400; a total amount of about of $1,775.

Collection of Crude Oil.

After the commencement of the drilling operation, the construction of collecting reservoirs in the immediate neighborhood of the derrick should be immediately proceeded with. Until lately, this was but seldom done in the Caucasus. Even at the present time, in many places, the bore-holes are surrounded by earthen walls for the collection of the free-flowing oil, and the soil is penetrated by ditches, in which the naphtha collects and then runs into a pit. When the oil cannot be pumped with sufficient rapidity into reservoirs, a naphtha lake is formed. Such naphtha lakes formerly served, instead of reservoirs, for storing the oil, the latter being carried in barrels upon camels or two-wheeled carts to the refineries.

In recent years, immense reservoirs, with a capacity of over 88,000 cwt., have been erected, especially in the Balakhani region, and are filled directly by means of pumps from the naphtha lakes or from the wells. These cylindrical reservoirs of sheet iron riveted together are placed without foundation upon the ground, and are provided with a flat, conical roof of sheet iron. The naphtha remains in the reservoirs for some time for the deposit of mud, sand and water, and is then conducted by means of pipe lines to the refineries.

In the United States the oil is pumped from the mouth of the well into tanks; the latter are either of wood with a capacity of about from 250 to 600 barrels, or of iron with a capacity of about 2,500 barrels.

In Galicia the crude oil is brought directly from the pits to the refineries by means of wagons. However, in recent years larger reservoirs have also been erected in the neighborhood of the wells from which the crude oil is transported by wagons or railroad to the refineries. The most recent boring enterprises in Western Galicia are in this respect provided with all modern improvements, they being furnished even with small pipe lines for conveying the oil to the nearest railway station.

In Germany the crude oil is conducted into smaller reservoirs in the immediate neighborhood of the wells, and after settling conveyed to the refineries, which, as a rule, are located but a short distance from the wells.

Transport of Crude Oil.

Facility of transport is one of the most important factors in the development of the mineral oil industry, and it may be said that the price of the oil and the prosperity of the industry are almost solely dependent on it. This is very clearly shown by the oil regions of Galicia, Roumania, and partially also of Germany. These countries possess large natural stores of crude oil, but the means of transportation are difficult and insufficient, so that they cannot find a suitable home market for their products, which are of good quality, and cannot prevent the importations of foreign producers provided with better means of transportation.

The Americans were the first to understand that the markets of the world could be conquered only by the proper solution of the problem of transportation. They created astonishing and standard contrivances in this direction by which they have obtained their object, so that up to the present time their products have encountered but slight competition.

Primitive methods. In Burmah the crude oil is placed in glass jars and transported in them about the country. The breakage of the jars and muck occasioned by the leakage is mentioned as one of the disagreeable adjuncts of the production in the neighborhood of Rangoon.[1]

In this country the Seneca oil of early days was transported in barrels or packed in bottles. During the first years of the excitement in the oil regions oil was transported in 40 and 42 gallon barrels, made of oak and hooped with iron. To prevent the oil from penetrating the wood the inside of the barrels is coated as follows: The barrels are first thoroughly washed, usually with a jet of steam, dried and heated. Hot glue is then put in and distributed over the whole surface. Then by a tube a pressure of about 20 lbs. per square inch is applied through the bung, and the glue is forced into the pores of the wood. Great difficulty has always been experienced in the transportation of crude oil in barrels, due to the fact that such oil invariably contains a trace of water, usually as much as 1 per cent., which, acting on the glue, causes the barrel to leak, and consequently a loss of oil. To remedy the difficulty and also to decrease the labor of handling the oil, early in 1866, or possibly in the latter part of 1865, tank-cars were introduced upon railroads entering the oil regions. Those first introduced consisted of an ordinary flat car, upon which were placed two wooden

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[1] Report on Petroleum, by S. F. Peckham.

tanks shaped like tubs, each holding about 2,000 gallons, or 4,000 gallons to a car.

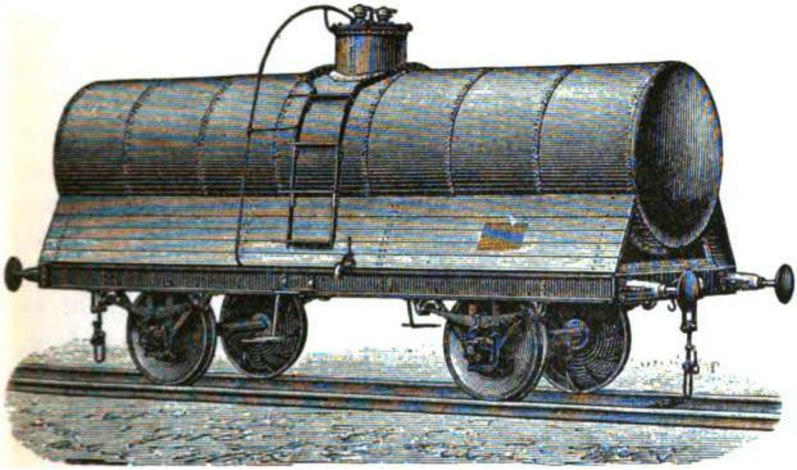
In the meanwhile transportation by water had assumed large proportions, quite too large for the volume of water usually flowing in Oil Creek, and the novel expedient of "pond freshets" was resorted to, to which allusion is made in the following terms in Henry's "Early and Later History of Petroleum."

"Arrangements were made with the mill owners at the head of Oil Creek for the use of their surplus water at stated intervals. The boats were towed up the creek by horses, not by a tow-path, but through the stream, to the various points of loading, and when laden they were floated off on a pond freshet. As many as 40,000 barrels were brought out of the creek on one of these freshets, but the average was between 15,000 and 20,000. At Oil City the oil was transferred to larger boats. At one time over 1,000 boats, 30 steamers, and about 4,000 men were engaged in this traffic. At times great loss occurred from collisions and jams. During the freshet of May, 1864, a jam occurred in Oil City, resulting in the loss of from 20,000 to 30,000 barrels."

In many places in India the transportation of oil is effected by means of camels, each camel carrying on its back two iron tanks filled with oil.

Tank cars. In 1871, the wooden tanks placed on ordinary flat cars began to disappear, their place being supplied by the boiler iron cylinder car of the present time. They are now used in transporting crude, illuminating and lubricating oils and other petroleum products, also residuum and spent acid. Fig. 57 shows the form of tank-car now in general use. The heads are made of $\frac{5}{16}$ inch flange iron, the bottom of $\frac{1}{4}$ inch, and the top of $\frac{3}{16}$ inch tank iron, and they weigh about 4,500 lbs. The tanks are about 24 feet 6 inches long and 66 inches in diameter, and hold from 4,500 to 5,000 gallons each. They are provided with an expansion dome and a man-hole, the latter being used for filling the tank. During the transport the man-hole is closed with an iron cover which is screwed to a flange on the tank. In the United States about 10,000 of such tank-cars are in use, while Russia has about 4000, about 2000 of which belong to the Nobel Brothers. The Russian cars traverse three regions, from which they go further into foreign countries.

FIG. 57.



1. The crude oil districts (Balakhani, Sabuntschi, etc.,) from which, besides in pipe lines, the crude oil is transported in tank-cars either to the refineries (Baku, Tschormy Gorodok, etc.,) or—what is done to a still greater extent—to the harbor of Batoum, where the crude oil is partially distilled and brought into storage tanks to be finally shipped in tank vessels to European, especially Austrian, harbors.

2. The second region for tank-cars embraces the transport of refined oil from Baku to Batoum. This line is used most because it supplies the great foreign commerce by means of tank vessels. At the present time 7000 cars per month are at an average transported from Baku to Batoum. In August, 1889, the number of cars was 6613. and in September of the same year, 6935.

3. The oil station of greatest importance next to Baku and

Batoum is the city of Zarizyn on the Volga. The oil is brought to the city in tank-vessels and stored in immense reservoirs, to be finally shipped in tank-cars through the entire Russian Empire, but especially to Moscow, Petersburg, Riga and Warsaw, where the oil is again pumped into reservoirs and finally transported to Austria-Hungary, Germany, and other foreign countries.

Tank vessels. Like the pipe lines, which will be described later on, tank-vessels have caused a revolution in transporting petroleum. The high freight which was formerly demanded for shipping oil in barrels or tin canisters by steamships, sailing vessels, etc., has been reduced to the minimum by the introduction of tank vessels. If we further take into consideration the saving in barrels, the price of which is increasing daily, and the avoidance of leakage, which, in shipping oil in barrels, frequently amounted to 10 per cent., and finally the saving of time in filling and emptying the barrels, the great advantage of tank-vessels will be readily understood.

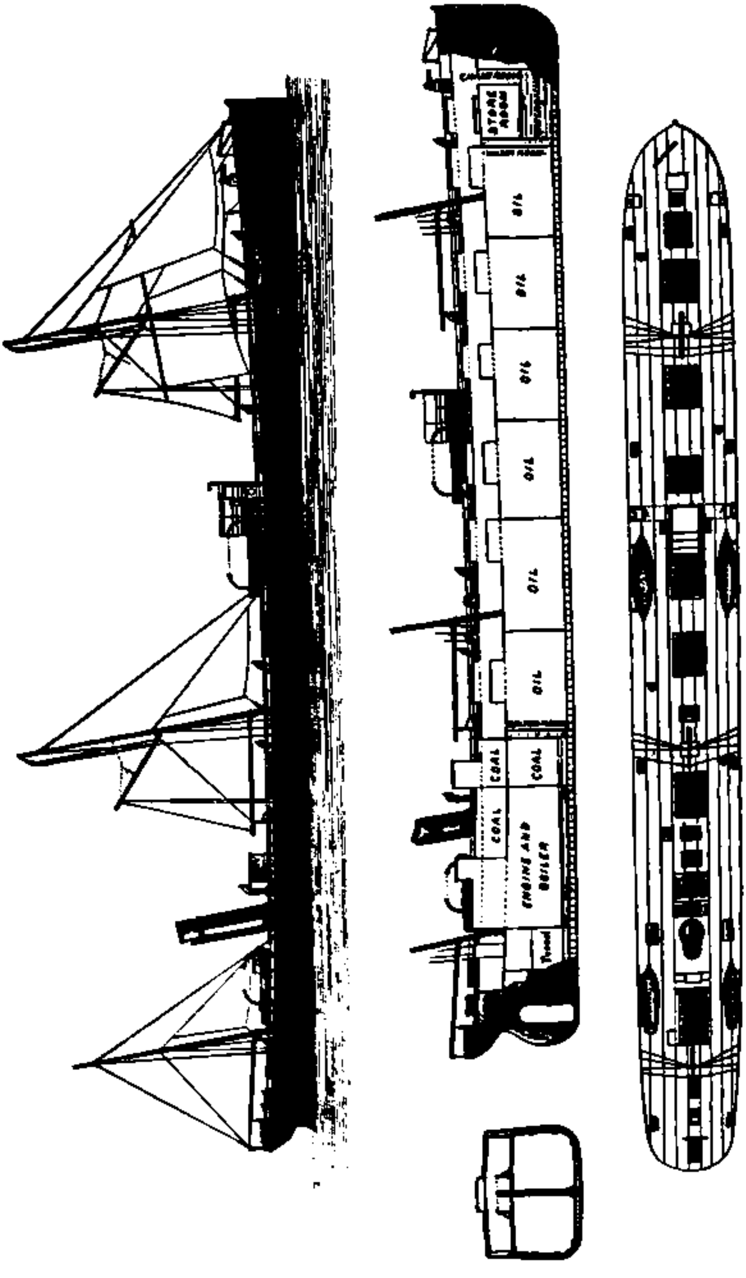
In 1871, the Astrachan merchants, Artemjeff, Ragosin and Schipoff commenced the transportation of crude oil and residuum in tank-vessels. They used for the purpose ordinary wooden vessels (barks), the oil being brought into the hold. The water enveloping the exterior of the vessel prevented the oil from penetrating the wood to any serious extent, the hold being not filled deeper with oil than the water line. The deck was loaded with oil in barrels or in iron tanks. A large number of these sailing vessels were soon engaged in the petroleum carrying trade on the Caspian Sea and Volga. But, of course, they were not sufficiently safe, because, notwithstanding the envelopment of water, the oil penetrated the planks of the vessel, thereby causing considerable losses, and even conflagrations. When Nobel, in 1871, laid the first pipe line in Russia, he also endeavored to improve this primitive method of tank-transportation. He first erected in the sailing vessels and barks which carried the oil across the Caspian Sea to Astrachan, and to Zarizyn on the Volga, cisterns similar to those used in steamers for storing drinking water, except that they occupied the entire hold of the vessel. The oil was pumped into these cisterns. In the same year he ordered in Sweden the tank steamer "Zoroaster." When delivered this steamer did not answer all requirements, but it was so improved by Nobel as to allow of its being used for the transportation of oil. Nobel was also the first who, to prevent the oil from penetrating into the boiler and engine rooms, and from becoming heated, separated the hold from the engine room by a partition filled with water the latter being constantly renewed. In case of leakage the oil can only reach the water, and, being specifically lighter, rises to the top. At the uppermost point apertures are provided through which the oil runs off.

Figure 58 shows the dimensions and construction of a modern tank steamer as built in English ship-yards. A clear and comprehensive description of one of the more recently built steamers, the "Charlois," is found in *The Marine Transport of Petroleum*, by George Herbert Little, an English naval architect.

"This vessel is 310 feet long, 39 feet beam, and 25 feet 3 inches deep, and is capable of carrying upwards of 3500 tons of petroleum, besides bunker coal, on a moderate draft.

"The requisite subdivision into eight tanks of moderate size is obtained by the introduction of nine thwart-ship bulkheads, which are very heavily stiffened and made extra thick to withstand the pressure due to any one tank being full, while the others are empty. In addition to these there is a longitudinal bulkhead running the entire length of the oil compartments in the centre of the ship, which further subdivides each tank into two. Wells or water spaces are formed at each end of the oil compartments, which are filled with water when the vessel is loaded with oil, and thereby isolate the oil from the rest of the ship and boiler-room, to prevent risk of fire. Each tank is provided with a smaller tank above, running up through the 'tween-decks to the upper deck, which is fitted to allow for the expansion and contraction of the oil, due to the difference in temperature, without permitting the oil to ever fall below

FIG. 58.


STORE ROOM
OIL
OIL
OIL
OIL
OIL
OIL
COAL
COAL
COAL
ENGINE AND BOILER
Tunnel

the level of the top of the tank proper, which is essential to the vessel's stability at sea. It is usual to carry these expansion tanks about half full of oil. The expansion tanks also serve the purpose of giving access to the tanks, proper man-holes and Jacob's ladders being provided. A special feature in this vessel, which the designers had particularly in view, is the fact that she could, with very slight alterations, be used for ordinary cargoes; the expansion tanks being arranged conveniently, and of extra size, for this purpose. This is, we think, an important point. The machinery and boilers are placed close aft, and clear of the oil compartments, and the saloon and officers' and engineers' cabins and gallery are abaft this, and therefore well clear of the tanks. The crew are berthed in the forecastle, and there is a long bridge amidships, with a shade or awning deck, connecting it to the poop. The shade deck was especially introduced by the designers to make the vessel more seaworthy, as she is employed in the Atlantic trade, and this considerably reduces the amount of exposed deck. The internal fittings of this vessel are most complete, and, as a further precaution against fire, she is lighted throughout by electric light on the incandescent principle, the engines and dynamos being placed in the engine room directly under the control of the engineers. There are also steam heaters for all the cabins and the crew. Two powerful pumps are fitted in the 'tween-decks with very complete piping arrangements, each pump being capable of discharging the entire cargo of oil in 30 hours. There is no double bottom for water ballast, but tanks are provided on both ends for trimming purposes. For ballasting the ship when light, two or more of the oil tanks are run up with water, special means being provided for this purpose; and when so laden the vessel is much steadier at sea than if carrying ballast in the ordinary double bottom; and as these vessels have to make one out of every two trips across the Atlantic light ship, this is very important."

Experience has suggested some minor improvements since the "Charlois" was built. The vessels of later construction have a somewhat greater carrying capacity. The expansion tanks are not so large, but extend the whole length of the oil tanks they are designed to relieve. The strength of the hull has been still further increased by the addition of another deck or horizontal partition running through the oil tanks, dividing each into an upper and lower tank. This iron partition, with its braces, adds materially to the stability of the ship both when empty and full.

An American firm has recently undertaken the construction of tank-vessels according to MacDugall's patent, and which are claimed to form the future basis of a new tank transport of petroleum. However, thus far the matter has not progressed beyond the experimental stage. The vessels are designed to be towed. They are cigar-shaped, with a deck resembling a whale-back.

In 1892, 59 tank-steamers were engaged in carrying petroleum from the United States, 27 of which took their cargoes from Philadelphia.

The appended table, from the Annual Report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania. Part III, Industrial Statistics, 1892, gives the names of the tank steamers that were engaged in carrying petroleum from the United States in 1892. There were fifty-nine in all. Those that carried cargoes from Philadelphia are designated by a star. The table shows the tonnage of each ship, her capacity to carry bulk oil, her length, breadth of beam and depth, and the flag under which she sails. A second table gives similar information in regard to the bulk sailing vessels that took cargoes, in 1892, from the United States.

LIST OF STEAMERS CARRYING PETROLEUM IN BULK FROM THE UNITED STATES TO FOREIGN COUNTRIES DURING THE YEAR 1892.

Name of Steamer.	Oil Carrying Capacity.		Registered Tonnage.		Dimensions of Steamer. (English feet).			Flag carried.
	In gallons.	In tons.	Gross.	Net.	Length.	Beam.	Depth.	
* Allegheny	1,200,000	3,480	2,914	1,910	320	42	26	British.
American	1,540,000	4,450	3,897	2,927	345	44	27	Dutch.
* Apcheron	650,000	1,800	1,864	1,441	271	37	22	Belgian.
* Aral	1,260,000	3,655	2,826	2,160	310	40	28	British.
* Astrakhan	1,500,000	4,350	3,438	2,236	330	42	28	do.
* Astral	960,000	2,800	2,249	1,465	281	38	25	do.
* Bayonne	1,400,000	4,060	3,294	2,150	330	42	28	do.
* Beacon Light	1,260,000	3,665	2,763	2,107	311	40	28	do.
* Bear Creek	1,100,000	3,195	2,411	1,573	294	37	26	do.
* Bremerhaven	1,350,000	3,920	3,393	2,179	339	42	26	do.
* Brilliant	1,435,000	4,165	3,162	2,411	319	42	29	German.
* Broadmayne	1,100,000	3,195	3,095	1,995	334	44	24	British.
Burgerm. Petersen	1,275,000	3,700	2,794	2,090	310	40	28	German.
* Cadagua	1,020,000	2,960	2,304	1,858	305	39	26	Spanish.
* Caucase	720,000	2,090	1,643	1,321	250	35	24	Belgian.
Charlois	1,200,000	3,480	3,002	1,978	310	41	27	British.
* Chester	1,175,000	3,410	2,834	1,872	311	39	25	do.
* Christine	850,000	2,465	2,293	1,642	280	37	25	Danish.
* Circassian Prince	980,000	2,845	2,243	1,486	272	38	26	British.
Darial	1,200,000	3,480	2,767	1,814	310	40	28	do.
Diamant	1,500,000	4,350	3,525	2,270	330	43	31	German.
* Elbrus	1,230,000	3,570	2,715	2,101	310	40	28	British.
* Elise Marie	1,425,000	4,135	3,194	2,424	318	41	22	German.
* Energie	1,225,000	3,555	2,765	2,074	310	40	28	do.
* Geestemunde	1,255,000	3,640	2,750	2,101	310	40	28	do.
* Glückauf	1,025,000	2,975	2,597	1,881	300	37	30	do.
Gut Heil	1,200,000	3,480	2,737	2,096	310	40	28	do.
* Hafis	800,000	2,320	2,123	1,621	270	36	21	do.
* Helgoland	1,100,000	3,195	2,397	1,563	294	37	26	do.
* Kasbeck	1,210,000	3,510	2,707	2,099	310	40	28	British.
* La Campine	1,100,000	3,195	2,542	2,007	310	39	26	Dutch.
* La Flandre	900,000	2,610	1,979	1,509	270	37	25	do.
La Hesbaye	1,155,000	3,350	2,701	1,948	300	39	29	do.
* L'Oriflamme	1,120,000	3,250	....	....	343	42	28	British.
* Lucerna	1,500,000	4,350	3,342	2,072	330	42	28	do.
* Lumen	1,100,000	3,195	2,357	1,554	294	37	26	do.
* Manhattan	1,400,000	4,060	3,300	2,153	330	42	21	do.
Mannheim	1,500,000	4,350	3,507	2,257	330	43	29	German.
* Mineral	500,000	1,450	1,304	849	249	30	23	British.
* Minister Maybach.	1,175,000	3,410	2,486	1,955	285	40	24	German.
* Ocean	1,170,000	3,400	2,835	1,872	310	39	25	British.
* Orange Prince	845,000	2,450	1,808	1,214	260	36	25	do.
* Oural	950,000	2,755	2,421	1,634	270	39	21	Belgian.
* Paula	1,190,000	3,455	2,675	2,160	285	40	30	German.
* Petriana	600,000	1,750	1,672	1,086	260	34	21	British.
* Petrolea	950,000	2,750	2,331	1,596	292	37	25	do.
* Phosphor	880,000	2,555	2,023	1,326	270	37	25	do.
* Prudentia	1,185,000	3,440	2,730	1,791	312	40	27	do.
* Robt. Dickinson	790,000	2,295	1,978	1,297	278	35	22	do.
* Rocklight	1,285,000	3,730	3,225	2,119	312	40	29	do.
* Russian Prince	1,200,000	3,480	2,716	2,107	310	40	28	do.
* Sophie	625,000	1,815	1,362	1,114	235	33	23	German.
* Standard	1,200,000	3,655	2,765	2,110	310	40	28	do.
* Tankerville	950,000	2,750	2,336	1,541	292	37	25	British.
* Vindobala	675,000	1,960	1,744	1,134	261	34	21	do.
* Ville de Douai	720,000	2,090	1,872	1,406	265	37	23	French.
* Weehawken	1,260,000	3,655	2,784	2,101	310	40	28	British.
* Wild Flower	1,020,000	2,960	2,650	1,745	300	40	18	do.
* Wilkommen	1,270,000	3,685	2,891	2,297	315	41	24	German.

* Took cargo from Philadelphia during 1892.

LIST OF SAILING VESSELS CARRYING PETROLEUM IN BULK FROM THE UNITED STATES TO FOREIGN COUNTRIES DURING THE YEAR 1892.

Name of Vessel.	Oil Carrying Capacity.		Registered Tonnage.		Dimensions of Vessel. (English feet).			Flag carried.
	In gallons.	In tons.	Gross.	Net.	Length.	Beam.	Depth.	
* [illegible]	[illegible]	[illegible]	....	[illegible]	154	33	19	Norwegian.
Hainaut	[illegible]	[illegible]	....	[illegible]	249	40	22	Belgian.
* [illegible]	[illegible]	[illegible]	....	[illegible]	190	38	22	Norwegian.
* [illegible]	[illegible]	[illegible]	....	[illegible]	201	36	23	do.
* [illegible]	[illegible]	[illegible]	....	[illegible]	249	40	23	do.
* Ville de Dieppe	[illegible]	[illegible]	....	[illegible]	217	36	21	French.

* Took cargo from Philadelphia during 1892.

Batoum is at present the principal harbor for the export of Russian petroleum, the tank steamers for foreign ports receiving here their cargoes of crude and refined oil. For storing the oil there are at Batoum 70 enormous iron tanks capable of holding 7,000,000 pud. The yearly export of naphtha amounts to 30,000,000 pud, which is almost exclusively shipped in tank-vessels. In 1889, 26 tank-steamers took their cargoes from Batoum. These steamers, or at least 25 of them, with a total capacity of 175,000,000 gallons, were especially built for the Russian trade.

The accompanying table (p. 217) of importations of refined oil at the principal harbors of England and the continent of Europe for 1888 and 1889, has been compiled by Messrs. Henry Funk & Co., of London. It shows the extraordinary growth of tank transportation by sea.

In consequence of this great development of tank transportation, storage tanks of considerable size have been erected in the various harbors. The table on p. 217 gives all the present tankages in England.

Statistics

Showing the Progressive Importations of Russian and American Refined Oil in Tanks.

IMPORTATION OF RUSSIAN AND AMERICAN REFINED OIL IN BARRELS AND TANKS, 1889 AND 1888:

A. English Harbors.

	1889.						
	American	Refined Oil.	Russian	American	Refined Oil.		Russian
	In barrels.	In tanks.	In tanks.	In barrels.	In tanks.	In barrels.	In tanks.
London	390,870	167,902	446,743	533,063	3,500	5,675	346,875
Liverpool and Barrow	250,966	113,289	227,733	280,349	....	6,633	160,495
Bristol, Cardiff, Gloucester and Sharpen	138,307	....	58,715	178,672	....	7,058	
Newcastle and Shields	30,788	14,489	....	19,365	....	....	12,790
Belfast	9,612	....	38,036	21,990	....	2,500	
	820,543	295,682	771,227	1,033,439	3,500	21,866	520,160

B. Continental Harbors.

	In barrels.	In tanks.	In tanks.	In barrels.	In tanks.	In barrels.	In tanks.
Hamburg	445,503	810,205	45,974	863,667	347,883	....	38,798
Bremen	37,204	1,109,317	24,038	187,506	614,966	....	38,295
Antwerp	240,490	559,372	233,158	677,582	68,909	8,264	178,136
Rotterdam	151,590	515,638	....	329,742	142,563		
	874,787	2,994,532	303,170	2,058,497	1,174,321	8,264	255,229

Petroleum Tankages.

London.

Wharfs.	Capacity in Barrels.	Proprietors.
Atlantic Wharf	27,000	At present leased.
Dudgeor's Wharf	40,000	London Oil Storage Co., Limited.
Manhattan Wharf	10,000	London Oil Storage Co., Limited.
At Purfleet	100,000	Anglo-American Oil Co., Limited.
" "	90,000	Tank Storage ond Carriage Co., Limited.
Rowath's Wharf	20,000	Davy and Goulden.
Thames Haven Wharf.	25,000	London and Thames Haven Petrol. Wharf.
	313,000	

Liverpool.

At Birkenhead	22,250	Liverpool Storage Co., Limited.
“ “	55,000	Anglo-American Oil Co., Limited.
“ “	52,000	Northwest Petrol. and Gen. Storage Co., Limited.
At Liverpool	107,250	Mersey Dock and Harbor Board.
	236,500	

Barrow (Distributing Depot of the Liverpool Market).

At Barrow in Furness .	50,000	Furness Railway Co.
“ “	50,000	Kerosene Co., Limited.
	100,000	

Bristol.

At Avonmouth	40,000	Bristol, South Wales and West of England Petrol. and Storage Association, Limited.
At Avonmouth	50,000	Anglo-American Oil Co., Limited.
	90,000	

Cardiff.

At Roath	20,000	K. Johnston.

Shields.

At Shields	6,000	Anglo-American Oil Co., Limited, Newcastle-on-Tyne.
At Shields	25,000	Crickson's Oil Co., Limited, Newcastle-on Tyne.
	31,000	

Hull.

At Hull	50,000	Anglo-American Co., Limited.

Belfast.

At Belfast	20,000	Bessler, Wachter and Co., London.
Total	859,500	

Pipe lines.[1] The magnitude of the petroleum interest made it necessary to find some mode of transportation even cheaper than a railroad. By force of circumstances, barges and tank cars for oil in bulk displaced the truck carrying oil in barrels. The pipe line in turn displaced the car and boat. The introduction of this mode of transporting oil is characteristic of the American spirit of enterprise and marks an era in the petroleum industry. The first suggestion of a pipe line for transporting oil was, as far as known, made to C. L. Wheeler by General S. D. Karns, of Parkersburg, West Virginia, in November, 1860.[2] Mr. Karns said that as soon as he could raise the money, he would lay a 6-inch gas-pipe from Burning Springs to Parkersburg and let the oil gravitate to the Ohio river, a distance of 36 miles.

For some reason this line was never laid. Some years later, the exact date is not known, a Mr. Hutchison, inventor of the rotary pump which bears his name, conceived the idea of forcing oil through pipes, and explained his plan to John Dalzell. Subsequently Hutchison's plans became a reality, the first pipe-line being laid from the Sherman well to the terminus of the railroad at Miller farm, a distance of about three miles. The inventor's idea of the hydraulic pressure of a column of that length was certainly very exalted, and he took elaborate pains to prevent the breaking of pipes. At intervals of fifty or one hundred feet were air chambers like those on pumps, ten inches in diameter, for the purpose of equalizing the pressure. These queer protuberances gave the line the appearance of a fence with ornamental posts, and excited great curiosity. The weak point, however, was the jointing, which, as the pipes were of cast-iron and imperfectly finished at their ends, was very defective, and the leakage from this cause was so great that little, if any, oil ever reached the end of the line. It was a success

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[1] For much of the matter regarding pipe lines comprised in the following pages we are indebted to the "Annual Report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania. Part III. Industrial Statistics." 1892.

[2] F. S. Peckham. Report on Petroleum.

theoretically, but a mechanical failure. Thus the expectations for easy and cheap transportation for crude oil raised by the building of the first pipe-line were ruthlessly dashed to the ground, and the inventor discontinued his experiments in despair.

In 1862, we believe, a bill was introduced in the Pennsylvania State Legislature to authorize the construction of a pipe-line from Oil Creek to Kittanning; but, owing to the vigorous opposition of those interested in teaming oil, it was not passed. Later a plan to lay a line down the Allegheny river to Pittsburgh, for the same reason, came to nothing.

Samuel Van Syckle, of Titusville, was the first to put down a working line. It was only four miles long, extending from Pithole to Miller's farm, and carried but eighty barrels per day. It demonstrated, however, the thorough practicability of moving oil in this way. The difficulty up to this time had been in making the joints of the pipe tight. Van Syckle overcame this; and, although his line faced an ascent of nearly five hundred feet, the oil was delivered at the farther end practically without loss. This line, together with another laid in the same year by Henry Harley, from Benninghoff to Shafer farm, passed into the control of a corporation known as the Allegheny Transportation Company, by which it was operated.

The owners and drivers of oil wagons saw that this mode of transportation must soon deprive them of occupation, and they did what they could to retard the progress of the work. They cut the lines, set fire to the tanks with which they were connected, and even threatened the proprietors and managers with personal violence. An armed patrol and the arrest of the ringleaders soon quelled this outbreak. The pipeage of oil was a great general improvement, and personal interest had to yield. To-day the oil region is a net-work of pipes; and great trunk lines, pulsing with the moving oil, supply the needs of New York, Philadelphia, Baltimore, Cleveland, Buffalo, Pittsburg, Chicago, and of many intermediate points.

The growth, however, was gradual. Lines were first laid only to the refineries in the oil region, and to railroads taking the oil out of the region. With the lengthening of the pipes and the increase of pressure to force the liquid to greater distances, men became more and more impressed with the possibilities of the new mode of transportation, and enthusiastic ones began to believe there was no point short of the seaboard to which the oil might not be sent. In 1875, an organization called the Pennsylvania Transportation Company was granted a charter, with power to construct a pipe-line to the seaboard. The only outcome of this venture was the building of various lines within the oil region. Short lines multiplied, and pipe after pipe from the producing fields to the refineries and railroad shipping points crossed and paralleled one another in every direction. Competing companies waged war upon one another, cutting rates to the point of doing business at an actual loss. When the producer had run his oil into the storage tanks of some of these concerns, he was not certain whether the certificate received (for they all issued certificates instead of paying cash for oil) had any value; yet he must either send the oil through the pipe nearest to him, or allow it to pass back into the earth from which it came. The concentration of these badly-managed competitive companies into some centralized organization with systematic and economical methods was a necessary consequence of the situation.

The United Pipe Lines' Association, first known as the Fairview Pipe Line, organized by Captain J. J. Vandergriff and George V. Forman, became the starting point for such a movement. This association was incorporated under the general act of April 29, 1874. Into it were merged from time to time the other local lines; the Antwerp, Oil City, Clarion, Union, Conduit, Karns, Grant, Pennsylvania, Relief, the Clarion and McKean divisions of the American Transfer Company, the Prentiss lines, the Olean pipe, the Union Oil Company's line at Clarendon, the McCalmont line, with others too numerous to mention.

The first trunk line was laid in 1875 from the lower oil country to Pittsburg. It consisted of 39 miles of four-inch pipe running from Carbon Centre in Butler county to Brilliant, a suburb of Pittsburg. The trunk line to Cleveland next followed, consisting of a six-inch line from Bear Creek to Hilliards, the first pumping station, and from there a five-inch line to Cleveland. The total length is about 111 miles. The trunk line to Philadelphia starts at Colegrove in McKean county, and extends about 235 miles to Philadelphia, six-inch pipe all the way. From Millway, the last pumping station before reaching Philadelphia, a five-inch branch runs down to Baltimore, a distance of about 66 miles. The Buffalo line is about 56 miles long, having its initial point at Olean, N. Y. It is four-inch pipe. The New York line consists of two six-inch pipes starting at Olean, N. Y., and running parallel to each other through the southern counties of New York State, to Saddle River, N. J., where the lines separate; one going down to the refineries at Bayonne, N. J., and the other going under the North and East rivers to the refineries at Hunter's Point; on Long Island. In addition to the two parallel six-inch lines, the New York line is looped at many of the stations; that is, extra lines are put in to relieve the pressure on the other lines and so increase somewhat their capacity: thus making the total length of pipe used 762 miles, the distance traversed by the line being 313 miles.

The Tide-Water line of six-inch pipe, extends from Rixford in McKean county to the refinery of the Tide Water Oil Company, Limited, at Bayonne, N. J., a distance of 284 miles.

The Southern Trunk line starts from Morgantown, W. Va., and extends to Philadelphia; a distance of 274 miles. This line is composed of six-inch and eight-inch pipe, the total length of pipe being about 364 miles.

We give below a table showing the actual length of each trunk line. In addition to this there are many other large lines connecting the various systems and different oil fields.

For example: Between Kane and Bear creek, a distance of 63 miles, there are five six-inch lines; from Kane to Colegrove, there are 22 miles of eight-inch pipe; from Colegrove to Olean, 30 miles of eight-inch pipe. The total pipe, including these large connecting lines and the double lines and loops, amounts to 3,000 miles.

Pittsburg Line, four-inch pipe.		*Miles.*
Bear Creek to Pittsburg		55
Buffalo Line, four-inch pipe.		
Olean to Buffalo		56.25
Cleveland Line, five-inch pipe.	*Miles.*	
Bear Creek to Simpson	29.81	
Simpson to Warren	30.23	
Warren to Mantua	22.16	
Mantua to Cleveland	28.59	
		110.79
Philadelphia Line, six-inch pipe.	*Miles.*	
Colegrove to Hunt's Run	23.41	
Hunt's Run to North Point	25.90	
North Point to Pine	25.73	
Pine to Latshaw	45.40	
Latshaw to Millway	51.94	
Millway to Philadelphia	62.50	
		234.88
Baltimore Line, five-inch pipe.		
Millway to Baltimore		65.80
New York Line, six-inch pipe.	*Miles.*	
Olean to Wellsville	28.54	
Wellsville to Cameron Mills	27.91	
Cameron Mills to West Junction	29.74	
West Junction to Catatonk	27.37	
Catatonk to Osborne Hollow	27.99	
Osborne Hollow to Hancock	29.86	
Hancock to Cochecton	26.22	
Cochecton to Swartwout	28.94	
Swartwout to Newfoundland	29.00	
Newfoundland to Saddle River	28.77	
Saddle River to Bayonne, N. J.	16.29	
Saddle River to Hunter's Point, N. Y	12.26	
Total (with loopings)		762.01

Tide Water Line, six-inch pipe.	*Miles.*	
Rixford to Olmstead	28.7	
Olmstead to County Line	36.0	
County Line to Muncy	53.5	
Muncy to Shuman	33.9	
Shuman to Hudsondale	27.65	
Hudsondale to Changewater	52.5	
Changewater to Bayonne, N. J	51.5	
Total		283.75

Southern Line, eight-inch and six-inch pipe.	*Miles.*	
Morgantown to Watson	33.88	
Watson to State Line	35.82	
State Line to Knepper	66.67	
Knepper to Millway	75.42	
Millway to Philadelphia	62.50	
Total (with loopings)		364.29

Crescent Pipe Line (*Mellon Line*), five-inch pipe.		*Miles.*	
Greggs to Milbank	about	48	
Milbank to Ingleside	"	24	
Ingleside to Saxton	"	30	
Saxton to Mount Holly	"	55	
Mount Holly to Florinal	"	40	
Florinal to Linwood	"	60	
Total			267

United States Pipe Line (*Emery Line*), double line, four-inch and five-inch pipe.		*Miles.*	
Titusville to Tarport	about	65	
Tarport to Westfield	"	60	
Westfield to Athens	"	55	
Total (two lines)			360

The trunk lines carrying Pennsylvania crude are nearly 3,000 miles in length; but this does not include the net-work of two-inch pipes that fairly cover the producing country, and serve as feeders for the trunk lines. A representative of the Standard Oil Company appearing before a committee of the State Legislature, in February, 1891, testified that the total length of lines transporting Pennsylvania crude was undoubtedly 25,000 miles; or, as one of the senators put it, "a girdle for the earth."

The lines are usually laid under ground[1] with bends, at intervals, to allow for expansion and contraction. The pipe for these trunk lines is made especially for them. It is wrought iron, lap welded, and comes in lengths of 18 feet. On each end coarse and sharp taper threads are cut, nine to the inch, and the lengths are connected with long sleeve couplings, also screwed taper. The pipe is tested to stand a pressure of 2,000 pounds to the square inch, made necessary by the tremendous pressure carried on some of the pumps. This is sometimes as high as 1,500 pounds. It can be appreciated by remembering that, in addition to overcoming the friction of the oil on the line, which increases enormously as the rapidity of the flow is increased, the large body of liquid is made to move with great speed. It was found that the friction on the 108 miles of six-inch pipe between Rixford and Williamsport, Pa., was equal to a column of oil 700 feet high—that is, had this line had a gradual descent amounting to 700 feet, the adhesion between the oil and pipe would have prevented any flow, with the pipe full of oil for the 108 miles.

At each station there are two or more storage tanks, of from 30,000 to 50,000 barrels capacity, the oil being received from the station next before into one of the tanks, while the pump is emptying another. In this way the movement of oil through the trunk lines is made incessant. Most of the stations are also provided with duplicate pumping machinery, so that there need be no interruption of the flow of oil even when one pump has to be stopped for repairs. The distance between stations averages 28 to 30 miles, but loops are sometimes laid around a station, so that one pump has moved oil as far as 110 miles.

Where the New York trunk line passes under the Hudson river it is double—that is, one pipe is placed inside of another with tight fitting sleeve-joints. The jacket pipe has its ends

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[1] Opinions are divided as to whether the pipes last longer lying free or underground. In Baku they lie free.

separated by a space of 12 inches to permit the enclosed pipe to be screwed home. The sleeve is then pushed over the 12-inch gap, and the whole space between the pipes is filled with lead poured in melted. The line is held in place on the bottom of the river by two sets of heavy chains parallel with the pipe and about twenty-five feet from it, one on each side. Every 300 feet a guide chain connects the pipe with these lateral chains, and beyond each one of these connections an anchor, weighing over a ton, keeps the whole in place. The line crossing the salt marshes approaching the river is laid in a rectangular wooden box, filled with hydraulic cement to withstand corrosion.

The pumping stations are located at central points in the valleys. These stations consist of permanent buildings, a boiler house and a pump house, which contain the necessary steam power, and a steam and oil pump combined in one. The pumps employed for this service are magnificent machines. Most of them have been built by the Worthington Company. Fig. 59 shows a pumping station of the "Transit Oil Company" with the Worthington system. The Worthington pumps have been described by the *Engineering News* and the *Scientific American* somewhat as follows:

"Each pump has four steam cylinders—two high and two low pressure—steam jacketed, each set working tandem, direct acting. Each pair of cylinders actuates two single-stroke rams of the exterior packed type. The engineer thus has the only possible source of plunger leakage always before him. The steam, going from the high to the low pressure cylinder, passes through a receiver, where it is heated. The valve boxes are subdivided into small chambers, with leather-lined metallic valves with low lift and large surfaces. The general dimensions are:

Diameter of low pressure steam cylinder	66″
Diameter of high pressure steam cylinder	33″
Diameter of plungers	9¼″
Stroke	37¾″

Horse power, 440.

Average duty, 105,000,000 foot pounds per 100 pounds of coal.

Rated capacity, 1,500,000 gallons against a pressure equal to 2,000 feet head of water."

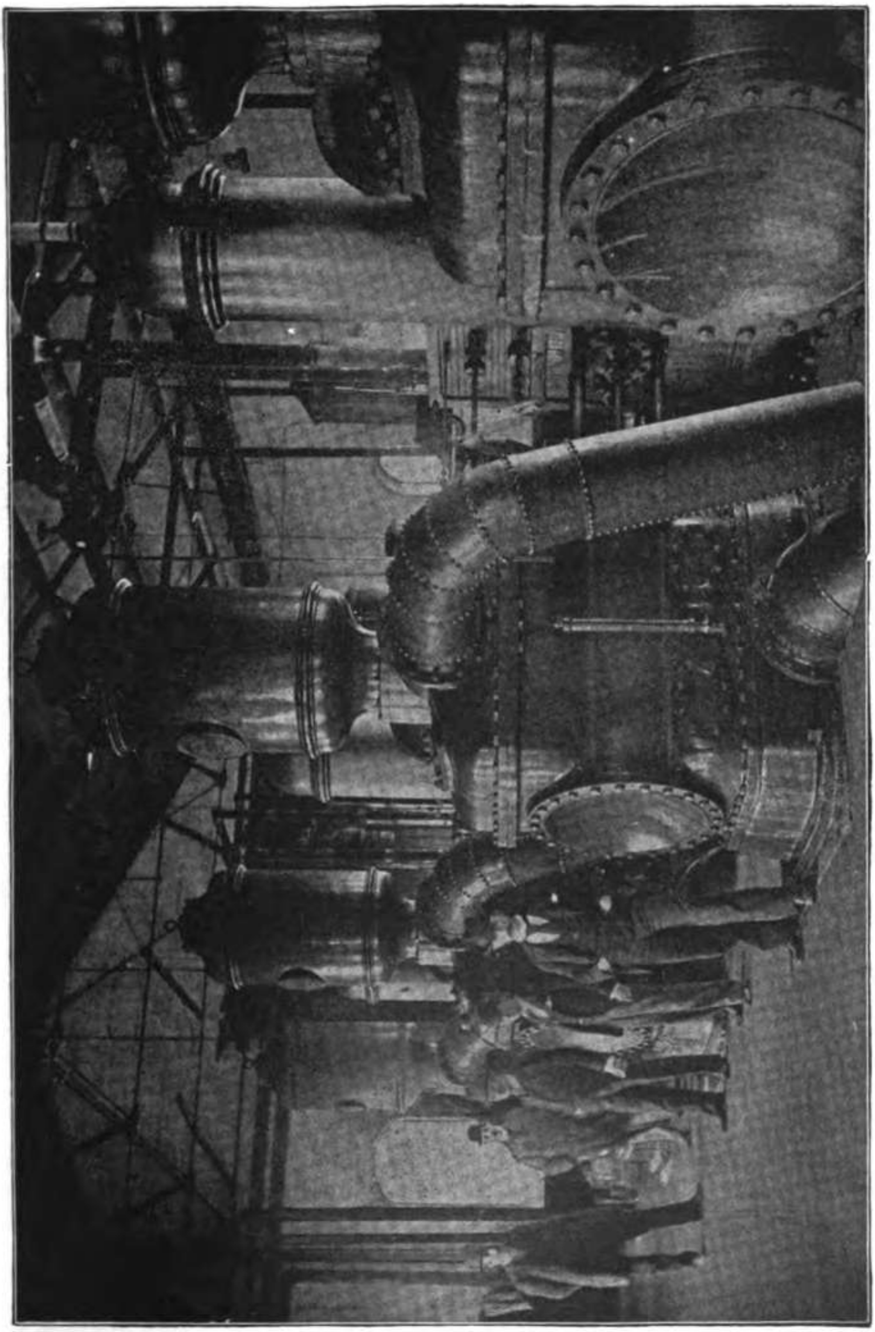

FIG. 59.

The disproportion of diameter between the steam pistons and pump plungers shows the nature of the service the pumps are designed to perform. To maintain an even pressure on the line, a pair of compensating cylinders and plungers at the outer end of the rams take the place of the usual air chamber or fly wheel. These are two vertical cylinders, each mounted on trunnions near its centre. "A heavy pressure is maintained by the accumulator and fluid on the rear of the plungers, tending to thrust them out. As the rams of the main pump move outward from the centre position the compensating cylinders swing on their trunnions and take increasingly oblique positions as the pump gets nearer the end of its stroke. The compensating rams are forced out during this period and re-enforce the action of the steam, whose pressure is getting lower owing to expansion. On the return stroke the compensating rams are pushed back against the accumulator pressure, their cylinders swinging back to the perpendicular position. In this period, therefore, the action of the steam at a high pressure in the steam cylinder is resisted by the rams. As the stroke returns from the center in the other direction the compensating rams act as in the other half stroke. By thus opposing the action of the unexpanded and resisting the action of the expanded steam, an almost even action is preserved at all periods of the stroke, and a nearly constant pressure is exerted on the liquid pumped." By this means the column of oil is kept continually in motion without any violent concussion on the line, as is generally the case with a direct-acting pump. During the last few years the National Transit Company have been building their own pumps, constructing for trunk line service enormous triple expansion crank and fly-wheel engines, which are superseding other makes of pumps on their lines. At each station there is generally one of these high-duty engines and a low-duty one for relief or emergency service. Most of the pumping is done by the machine just described, the other being employed when the main pump is being repaired or adjusted.

A station equipped with a high-service pump has also seven or eight horizontal tubular boilers, 80 to 100 horse power each. Six of the boilers are fired at once. They are placed in a boiler-house 40 feet square, built of brick and covered with a corrugated iron roof. The pumps are in a separate brick building, being separated for greater safety from fire. The stations are lighted by electricity, as the pump never stops moving the oil forward every day and night in the year. The stations are connected with one another and with the main offices of the pipe lines by independent telegraph wires. When a producer's tank is measured and accepted by a gauger and the oil passed into the pipe line, a report is telegraphed to the central station of that section of the field. A complete record of the capacity of each tank in the field is here kept, by which the feet and inches of the oil indicated by the despatch are at once converted into barrels and placed to the credit of the producer on the books of the pipe line. By this means, at the end of each day, an accurate return can be made of the oil received; which, checked by an equally accurate report of the oil delivered, enables the pipe line to know their stocks at all times.

At each station there are two or more receiving or storage tanks built of light boiler iron; the usual size being about 90 feet in diameter, and 30 feet high. These tanks have conical roofs of wood covered with No. 20 iron. Each tank holds about 30,000 barrels of oil. A general idea of the plan of construction of storage tanks can be learned from the following specifications under which the tanks of many of the pipe lines are built:

SPECIFICATIONS OF STORAGE TANKS.

Capacity (Barrels of 42 Gallons Each) About	1,000.	2,000.	3,000.	4,000.	5,000.	10,000.	15,000.	20,000.	25,000.	30,000.	35,000.
Diameter of tank, in feet	30	30	30	35	43	54	66	78	86	86	92
Height of tank, in feet	8	16	24	24	20	25	25	25	25	30	30
Number of rings in shell	2	4	5	5	4	6	6	6	6	7	7
Thickness of first ring (Birmingham gauge)	No. 7	No. 5	No. 3	No. 3	No. 3	No. 3	No. 3	No. 2	No. 1	No. 0	No. 00
Thickness of second ring	No. 8	No. 6	No. 4	No. 4	No. 4	No. 3	No. 3	No. 3	No. 2	No. 1	No. 0
Thickness of third ring	....	No. 7	No. 5	No. 5	No. 5	No. 4	No. 4	No. 4	No. 3	No. 2	No. 1
Thickness of fourth ring	....	No. 8	No. 6	No. 6	No. 6	No. 5	No. 5	No. 5	No. 4	No. 3	No. 2
Thickness of fifth ring	....	....	No. 7	No. 7	....	No. 6	No. 6	No. 6	No. 5	No. 4	No. 3
Thickness of sixth ring	....	....	....	....	....	No. 7	No. 7	No. 7	No. 6	No. 5	No. 4
Thickness of seventh ring	....	....	....	....	....	....	....	....	....	No. 6	No. 6
Thickness of bottom plates	No. 7	No. 7	No. 7	No. 7	No. 7	No. 7	No. 6	No. 6	No. 6	No. 6	No. 6
Thickness of sketch plates	No. 7	No. 7	No. 7	No. 7	No. 7	No. 7	No. 6	No. 6	No. 6	No. 6	No. 5
Size of bottom angle iron, in inches	2½×2½×5/16	2½×2½×5/16	2½×2½×5/16	2½×2½×⅜	2½×2½×⅜	2½×2½×⅜	3×3×⅜	3×3×⅜	3×3×⅜	4×4×½	4×4×½
Size of top angle iron, in inches	2×2×5/16	2×2×¼	2×2×5/16	2×2×¼	2×2×¼	2×2×¼	2×2×5/16	2×2×¼	2×2×¼	2×2×¼	2×2×5/16
Thickness of sheets for light nailed roof	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20	No. 20
Thickness of sheets for tight riveted roof	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12	No. 12

Cleaning Pipe Lines.

All crude petroleum contains more or less amorphous or uncrystalized paraffine or wax. Water mixed with crude oil forms an emulsion or soapy deposit. The paraffine is known in the oil region as "sucker-rod wax," because it collects on the rods used for pumping wells. The emulsion is locally known as "B. S." These two sediments, together with the impurities naturally incident to the mining of petroleum and its transfer from point to point, gradually choke the pipe lines, particularly in colder weather. To clean them, a curious instrument called a "go-devil" is sent through the pipe. These scrapers or brushes have at different times been of various designs, the one now used being the improved instrument that experience has shown is best suited to the work. It is a spindle with a ball and socket joint near its center so that it can follow the bends in the pipe. This spindle is fitted with steel blades set radially. It is kept in position in the pipe by three arms both in front and rear, with a guide-wheel on the end of each arm. Oblique vanes put in motion by the moving oil rotate the spindle, and the steel blades scrape the pipe. At the rear end of the "go-devil" a piston that approximately fits the pipe, gives the instrument a forward motion, being impelled by the oil pumped through the line. Until within a few years, it was customary for men to follow the scraper in its trip, knowing where it was by the whirring noise it made; any obstacle being located by the stopping of the "go-devil." This is no longer thought necessary. A catch-box is placed at the other end of the line, and the time of the trip is so well known that the arrival of the little traveler can be quite closely timed. But the lines are regularly patrolled to promptly detect any leaks, although the system of checking from tank to tank makes it impossible for any serious break to occur without detection.

Loading Racks.

The racks are used for loading oil from pipe lines into tank cars, and are so arranged that any number of cars from one to an entire train can be loaded at the same time. They are constructed after the following general plan: The main oil line runs alongside the railroad track, and perpendicular branches are carried up at intervals, equal to the length of a tank car. A platform of a convenient height is erected, and each particular branch-pipe is provided with a stop-cock and an elbow above it. To this elbow is attached an adjustable pipe long enough to reach the man-hole of the tank car as it stands upon the track. To load a train, it is run upon the track in front of the "rack;" the man-hole plates are all removed, the adjustable pipes placed in position to discharge the oil into the tanks, and the oil turned on. In this way as many cars as the rack will hold, perhaps 20, holding 2000 barrels of oil, can be loaded in an hour and a half.

Pipe Line Companies.

The trunk lines are controlled by the National Transit Company; the Tide-Water Pipe Company, Limited; the Octave Pipe Line; the Southwestern Pennsylvania Pipe Lines; the Eureka Pipe Line Company; the Buckeye Pipe Line Company; the Southern Pipe Line Company; the Charles Miller Pipe Line; the Western and Atlantic Pipe Line; the Elk Pipe Line; the Crescent Pipe Line (Mellon Line); the Producers' Pipe Line; the Producers and Refiners' Oil Company, Limited; the United States Pipe Line (Emery Line), and the New York Transit Company. The first two mentioned are the most important. These companies move the oil from the region to the terminus of their lines. The National Transit Company does a very large proportion of the entire business. We believe it holds the original charter granted to Andrew Howard and J. S. Swartz and others under the name of the Pennsylvania Company, by the Act of April 7, 1870. In 1880, it absorbed the business and plant of the American Transfer Company; and, on April 1, 1884, the business and plant of the United Pipe Lines—that branch of the organization being since known as the United Pipe Lines Division of the National Transit Company.

Pipe Line Certificates.

The National Transit Company and the Tide-Water Pipe Company, Limited, are the only lines issuing certificates for crude petroleum received. These are printed acceptances for crude, and are negotiable the same as a certified check. We give below copy of a certificate of the National Transit Company.

Acceptance
No..... Oil City, Pa.,............18....
NATIONAL TRANSIT COMPANY, (1,000)

Through its UNITED PIPE LINES division,
Deliver to...................... or order,

One Thousand barrels of crude petroleum (of 42 gallons each) on the following terms, which are agreed to by the holder hereof:

1. It is agreed that the petroleum mentioned in this order is held by the National Transit Company, subject to a transportation charge of twenty cents per barrel, and a storage charge which will be at the rate of twenty-five cents per day per thousand barrels, as long as the market price of certificate oil is below one dollar per barrel; thirty-five cents per day when the market price is from one dollar to one dollar and fifty cents per barrel, and forty cents per day when the market price is above one dollar and fifty cents per barrel; no change, however, to be made in rate of storage on account of prices going above or below the prices named, unless the market price remains above or below the specified point for thirty consecutive days, and that the point of delivery of such oil shall be within the United Pipe Lines Division.

2. It is further agreed that this order shall be returned to the National Transit Company for exchange within six months from date of issue, or be subject to a storage charge of one twentieth (1-20) of one cent per barrel daily thereafter until returned.

3. It is further agreed that the National Transit Company shall not, in any event, be liable for any loss of crude petroleum resulting from lightning, fire, storms or any other unavoidable causes, it being distinctly understood and agreed that any such loss or losses shall be charged pro rata upon all petroleum in its custody at the time of such loss or destruction, and that the quantity of petroleum called for by this order shall be reduced by its proportion of such loss or destruction.

4. It is further agreed that transportation and all accrued storage charges shall be paid on the amount so deducted.

Order Accepted.
No........................Agent....................Registrar.

Not good until accepted
by.........................
Agent at...................

The system of issuing these certificates is, briefly, as follows:

When a producer wishes to deliver oil from his tank, he notifies a representative of the pipe line, who measures the oil and gives a voucher for it, running it into the line. The oil thus received is treated the same as a deposit in a bank. Against it certificates are issued in lots of one thousand barrels each, at the request of the owner. It is in these that the Oil Exchanges deal. It is needless to take space to describe these exchanges, located at New York, Oil City, Bradford, Pittsburgh, Philadelphia, Titusville, and elsewhere; nor the speculation in oil certificates. The largest number of clearances reported for any one year, is that for 1886, footing up 4,593,379,000 barrels. This speculative feature of the industry has almost entirely disappeared. It is with some curiosity that we read in the U. S. Census Report for 1880, the following, such excitement having now become so completely a thing of the past:—

"The fluctuations in the price of petroleum, during the census year, rendered a speculative investment in the article an object of exciting interest. June 1, 1879, was Sunday. The market opened on the 2nd, at 74⅜ cents per barrel. It continued to fall, with little disposition to rally, until on the 17th it closed at 64⅜; and after fluctuating between 65 and 68 for four days, it reached 75, and dropped to 69⅜ on the 25th. It hovered about 70 until the 9th of August, when it began to fall, reaching 64⅜ on the 27th. A slight rally held it at about 66 until the 7th of September, when an upward movement began, reaching 96¼ on October 9th. It remained near 91 until the 10th of November, when it again moved upward, reaching $1.27½ on the 21st, closing that day at $1.22½. On the following day it ranged between $1.22½ and $1.10⅝, closing at $1.18⅛, from which it rallied, reaching on the 2nd of December $1.28⅛. Between the 10th and 18th it ranged between $1.27½ and $1.10, and fluctuated greatly between $1.18 and $1.09 from this time to January 15th, 1880, when it went down in three days to $1.05, and steadily declined with scarce a rally, till, on March 9, it touched 85⅝. It hovered between 85 and 90 till April 6th, when it again commenced to decline, reaching 71¼ on the 21st. On the 5th of May it closed at 72½, and by the 26th had again reached the latitude of 93¾, closing on the 31st at 98¾. It will thus be seen that the certificates of oil in tank were worth that year from 64⅜ cents to 1.28⅛ per barrel, and this variation of almost 100 per cent. occurred between August 27th and December 2d, an interval of only sixty-eight days."

In the Caucasus the crude oil, as previously mentioned, was formerly transported to the refineries, a distance of over 6 miles, by means of two-wheeled carts (arbas), 10,000 of such carts making two trips a day, of course only in good weather. In bad weather, high winds or rain, the arbas could, as a rule, not be used, the roads being then impassable. Besides, during the busiest portion of the year traffic between the oil regions and the refineries was frequently interrupted by strikes of the drivers (mostly Tartars and Persians), who raised the charge for transporting the oil, which frequently amounted to 8 copecks per pood.

Under such conditions the profitable development of the industry was impossible, and the refiners and producers of crude oil were glad when they could work without loss. But since 1875, the industry, by the wonderful energy and ability of the brothers Nobel, especially of Ludwig Nobel, has received such an impetus that at present it almost equals the American oil industry. In 1875, Robert Nobel began refining at Baku in a small way, and was afterwards joined by his brother Ludwig. The Nobel Brothers soon saw that with the existing facilities of transport the profitable development of the business would be impossible. They, therefore, proposed, in 1876, to the other proprietors of oil wells to jointly build a pipe-line from the oil region to the refineries, but were everywhere met with scorn and distrust. Ludwig Nobel then laid the project before a number of English capitalists with the proposition for them to form a stock company with a capital of 3,000,000 roubles. The carrying out of this project was prevented by the war between Russia and Turkey, and Ludwig Nobel, at his own expense, then laid down a pipe-line eight miles long.

When Nobel commenced to build his line, the other refiners and producers of oil combined against him, and to compete with him, demanded from the Government a concession to construct a railroad on the same line, which, however, was not granted. When the pipe line was finished and in working order, the producers and refiners, who had sneered at and objected to the enterprise, saw its advantage and requested Nobel to pipe their oil also to the refineries. The line did not only pay its expenses the first year, but made a handsome profit.

The first pipe-line was arranged as follows:[1] The pumping station and a large iron tank were erected at Balakhani alongside Group XV of the naphtha wells. In the pumping station a 37-horse power engine drove a pump which forced the oil into the tank and the pipe line. The latter is about six miles long and connects the pumping station with Nobel's refinery in Blacktown, Baku. The pipes lie free upon the ground and make many curves and bends according to the condition of the surface of the ground. They are 5 inches in diameter and the oil passes through them with a velocity of over 3 feet per second. The station at Balakhani is situated 207 feet higher than the receiving station at Blacktown. To fill the principal tank at Balakhani with oil, there are several pumps which force the oil from the bore-holes to the principal station. At the receiving station at Blacktown the oil is distributed in different tanks and used as needed. The cost of building this line was about 800,000 marks (about $200,000). It reduced the expense for transporting the crude oil about one-third.

After the completion of this line the Baku Naphtha Company constructed a pipe line from Group XV of the Balakhani region to their refinery in Surakhani, and later on, from there to a narrow sand-bank at Sichsk on the Caspian Sea where they built a harbor. The total length of this line is about 9½ miles.

In 1878, more pipe lines were laid; the one constructed by M. Mirsojeff from Balakhani to his refinery in Baku is over 8

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[1] Victor Ragosin: Die Naphta und die Naphta Industrie.

miles long. The diameter of the pipes is 4 inches. The Lianosoff pipe line from Group VII to Baku is about 8½ miles long with pipes 3 inches in diameter. The pipe line of the Caspian Company pipes the oil from Sabuntchi to the railroad station; from there the oil is carried in tank cars to the village Kapsili, and from there through a pipe line to the refinery situated in the vicinity of the village.

Thus one pipe line after another was constructed, and to-day there are about 21 such lines which annually forward about 20 millions of barrels. Beside the lines leading from the oil region to Baku and its vicinity, there are a number of branches which lead from the 21 principal lines to the refineries. The total length of these lines is at present about 125 miles. A map of the pipe lines is given in Fig. 60.

There has recently been much talk about a projected pipe line for refined oil which is to be constructed from Baku to Batoum, so as to connect the Caspian with the Black Sea.

Petitions have been again and again submitted to the Government to construct such a line or grant concession for its construction. But notwithstanding the manifest advantage of such a line, the Government will not permit its construction, because the railroad and cars which were especially built for the transport of oil would become comparatively worthless, involving a loss of several millions of roubles. However, to give the Baku oil industry a better chance for competition, the Russian Treasury Department has recently bought 1000 new tank cars for the Baku-Batoum railroad, while at the same time it is intended to reduce the freight, so that by granting these accommodations American competition in European markets may be considerably impaired.

In Germany the only pipe line is that of the Petroleum Company, which leads from the oil regions to a collecting tank of about 2,000 barrels capacity. From there the oil is pumped to the station "Peine" where the refinery is located. The total length of the line is about 6½ miles; the pipes have a diameter of 2.36 inches.

In Galicia the facilities for transport, notwithstanding the considerable production of oil, are quite unsatisfactory. Where the refineries are not located in the immediate neighborhood of the wells, the oil has to be transported to them in barrels

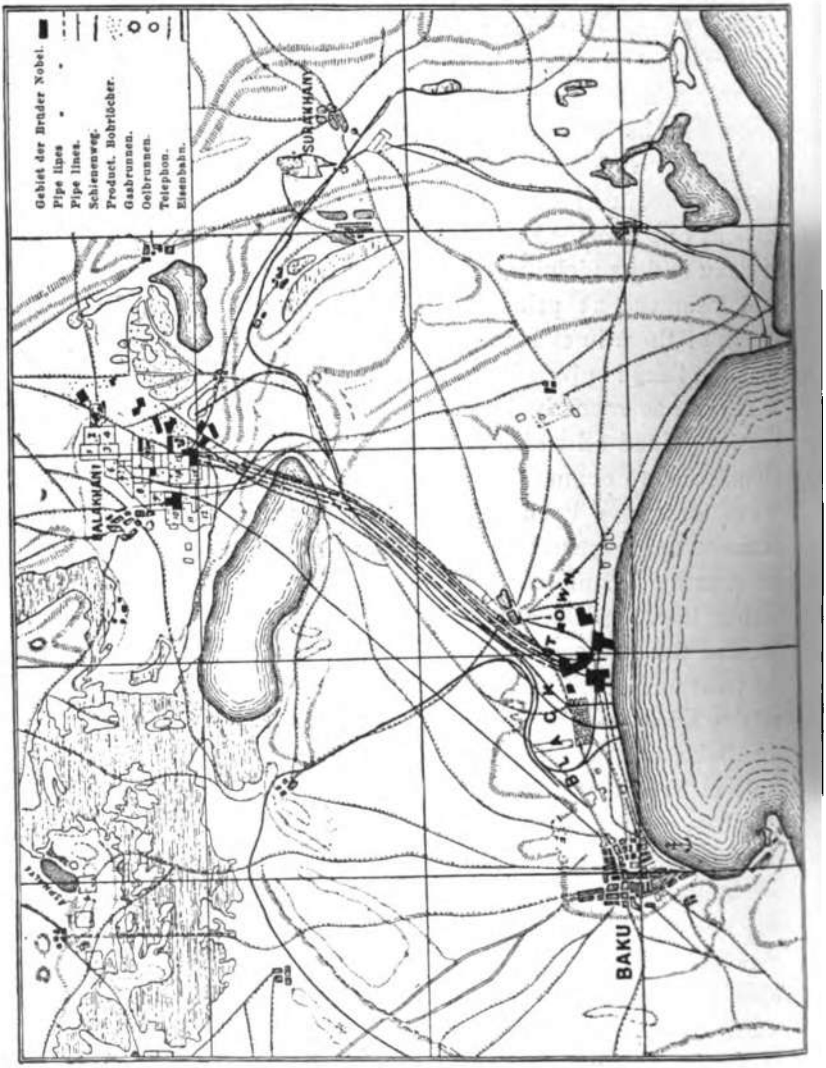


FIG. 60.

upon wagons. Pipe lines of any considerable length and importance do not exist, and all the progress made in other oil regions has not been utilized, because of want of capital, which together with the fact that many of the oil lands are in questionable hands is a hindrance to prosperity.

Tank wagons. The delivery of oil to retail dealers and householders by tank wagons is extending the idea of bulk transportation to its furthest limits. That there must be economy and other advantages in this method of transportation is indicated by the strong foothold it has gained, as it is quite generally adopted in the larger cities and towns of the United States.

FIG. 61.

A tank wagon, Fig. 61, consists of a horizontal cylinder of steel about 3½ feet in diameter, and 8 feet in length, mounted on four wheels similar to those used on heavy trucks. The capacity varies from 250 to 1,000 gallons, the larger sizes being used in cities having paved, level streets; the smaller sizes in hilly outlying districts, or in sections where the trade is limited. A few of the larger wagons are rigged for three horses. Each tank has some sort of a manhole on top for the admission of the oil, and some one of the various designs of outlet cocks and measuring devices for drawing out the oil. These, with the receptacle for the cans for carrying the oil into stores, the driver's seat, and in fact all the minor features of the plan of the wagons, differ in different cities.

CHAPTER VIII.

CRUDE OIL.

THE properties, occurrence and genesis of petroleum have been fully discussed in Chapters III, IV, V and VI. For practical purposes the theoretical speculations regarding the origin and chemical composition of petroleum are of secondary interest. In the practice the criteria for the determination of the value of a crude oil are of a very definite character, fractional distillation, which gives a clear picture of the composition of the oil, *i. e.*, of the proportions of essences, illuminating and heavy oils, being first in order, associated with the determination of the specific gravity.

In the practice these two examinations suffice, as a rule, for the determination of the value of a crude oil, the determinations of resin, sulphur, creosote oil and acid belonging to the scope of more detailed examinations. Photometric measurements for the determination of the burning value of the fractions requires a special expense for apparatus and contrivances, so that they can be used in rare cases only for the determination of the value of crude oil.

Fractional distillation, determination of the specific gravity and tests for resin, etc., will be discussed in this chapter, while photometric measurements will be treated of and explained in Chapter XI.

Fractional Distillation.

Since oils from various districts differ in regard to their chemical composition, the determination of the specific gravity alone does not suffice for the practice. Although it is generally accepted as a rule that specifically heavier oils are of less value, this holds good only for comparing the oils of one district with one another. Petroleum being a mixture of many and heterogeneous hydrocarbons, the relative quantities of which in the particular varieties vary very much and do not occur in conformity with any law, a specifically heavier oil may, under certain circumstances, yield in the practice better results than a specifically lighter oil.

While, for instance, Pennsylvania oil of 0.855 specific gravity is considered of low value, an oil of the same specific gravity from the Caucasus belongs to the best varieties. In the first kind the relative proportion of illuminating oil to other portions of the oil is less than in the Caucasus oil. Hence, fractional distillation is the only sure guide in regard to the yield of illuminating oil.

In handbooks, etc., numerous analyses of crude oil made in the laboratory are as a rule given, which as far as manufacturing on a large scale is concerned generally bear the stamp of inaccuracy, they presenting in very rare cases only a true picture of the yield of illuminating oil attained in practice.

This is a well known fact to the practical refiner, and is due to the circumstance that laboratory analyses only give the result of what is known in practice as first distillation. The yield in operating on a large scale is, as a rule, greater, the difference varying, according to the derivation of the oil, between quite wide limits (5 to 25 per cent.). In executing an analysis the derivation of the oil should always be taken into consideration, and the properties of the fractions distilling over before and after the illuminating oil should be determined. While in the separation of the various fractions, the essences distilling over up to 302° F. cannot be separated as belonging to illuminating oil, a small portion of them—that having the highest boiling point—may be mixed with the petroleum without injury to its quality, when the heavy oils distilling over after the illuminating oil can also be used for illuminating oil, this having been proved by experiments on a large scale. In this case the specific gravity of the heavy oils should not be too high and their color not too dark; further, they must not suffer partial decomposition, this being of special importance, otherwise the yield of illuminating oil will be decreased by the formation of volatile hydrocarbons, and the burning value impaired by the formation of non-saturated hydrocarbons.

A few examples will suffice to show the difference between laboratory analyses and the results on a large scale:

Pennsylvania crude oil, analyzed by Chandler.

Specific gravity 0.813.

Benzine	15.5 per cent.
Illuminating oil	55.5 "
Paraffin oil	19.5 "
Coke and loss	10.0 "

Bradford crude oil, analyzed in the factory-laboratory of Dr. Veith.

Specific gravity 0.819.

Benzine	10.5 per cent.
Illuminating oil	63.5 "
Paraffin oil	17.0 "
Coke and loss	9.0 "

The same oil distilled on a large scale, gave, after several weeks' distillation, the following average result:

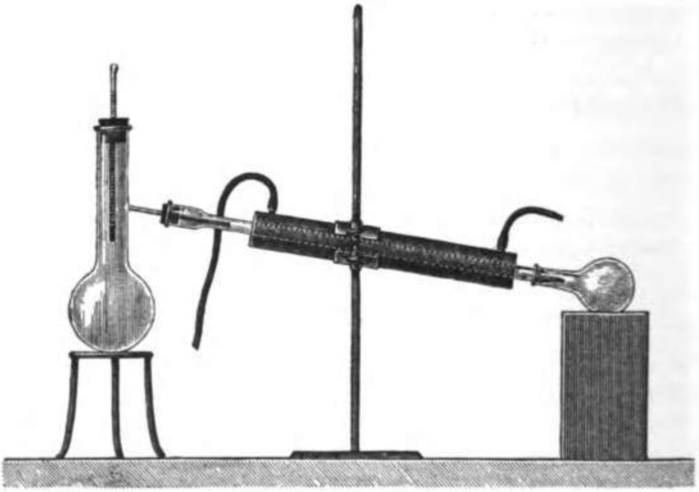
Benzine	10 to 12 per cent.
Illuminating oil	80 "
Paraffin oil	2 "
Coke and loss	6 to 8 "

Similar results were obtained with a Roumanian oil, which on a small scale yielded 15 per cent. benzine and 40 to 45 per cent. illuminating oil, and on a large scale, 60 per cent. illuminating oil and only 10 per cent. benzine.

The difference between the results obtained in the laboratory and in the practice is greater with crude oils containing benzine, and smaller with oils poor in benzine, or with oils with specifically heavier fractions after the illuminating oil, an example of the latter being the Russian oils, in the case of which the two results nearly agree.

A few of the many distilling apparatuses for laboratory use may here be mentioned. The principal difference is in the condensation, which may consist of a simple tube condenser or surface condensers or air condensers of various shapes. The most simple form is shown in Fig. 62. The retort, which is filled with the fluid to be distilled, is either directly connected, as shown in the illustration, with a Liebig condenser by a tube fitted in the side of the neck, or is provided on top with a tubulure having one, two or more bulbs. In this tubulure a thermometer is placed. From the side of the tubulure a small tube leads to the cooling contrivance where the vapors condense to be caught in the receiver. The object of the tubulure is to force the heavier volatile fluids which condense in the bulbs to flow back into the retort, and allow only the volatile portions corresponding to the temperature to escape through the lateral tube, thus rendering possible a thorough separation of the different portions.

FIG. 62.



Linnemann has improved this method with the tubulure by placing in the wide tube Fig. 63, in which the vapors ascend, from five to eight small cups of platinum wire, Fig. 64, eight such cups being used for fluids with a boiling point below 320° F., six for fluids with a boiling point up to about 356° F., and five for fluids with a boiling point up to 482° F. Le Bel's arrangement, Fig. 65, is similar to the one just described. In these cups, as well as in the bulbs, more fluid is condensed than can flow through the meshes; the vapors are thus washed and come successively in contact with layers of fluid whose temperature is lower, so that only the most volatile portions can reach the condenser.

Since with this arrangement of the apparatus the tube and the bulbs become gradually filled with fluid, and since all the vapor condenses, the flame has from time to time to be removed to allow the fluid to flow back. In order not to retard the progress of distillation it is more suitable to use the Henninger tubulure, Fig. 66, in which are also placed cups or balls of platinum wire; the condensed fluid, however, runs off through the lateral tubes. To limit the radiation of heat, the tube, during the further progress of distillation, is surrounded with a sheet-iron jacket, so arranged that the escape towards the top of the hot current of air is gradually cut off, and the air surrounding the tube is constantly more strongly heated. With any one of these apparatuses (Linnemann's, Le Bel's, Henninger's) a sufficient separation of the different fractions is obtained and, what is of special importance, parallel determinations yield results which perfectly agree.

In France Regnault's apparatus, Fig. 67, is employed by custom houses. *A* is a small copper cylinder provided at *b* with a small tube bent downward. This tube passes into the brass condenser *B*, which ends, above and below, in two narrow metallic tubes *g* and *i*. The condenser is secured in the metallic cylinder *f*, which is arranged as a cooler for the reception and discharge of water. The apparatus is secured to the trevet *P*. The latter is provided with a horizontal board *h l* which serves for moving the stand *V*, which carries five cylinders graduated in cubic centimeters, standing alongside one another. Each of these graduated cylinders (1, 2, 3, 4, 5) can be placed under the mouth *i* of the condenser *B*. 100 cubic centimeters of the oil to be tested are introduced into the cylinder through the tube *a*. The cylinder may be filled one-third full. The thermometer *T* is so secured in the tube that it does not dip in the fluid and its bulb lies near the discharge pipe. The cylinder *A* is finally heated by means of a gas or spirit-flame.

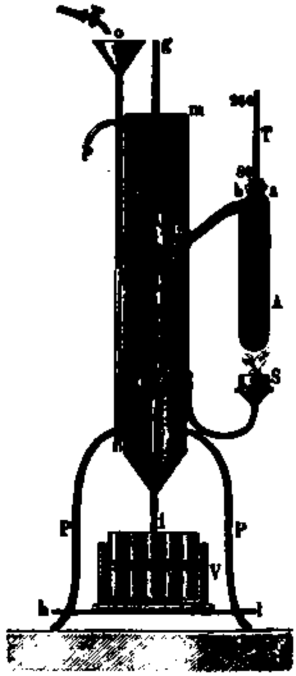
FIG. 64.

FIG 63.

FIG. 65.

FIG 66.

FIG. 67



The oils contained in the crude product boil at different temperatures and may, for instance, be divided into the following fractions:

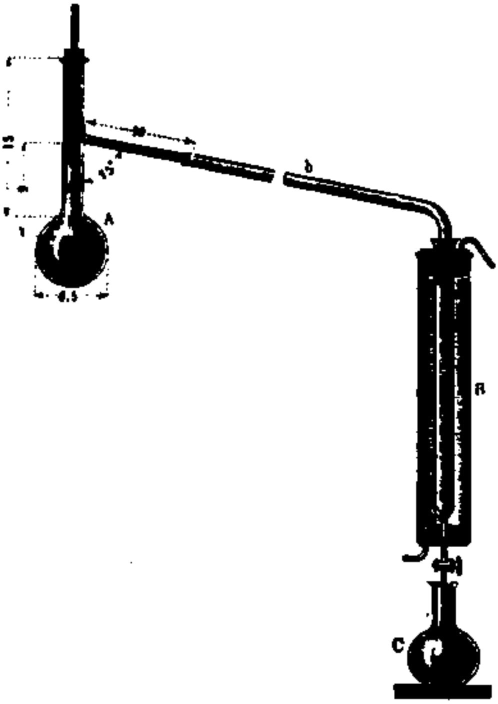
Those which distil below 302° F.

Those which distil at 302° to 356° F.

Those which distil at 356° to 410° F.
Those which distil at 410° to 464° F.
Those which distil at 464° to 518° F.

The stand *V* is now placed so that cylinder *No. 1* is under the discharge opening while the fluid is brought to the boiling point. As long as the temperature does not exceed 302° F., the distillate is caught in cylinder *No. 1*, between 302° and 356° F., the distillate is caught in cylinder *No. 2*, and so on, until with a temperature of 464° to 518° F., cylinder *No. 5* comes under the discharge opening.

Fig. 68.



The volumes of oil in each of the five graduated cylinders are noted down, and the volumes obtained considered as corresponding weights in the original mixture of oils. This method is not very accurate, since the specific gravities and volumes vary in their behavior according to the fractions, though for technical purposes this error is not of great importance.

To secure a uniform method of distilling, C. Engler has proposed an apparatus constructed by himself which does good service for laboratory purposes. The apparatus, Fig. 68, consists of an ordinary round flask, *A*, 2½ inches in diameter, with a neck 0.59 inch in diameter and 5¾ inches long.[1] The height of the delivery-tube for the vapors above the uppermost portion of the flask is 2.55 inches. The copper tube *b*, 0.39 inch in diameter and 17.71 inches long, serves as cooling apparatus, and, for the reception of the distillates, the burette *c*, proposed by Thörner, which is cooled on the outside by the water reservoir *B*. By this means the fractions can also be readily measured and weighed in the flask *C*. For each distillation about 100 cubic centimeters are used, and so rapidly distilled that from 2 to 2.5 cubic centimeters pass over per minute. Every time when a point of fraction is reached the lamp is removed and the thermometer allowed to fall at least 20° C., when heating is renewed to the same point of fraction and continued as long as perceptible quantities pass over.

The results of Engler's examinations of various kinds of oil, which were executed under always equal conditions, are given in the appended table:

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[1] The figures in the illustration refer to centimeters.

Crude Oil from		Specific Gravity at 17° C.	Commencement of boiling °C.	Up to 130° C.	130° to 150° C.	150° to 170° C.	170° to 190° C.	190° to 210° C.	210° to 230° C.	230° to 250° C.	250° to 270° C.	270° to 290° C.	290° to 300° C.	Up to 150° C. Essences.	150° to 300° C. Illuminating oil.	Over 300° C. Residuum.
				Per cent. by volume.												
Pechelbronn (Alsace), bore-hole 146.	C.c.	0.906	155	....	....	....	1.5	1.5	4.5	5.5	6.0	6.5	5.0	....	30.5	69.5
	Gr.			....	....	....	0.9	1.4	3.2	4.4	4.9	5.4	4.6	....	24.8	......
Pechelbronn II, bore-hole 213......	C.c.	0.885	98	6	4	4	4	3.5	3.5	3	4.5	4	3	10	29.5	60.1
	Gr.			4.3	2.8	3	3.2	2.9	2.9	2.4	3.6	3.7	2.6	7.1	24.3	......
Oelheim (Hanover)	C.c.	0.899	170	....	....	....	4.75	5.25	6	4	5	5	2	....	32	68
	Gr.			....	....	....	3.2	2.6	4.8	3.4	4.3	4.3	1.8	....	24.4	......
Tegernsee	C.c.	0.815	55	16	8	6	5.5	4.5	5.5	5.5	6.5	5.5	4	24	43	33
	Gr.			11.7	6.1	4.8	4.2	3.7	4.3	4.5	5.1	4.7	2.9	17.8	34.4	......
Pennsylvania I....................	C.c.	0.8175	82	15	6	5	5	5	5.75	4.75	6	4.75	2	21	38.25	40.75
	Gr.			10	4.6	4	4	4.1	4.5	3.8	5	4.0	1.7	14.6	31.1	......
Pennsylvania II..................	C.c.	0.8010	74	24.5	7	4.5	4.5	6.5	5	4.75	3.25	4	2.5	31.5	35	33.5
	Gr.			16.8	4.7	3.2	3.3	4.8	4.3	4.2	3	3.9	2.5	21.5	29.2	......
Galicia (Sloboda)	C.c.	0.8235	90	16	10.5	10.25	6.5	6.5	7	6.75	6	3.5	0.5	26.5	47	26.5
	Gr.			11.3	7.6	7.6	5.2	5.3	5.6	5.5	5.6	2.8	0.45	18.9	38.05	......
Baku (Bibicybat).................	C.c.	0.8590	91	16	7	6.5	6.5	5	5	5	5.5	3.5	1	23	38	39
	Gr.			11	5.7	4.9	5.1	4.1	4.2	4.2	4.7	3.1	0.9	16.7	31.2	......
Baku (Balakhani-Sabuntschi)	C.c.	0.810	105	3.75	4.75	5.5	4.75	5.25	5.0	7	4.75	5.5	1.75	8.5	39.5	52
	Gr.			2.7	3.4	4.3	4	4.3	4.1	5.6	4.1	4.6	1.6	6.1	32.6	......

Besides the normal distillations, which can be executed in small quantities only, larger quantities of crude oil must also be fractionated in the refinery-laboratory in order to make refining experiments, determinations of the burning points, etc., of distillates. About three quarts are as a rule used, the distillates being divided into 10 to 20 fractions.

From the rising specific gravities a curve may be constructed by graphic delineation which in a simple manner gives a clear idea of the composition of the crude oil and renders possible the determination of its value. Fig. 69 shows the results of the distillation of an American crude oil.

A comparison of such curves can, however, be made only with oils of the same derivation, since, according to the chemical nature and condition of the oils, the difference in the specific gravities, and hence, also the form of the curve, may vary.

In many cases the determination of the specific gravities of the fractions alone is not conclusive, and the temperature at which the separate fractions are separated must also be especially taken into consideration. This fact has been fully appreciated in Engler's standard distilling determination. The limits of temperature between which the separate fractions have to lie are not easily determined, and besides the choice of the distilling vessel, the position of the thermometer in the latter is also of influence. Even with the most accurate determination of the temperature, a thermometer-correction for the lower temperature of the mercury thread projecting from the vessel has to be made, the formula for which is:

$T = t + 0.000143\, n\, (t - t')$[1],

wherein *T* represents the corrected temperature, *t* the temperature observed, t' the medium temperature of the mercury thread, *n* the length of the projecting thread in thermometer degrees, 0.000143 the empirical coefficient situated near the

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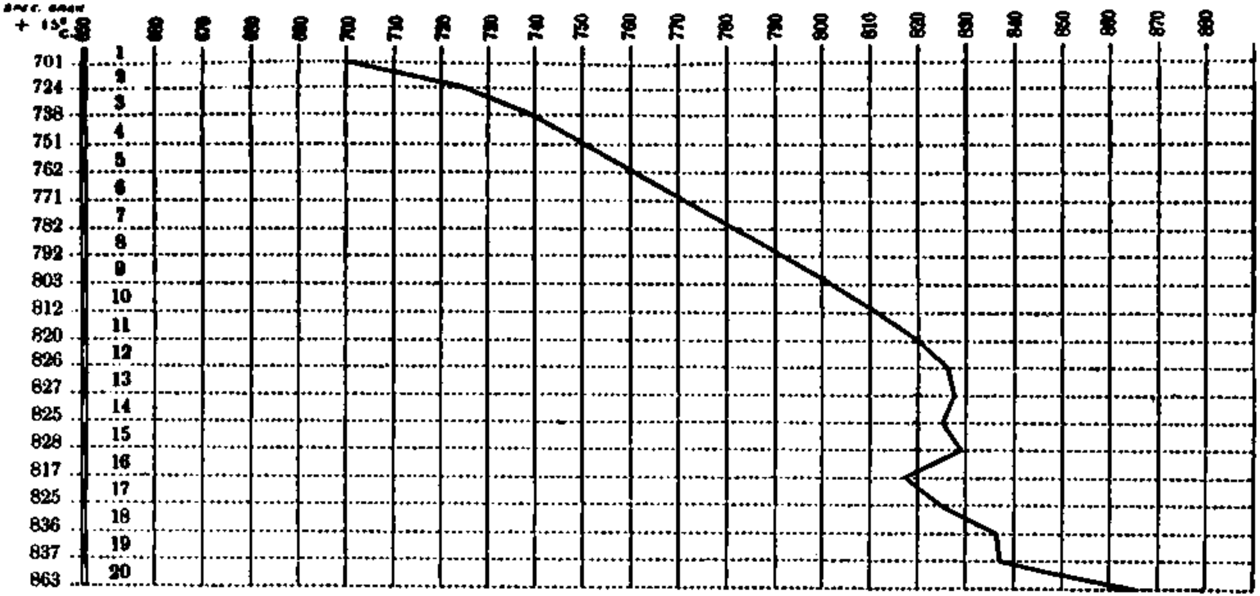
[1] T. E. Thorpe. Jour. of the Chem. Soc., 37, 160, 1880.

FIG. 69. Analysis of American Crude Petroleum. Average Density Curve.



		Average Specific Gravity.	Color.	Density.	Igniting Point.	Weight.
Resume for 3 liters=2.458 kilo.	Essences (light)	701 to 724	White	0.712	....	0.2138 kilo.
	" (heavy)	738	"	0.738	Ordinary temperature	0.1107 "
	Oils (light)	751 to 827	Yellow	0.805	Abel test +17° C.	1.2066 "
	" (heavy)	825 to 863	Brown	0.833	" " +34° C.	0.8747 "
	Coke	....	....	....	....	0.0420 "
	Loss	....	....	....	....	0.0100 "
					Total	2.4578 Kilo.

apparent expansion coefficient of the mercury in the glass (0.000154).

The difference between the observed and corrected temperatures may be up to 3½° C., a fact which in an accurate fractional distillation must unquestionably be taken into consideration. The importance of this fact was especially shown, in 1887, during the negotiations for adjustment between the two divisions of government of the Austria-Hungary monarchy. The question at issue was the protection of the threatened Galician crude oil industry, which demanded higher import duties on American and Russian oils (the latter being called *Kunstoele*—artificial oils). Both governments (Austrian and Hungarian) appointed experts who executed numerous distillations with these crude oils in order to establish the difference between artificial oil and crude oil. The experiments were, however, without results.

As a criterion for an artificial oil, i. e., an oil once distilled which has been colored and made specifically heavier by the addition of residuum or crude oil for the purpose of importing it as crude oil at a lower duty, the following test has been proposed: 500 cubic centimeters of the crude oil are refined with 3 per cent. of concentrated sulphuric acid and purified with ½ per cent. concentrated lye. The resulting oil of a wine-red color is brought into a small flat-burner lamp and the latter is lighted. The flame is then set at a certain height and, if after burning for two hours it sinks at the utmost ½ centimeter, the oil is to be considered illuminating oil and be subject to the higher duty. Attempts to introduce this method, however, met with no encouragement, and in further experiments the distilling method alone was adhered to. After many negotiations a mode of distillation was agreed upon, most factories accepting Engler's method. Great attention was next paid to the position of the thermometer-bulb in the vessels. How great a difference there may be in the yield according to the arrangement of the thermometer-bulb is clearly shown by the following parallel experiments with American and Russian so-called artificial oils. Three series of experiments were made:

I. *Normal Position.*

The oils were distilled up to 572° F., the principal fractions of the distillate being up to 302° F., between 302° and 518° F. and between 518° and 572° F. These fractions were divided into separate smaller ones.

A. *American crude oil, specific gravity 0.826.*

Used for distillation 411 grammes.

1. Up to 302° F. were obtained 7 grammes.

B. *Russian artificial oil, specific gravity 0.8405.*

Used for distillation 412.5 grammes.

1. Up to 302° F. were obtained 0.5 gramme.

2. Fractions between 302° and 518° F.

Intervals of temperature.	Cubic centimeters.	Specific gravity.	Yield.		Intervals of temperature.	Cubic centimeters.	Specific gravity.	Yield.	
			Gr.	P. c.				Gr.	P. c.
302° to 359.6° F.	50	0.742	37	9	302° to 359.6° F.	50	0.775	38	9.2
359.6° to 413.6° F.	50	0.762	38	9.3	359.6° to 392° F.	50	0.788	39	9.4
413.6° to 482° F.	50	0.873	39	9.5	392° to 413.6° F.	50	0.803	39.5	9.6
482° to 518° F.	39	0.798	24	5.8	413.6° to 438.8° F.	50	0.819	40	9.7
					438.8° to 471.2° F.	50	0.833	41	9.9
					471.2° to 505.4° F.	50	0.843	41.5	10.1
					505.4° to 518° F.	50	....	12	2.9

3. Fractions between 518° and 572° F.

Obtained 0.815 specific gravity, 24 gr.=5.8 p. c.

411 gr. American crude oil yielded:

1. Up to 302° F.................. 7 gr. =1.7 per cent.
2. 302° to 518° F..................144 gr. (0.769)=35.3 per cent.
3. 518° to 572° F.................. 24 gr. (0.815)=5.8 per cent.

Total yield (between 302° and 572° F.) 168 gr.=41.1 per cent.

Obtained 0.845 specific gravity, 45 gr.=10.9 p. c.

412.5 grammes Russian crude oil yielded:

1. Up to 302° F............... 0.5 gr. =0.01 per cent.
2. 302° to 518° F. ....251.0 gr. (0.810)=60.8 per cent.
3. 518° to 572° F............... 45.0 gr. (0.854)=10.9 per cent.

Total yield (between 302° and 572° F.) 29.6 gr.=71.7 per cent.

II. *Distillation with the Thermometer-Bulb in the Gas-Space.*

A. *American crude oil, specific gravity 0.826.*
Used for distillation 392.5 grammes.

B. *Russian artificial oil, specific gravity 0.8405.*
Used for distillation 394.5 grammes.

1. Up to 302° F.

Intervals of Temperature.	Cubic Centimeters.	Specific Gravity.	Yield, Grammes.	Intervals of Temperature.	Cubic Centimeters.	Specific Gravity.	Yield, Grammes.
122° to 212° F.	50	0.738	36	122° to 212° F.	50	0.775	38
212° to 248° F.	50	0.760	37	212° to 230° F.	50	0.788	39
248° to 302° F.	60	0.783	46	230° to 302° F.	83	0.808	67
122° to 302° F.	160	0.763	119=30.3 p.c.	122° to 302° F.	183	0.794	144=36.5 p.c.

2. From 302° to 491° F.

Intervals of Temperature.	Cubic Centimeters.	Specific Gravity.	Yield, Grammes.	Intervals of Temperature.	Cubic Centimeters.	Specific Gravity.	Yield, Grammes.
302° to 365° F.	50	0.805	40	302° to 338° F.	50	0.831	41
365° to 410° F.	50	0.826	41	338° to 347° F.	50	0.842	41.5
410° to 455° F.	50	0.840	41.5	347° to 374° F.	50	0.854	42
455° to 491° F.	76	0.840	41.5	374° to 437° F.	50	0.865	42.5
		0.831	22	437° to 491° F.	69	0.872	61
302° to 491° F.	226	0.823	186=47.35 p.c.	302° to 491° F.	269	0.855	228=57.8 p.c.

With the heating arrangements provided, it was impossible to establish a higher temperature than 491° F., the thermometer sitting too high.

III. *Distillation with the Thermometer-Bulb dipping in.*

A. *American crude oil, specific gravity, 0.826.*
Used for distillation 434 grammes.
1. Obtained up to 302° F. 3 grammes.

B. *Russian artificial oil, specific gravity 0.8405.*
Used for distillation 436 grammes.
1. Obtained up to 302° F. ½ gramme.

2. Fractions obtained between 302° and 518° F.

Intervals of temperature.	Cubic centimeters.	Specific gravity.	Yield, grammes.	Intervals of temperature.	Cubic centimeters.	Specific gravity.	Yield, grammes.
302° to 374° F.	50	0.740	36.5	302° to 374° F.	50	0.774	38
374° to 428° F.	50	0.760	37	374° to 392° F.	50	0.786	39
428° to 518° F.	65.5	0.782	53	392° to 428° F.	50	0.800	39.5
				428° to 464° F.	50	0.818	40
				464° to 500° F.	50	0.829	40.5
				500° to 518° F.	25.5	0.837	20.5
302° to 518° F.	165.5	0.765	127	302° to 518° F.	275.5	0.804	217.5

3. Fractions obtained between 518° and 572° F.

518° to 572° F.	32	0.792	27	518° to 572° F.	16	0.846	55

434 grammes of crude oil yielded up to 572° F.:

1. Up to 302° F.............3 grammes = 0.7 per cent.
2. 302° to 518° F. ....165.5 grammes (0.765) =38.1 per cent.
3. 518° to 572° F. .... 27 grammes (0.792) = 6.2 per cent.

Total yield (between 302° and 572° F.)=192.5 gr.=44.3 per cent.

436 grammes of artificial oil yielded up to 572° F.;

1. Up to 302° F........... ½ gramme =0.01 per cent.
2. 302° to 518° F. ....217½ grammes (0.804)=47.6 per cent.
3. 518° to 572° F. .... 55 grammes (0.846) = 12.6 per cent.

Total yield (between 302° and 572° F.)=272.5 gr.=60.2 per cent.

In the first, the so-called normal distillation, the thermometer-bulb dipped in the prescribed manner, into the layer of oil, up to 446° F., and after that, in consequence of the decrease in the volume of the fluid, into the gas-space. The thermometer itself up to about 392° F., sits in the neck of the retort. Distillation proceeded drop by drop, and lasted 1½ to 1¾ hours.

In the second series of experiments the extreme method of placing the thermometer so that the bulb was entirely in the gas-space close in front of the neck of the retort was adopted.

In the third series the thermometer-bulb was, during the entire progress of distillation, in the fluid about ¾ inch from the bottom.

Resumé of the Final Results of the Three Experiments.

	Used. Grammes.	Distillate Obtained. Grammes.	Up to 572° F. Per Cent.
I. (With the thermometer-bulb in the oil up to 446° F., afterwards in the gas-space)	American 411	168	41.1
	Russian 412.5	269	71.7
II. (With the bulb in the gas-space).....	American 392.5	305	77.6
	Russian 394.5	372	94.3
III. (With the bulb dipping in the oil)....	American 434	182.5	44.3
	Russian 436	272.5	60.2

From the above resumé it may be seen how different the results of the distillations may be with the thermometer at varying distances from the boiling fluid.

It is, therefore, absolutely necessary to adhere to a definite standard regarding the position of the thermometer-bulb, for instance, to that proposed by Engler.

Specific Gravity.

The determination of the specific gravity is in the practice exclusively effected with aerometers, Beaumé scale (chiefly used in this country), or with specific gravity and Beaumé scales, both referred to water as unity.

The specific gravity of petroleum varies between very wide limits, from 0.780 that of many Italian oils, while Roumanian and East Indian oils, which are rich in paraffin, show even 1.3.[1] The difference in the specific gravities is dependent not only on the locality, but also on the depth of the wells from which the oils are obtained. Although general rules, according to which the densities decrease with the depth of the wells, cannot be laid down, the results of borings in different regions have shown that, independent of the upper layers partially resinified by oxidation, the oils become more thinly fluid with an increasing depth. The reason for this phenomenon may be explained by the fact, that the greater the depth at which the oil is found, the less chance there is for the volatilization of the lighter portions, this being prevented by the overlying masses of earth. This also explains why crude oil from bore-holes is specifically much heavier than that from flowing wells; oil pumped continuously is also much lighter than when pumped periodically.

The specific gravity of crude oils is influenced by gases dissolved in it as well as by water held in suspension. When the oil is for some time exposed to the air, the specific gravity rises perceptibly in consequence of the separation of the dissolved gases—this loss according to Tumsky sometimes amounts to 35 per cent. (?)[2]—as well as by the oxidation of the hydrocarbons, whereby the properties of the crude oil are changed to such an extent as to render it, after long standing, unfit for obtaining illuminating oil from it.

In determining the specific gravity, the temperature at which the process is executed has to be taken into consideration, since the volume changes with the temperature. With the assistance of the expansion-coefficient the specific gravity may also be determined for other temperatures. The specific gravities are generally referred to 12° Reaumur = 15° C. = 59° F., and values perfectly accurate for the practice are obtained by taking 0.0008 as the expansion coefficient for 1° R., whereby,

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[1] Tumsky, Technologie der Naphtha, S. 711.

[2] Ibid., S. 37.

with a temperature of the oil above 12° R. (59° F.), the corrections have to be added, and below 12° R. (59° F.), subtracted.

The table given below is very useful in the practice, for the better management and still more precise reduction of the densities of mineral oils.

If the observed temperature of the crude oil is 12° R.=15° C.=59° F., the figure read off on the aerometer scale gives directly the so-called true density for 12° R.

If, however, the thermometer shows another temperature, in which case the figure read off on the aerometer scale is called the "observed" or apparent density, the true density is found from the observed density and the temperature with the assistance of the reducing table given below as follows: The table has two entries, one in the uppermost horizontal column giving the statements read off on the aerometer, hence the observed or apparent densities from 750 to 890, and the other in the first three vertical columns to the left for the statements of the Réaumur, Centigrade and Fahrenheit thermometers. Where a vertical and horizontal line cross, the reduction to 12° R., or 15° C., or 59° F., corresponding to the observed density and temperature, is found. To obtain the true density for the normal temperature of 12° R.,=15° C.=59° F., the reduction found has to be deducted from the observed specific gravity for temperatures below 12° R., and added for temperatures above 12° R.

If, for instance, in examining a mineral oil, its density on the scale of the aerometer is found to be 810, and the thermometer shows the temperature of the oil to be 18° R.=22.5° C.=74.75° F., the figure 810 has to be found in the uppermost horizontal column, and the vertical column belonging to it followed down to the line on which, in the first three columns to the left, which contain the degrees of temperature, stand the figures 18, 22.5, and 74.75. On the crossing place will be found as an addition the figure 5.2, which has to be added to the observed density 810, making 815.2 the true density of the oil at 12° R.=15° C.=59° F.

Table for the Reduction to the normal temperature of 12° R.=15° C.=59° F. of the Densities of Mineral Oils, observed on a glass Aerometer at the Temperatures given.

(Density of water at 12° R.=1000.)

Temperature.			Observed Density.														
°R.	°C.	°F.	750	760	770	780	790	800	810	820	830	840	850	860	870	880	890
			Add														
0	0	32	11.7	11.5	11.3	11.1	10.9	10.7	10.5	10.4	10.2	10.1	10.0	9.9	9.8	9.7	9.6
1	1.25	34.25	10.7	10.5	10.3	10.1	10.0	9.8	9.6	9.5	9.4	9.3	9.1	9.0	8.9	8.9	8.8
2	2.5	36.5	9.7	9.5	9.4	9.2	9.0	8.9	8.8	8.6	8.5	8.4	8.3	8.2	8.1	8.1	8.0
3	3.75	38.75	8.7	8.6	8.4	8.3	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.4	7.3	7.2	7.2
4	5	41	7.7	7.6	7.5	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.6	6.5	6.4	6.4
5	6.25	43.25	6.8	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.9	5.8	5.7	5.7	5.6	5.6
6	7.5	45.5	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.2	5.1	5.0	5.0	4.9	4.9	4.8	4.8
7	8.75	47.75	4.8	4.7	4.6	4.6	4.5	4.4	4.3	4.3	4.2	4.2	4.1	4.1	4.0	4.0	4.0
8	10	50	3.8	3.8	3.7	3.6	3.6	3.5	3.5	3.4	3.4	3.3	3.3	3.3	3.2	3.2	3.2
9	11.25	52.25	2.9	2.8	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.5	2.4	2.4	2.4	2.4
10	12.5	54.5	1.9	1.9	1.8	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.6
11	13.75	56.75	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
12	15	59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
			Deduct														
13	16.25	61.25	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
14	17.5	63.5	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6
15	18.75	65.75	2.8	2.8	2.7	2.7	2.7	2.6	2.6	2.5	2.5	2.5	2.5	2.4	2.4	2.4	2.4
16	20	68	3.8	3.7	3.7	3.6	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.3	3.2	3.2	3.2
17	21.25	70.25	4.7	4.6	4.6	4.5	4.4	4.4	4.3	4.2	4.2	4.1	4.1	4.1	4.0	4.0	4.0
18	22.5	72.5	5.7	5.6	5.4	5.4	5.4	5.2	5.2	5.1	5.0	5.0	4.9	4.9	4.8	4.8	4.8
19	23.75	74.75	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.8	5.7	5.7	5.6	5.6	5.5
20	25	77	7.5	7.4	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.5	6.5	6.4	6.4	6.3
21	26.25	79.25	8.5	8.3	8.2	8.1	7.9	7.8	7.7	7.6	7.5	7.4	7.4	7.3	7.2	7.2	7.1
22	27.5	81.5	9.4	9.2	9.1	8.9	8.8	8.7	8.6	8.4	8.3	8.2	8.2	8.1	8.0	8.0	7.9

The observed specific gravity in the uppermost horizontal column progresses from 10 to 10 degrees. It suffices in all cases to enter the table with the figure divisible by 10 nearest to the observed density. Thus, for instance, if on the aerometer scale a density of 833.5 or 836 has been observed the table in the first case would have to be entered with 830, and in the latter with 840. It is also in most cases permissible to ignore the fraction of a degree less than ½, and to take the full degree when it amounts to ½ or more.

In laboratories various instruments are used for more exact determinations of the specific gravity. These methods of determination will be treated of in the Chapter on Oil Tests.

Determination of Resin.

The resinous products present in crude oil give it its characteristic dark to black color.

The content of resin is best determined as follows: Add to a certain volume (generally 40 cubic centimeters) of crude oil, a like volume (40 c. c.) of benzine free from fat, and mix thoroughly in a graduated cylinder. Then add 20 c. c. of concentrated sulphuric acid of 60°, shake vigorously for a few minutes, and allow to settle until the mixture standing over the brown sulphuric acid has become perfectly transparent and an increase in the precipitate is no longer observed. The increase in the volume of the sulphuric acid gives the content of resinous products.

If, for instance, 40 c. c. crude oil and 20 c. c. sulphuric acid have been used for the determination of resin, and the volume of the sulphuric acid has, after the test, increased by 3 c. c., the content of resin expressed in per cent. amounts to $40 : 3 = 100 : x$; $x = 7.5$ per cent. The content of resin is closely connected with the specific gravity and the color of the oil. The specifically heavier and the darker the oils are, the greater the content of resinous products, which, generally speaking, varies between 10 and 25 per cent.

All other examinations being essentially identical with the tests for illuminating and lubricating oils, which will be discussed in detail in the Chapter on Oil Tests, only the determination of sulphur will here be briefly given.

Determination of Sulphur.

The disagreeable odor of petroleum is chiefly due to a content of sulphur combinations. The principal quantity of these combinations being present in the most volatile portions, as carbon disulphide, thiophene, etc., and being themselves of a very volatile nature, an accurate determination of sulphur is not easily made, but may be attempted as follows: Heat 0.5 gramme of the crude oil with about 20 to 25 c. c. of concentrated nitric acid in a hermetically closed tube to from 320° to 356° F. The resulting product, after driving off the principal quantity of the nitric acid, is diluted with water, mixed with barium chloride and the sulphur determined as barium sulphate. *Or*, for the purpose of oxidizing the sulphur contained in the oil to sulphuric acid, treat 0.5 gramme of the oil with concentrated nitric acid and potassium chlorate remainder, and evaporate with concentrated nitric acid. The rest of the analysis is executed in the customary manner by evaporating, dissolving, precipitating with barium chloride, etc. The content of sulphur in various crude oils has been previously given in Chapter IV, Chemical Constitution.

CHAPTER IX.

MANUFACTURE.

Distillation — Condensation — Refining — Continuous Distillation—Production of Lubricating Oils.

THE greater portion of all the crude oil produced is used for the manufacture of light products or essences (benzine, etc.,) illuminating oil, and in working the residuum into lubricating oils, etc. This is done in factories called refineries. This term actually refers only to a special process of manufacture, but is now used as a general designation. In many factories, especially in this country, the process of treating the crude oil is carried through only to a certain limit, the products thus obtained being subjected to final manipulation in other factories, the actual refineries. There are manufacturers of lubricating oils who confine themselves exclusively to this class of products, and there are makers of illuminating oils who refine these only. There are also refiners of the light products of petroleum who devote themselves exclusively to this branch of the business. What is " residuum " to the refiner of illuminating oils becomes " crude material " to the manufacturer of lubricating oils. What is a " by-product," such as benzine, and sold as such by the maker of illuminating oils, becomes " raw material " to the gasolene manufacturer.

The process of working crude oil is with few exceptions as follows: The crude oil is subjected to distillation, whereby the products obtained are, after condensation, divided into fractions according to their specific gravity, color and special properties. These fractions, called distillates, are in most cases subjected to a purifying process consisting of a successive treatment with chemicals (sulphuric acid, caustic soda, etc.). The residuum is utilized for the manufacture of lubricating and heavy oils, and as fuel, etc.

Location of a Refinery.

The choice of a suitable place for an establishment of this kind is of prime importance. A mistake in this matter will probably be fatal. The close competition will not allow anything short of minimum charges in the way of transportation of the crude material or any deficiency in the convenience of placing the refined product directly in the hands of consumers; whether this be intended for export or for the home trade. If the oil is intended for export it is manifest that the refinery should be so situated that sea-going vessels of large tonnage may receive their cargoes at the wharves immediately adjacent to the works. It is also of great importance that they be located with reference to railroad facilities, whether the crude oil be received through pipe-line or not, for the reception of supplies of coal, sulphuric acid, etc. Formerly the largest refineries in this country were situated in the oil region, or at least upon the line of the railroads issuing from that section. They were usually built upon the sides of hills; the storage tanks being placed upon the highest points, so as to admit of the crude oil flowing by gravity into the stills. A few establishments of very large size were thus placed on the banks of the Allegheny River, a few miles outside of Pittsburg. The supply of crude oil was brought to them by the Allegheny Valley Railroad, switches from which road entered the works, both furnishing the crude and receiving the refined product.

The establishment of the pipe-lines and the growth of the export trade have entirely changed the condition of affairs, which at one time in the history of the oil business made such locations highly advantageous. In this country, the largest works now in operation are at Hunter's Point and Newton Creek, Long Island; Bayonne, New Jersey; Point Breeze, at the junction of the Delaware and Schuylkill Rivers, Philadelphia; at Thurlow on the Delaware River, a few miles below

Chester, and also near Baltimore, Maryland. Besides the facilities of shipment these refineries have the advantage of being in close proximity to large manufactories of sulphuric acid and chemical fertilizers, which purchase and utilize in the manufacture of super-phosphate of lime the immense quantities of refuse acid daily discharged from them. In this country, as well as in Russia, the crude oil is, as a rule, carried by means of pipe-lines directly into the still or smaller reservoirs. In other regions where these means of transportation do not exist (Galicia, Roumania, Germany, and some portions of America) the crude oil is transported either in the primitive way—in barrels—or, in more modern refineries, in tank-cars.

In Russia most of the refineries are located at Baku, in the portion called Blacktown (Tschorny-Gordog). The ground on which the refineries stand belongs to the City of Baku, and the proprietors rent from the city lots of about 50 x 40, or 40 x 60 sachens.[1] The average rent per year is 100 rubles per 1000 square sachens, and since a refinery of medium size, producing about 100,000 pood of kerosene per annum, requires about 1000 square sachens, the rent for 1 pood of kerosene amounts to 0.1 copeck, besides a so-called value-interest (ozenotschni) of 0.15 copeck per pood.

A soft shell limestone with clay as mortar serves as building material; lime, which is very expensive, being used only in rare cases. The latter is chiefly burnt at Surachani, the holy fires being utilized for the purpose, and one pood of it delivered at Baku costs 10 copecks.

Preparatory Operations.

The crude oil when delivered is stored in tanks to settle, whereby mechanically admixed water, mud, sand, etc., are separated. This settling is of prime importance, and in refineries possessing no large tanks the clearing of the crude oil may be effected by coupling several smaller tanks. Filling the stills with dirty crude oil may cause various disturbances. In-

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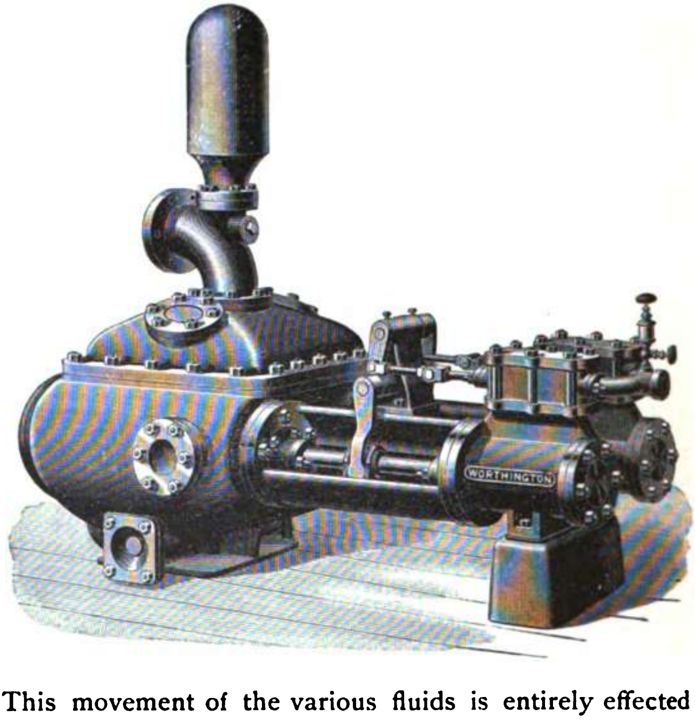
[1] 1 sachen = 2.134 meters = 7 feet 1.213 inches.

dependent of the greater consumption of fuel for the evaporation of the water and the danger of the oil rising too much, the portions of the still exposed to the fire may become red-hot and be prematurely destroyed in consequence of mineral sediments depositing on the hot still walls.

Formerly the crude oil was exclusively received in barrels which were rolled from the cars upon a skid placed upon the receiving tank, buried in the ground; the bungs being knocked out, the contents were allowed to flow through a sieve, or wire screen, into the tank. At present the crude oil is generally received in iron tank cars which are run on the track alongside of the works; a pipe commensurate with the capacity of the car runs parallel with the track; it is fitted with a number of openings at distances from each other equal to the length of the tank cars. These are each provided with a vent underneath, to which is fitted a flexible pipe and stop-cock, and when all the connections are thus made between the cars and the underground pipe, the stop-cocks are opened, the oil flows into the pipe, the steam pump is set to work, and in a very short time the contents of a train of cars are placed in the storage tanks. The large refineries near New York and at Point Breeze, (Philadelphia), Pittsburgh and Cleveland, and a few other places, are connected with the pipe-line service. The oil is received by these through the pipe-line directly into the storage tanks. In some cases the oil is conveyed a part of the distance from the wells through pipes, and delivered at this terminus in distributing cars, from which it is placed in tank cars and conveyed in these to its destination. Formerly the contents of the tanks or cars were determined by the actual measurement in cubical inches regardless of the temperature; but as it is well known that oil is subject to the same changes of volume according to the temperature that other liquids are, the measurements of oil are now made to conform to the same law, and hence extensive and most comprehensive tables have been formulated to assist in the ready computation of the contents of any vessel designed to contain it.

The oil business is of such a nature that not every mode of working customary in other industries can be employed in it. The operation consists, with the exception of isolated modifications, in a continuous circulation of liquids, viz., of the crude oil from the storage tanks to the stills, of the products of distillation from the respective reservoirs to the refining apparatuses, of the finished products into tanks, and from there finally into barrels and cases for shipment.

FIG. 70.



This movement of the various fluids is entirely effected by means of pumps, the pumps used being either such as transmit the oil, water, etc., by suction, or air-pumps (compressors) of special construction which, by pressing upon the fluids (oil, acid, lye, etc., in closed vessels), forward them.

For working on a large scale suction pumps are to be preferred, as they can more rapidly be set to work and disturbances are more certainly avoided. On the other hand, air-pumps are very suitable for working on a smaller scale, they having the advantage that the fluids (oils) remain free from water; while in working with suction-pumps, especially with direct-acting steam pumps, some condensed water is unavoidably carried along with the oil, which has a disturbing effect upon the finished product or upon the oil to be refined, the oil in the first case being liable to be turbid, and in the latter, a dilution of the chemicals used would be the consequence.

The direct acting steam pumps mostly used in this country are the Worthington pump, Fig. 70, and the pump manufactured by the Knowles Steam Pump Works of New York, Fig. 71. Both these pumps are distinguished by their quiet and uniform running and their small consumption of steam.

FIG. 71.

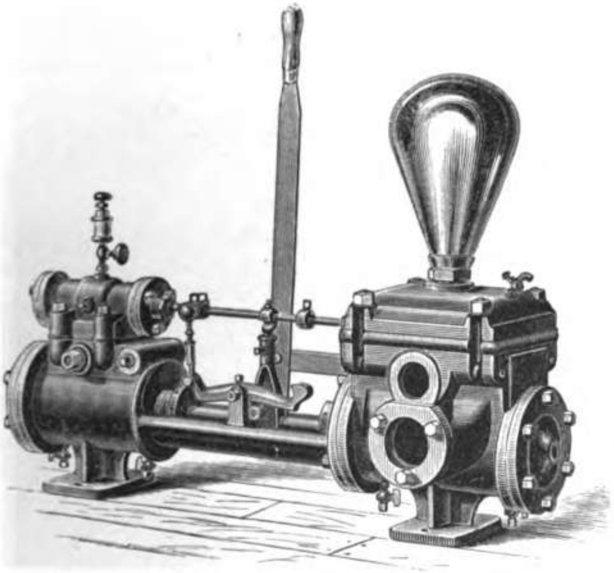


Fig. 72 shows a compressor manufactured by the Knowles Co. The greater the proportion of the steam piston to the air—or compression—piston is, the greater the power of these

FIG. 72.

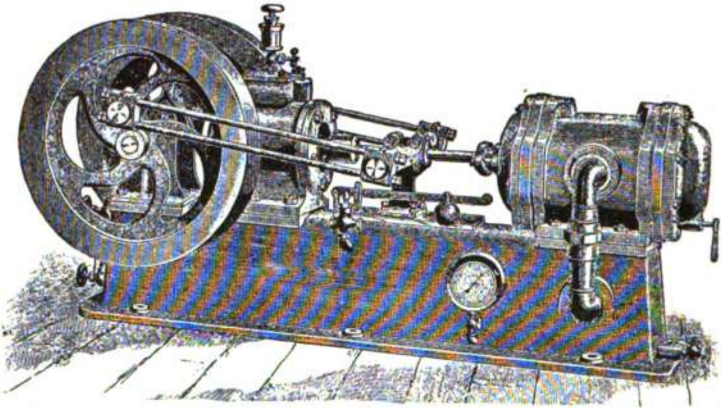


FIG. 73.

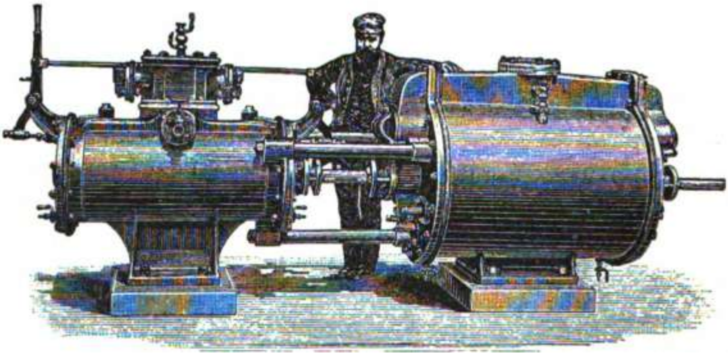
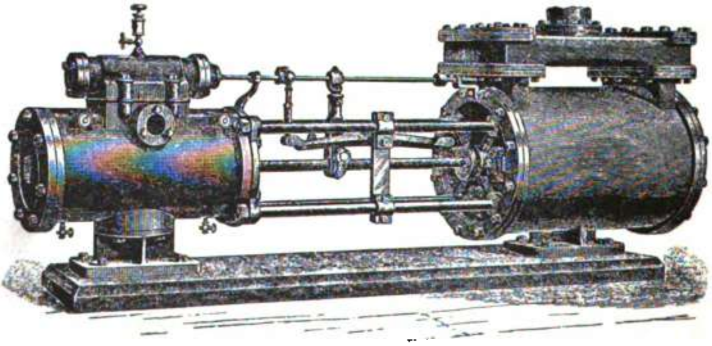


FIG. 74.



pumps. The air piston requires to be constantly cooled, since the air and the piston are heated by the rapid rotation and strong friction.

The process of treating the oil with chemicals, which will be described later on, is assisted by the introduction of air. Figs. 73 and 74 show such air pumps for mixing the oils with chemicals in the refining apparatuses. The principal requirements of such pumps are: quiet, uniform running, the suction of large quantities of fluid at one time, and a correspondingly long stroke. As a rule, air-pumps sucking 785 to 1,309 cubic yards of air per hour suffice to keep 22,000 to 33,000 gallons of fluid in constant agitation.

Distillation.

The crude oil, being freed from mechanical admixtures by settling, is subjected to distillation. This operation consists in an evaporation of the constituents of the crude oil, which mostly distil over without being decomposed and are then again condensed. The object of this fractional distillation is to obtain products which, after having been subjected to further purification, are more or less limpid and transparent, and answer all demands for illuminating purposes. As petroleum in its crude state is composed of an almost indefinite number of differently compounded hydrocarbons, varying in volatility, and as the manufactured products are almost countless in number, it will be readily understood that the methods of manufacture must be many, complicated and delicate. In the early days of the industry but one product—refined oil—was sought for, and today the staple article of manufacture is the same product, secured, however, in many grades. But the possibility of producing other valuable products soon became apparent, and each year, experience and study in the art, have developed an almost unlimited extension of the uses of petroleum.

The distillation of crude oil is, however, not of modern origin. Thus Johann Lerche who, in 1735, visited the Caspian Sea, writes that the petroleum found in the Caucasus did not burn when used in its original state; but when distilled it was obtained of a pale yellow color and limpid as alcohol, and was readily ignited. Although later travelers do not mention petroleum, it is a well-known fact that the inhabitants of the Caucasus were at an early date familiar with the distillation of naphtha. Certain it is, that the brothers Dubinin, serfs of the Countess Panin, had, as early as 1825, fitted up a still at Mosdok. Some communications regarding the operations of the brothers Dubinin, are found in the archives of the chief administration of the Caucasus, and in documents of 1846, in which they solicited from the government a reward for their efforts in introducing and propagating the distillation of naphtha in the Caucasus.

In their petition to Prince Woronzoff, they mentioned some of the authorities and inhabitants of Mosdok as witnesses that they had carried on the industry since the year 1823, and had instructed many of the Don Cossacks in the art of "converting black naphtha into white." For this, and to assist them in further efforts, they asked the government for a loan of 7,000 rubles for ten years without interest. For various reasons their request could not be granted, and their experiments fell gradually into oblivion.

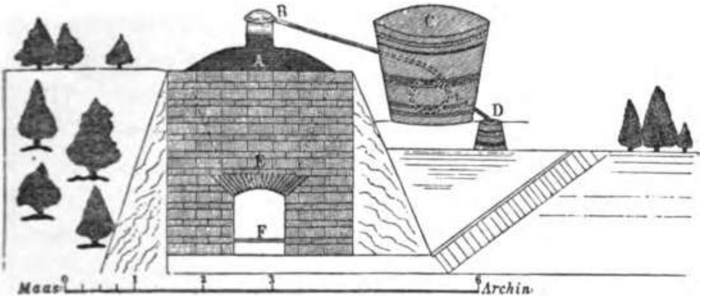
The process of distillation as well as the arrangement of the plant was very primitive. With a description of their process the brothers Dubinin also furnished a sketch of their factory, which is still in the archives. Fig. 75 is a copy of their drawing. *A* is an iron boiler bricked in an oven; this boiler had a capacity of 40 buckets full of naphtha. *B* is a copper lid for covering the boiler after filling. *C* a copper worm leading from the lid and passing through a vat containing water. *D*, a wooden bucket for catching the "white naphtha." *E*, brickwork. *F*, fire-place with draft.

From 40 buckets of black naphtha they obtained 16 of white. The white product thus obtained was not furthur purified, but was sold in Nishni Novgorod.

In the United States experiments in distilling petroleum were also made at an early date. Professor Benjamin Silliman, Sr., in 1833, wrote:[1] "I have frequently distilled it in a glass retort, and the naphtha which collects in the receiver is of a light straw color and much lighter and more inflammable than petroleum. On the first distillation a little water rests in the receiver at the bottom of the naphtha, from which it is easily decanted, and a second distillation prepares it perfectly for preserving potassium and sodium, the object which has led me to distill it."

In 1862, Isaiah Warren and his father, being in the lard oil and candle trade in Wheeling, West Virginia, commenced the distillation of West Virginia petroleum in three 15-barrel stills. The stills in general use at this time were made in three parts, bolted or riveted together, and consisted of a cylindrical cast iron body, to which were attached a boiler plate bottom, and a cast iron dome and goose neck. They held about 25 barrels, were heated from the bottom and bricked up on the sides, and were sometimes protected from the direct action of the fire by fire-brick. These stills were charged with crude oil, the charge run off, the still cooled, and the coke cut out, often with a cold chisel. When four-fifths of the oil had been run off, the remainder was, when cold, as thick as pitch. At this time some of the refiners introduced steam, which mechanically expanded

FIG. 75.



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[1] Am. Jour. Science and Arts, (1) xxiii, 101.

and carried over the last volatile portions of the charge, leaving a compact coke, while others distilled to coke without steam. The use of superheated steam in the distillation of natural petroleum was, in 1860, introduced in this country by Mr. Wilson, a manufacturer of stearic acid. Steam under moderate pressure was also frequently used throughout the entire distillation, both above the charge and injected through it. In the latter case it becomes superheated, as the boiling point of the oils rises above that of water. It was, however, considered preferable with the dense paraffin oils to superheat the steam before it entered the oil. Sometimes, after the charge in the retort was partly run off, it was the practice to allow a stream of fresh oil to enter the still about as fast as the vapors were condensed. In this way about twice the ordinary charge could be distilled and the residue of the whole run down to coke. The light naphthas were first taken off and were used for fuel. The distillate was then run to illuminating oil until the specific gravity reached 36° Bé. = 0.843, and the remaining charge run down till the distillate became of a greenish color.[2] Some manufacturers redistilled the illuminating oil and refined it.

Crude Oil Stills.

Experience has narrowed the style of stills down to two, their competing merits being a source of much controversy among practical men. These are known as the cheese-box and cylinder stills.

The *cheese-box still* is shown in Figs. 76 and 77. It is 30 feet in diameter and 10 feet in height. It is supported by circular brickwork in which are built 17 fire places, all communicating with a central flue. The bottom has a double curvature. The discharge pipe of the still enters on the side; on the inside is a swing-joint suspended by a chain wound around a shaft which is operated from the outside of the still. From

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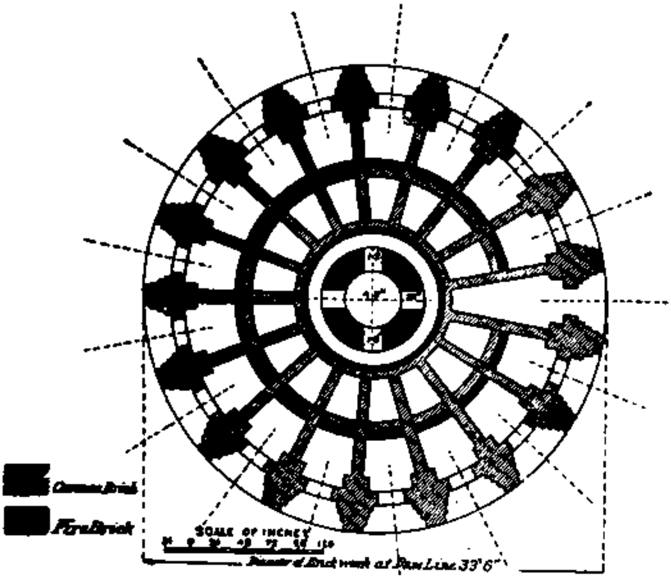
[1] Jour. Franklin Institute, 338, 1860.

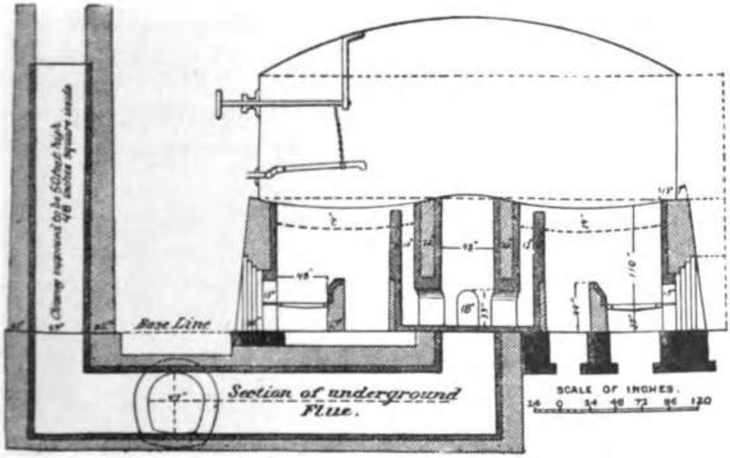
[2] S. F. Peckham. Report on Petroleum.

FIG. 76.



HORIZONTAL SECTION OF CHEESE-BOX STILL SETTING.

FIG. 77.



VERTICAL SECTION OF CHEESE-BOX STILL SETTING.

the top of this still project three pipes, each connecting with a drum stretching across the whole diameter of the still. From this drum proceed 40 3-inch pipes leading into the condensing tanks. In some stills, at the point where the vapors pass into the drums, a perforated steam-pipe is placed. This is employed only during the "cracking" process, and is thought to greatly improve the quality of the oils, both in respect to color and gravity, although the arrangement is not to be found in many refineries.

The still is provided with man-holes, for the double purpose of allowing the workmen to enter and clean it, and occasionally to inspect its condition. One is placed upon the top of the still, a second near the bottom plate, which allows the refuse coke to be conveniently thrown out. The covers of these man-holes are generally fastened in their places by means of screw-bolts and nuts. Many of the most expert and careful refiners use pyrometers in their stills; they are often of great assistance both to the fireman and the distiller. Large size stills are built of the very best quality of boiler-iron, of $\frac{3}{8}$ or $\frac{5}{16}$ inch thickness, securely caulked. The bottoms are of steel of the same thickness. The increased expense in the use of steel for the bottoms is more than compensated for by their enhanced durability and safety.

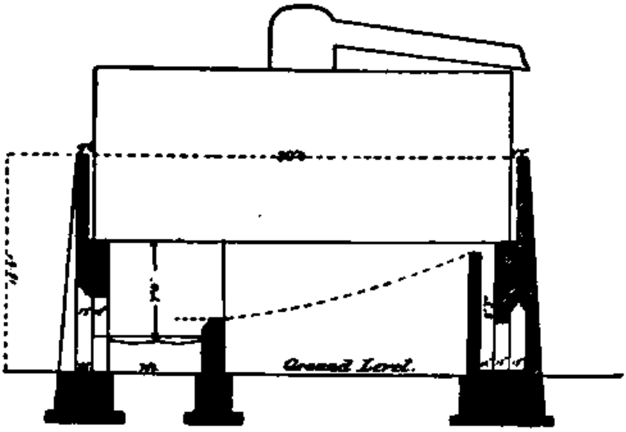
The still is provided with steam-pipes both closed and perforated. The steam issuing in jets from the perforated pipe has been found to facilitate distillation by carrying over mechanically the oil vapors.

Cylinder stills. Diagrams of a cylinder still much used in this country are represented in Figs. 78 and 79. The stills are frequently set in banks of two or more, there being considerable economy in thus placing them. The still is a simple horizontal steel or wrought iron cylinder 12½ feet or a little more in diameter and thirty feet or a little more in length.

A cylinder of this size holds about 600 barrels of crude oil, and is the size generally found at the seaboard works.

A circular dome about 5 feet in diameter and 4 or 5 feet high is set on the top of the still in the centre as an outlet for the rising vapors, a wrought-iron gooseneck 15 inches in

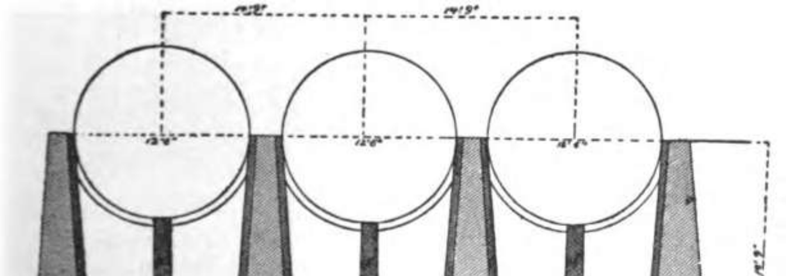
FIG. 78.



LONGITUDINAL-VERTICAL SECTION OF CYLINDER-STILL.

diameter conducting them to the condensing apparatus to be described later on. The still rests on brick-work which sur-

FIG. 79.

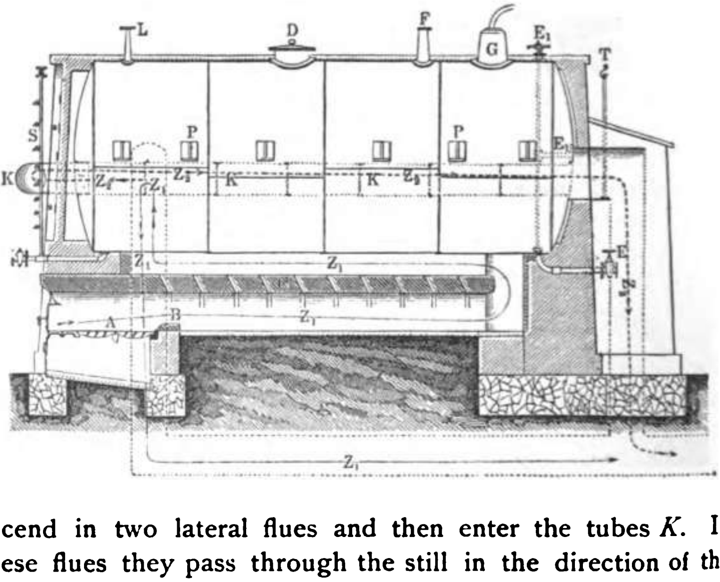


TRANSVERSE-VERTICAL SECTION OF CYLINDER-STILL.

rounds the lower half, the upper half being left exposed to facilitate the "cracking" or destructive distillation of the oil. A double fire-box is built under the front quarter of the still, but, by having the flue for the exit of the gases of combustion in the rear, the heat is applied to the whole length of the bottom and well upon the sides of the cylinder. The still is also provided with man-holes, with steam-pipes of various plans, charging and draw-off pipes, gauges, vacuum and pressure valves, etc.

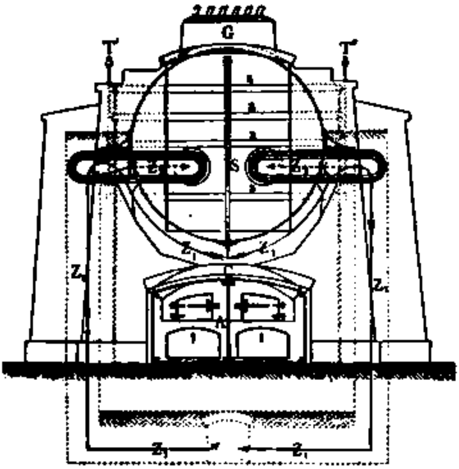
Another form of cylinder still is shown in Figs. 80 and 81. The still is suspended to the brackets *P*, while both ends of it rest upon brickwork. The gases of combustion pass in the direction of the line Z_1–Z_1, below and then above the arch *C*, ascend in two lateral flues and then enter the tubes *K*. In these flues they pass through the still in the direction of the line Z_2–Z_2, and enter the chimney at the back. The tubes *K* of riveted sheet iron are, on the one hand, connected with the lateral tubes, and, on the other, pass through the front plate of the still. They traverse the entire length of the still, pass out through the back plate, and enter the chimney. When the

Fig. 80.



still is filled and in operation, the gases of combustion traverse the described passage; they ascend in the lateral flues and, the slide T being open and the slides T_1 and T_2 closed, they pass through the tubes and reach the chimney. When distillation has progressed so far that the level of the oil is below the tubes, the slide T is closed and the slides T_1 and T_2 are opened; there being no draught in the tubes, the gases of combustion then pass directly into the chimney. The whole arrangement is very advantageous, it allowing of a ready regulation of the operation and thorough utilization of the heat. It has, however, the disadvantage of the operation being more dangerous. The heating tubes must be very carefully made, otherwise they may become leaky and constitute a source of danger from fire.

FIG. 81.



This form of still is suitable for working larger quantities of oil, and the heating being very intense, it may be given a capacity of from 400 to 700 barrels. The thickness of the boiler-plate for constructing the still should be in accordance with its capacity and somewhat greater than for other stills, since the arrangement of the fire tubes requires a stronger construction.

The still is provided with all other contrivances previously described, such as man-holes, steam-pipes, gauges, etc. On account of its greater capacity the gas dome is larger and it is provided with a greater number of condensing pipes, generally from five to seven. The discharging contrivance with the valve E_1, which is regulated from above, may be highly recommended. It consists of a round rod, which carries on its lower end a valve that fits in a valve-seat; the upper end of the rod passes through a stuffing box. For opening or closing the valve the rod is not turned, but lifted by means of a toothed gearing. This seemingly slight circumstance is of great importance, since, if the rod were turned and not lifted, it might be readily twisted in consequence of changes of temperature in the still, whereby the valve would be rendered useless. For indicating the level of the fluid in the still in some refineries a contrivance S is used, which will be described, without, however, recommending its employment.

The arrangement is readily understood from the illustration. On the outside of the still a vertical pipe is connected by a horizontal pipe with the lowest point of the still. On the vertical pipe, at determined distances from each other, are small test-cocks; by opening these cocks the level of the fluid in the still may be ascertained. The disadvantages of this arrangement may be readily understood. In order to control it the tube must be placed on the front of the still, hence near the position of the stoker. By the careless opening of a cock or leakage of the connections, the oil may readily reach the fire and ignite; thus a fire was actually caused in a large Buda-Pesth refinery.

The so-called *wagon still* derives its name from its resemblance to an American passenger railway car. Figs. 82 and 83 show a form of this still used in Baku. It consists of the box-like still *A*, of wrought iron plates riveted together. It is 23 feet long, 14 feet in diameter and 10 feet high (counted from the deepest part of the bottom to the dome). It is provided with three domes *a* which convey the vapors to the condenser; *b* is a man-hole, and *c* three pipes for the discharge of the residuum. The arrangement of the stays in the interior of the still, as well as the brick work with flues B and B_1 is plainly shown in the illustrations. In order to protect the bottom of the still the flame of the residuum-burners *c*, which open into the arched flues B and B_1, first strikes through beneath fire-proof arches, turns at the end of the still, the bottom of which is there pro-

FIG. 82.

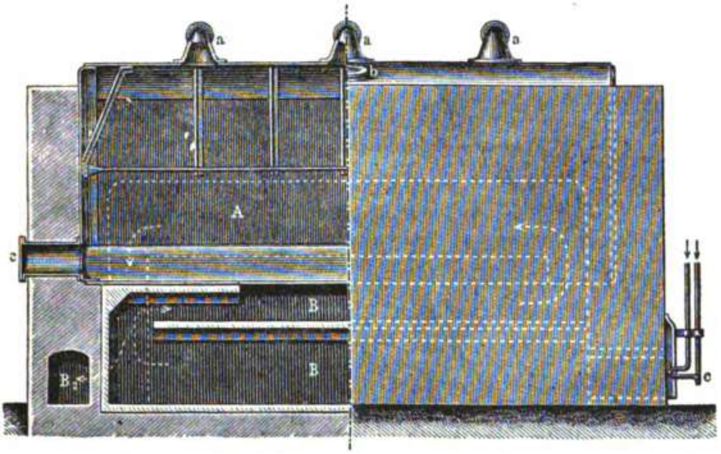
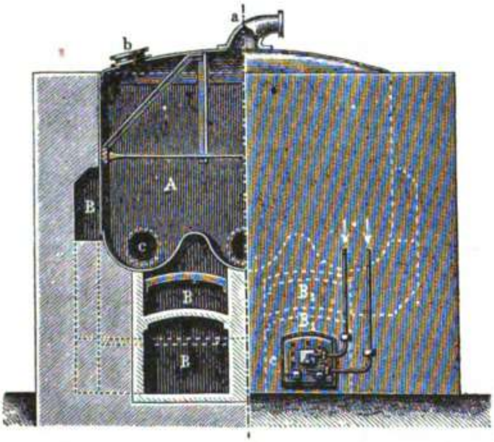


FIG. 83.

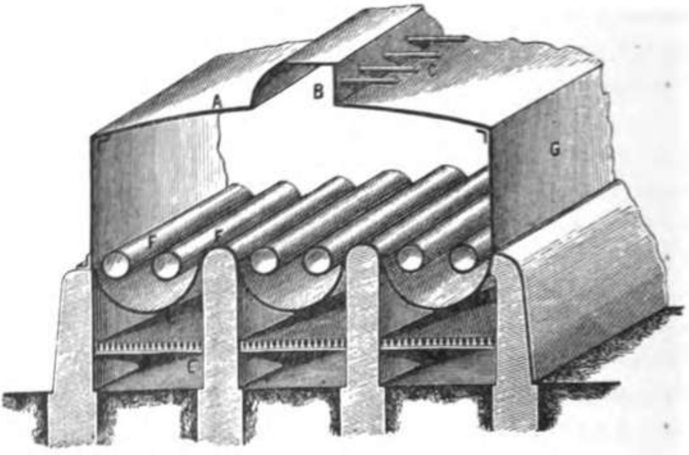


tected by fire-bricks, to the front, ascends, turns on both sides of the still, first backward then downward and escapes into the chimney through the flue B_1.

With a capacity of such a still of over 77,000 lbs., and a charge of 66,000 lbs. of crude oil, 2½ distillations, hence 154,000 to 176,000 lbs. of Russian crude naphtha, can be distilled in 24 hours, which corresponds to a daily production of from 44,000 to 55,000 lbs. of illuminating oil from Caucasus crude oil.

The wagon still shown in Fig. 84 has a length of about 46 feet and a capacity of 2,500 barrels. To utilize the heat or the hot gases to the best advantage, the bottom has three tray-formed depressions, in each of which lie two flues *F*. The flame strikes at *E* backward beneath the bottom, then forward through both the flues, and passes into a chimney. Each depression is provided with a fireplace and chimney, and has on the front side a tar-hole, which is closed like a manhole, and serves for the discharge of the residuum. The cap *A* carries on the end opposite the fire-place the pipe conveying the supply of crude oil, and running its entire length, a headpiece, *B*.

FIG. 84.



to one side of which are fitted 35 pipes, *C*, each 2½ inches in diameter. These pipes are uniformly distributed and serve for carrying off the gas and vapor. They all lead to a condenser, which may also receive the pipes of another distilling apparatus.

The stills are frequently heated with crude oil, or the residuum. The arrangements for this purpose will be described in detail in speaking of the use of petroleum as fuel.

In some refineries superheated steam is used as fuel, but the expense of operation is thereby much increased, since the quantity of coal required for the generation of steam and its superheating is considerably greater than that needed for direct heating. Although with the use of steam decomposition of the crude oil does not readily take place, the products of distillation are of less value than those obtained by direct heating, because the directly acting superheated steam carries along particles of heavy oil and even of crude oil, and thus contaminates the distillates In the production of lubricating oils, superheated steam, however, plays an important part, and in speaking of them, its nature and generation will be discussed.

Where crude oil is comparatively dear, and other fuel is not cheaper, coal is used for direct firing.

No general rule can be laid down for the choice of a fuel; that which is cheapest and most readily obtainable will of course be used. A comparison of the different varieties of coal shows, however, that the quality of the fuel deserves due consideration, since the consumption of fuel is less and the operation can be more readily regulated by the use of the best quality of coal.

The *gas dome or head* forms an important part of the still. Drops of oil carried along with the gases are retained in it, and it is, therefore, advisable to insert in it nets to prevent the oil from spurting over. In many refineries, chiefly at Baku, a special dephlegmating contrivance is placed between the dome and the still to retain the heavy oils which are mechanically carried along; they either run back into the still or are directly drawn off. This arrangement is of advantage only in working crude oils poor in illuminating oil.

The head or gas dome is of various forms and its location on the still differs in different constructions. The old bomb-shape with goose-neck has been abandoned, at least in refineries working on a large scale. Its present form is, as a rule, that of a cylinder with a circular or an elliptical cross section. For more rapid cooling it is generally constructed of wrought iron, and seldom of cast iron. Its proportions should be in accordance with the capacity of the still. With too small a dome condensation proceeds badly, since the still evolves proportionally more gases than the dome can hold, which, in case they cannot escape from the still, produce a tension in the latter and cause disturbances in the distillation. With too large a dome condensation is also defective on account of the heavy parts being readily carried along. For the distillation of crude oil a larger dome is used than for the distillation of the residuum, because in the first case stress is laid upon a partial condensation, while in the latter case provision has to be made for the rapid conveyance of the gases.

The dome is generally placed on the highest point of the still, though on very large stills it is occasionally found on the side. It should always be on the side of the still nearest to the condensing apparatus, so as to make the connection with the latter as short as possible. There are, however, many stills with the dome on the opposite side or in the centre of the still. The connection of the dome with the condensing apparatus is effected by means of pipes, the number and shape of which vary very much. Frequently a single conical pipe, which starts from the side of the dome and becomes gradually narrower, forms the connection with the condensing apparatus. But the use of several pipes is advisable. They consist of 3 or 4-inch gas pipes which rise either from the lid or from the side of the dome. The inclination of the condensing pipes is also of importance, because as a part of the condensation—namely, that of the heaviest oils—takes place in the dome and in the pipes by air-cooling, it will be readily understood that with inclined pipes a portion of the heavy oils will flow back into the still and be decomposed on its superheated sides. This is the case if the condensing pipes are but slightly inclined. In arranging the distilling apparatus, it is, therefore, recommended to take the composition of the oil into consideration. If oils poor in illuminating oil are to be worked, the dome should have a more elliptical cross section and the pipes leading to the cooling apparatus should be slightly inclined. By this means the heavy oils carried along condense sooner, become decomposed and increase the yield of illuminating oil. On the other hand, when working oil rich in illuminating oil, or when the residuum is to be utilized, horizontal pipes or pipes with a slight downward slant are used.

Condensing Apparatus.

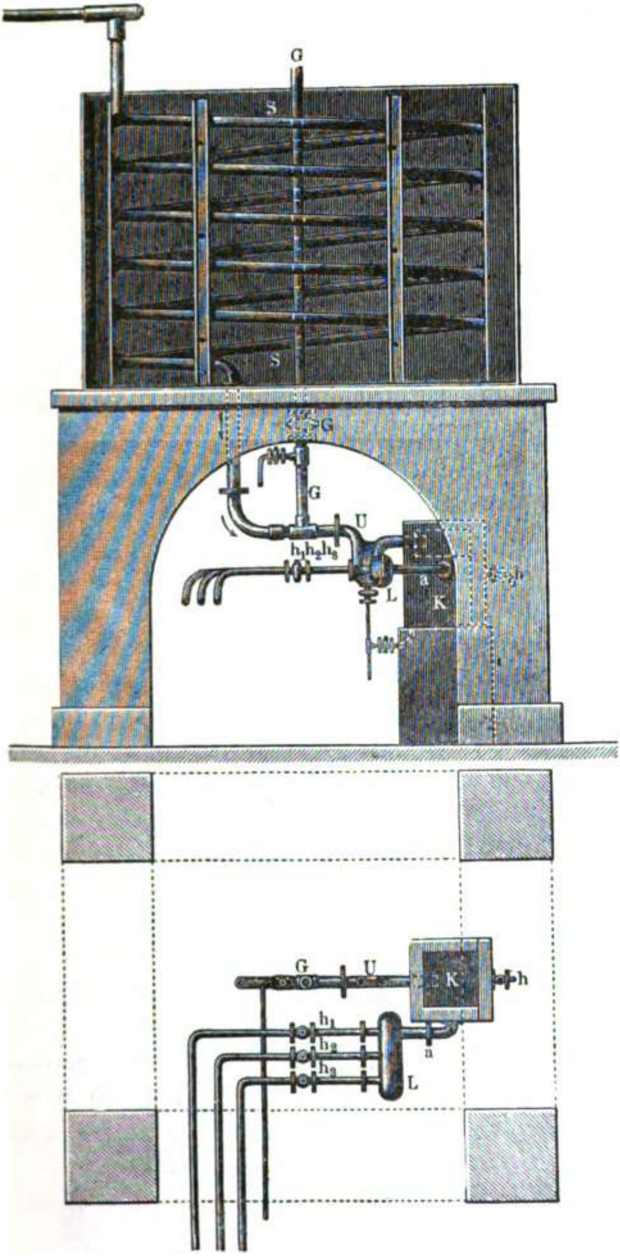
The condensing apparatus serves for condensing the vapors of the crude oil evolved in distillation. The portion of the apparatus intended for the absorption of the latent heat of the vapors is generally constructed of copper or iron, these metals being good conductors of heat. Successful condensation depends on the size of the cooling surface and the temperature of the surroundings; the lower the latter the smaller the cooling surface may be, and *vice versa.* Cooling is, as a rule, effected by means of water, though in exceptional cases air is used for the purpose. Crude oil or residuum is occasionally used for cooling, for instance, in winter when the water in the condensers freezes; this effects at the same time a saving in fuel in consequence of the preparatory heating of the oil or residuum. In the practice condensers with a much greater surface than necesssary, according to calculation, for the mere condensation of the vapors to a fluid are used, the purpose being to cool the latter to such a degree that even the lightest portions cannot volatilize. In many refineries at Baku and also in the United States the distillates leave the condensing apparatus warm and even hot, the cooling water being not changed and even allowed to become boiling hot. It is claimed that by this means distillates with a high burning point are obtained. The disadvantage of such an arrangement will be readily understood when it is considered that the advantages claimed are effected at the expense of quality and yield.

The cooling of the vapors is effected on the sides of the pipes, no actual condensation taking place in the interior. Hence the condensing surface is augmented by an extended pipe system with a narrow cross section, the relative cooling surface being thereby increased. It must, however, be taken into consideration that with the use of too narrow pipes, distillation and condensation may be disturbed by friction in the pipes. For pipe condensers the counter-current system is decidedly the best; the cold water on entering the condensing apparatus meets the completely condensed oil and only cools it off. On passing through the pipes the water becomes gradually warm and meets hotter, though condensed products of distillation, so that at the point where it leaves the apparatus it is just capable of condensing the oil vapors.

The use of air for condensing purposes is not practicable, since in consequence of its slight capacity for heat and its bad conducting power the apparatus would be required to be much larger (nearly two hundred times as large) to produce the same condensing effect as water. Air can only be used with advantage in winter, but it is absolutely necessary in the production of machine oils, etc., which will be considered later on. In case of a lack of water and great differences in temperature between the seasons of the year, a form of condenser in which water condensation is supplemented by an arrangement for aërial condensation is employed.

Originally condensers were of copper coils, which were soon supplanted by coils of iron pipe in an iron tank. Coils of pipes are still sometimes used, but the general plan for condensers is to have straight pipes of convenient lengths laid one above another and connected together by return bends or manifolds in a rectangular box of iron or wood. The arrangement is shown in Fig. 85. The worm *S* consists of straight pipes connected with each other by knees. The arrangement

FIG. 85.



of the separate pipes in a square is effected by each pipe joining the preceding with a slight fall, so that the product of condensation flows slowly through the pipe-system and is thus completely cooled. According to the quantity of the products of distillation the dimensions of the pipes and their number have to be changed, whereby it must, however, be taken into consideration that increased condensation improves the yield. For a still having a capacity of from 500 to 700 barrels, a condensing apparatus consisting of six rows of pipes each from 5 feet to 10 feet long suffices. The initial diameter of the pipes should be 9¾ to 7¾ inches with a gradual reduction to from 1¾ to 3 inches. Such reduction of the pipe system is advisable, since by successive condensation the volume of the products of distillation is gradually decreased.

The pipes are held together by an iron frame, and lie, as previously stated, in a box of iron or wood. The supply of water enters at the lowest point, while the heated water leaves the box through an overflow-pipe. Although this condensing apparatus is much used, it cannot be recommended in all cases, its principal advantage consisting in that it occupies the least space. Its form, however, is a disadvantage, since paraffin and sulphur may readily deposit, causing obstructions in the pipes and disturbances in the operation. This objection applies chiefly to spiral pipes, but also to pipes connected by knees. Hence provision must be made for the condensing water to run off much hotter, and experience has proved that with the use of this condensing apparatus more non-condensable gases are obtained and the distillates do not show such favorable behavior in the subsequent refining.

Closely related to the above described condensing apparatus is the pipe-condenser of cast iron described by Engler.[1] It consists of 24 cast iron pipes, becoming gradually narrower and communicating with each other. The pipes are arranged in series of fours lying one above the other, and series of sixes lying one alongside of the other.

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[1] Dingler's Polytech. Jour., 260, 438.

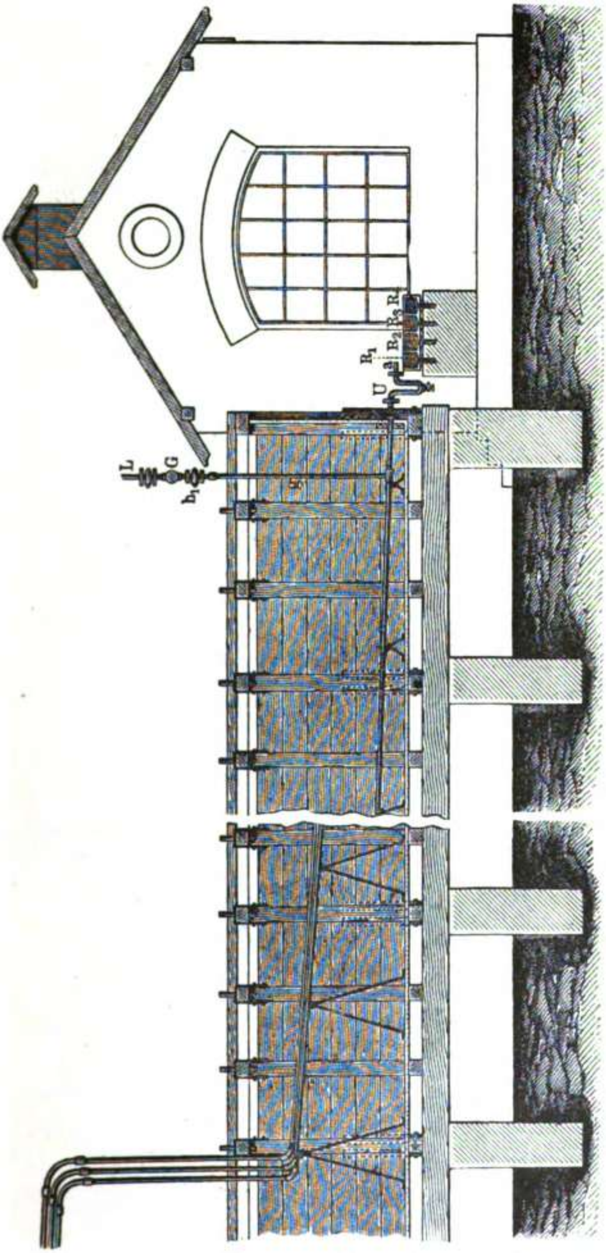
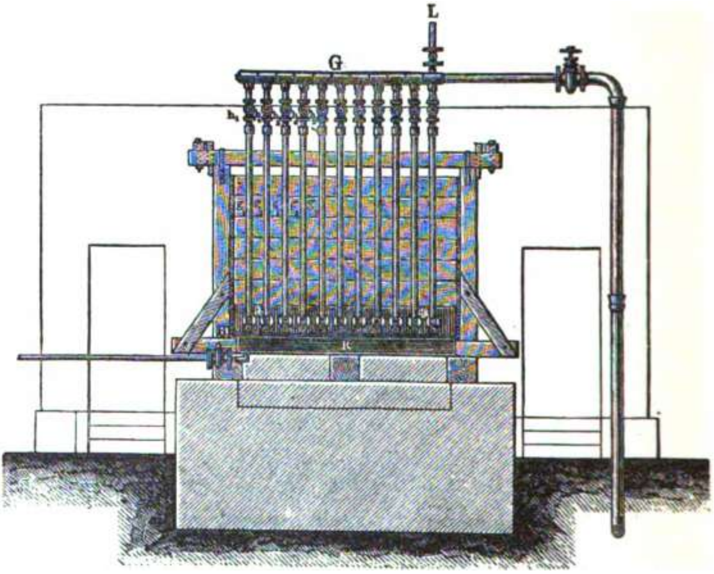


Fig. 86.

Parallel pipe condenser. Where space permits the parallel pipe condenser with straight pipes may advantageously be used. Figs. 86 and 87 show the arrangement of this system. It consists of a spacious wooden box 295 to 328 feet long. The entire structure rests upon strong pillars, and must be so joined together with a strut-frame that no leakage and sinking of the box can be caused by the pressure of the water and the pipes, as well as by changes in the temperature of the water. The front sides of the box generally rest upon a small structure which contains the contrivance for distributing distillates to be described later on. The arrangement of the pipes is very simple, From the gas dome the aërial condensing pipes lead with a slight inclination to the condensing apparatus, turn off at a right angle above the latter, and with a slight fall run parallel the entire length of the condensing apparatus to the arrangement for distributing the distillates. The pipes rest upon supports which gradually become lower. The

Fig. 87.



diameter of the pipes at the dome is, as a rule, about 3 inches, but is gradually reduced to about 1½ to 1¾ inches where the pipes leave the apparatus. The pipes are connected one with the other by coupling boxes. This simple arrangement makes stoppages next to impossible, and the length of the pipes insures perfect condensation. The water enters at the lowest point near the bottom and runs off through an overflow-pipe on the other end. Repairs are seldom necessary. From time to time, generally once or twice a year, the water is drawn off to clean the pipes from an accumulation of mud.

Another form of condensing apparatus, which is, however, seldom used, is the so-called box-condenser. It consists of a closed box with perpendicular pipes through which the water circulates, while the condensation of the oil vapors is effected in the box. With this arrangement condensation must, of course, be incomplete and irregular.

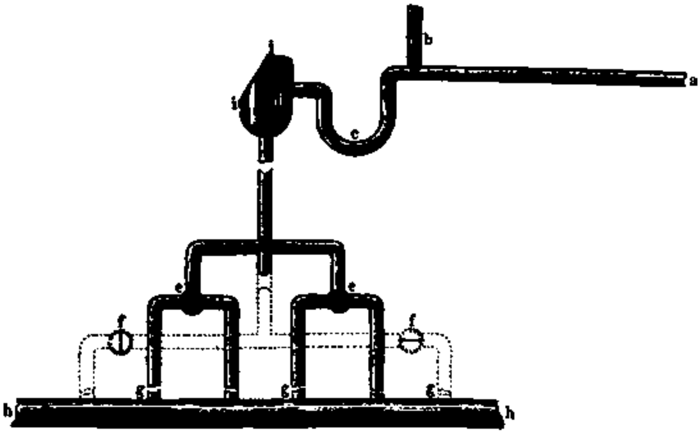
Lawrence's system of condensation has recently been introduced in some refineries, and found to work quite satisfactorily. It consists of a tall, narrow box, the longitudinal sides of which are made of corrugated metal. The oil vapors circulate in the interior, while cold water constantly runs down on the outside of the box, and by its evaporation reduces the temperature of the oil, whereby, it is claimed, a more powerful condensation is effected.

Distribution of the Distillates and Catching of the Gaseous Products.

There are various means of regulating the discharge of the distillates from the condensing pipes; in the most simple form they run directly from the condensing pipe into the storage tank, while the non-condensable gases pass out from the end of the pipe. In well arranged refineries a distribution of the products according to their properties is effected at the point where they leave the condenser, a contrivance being also provided for the purpose of separating and carrying away the gases. Such arrangements are shown in Figs. 85, 86, 87, 88.

In Fig. 86 the product of condensation passes from the condensing apparatus through the inverted siphon *U* into the box *K*. By this inverted siphon the gas is prevented from passing out with the oil, the latter forming, so to say, an automatic fluid seal. The gas is forced to pass into the open air through the vertical pipe *G*, or, by closing a stop-cock in this pipe and opening another in the branch-pipe *G*, is conducted either to the gas-holder, or further on and burned. The distillate enters the box *K* where the water which has been evaporated and condensed with the oil is allowed to settle, and is from time to time discharged through the cock *h*, while the oil runs off through the pipe *a* and the distributor *L*. This distributor consists of a cast-iron pipe provided on the sides with three or more branches with the cocks h_1, h_2, h_3, etc.; from the latter, pipes lead to the distillate tanks. For cleaning the syphon *U* and the box *K* small cocks are placed at their lowest points through which mud, etc., is discharged. The box *K* is provided with a small glass door, so as to enable the workman to control the color and course of the distillate. The specific gravities may here also be determined, and by closing or opening either of the cocks, h_1, h_2, h_3, the distillate be discharged in any tank desired.

FIG. 88.



Another very convenient arrangement for the reception and distribution of the distillates is shown in Fig. 88. It is much used in this country and is very similar in principle to the one previously described. The distillate enters at *a* and passes through the siphon *c*. The gases are forced to pass out at *b* while the distillate runs into the cast-iron box *d*. The latter is provided with the glass *i i*, through which the progress of the distillate can be observed. From the box the distillate runs through the distributing pipes, distribution being effected by means of the three-way cocks *e e* and the ordinary cocks *f f*. Through the pipes *g g g* the distillate runs into the collecting tanks.

In Figs. 86 and 87 is shown an open method of distribution tanks. With sufficient condensation and complete separation of the gases this method is, in many cases, to be preferred to closed distribution. The separation of the fractions is more simple, and, when several stills are in operation, the control of the progress and the quality of the distillates is more readily accomplished. As seen from the illustration, the arrangement is very simple. The distillates leave the condensing pipes *a a a* on the front side of the cooling box in the small building, pass through the siphon *U* and run according to their quality—which is regulated by the application of smaller or larger sheet-iron pipes—into the gutters R_1, R_2, R_3, R_4. These gutters of cast-iron are as long as the front side of the condensing apparatus and run parallel with it. On one end the gutters are provided with a small pipe and a cock *H*, by means of which the distribution of the distillates is effected. The condensing pipes *a a a*, at a short distance from the point where they leave the condensing apparatus, are provided with the vertical pipes g_1, g_2, etc., and with the cocks h_1, h_2, h_3. The gas shut off by the syphon ascends in these pipes and—when the cocks are open—through the horizontal pipe *G* into the gas holder, to be used for illuminating and heating purposes.

When in the commencement the evolution of illuminating gas is still slight, or when towards the end of the operation it becomes so large that the gas-holder cannot hold it, the cock *L* is opened and the gas escapes into the open air.

Tanks for the Distillates.

Through the distributing pipes the distillate runs into the collecting tanks, the size and number of which depend on the mode of working, so that no definite directions can be given in this respect. Regarding their arrangement the following may be laid down as a general rule: The total capacity of the tanks should, chiefly for the sake of safety, be at least equal to that of the still, because as they have to be at a sufficient distance from the still they form the first and safest place of storage for the oil, and in case a still should leak, its contents may be conducted into the collecting tanks through a provisional conduit.

The construction of the collecting tanks varies. They are, as a rule, of a cylindrical shape, closed in most cases and provided with man-holes. They are generally made of iron, though wood is sometimes used. They are now almost universally placed underground in order to give the distillate a free fall from the distributor; with the latter they are connected by a system of pipes. To prevent their contents from freezing they are provided with a steam coil, and at the lowest point are furnished with a contrivance for the discharge of the separated water. A contrivance may here be mentioned, which has been found useful in practice when it becomes necessary to pump one or the other of the fluids from a vessel containing two fluids of different specific gravities. For this purpose the suction pipe, which reaches nearly to the bottom of the vessel, carries a movable double elbow with a horizontal pipe. By lifting or sinking the elbow the fluid may be sucked off at every level.

Process of Distillation.

Distillation is carried on either periodically or continuously. Continuous distillation will be discussed later on. Periodical distillation is used everywhere, even in the largest refineries, when the supply of crude oil is not steady and sufficiently large.

The still is filled in the manner previously described by means of pumps, or from tanks placed at a higher level. To allow for the expansion of the oil, the still, according to its shape, is filled ¾ to ⅔ full. The crude oil is brought into the still either cold or preparatorily heated by the residuum, after which the actual distilling process commences.

The fire being kindled it is at first kept low, because if any water is present, which is recognized by a suspicious bumping, it is capable of hurling out the contents of the still, if there is not sufficient empty space. With a gentle fire the fluid is agitated without causing injury, and the first traces of the lightest products of distillation and of water appear in the condensing apparatus. The quantity of water constantly increases until the water in the still boils. This is designated "boiling of the still." The quantity of water then decreases suddenly, and a quite uniform stream of distillate runs from the "outlets." The fire is now somewhat increased and kept low only when oils containing benzine are distilled until the change to illuminating oil is made. During the distillation of illuminating oil a strong fire is kept up. When distillation has progressed so far that specifically heavier and darker oils appear, the fire is slackened, and the distillate runs off, even in the largest refineries, in a stream not thicker than the finger. At this stage of distillation a decomposition of the oil, the so-called "cracking," takes place. If circumstances permit to keep up distillation in this manner with a slackened fire, a considerable portion of the heavy oils may be converted into light oils and mixed with the illuminating oil.

According to the yield of the oils these general rules have to be modified. With oils poor in illuminating oil, the residuum of which is not very valuable, distillation must be forced more and the decomposition of the heavy oils can be continued longer than with oils rich in illuminating oil, or with oils the residuum of which is valuable for the fabrication of lubricating oils.

The products of distillation may be divided into two principal groups: *a*. Light oils, essences, or, as commonly called, benzine. *b*. Illuminating oil or petroleum. Distilling for heavy oils, after illuminating oil, is but seldom done in the crude oil still. The heavy oils remain in the residuum, which is discharged and then worked by itself.

The benzine obtained in distilling crude oil can but seldom be used as such, it being generally subjected to redistillation and purification in apparatuses to be described further on. Sometimes, however, a separation is effected while distilling the crude oil, and the product thus obtained is either used as it is, or subjected to chemical purification. The lightest products, such as petroleum-ether, etc., are generally caught, gasolene and ligroin being also obtained. This mode of working is, however, not advisable, because the products thus obtained are of less value; the carrying along of heavy oils with these light products being unavoidable, so that they can never be obtained free from fat and water-clear. In every well-arranged refinery working crude oils containing benzine, only one light product, viz., crude benzine, is obtained in distilling crude oil. The point at which the distiller "cuts off" his benzine and directs the product into the illuminating oil tank varies according to the kind of oil he manufactures, the quality of the oil being largely determined by local conditions, by the laws regarding the burning point, and by commercial usage. Where no importance is attached to the specific gravity and burning point, the distiller will endeavor to introduce into the illuminating oil as much as possible of the heavier constituents of the essences, and increase the gravity by the addition of heavy oils. In other localities he will separate as much benzine as is necessary to obtain a good product. In almost all civilized countries the test of 21° Abel[1] is the permitted limit. As a rule, a specific gravity of 0.740 to 0.760, which corresponds to a boiling point of 302° F., may be designated as the point at which the dis-

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[1] See Chapter on "Tests."

tiller should cut off his bezine and direct the product into the illuminating oil tank.

The properties, as well as the specific gravity, of the first product of distillation, viz., the crude benzine (also called crude naphtha) vary very much. It is a very mobile liquid of a slightly yellowish color, due to the presence of heavy oil, and of a penetrating odor caused by a very volatile body containing sulphur; its specific gravity varies between 0.700 and 0.730.

The second principal product of distillation consists of the illuminating oil distillate. When only an average quality is to be produced from a certain crude oil no further fraction is made, distillation being continued as long as color, specific gravity and inflammability will permit. The average specific gravity illuminating oil must show to be marketable varies in different localities. Thus the commercial varieties produced in the United States show from 44° to 45° Bé. (0.805 to 0.810 specific gravity) while the Russian illuminating oils show 41° to 42° Bé. (0.820 to 0.824 specific gravity). Galician and Roumanian illuminating oils generally show 43° to 44° Bé. (0.810 to 0.815 specific gravity.)

While no definite directions can be given, the product obtained between the specific gravities 0.750 to 0.860 and 0.870 is considered illuminating oil distillate. If besides the ordinary commercial varieties, special qualities, such as head-light oil, are to be produced, the lighter products of distillation are kept out until the Beaumé scale indicates 56°. In this process a large percentage of oil between 62° and 56° is obtained, which may be returned to the benzine tank, but is generally reserved for the manufacture of a lower grade of oil.

The properties of illuminating oil distillate vary very much. It generally represents a very mobile fluid of a yellow to brownish, and sometimes red-brown color, and shows strong fluorescence, mostly playing into blue, but sometimes, with too rapid distillation, into green. Its odor also varies very much; oils which contain much oxygen have the characteristic odor of creosote, while other oils, for instance Russian, have an agreeable odor reminding one of camphor. The specific gravity varies between 0.795 (head-light oil) and 0.830 (lower grades of Russian illuminating oil.

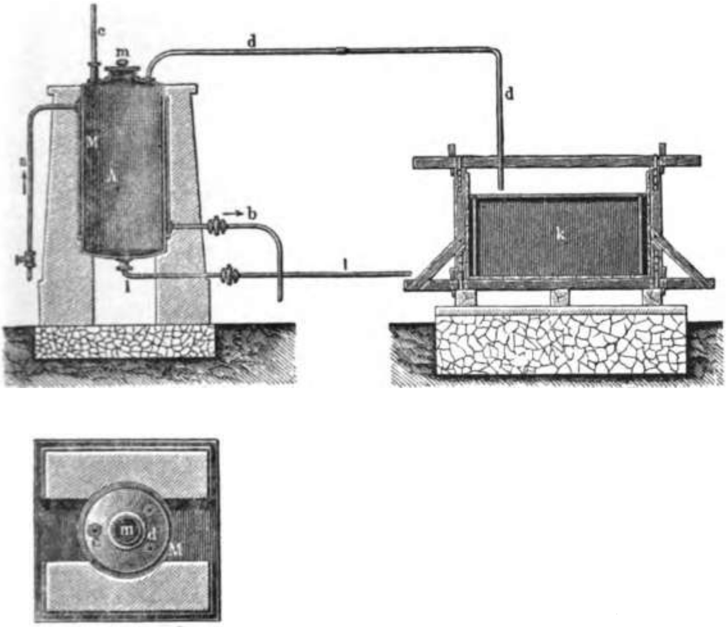
The flashing point of the distillates also varies, it being generally at 21° C. (69.8° F.) determined by the English test (Abel's). It must, however, be remarked that after purification, in consequence of the action of the air, the flashing point rises in many cases 4° to 5° C. Russian oils in the form of distillates have a flashing point of 26° to 29° C. (78° to 84.2° F.). To make them marketable the distillates have to be subjected to a further process, namely, to purification with chemicals.

Manufacture of the Light Products or Essences into Benzine, etc.

In distilling crude oil, crude benzine is obtained before illuminating oil. It consists of a mixture of very volatile hydrocarbons of specific gravities 0.630 to 0.745. The division of these hydrocarbons has been given on p. 74. The further manipulation of the crude benzine consists in redistillation generally with indirect steam, and subsequent treatment of the products obtained. Fig. 89 shows the most simple form of a rectifying still. The still *A* is surrounded by a double jacket *M* through which steam passes in. To assist distillation a steam coil is sometimes placed in the interior of the still. The steam having a temperature of 266° to 284° F. passes in the direction of *a*, and passes out, together with the water of condensation, in the direction of *b*. The crude benzine is brought into the still through *c*. *m* is a man-hole, *l* the discharge-pipe for the residuum, *dd* the condensing pipes for the benzine vapors, and *k* the cooling box. Distillation is effected by filling the still three-fourths full and admitting steam into the jacket and the coil; drops of the most volatile portions appear immediately in the cooling apparatus. The products of distillation should at once be run into balloons or barrels, or through a closed distributing apparatus into tanks placed underground or thoroughly protected from the heat of the sun. The products thus obtained are either sold as they are, or the heavy essences—the *B* and *A* naphtha—are purified. In the still remain some water and a residuum consisting of the constituents of the essences which boil at a higher temperature, and fractions of illuminating oil carried along in the distillation of the crude oil. The residuum is discharged through *b* to the illuminating oil distillate.

With the still above described, different fractions of benzine

FIG. 89.



can be produced, but the lightest which are obtained seldom show a specific gravity below 0.650 to 0.660. The apparatus has the disadvantage that each fraction contains at the same time portions which boil at a lower and higher temperature, a defect partially due to the vertical arrangement of the still.

Figs. 90a, b, c, show a modified rectifying still, which

FIG. 90a.

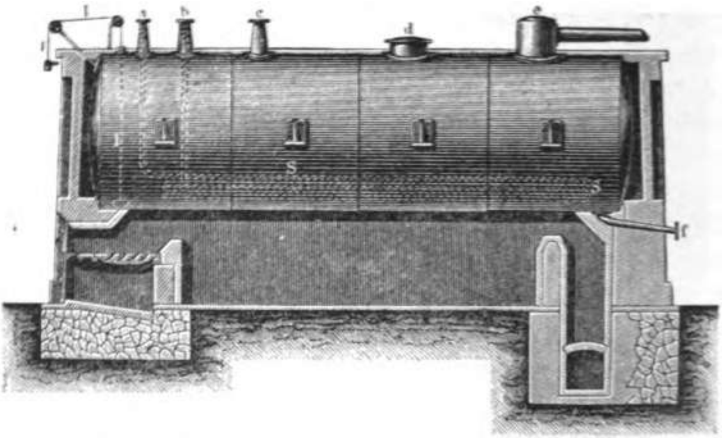


FIG. 90c.

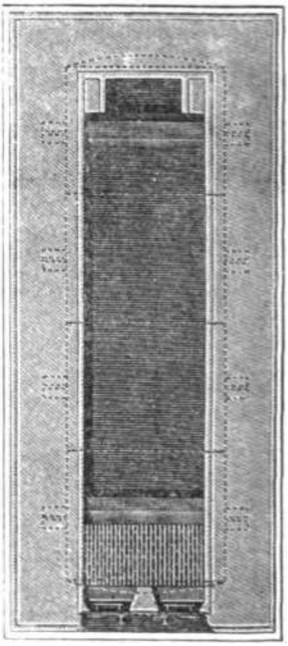
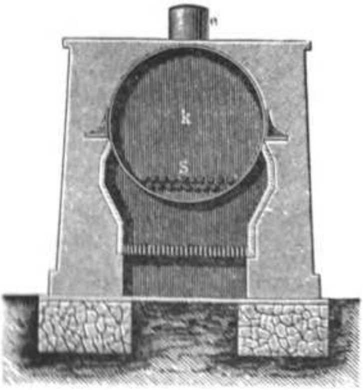
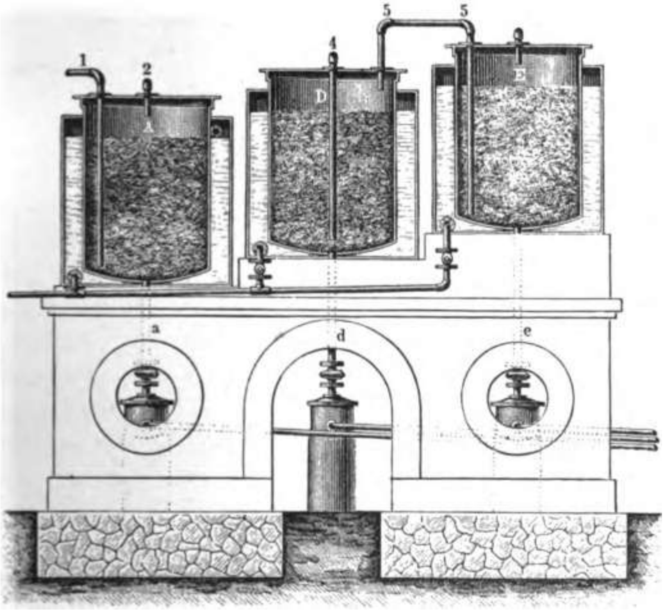


FIG. 90b.



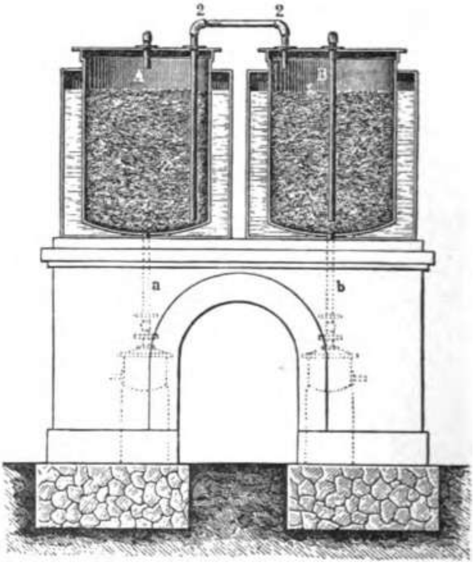
facilitates the production of essences with a lower boiling point. Rectification is effected by means of a steam coil, and is assisted by a gentle direct fire. *k* is the horizontal, cylindrical still, *b*, *a*, apertures for the admission of steam of high tension which circulates in the 130 to 160 feet long copper-coil *S*. The benzine is brought into the still through *c*; *d* is the man-hole, *e* the head, *l* the float-gauge, *f* the contrivance for discharging the residuum. The mode of operation is readily recognized from the illustrations. The still being filled four-fifths full, a gentle fire is started and maintained to prevent the steam from being condensed too much. The hot steam is admitted at *a*, and circulates in the coil *S*. Distillation proceeds with great intensity and uniformity. Condensation may be effected in various ways.

FIG. 91a.



Figs. 91 a, b, c, d, show a condensing apparatus which may be used with special advantage where very volatile products are to be obtained, and where correct fractions, *i. e.*, uniform initial and final boiling points between not too great intervals, are of importance. This condensation, which may be called "partial condensation," is based upon a very original principle. It consists in the essences possessing the property of boiling rapidly in the presence of bodies with large surfaces, for instance, iron turnings. The arrangement of the apparatus to be described here is based upon this principle.

FIG. 91b.



A, *B*, *C*, *D*, *E*, are cylindrical iron vessels, hermetically closed with an iron lid and filled three-fourths full with iron turnings, cleaned and freed from fat. Such iron turnings are also placed in the cooling boxes, in which the water is constantly renewed. *F* is a worm, generally of tin, resting in a cooling box, which to make cooling more effective may be filled with ice. The entire plant is arranged in the form of steps, so that two cooling boxes, in this case *A* and *B*, next *C* and *D*, and finally *E* and *F*, are at the same level. Cooling is effected by a counter-current

FIG. 91c.

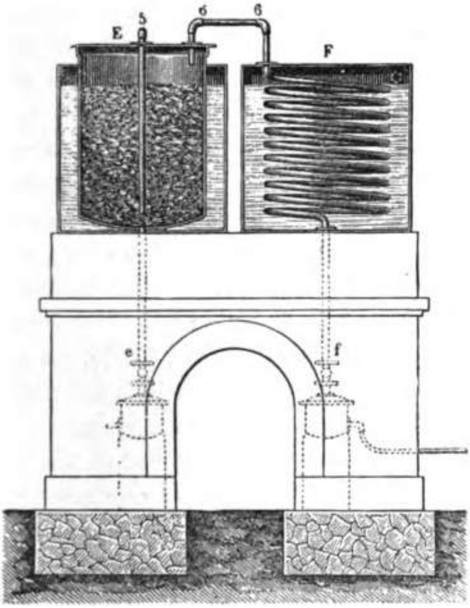
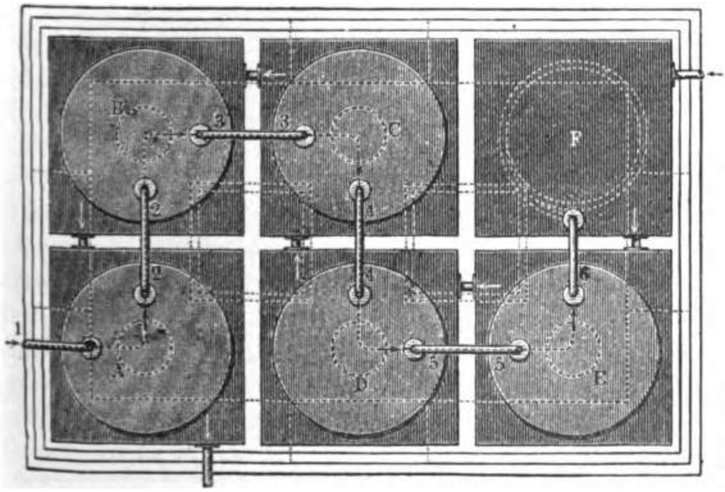


FIG. 91d.



system, which is regulated by an overflow-pipe, so that the cold water enters at *F*, and after passing *E D*, *C B* is discharged at *A*. From the cylinders a vertical pipe *a* to *f* leads to the closed distributor of the distillates, and from there into the closed collecting tanks.

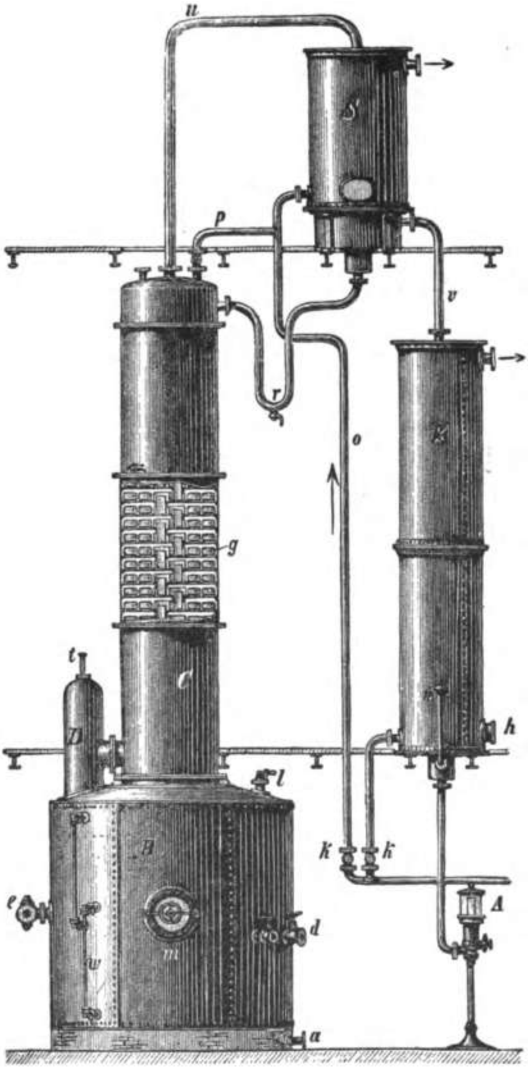
The mode of operation is as follows: At 1 the vapors enter the cooling cylinder and while a small portion—the heaviest—condenses and runs off at *a*, the greater portion volatilizes upon the iron turnings and passes over to *B*, where a similar process takes place. The vaporized portion passes over to *C*, from there to *D*, and from *D* to *E*, the condensed portions, which constantly become lighter and more volatile, running off everywhere. In *F* the most volatile portions are condensed, while the non-condensable portions escape as gases.

In the commencement of the operation the cocks on the pipes *a* to *f* are closed; during the operation they are from time to time opened to discharge the condensed products when a sufficient quantity of them has accumulated in the cylinders.

Distillation in a column still is a customary and very useful method of refining benzine. With slight modifications nearly every kind of still used for rectifying alcohol or distilling benzol may be employed. A still with an upright body is, however, not well adapted for the purpose, because its active, *i. e.*, its vaporizing surface, decreases in the same degree as the contents of the still are reduced, and with rising boiling points a heating surface that constantly becomes smaller is obtained.

Fig. 92 represents Heckmann's naphtha still with vertical body. Distillation is effected by means of steam in a coil, the steam entering at *a*, *d* and *e*. Before reaching the column *C*, the vapors pass through the dome *D*. The column *C* consists of a sheet-iron cylinder with horizontal iron plates *g*, the openings of which are partially closed by valves. The vapors pass through the openings of the plates and are partially condensed, the condensed fluid running back, while the non-condensed fluids pass through *n* into the condenser *S*, where they are condensed, the condensed fluids flowing back through the pipe *r*. The vapors then pass into *k*, and from there into the apparatus *A*.

FIG. 92.



Heckmann's still, with horizontal body, is arranged in a similar manner.

The rectified products now possess nearly all the properties that render them useful, but no matter how carefully they may have been rectified, they still possess a disagreeable, pungent odor, this being especially the case with the *C*-, *B*-, and *A*-naphthas. This odor is especially perceptible when the essences completely evaporate and may be considered free from fat, *i. e.*, when a sample evaporates at the ordinary temperature without leaving a perceptible trace—a grease spot—behind. This odor may be covered by the addition of very volatile oils with an agreeable odor, which is called scenting or perfuming the essences. It is, however, advisable to render the benzine odorless by subjecting it to chemical purification. The manner of effecting such purification will be discussed later on, but a few special apparatuses for the purpose may here be described.

Fig. 93a and Fig. 93b show a purifying apparatus called an agitator. *A* is a cylindrical vessel with a conical bottom. It is lined with lead, and provided with a lid *D* which can be hermetically closed. It rests upon solid brick pillars, and is provided with a gallery and a pipe system for the fluid and the chemicals. The three-way cock *C* placed on the lowest point of the agitator serves for discharging the waste-products, the wash-water, and the purified product.

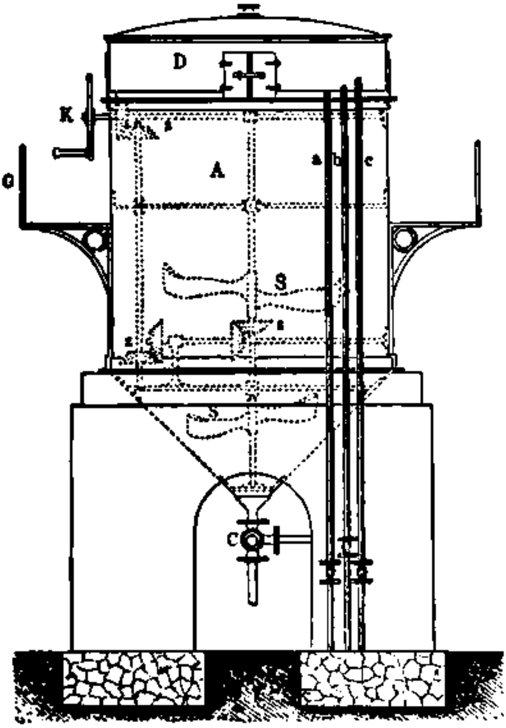
When the apparatus *A* has been filled to a certain height with the product to be purified, and the latter has been ascertained to be free from water, it is thoroughly mixed with sulphuric acid by means of the stirring apparatus *S*, or in some agitators by means of an Archimedean screw. As seen in the illustration, the stirring apparatus is set in motion by the crank *K* and the bevel gearing *zz*. Treatment from ½ to 1 hour with ¼ to ½ per cent. of concentrated sulphuric acid suffices, after which the acid, now of a red-brown color, is drawn off.

The acid product is of a light brown-yellow color and an acrid odor of sulphurous acid, while the original odor has entirely disappeared. The fluid is then treated with a small quantity of dilute caustic soda solution until it is perfectly water-clear and has lost the odor of sulphurous acid. The caustic soda lye is then drawn off, and the benzine, which clears rapidly, is ready to be filled in vessels for use.

In this treatment care must be taken to effect the mixing process as quickly as possible, because the most valuable products vaporize very rapidly.

Fig. 94a and Fig. 94b show a plant used in some refineries.

FIG. 93a.



With this arrangement mixing is not required. As will be seen from the illustrations, the naphtha has to pass through boxes filled with chemicals, and arranged in the form of steps. The vessels 1, 2, and 3 contain sulphuric acid, 4 and 5 the caustic soda solution and wash-water, and 6 a filter filled with common

FIG. 93b.

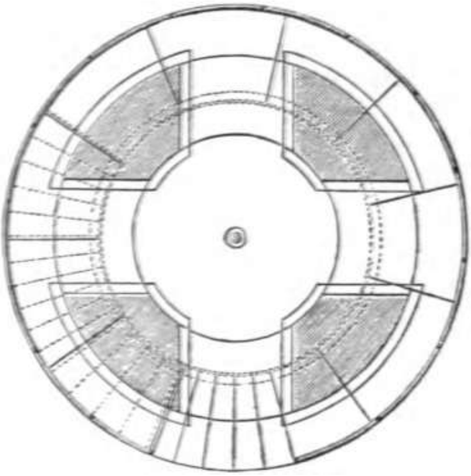


FIG. 94a.

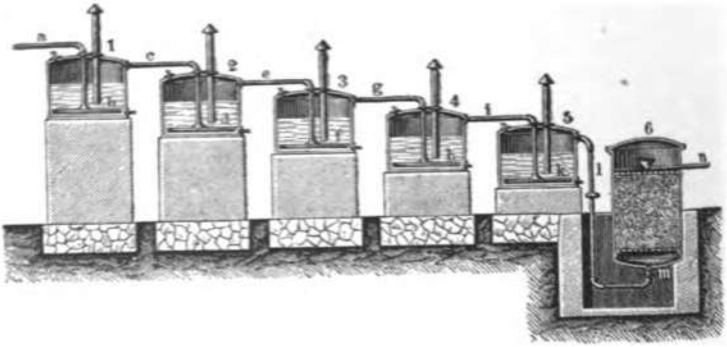
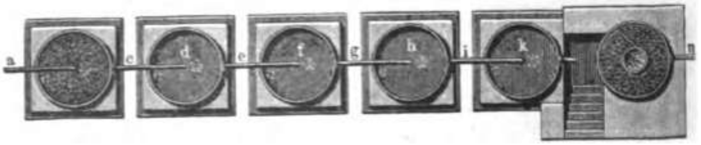


FIG. 94b.



salt and saw dust. At *a* the products pass from the rectifying division through the sieve-bottom *b* into box 1, where they are partially treated with sulphuric acid. They next pass through *c* into box 2, where they are again treated with acid, and after being thorougly refined pass by their own pressure through the pipe *l*, and at *m* enter the filter 6 and run off.

The advantage claimed for this apparatus is that, after it is closed, even the most volatile essences can be refined without loss. No satisfactory information could be obtained regarding its working capacity.

Treatment of the Illuminating Oil Distillate.

Chemical Purification. To render the illuminating oil distillate marketable it has to be subjected to a chemical purification by being treated with sulphuric acid and soda lye.

Even as late as the early sixties illuminating oil was brought into commerce with a dark lemon-yellow to dark red color. This coloration is partially caused by iron salts which are formed by the action of the free acids in the petroleum upon the iron tanks, and dissolve in the distillate. It was endeavored to get rid of it by treating the distillate with soda lye and also with lime solutions. However, the oil thus treated deposited, after burning a short time, a solid crust upon the wick which prevented the oil from rising. It was then tried to free the oil from the lyes by washing it with dilute hydrochloric acid, but it burnt badly after such washing and retained its characteristic yellow color. About 1865, Eichler of Baku treated petroleum with sulphuric acid and lye, and thus created a method which, generally speaking, has remained unchanged up to the present time.

The action of sulphuric acid upon petroleum distillates has not yet been fully explained. It is known that the crude distillates contain, besides hydrocarbons, *upon which it is supposed* sulphuric acid does not act, other admixtures which by the action of the sulphuric acid and caustic soda is either entirely removed or partially changed.

As far as known these admixtures consist of aromatic hydrocarbons, fatty acids and acids of the series $C_nH_{2n-2}O_2$, phenols, tarry matter, sulphur combinations, etc. The action of the sulphuric acid upon these admixtures differs, they being partially destroyed or dissolved and changed to sulphonic acid combinations, while another portion remains almost entirely unchanged, and is removed only by the subsequent treatment with lye. The volume of the distillates becomes constantly smaller, while that of the sulphuric acid increases in consequence of the absorption of the admixtures. The loss by distillation frequently amounts to from 5 to 8 per cent. The concentrated sulphuric acid forms with the aromatic hydrocarbons sulphonic acids, and with many non-saturated hydrocarbons direct combinations, while the tarry matter dissolves in the sulphuric acid and imparts to the fluid a dark brown color. It has been ascertained[1] that the sulphuric acid also withdraws the oxydized bodies from the distillate, so that by continuing the treatment of the latter with sulphuric acid all the oxygen may be removed from the petroleum; and if the brown sulphuric acid obtained after treating the distillate be diluted with water, an emulsion is formed upon the surface of which floats an oily fluid containing oxygen which possesses a specific odor, reminding one partially of camphor and also of oil of turpentine. In the ordinary treatment of the distillate with sulphuric acid a portion of the organic acids and of the phenoles remains unchanged. For the saturation and removal of these, as well as for neutralizing the sulphuric and sulphonic acids retained in the distillate, soda lye is used. Hence the process of chemically purifying the illuminating oil distillates consists in the removal of the *injurious* admixtures by means of sulphuric acid and soda lye, whereby an entire series of chemical reactions takes place, which are recognized by the fluid becoming heated. However, the action of the sulphuric acid is not so simple as may be supposed at the first glance; just the reverse, its func-

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[1] Tumsky. "Technologie der Naptha."

tion is quite complicated. *In treating the distillates with sulphuric acid, sulphurous acid is always evolved, a phenomenon which cannot be explained by the above mentioned reactions.* Hence in treating the distillates with acid other additional processes must take place which produce the evolution of sulphurous acid. These processes, however, are not yet explained. It can be readily understood that the appearance of sulphurous acid is rendered possible only by the reduction of sulphuric acid, but with our present knowledge of the chemical nature of petroleum no definite answer can be given to the question what these reducing agents are and in what manner they act. Repeated experiments in treating distillates ten to fifteen times with large excesses of sulphuric acid always showed a reaction of the latter on the oils,[1] which could be recognized by the color of the acid, so that the function of the latter is more profound than might be expected. If the action of the sulphuric acid were limited to the separation and destruction of the admixtures, complete purification would be attained with the use of an excess of acid. But since all the injurious admixtures cannot be destroyed, no matter how long and with how much acid the distillates may be treated, as evidenced by the dark brown color of the sulphuric acid and the evolution of sulphurous acid, these phenomena would lead to the conclusion that the sulphuric acid exerts an oxidizing effect on the hydrocarbons themselves. This view is partially confirmed by the following facts: Nordhausen sulphuric acid (fuming sulphuric acid $H_2S_2O_7$) acts more energetically upon the distillates and purifies them better than ordinary sulphuric acid, H_2SO_4. This must be ascribed to the sulphuric anhydride which possesses greater oxidizing power than the hydrate. Besides greater heating of the distillates than is the case with ordinary sulphuric acid, there is also a smaller yield of illuminating oil, which may be explained by a more energetic oxidation of the hydrocarbons. Now, if the well-known phenomenon of the oxidation by the air

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[1] Tumsky. "Technologie der Naptha."

of the crude distillates as well as of the refined product is taken into consideration, the ability of the hydrocarbons of petroleum to resist reagents may be strongly doubted. If air at an ordinary temperature oxidizes the hydrocarbons, then sulphuric acid can certainly exert an oxidizing effect with the evolution of sulphurous acid, especially at a somewhat higher temperature and in the presence of large quantities of heated air. The coloration of the acid is due to the solution in it of the tarry products contained in the unrefined oil, which, however, may also be formed by the oxidation of many constituents of the distillate. These tarry substances are generally combinations containing oxygen and are removed by purification, so that the content of oxygen of the distillate is decreased, which can be proved by elementary analyses.[1]

Oil treated with sulphuric acid contains less oxygen than unrefined oil. Finally in treating the distillates with lye, combinations containing oxygen—the phenoles and acids—are also separated.

The property of an unrefined or badly refined distillate becoming dark on exposure to the air is explained by the oxidation of the naphtha or kerosene acids, of the phenols, the tarry substances, and partially of the hydrocarbons themselves. By removing these admixtures (the phenoles, acids and tarry substances) a nearly colorless petroleum can be obtained, which, however, in time again becomes yellow, which is due to the oxidation of the hydrocarbons by the action of the air. In purifying the distillates with sulphuric acid the bad-smelling constituents are also destroyed, and with the use of an excess of sulphuric acid petroleum with an agreeable odor characteristic of pure hydrocarbons may be obtained.

For the chemical purification of the distillates ordinary sulphuric acid of 66° Bé. is generally used, fuming sulphuric acid being employed only in rare cases for varieties of oil difficult to purify, as for instance, Galician oils which contain a large quan-

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[1] Tumsky. "Technologie der Naptha."

tity of admixtures. As previously stated, fuming sulphuric acid acts more energetically and, therefore, of it smaller quantities are required.

The quantity of acid required for purification, as well as the duration of the process itself, depends on the degree of purity of the distillates, the latter quality being closely connected with the properties of the crude oil and the manner in which it has been distilled. Thus, the distillates from Canadian oil, for instance, require much more acid and time than distillates from Pennsylvania oil. The quantity of acid required is dependent also on the specific gravity of the distillates; the greater the specific gravity of the oil the more acid is necessary. Oils which have been exposed to the air for some time, as well as distillates which have been subjected to overheating, are difficult to purify, and in both cases the quantity of reagents has to be considerably increased. It is, therefore, difficult to specify the exact quantities of acid or of lye required for the refining process, and only the limits between which a determined quantity of the chemicals varies in proportion to the purity of the distillates and the requirements of the market, etc., can be indicated.

In treating the distillates with sulphuric acid the latter might apparently produce polymerism of the hydrocarbons, in consequence of which the specific gravity would rise. This, however, has not been observed in practice, and even specifically lighter oils have been obtained when the distillates were subjected to the action of larger quantities of acid for a longer time, which can be explained only by the fact that decidedly more heavy tarry substances are removed than specifically heavier products can be produced by the eventual polymerism of the hydrocarbons.

As a substitute for sulphuric acid various reagents are used. Thus the chromates, potassium permanganate, chloride of lime, chloride of tin, nitric acid and other chemicals purify and bleach as well as deodorize petroleum. However, the high price of these reagents prevents their introduction in the practice as a substitute for sulphuric acid. In purifying Canada oil dilute nitric acid is sometimes used.[1] For the removal of the bad-smelling sulphur combination, a large number of directions of more or less doubtful value are known. Thus, for instance, treatment with lead oxide and subsequent purification with sulphuric acid (H. Frash, American patent No. 378,246); effect of a mixture of blue vitriol, caustic soda, common salt and water and digestion with flowers of sulphur, which, it is claimed, renders the treatment with sulphuric acid superfluous (Kennedy, German patent No. 43,145); and finally conducting the petroleum vapors over hot iron or copper (Pitt and Van Bleck, German patent No. 45,958). Mawbery and Smith found that these sulphur combinations consisted, especially in Ohio petroleum, of ethyl, propyl and butyl sulphides, which has, however, been refuted by Kast.

After the treatment with acid the distillate is several times washed with water to remove the greater portion of the suspended acids, and then treated with solution of caustic soda. Although the carbonate of soda is cheaper, it cannot entirely replace the caustic soda. It might serve for neutralizing the sulphuric acid, but as other admixtures (phenoles, naphthalic acids) which are insoluble in the acid have also to be removed, the use of caustic soda is unavoidable. It has been endeavored to replace the caustic soda by cheaper basic bodies, and aluminium hydrate, ferric oxide, magnesia and other insoluble oxides, as well as lime, have been used in the practice, but on a very limited scale. In the smaller refineries of the Caucasus where fresh water is scarce, lime in the form of milk of lime or of a fine powder is occasionally used for washing the oil. Methods for purifying the illuminating oil without the use of an alkali have also been proposed. Thus the illuminating oil after treatment with sulphuric acid is to be mixed with different pulverulent substances, for instance, with sand, pulverized glass, clay, flour, etc., the purpose being to carry down the tarry products.

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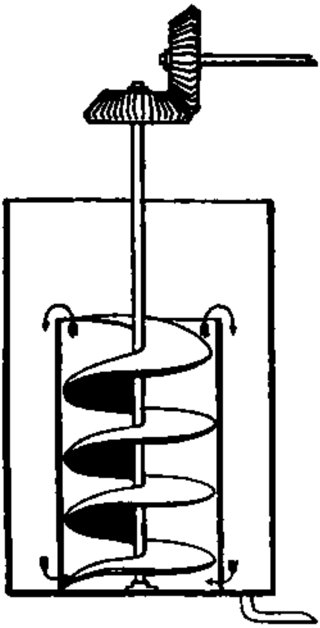
[1] Tumsky. "Technologie der Naptha."

The distillates are subjected to the action of the chemicals in an apparatus called an agitator. These agitators are mostly iron cylinders generally deeper than they are wide; in very small refineries wooden vats lined with lead are occasionally used. The chemicals being specifically heavier than the distillates, their action is promoted by intimately mixing them with the latter by mechanical means. Formerly this was done by stirring by hand. An advance in this respect is an apparatus with mechanical stirrer as shown in Fig. 95, the mixing being effected by means of an Archimedean screw. The apparatus being filled the machine is set in motion and the acid or lye allowed to run into the inner cylinder in which revolves the Archimedean screw. The screw lifts the mixture of oil and acid, or of acid and lye to the upper end, where it runs over the outer cylinder and after sinking down is again sucked

FIG. 95.



into the inner cylinder through holes in the bottom, the circulation, as indicated by the arrows, being continued uninterruptedly as long as the machine works.

For working large quantities of oil at one time mixers of this kind with mechanical stirring apparatus are, however, not suitable.

The most powerful and effective method of mixing the oil and the chemicals is by means of compressed air. However, before discussing the effect of mixing by means of air and the arrangements required for the purpose, a few words may be said in regard to the mixing apparatuses themselves and their construction.

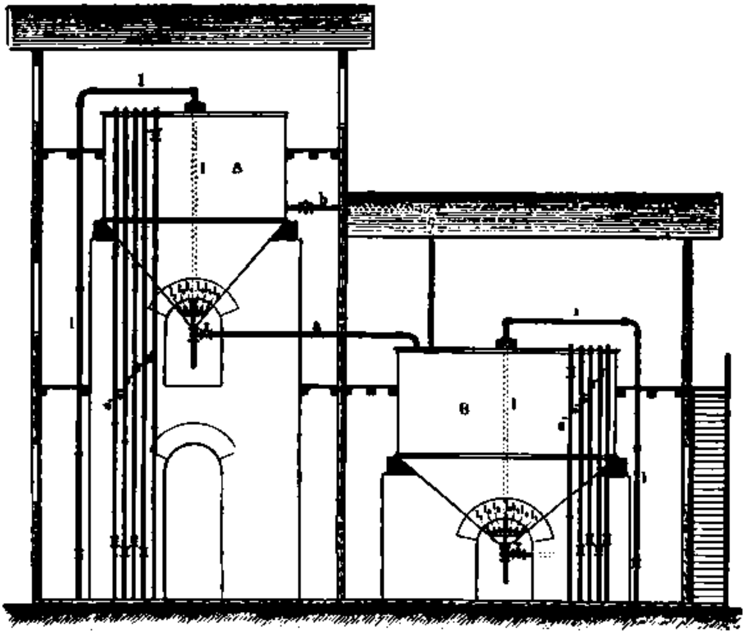
The refining apparatuses are constructed nearly everywhere according to the same principles. They consist of upright cylindrical iron vessels with conical bottoms. They rest upon strong brick or stone piers, or upon an iron construction, and, when located in a closed building, are open on top. When standing in the open air they are provided with a light iron cap fitted with trap-doors which serves the purpose of preventing rain from entering. They are as a rule constructed of wrought iron, the thickness of the plates varying between 2.36 and 3.15 inches. The conical bottom is generally somewhat thicker. The apparatuses are, as a rule, lined with lead. The lead lining may, however, be omitted if distillates absolutely free from water are treated and dilution of the acid is not to be feared; when treatment with acid and lye is not effected in one vessel, the lye agitator also need not be lined. In refineries where it is difficult to obtain distillates free from water the use of lead linings is absolutely necessary, otherwise the dilute acids attack the sides of the iron vessels and soon destroy them; besides, the iron salts color the petroleum and produce turbidity. The lead plates are laid on the sides of the agitator and lapped over the edges and soldered together, so that, as it were, they hang in the apparatus. Strips of wood are generally placed vertically between the iron plates and the lead lining. The lead plates need not be thicker than from 0.15 to 0.23

inch, or in very large apparatuses, 0.31 inch. Regarding the shape of the agitators it is best to make them much deeper than wide, because a more intimate mixture of the chemicals can be effected in a narrow tall vessel, the current of air acting more intensely and upon the entire surface, while in a low, broad apparatus the distillate on the edge is but slightly agitated, and, hence, less attacked by the chemicals. The same rule applies to the conical portion of the apparatus, this mode of construction allowing of a far more rapid settling of the chemicals used in the purification. The most essential portion of the agitator is the arrangement for the conveyance of air. Independent of the many possible modifications, which cannot here be discussed, two systems may be distinguished. 1. Conveyance of air from above to below the so-called upper air-blast. 2. Direct conveyance of air from the lowest point of the agitator, the so-called under-blast. As regards the mode of action there is no essential difference between the two systems. In the first case, as will be seen from the description of the illustrations to be given later on, the air ascends through a pipe-system on the outside of the agitator to the centre of the latter and from there to the lowest point, where it passes out through a distributing contrivance and in ascending mixes the fluid. In the second case, the air passes in at the lowest point and ascends through a similar distributing system. The consumption of power and the effect produced are the same in both systems. However, the upper air-blast system is safer, because should the blast from one cause or another be stopped or the valves become leaky, it is impossible for the fluid to penetrate to the compressors.

The refining apparatuses may be divided into two principal systems. In the first system the entire process of purification, from the treatment with sulphuric acid to washing out the last traces of lye, is effected in one apparatus, while in the other, separate vessels are used for the operations of acidification and alkalization. Although the plant according to the first system is cheaper, but one apparatus, which may be erected in the open air, being required, that according to the other system is more advantageous, because the refined product is much better and with an equal capacity a greater quantity can be refined in the same time. The choice of one or the other system depends on local and other conditions.

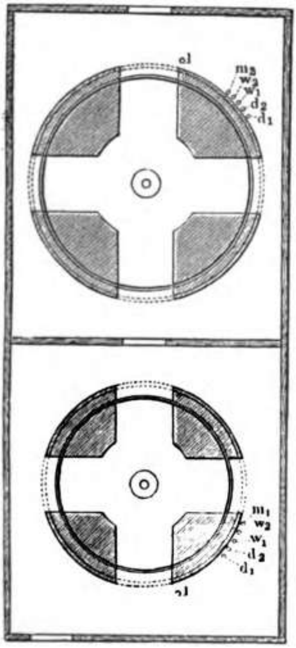
Fig. 96a and Fig. 96b show the arrangement of an agitator according to the second system. It consists of two cylindrical vessels open on the top; the bottom is funnel-shaped. The apparatus is erected in a closed building to protect it from the weather. Both vessels rest upon brick piers and are so placed that the lowest point of the acid-agitator *A* is at a higher level than the upper edge of the lye-agitator *B*, so that the acidulated oil can directly run through the pipe *a* into the agitator *B*. The pipe *b* on the acid-agitator serves the purpose of discharging a portion of the clarified oil. The upper agitator *A* is lined

FIG. 96a.



with lead, but the lye-agitator *B* does not require such protection. The mixing of the fluid in both agitators is effected by means of air, the latter passing in both agitators through the pipe *l* and is distributed through the spider *s*. The latter consists of a cast-iron body bent upwards and downwards in the form of a cone. The upper conical portion is screwed to the pipe *l*, while a portion of the air passes out through the lower end to keep the acid which deposits on the bottom in constant motion. On the edges of the spider are lateral openings l_1, l_2, l_3, l_4, etc., in which are screwed small pipes bent upwards, through which the greater portion of the air passes out. The distillates are pumped through the pipes d_1, d_2; w_1, w_2 are pipes for the wash water, while the pipes m_1 and m_2 serve for transferring the chemicals by means of a pump through the agency of compressed air. These pipes are generally placed

FIG. 96b.



in the centre of the apparatus and terminate in a spiral with numerous openings through which the acid and lye pass out. In place of a spiral, a Segner wheel is also used. In vessels with funnel-shaped bottoms the waste products deposit rapidly, and the danger of a small portion of the distillates being carried away and discharged with them is reduced to a minimum.

Attention may here be drawn to the unsuitableness of agitators with straight or but slightly curved bottoms and with discharge cocks on the side. No matter how carefully the waste products may be discharged, a small quantity of them always remains behind in the apparatus; and the separation of the fluids being difficult to execute, a small portion of the distillates is unavoidably carried along.

A suitable discharge arrangement is shown in Fig. 96 a. It consists of a metallic three-way cock with large bores to prevent choking up by thicker tarry substances. From the three-way cock one pipe leads to the tanks for the refuse acid and soda washings, another to the drain for discharging the wash water, and a third serves for conducting the refined product to the filters, lead tanks, etc.

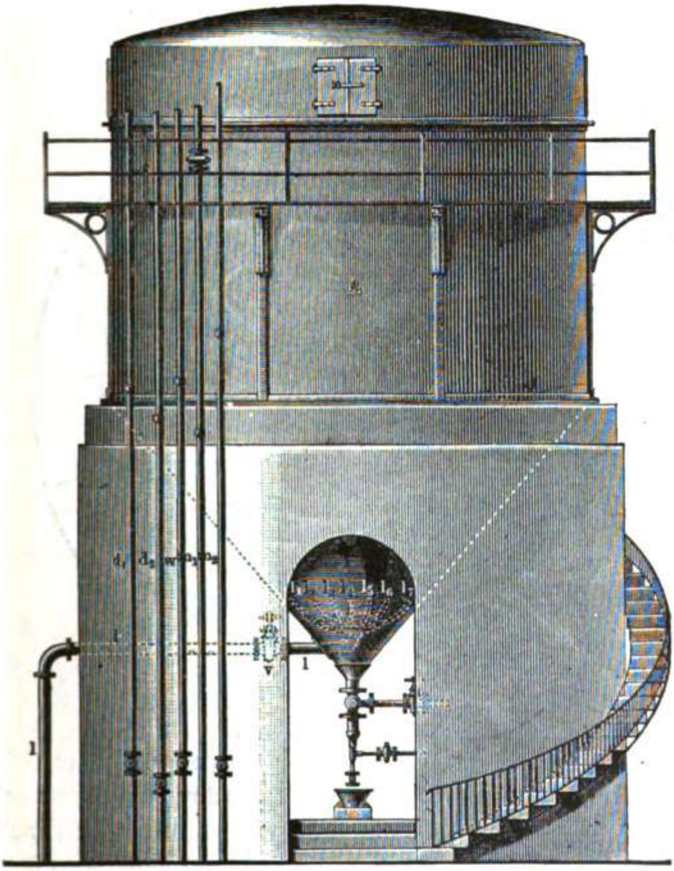
The operation with the agitator above described is essentially as follows: The oil is pumped or allowed to run into the acid-agitator and permitted to settle. The deposited water is then drawn off, and the distillate, if it has been taken from different tanks, is uniformly mixed by a few air-blasts. A sample of the distillate is then immediately tested in the laboratory for the approximate determination of its specific gravity and flashing point, and the quantity of sulphuric acid to be used. The quantity of the latter varies according to the purity and origin of the distillate. For purifying Russian distillates 1½ to 2½ per cent. are used, for American distillates 2 to 3½ and even 4 per cent., the quantity required increasing with the yield of crude distillate, since the heavier oils consume much more acid. Galician and Roumanian oils are treated with 3 to 5 per cent. or more, and even with fuming sulphuric acid. The quantity of acid determined by experiment or experience is brought into the monte-jus. Treatment with all the acid at one time, as carried on in some refineries, is objectionable, the acid being not nearly so effective as the same quantity used in several portions. If used at one time a portion of the acid is rendered ineffective by its molecules being enveloped by the admixture of tarry substances. Furthermore, with such large quantities it is difficult to attain an intimate mixture and thorough action of the acid, and besides, its efficacy is considerably decreased by any water held in suspension.

Generally the sulphuric acid is used in two or three portions, a small quantity, about one-tenth to one-fourth per cent., being first added. The distillate being agitated by the air blast, the above mentioned quantity of sulphuric acid is forced into the agitator and allowed to act with constant agitation for about a quarter of an hour, when agitation is interrupted and the product permitted to stand quietly for about one-half hour. The acid which deposits is generally of a light to dark brown color, and considerably diluted by water withdrawn from the distillate. If the latter contains much water the effect produced by the acid is but slight and the distillate has to be treated once more with another small portion of acid. It is then treated with a larger portion, generally one-half the quantity of the remaining acid. For this purpose the distillate is agitated, and when the determined quantity of acid has been forced in, agitation is continued for one-half to one hour. Samples are from time to time taken, and the degree of efficacy of the acid is judged by the manner in which it settles. If the black colored acid settles rapidly in small beads this portion of the operation may be considered finished, otherwise the acid settles slowly in the form of small long-drawn out drops which adhere to the sides of the test glasses. Agitation is then interrupted and the distillate allowed to settle for two or three hours until a sample of it shows but slight traces of suspended acid. The waste acid of a dark brown to black color is then drawn off and the operation repeated in a similar manner with the remaining quantity of acid. The treatment with acid may be considered finished when a sample of the distillate forms a milk-white emulsion when mixed with dilute lye. From a series of such tests made one after the other, the proper moment can be readily determined. After allowing sufficient time for the acid to settle, the latter is discharged and the distillate drawn off into the lye-agitator. At this stage the distillate has an odor of sulphurous acid and a peculiar red-blue fluorescent color, due to its own color and the very finely-divided tarry particles suspended in it. Washing after acidulating is generally effected by treating the acid distillate with large quantities of water. The water is introduced into the agitator above the surface of the oil through a rose or perforated pipe which runs around the entire circumference of the tank. As the water percolates through the body of the oil the acid is gradually removed, and while the water is thus flowing on at the surface of the oil it is allowed to escape in a constant stream from the bottom. This water percolation continues without agitation until as nearly as possible all traces of acid have disappeared. The stop-cock at the bottom of the agitator is now closed and a fresh portion of water added, and the air-pump again set in motion. By this means the oil is thoroughly washed. In the meanwhile the dark color of the oil changes to a dirty yellow-white. A solution of caustic or carbonate of soda of 2° to 4° Bé. is then added with constant agitation. The oil gradually acquires a milk-white color, and when the calculated quantity of lye, generally between one-half and one per cent., has been added, agitation is after a short time interrupted, this being of great importance since, when agitation is continued too long, emulsions difficult to separate are formed. The soda solution is then withdrawn and the oil washed to remove any traces of soda. Some manufacturers purposely avoid this final washing, with an idea that a trace of soda has a preservative effect upon the oil. The actual process of purifying may now be considered finished.

The refined product is a fluid of a yellow to white color, transparent or turbid from water held in suspension, and possesses an odor which is not disagreeable. It may be considered finished as regards flashing point and specific gravity. The oil is now allowed to flow by gravity, or is pumped into the settling tanks or filtering apparatus to be described later on.

Fig. 97a and Fig. 97b show a refining apparatus in which the distillate is entirely finished, the illustrations also showing the arrangement of the under-blast. For the treatment of the same quantity of distillate the capacity of such an apparatus must be considerably larger, since besides the longer time re-

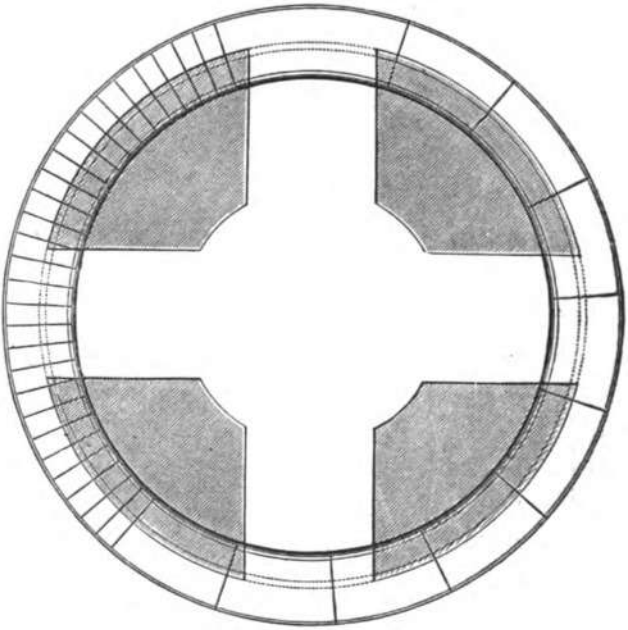
FIG. 97a.



quired for refining, there must be sufficient space for the wash waters.

The arrangement will be readily understood from the illustrations. The apparatus consists of a cylindrical tank with a conical bottom; the latter should be very deep to facilitate the rapid settling of the chemicals. The apparatus is generally erected in the open air, and is provided with a light iron roof

FIG. 97b.



fitted with lateral holes for the pipe conduits, etc. The dimensions of the apparatus vary according to its capacity. It is generally between 10 and 15 feet in diameter, and including the cone between 20 and 30 feet high. The pipes for the distillate, chemicals and water (d_1, d_2, w, m_1, m_2) are arranged similar to those of the agitator previously described, but the manner of agitating the contents by means of air differs. The air conduit l enters the agitator A near its lowest point and terminates in the spider *s*, which is provided with lateral openings and the air tubes l_1, l_2, l_3, etc. The air valve *F* prevents the fluid from flowing back into the air-compressor; it is only opened when the latter is in action, otherwise the effect is the same as that previously described and the operation is carried on a similar manner. The quantity of acid and the time during which it is allowed to act are the same as with the agitator previously described, as well as the means of transferring the chemicals. The quantities of calculated acid are as a rule measured out in the monte-jus, but each filling of the latter renders it necessary to discharge the air from the apparatus, a process which is both time-consuming and expensive, because it requires considerable time to discharge the air from the apparatus and to again produce pressure after filling, it being necessary for the latter purpose to put the air-compressors again into activity. To avoid this an automatically acting apparatus may be used with advantage. It consists of a hermetically closed cast-iron box with three compartments, the contents of which are accurately known. From the monte-jus the acid is forced into this box. When one of the compartments is full it is automatically emptied and closed. Since every compartment holds the same quantity of acid, the number of boxes emptied gives the amount of acid used. When sufficient acid has been introduced, the connection between the box and the monte-jus is closed, the latter, however, remaining under pressure so that it can at any time be put in operation. The introduction of concentrated lye is effected in a similar manner.

In the agitator under consideration, the acidulated oil requires more time for settling to get rid of the last traces of acid. Taking this fact into consideration, it is evident that the wash water will unavoidably dilute the acid still retained, whereby the sides of the tank are attacked, while the color and quality of the oil suffer at the same time in consequence of strong heating and separated tarry particles. When the oil is nearly clear or contains but little acid in suspension, washing is immediately commenced. Large quantities of water, in powerful jets, are forced through the body of the oil until it is nearly neutral. The treatment with soda and the final washing process are the same as with the agitator previously described.

The sulphuric acid used and the lye form the waste-products of the refining process. Both contain in solution or chemically fixed the constituents withdrawn from the distillate. The waste or sludge acid is a tarry fluid of a light brown to black color and a disagreeable acrid odor which is largely due to sulphurous acid. It is the most disagreeable and troublesome waste product, its further utilization in the refinery itself being difficult and limited. For economic reasons a portion of the sludge acid may be again used. For instance, acid which has been used in refining benzine is still of a sufficiently high grade and light color to be employed for the preparatory acidulation of illuminating oil for the purpose of freeing the latter from water, while the last portions of the acid used in refining illuminating oil, which is also of a high grade and light color, may be utilized for refining oils of a lower grade. The sludge acid from refining lubricating oils may be mixed with lime or sawdust and used for firing. It is, however, extremely difficult to utilize the principal mass of sludge acid obtained in refining illuminating oil. A number of directions have been given for this purpose, but they are available only in isolated cases. Where sulphuric acid is expensive, as, for instance, in the Baku districts, it may be regenerated by diluting it with three to four times the quantity of water, whereby all the oil is separated. The dilute acid, which is of a rust-brown color, is concentrated in iron kettles or lead pans to 60° Bé., and used for subordinate purposes. In this country the sludge acid is generally sold to manufacturers of chemical fertilizers and superphosphate of lime. The refuse soda solution is generally also of a dark color. It may be used for neutralizing acid and in the production of ordinary soaps, though as a rule it is permitted to flow away without any attempt to utilize it.

Before describing the further treatment of the refined oil, a refining process that is but seldom used may be mentioned. Many petroleum distillates obtained chiefly by the decomposition of heavy oils and containing much oxygen, and from which these oxidized products cannot be sufficiently withdrawn by the acid, have to be treated before acidulation with concentrated lye of 25° to 30° Bé. The action of the lye upon the distillate is, under these conditions, actually surprising. The crude distillate of a dark color and disagreeable odor is entirely changed after being for some time treated with the lye. It represents a fluid of a light color and slight odor, while the lye used has been converted into a fluid of a brown-black color and bad odor. This distillate can be treated better and with less acid after the lye has performed a portion of the work of the acid by withdrawing a great part of the tarry matters (acid, phenoles, sulphur combinations, etc.). The further process of refining does not differ from those previously described, only the last lye, used for neutralizing the acid, must be very dilute.

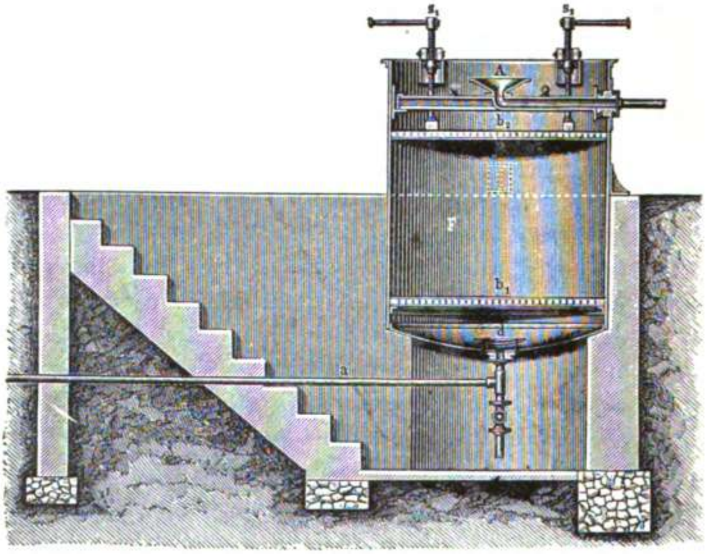
After the treatment with chemicals, etc., the illuminating oil is still, not yet marketable. It is turbid from water and particles of lye held in suspension, and has to be cleared before it is ready for sale. Clearing is generally effected in open shallow pans exposed to the light, or the oil is subjected to filtration. Where the work is carried on continuously and on a large scale, filtration is generally necessary, because in the season of the year when the consumption of oil is greatest even a great number of large settling tanks would prove insufficient.

Filtration.

Filtering of the illuminating oil is a mechanical operation and consists in the absorption of suspended particles of water. Although a number of filtering materials are suitable for the purpose, saw-dust and common salt, and occasionally animal charcoal are, as a rule, used. Saw-dust on account of its cheapness and great porosity is an excellent absorbent. When employed in layers of sufficient depth it is capable of withdrawing all the water from the oil, but its effect is only a limited one, it becoming more and more saturated with the water retained. A not less effective and cheap absorbent is common salt; being very hygroscopic it withdraws the water and is dissolved by the water retained.

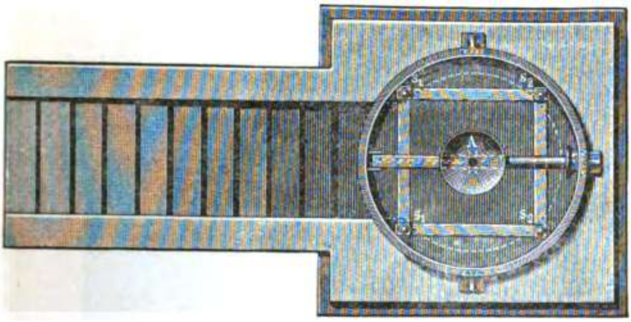
In the practice one or the other of these filtering materials, or a combination of both, is generally used. Fig. 98a and Fig. 98b show the arrangement of a filter. It consists of an upright iron cylinder, deeper than wide, with a conical or curved bottom. The refined oil enters at the lowest point and runs off through an overflow pipe or still more suitably through a funnel. In Fig. 98 a, the oil enters the filter *F* through the pipe *a*. On entering the filter the oil pushes against the lid *d*, whereby a portion of the water is separated. The oil then passes through the bottom b_1, which consists of a one-inch thick oak board perforated like a sieve and covered with linen for the retention of foreign bodies. Upon this bottom the filtering material is piled, the first layer consisting, as a rule, of saw-dust, next

FIG. 98a.



comes a two-inch layer of common salt, then a layer of saw-dust, and so on alternately up to a certain height. In many cases the filter is open on top, but to prevent saw-dust or salt from being carried along, and to accelerate the filtering process, an oak bottom b_2 arranged similar to b_1, is placed upon the filtering material and can be firmly pressed down upon it by means of the screws s_1, s_2, etc. The oil penetrates the filtering materials, ascends to the funnel A, runs into the latter, and from there to the tanks. The oil is now ready for sale.

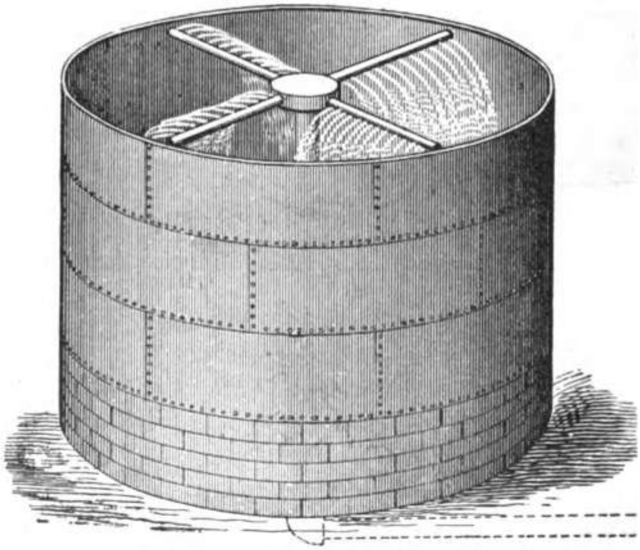
FIG. 98b.



In refineries where filters are not used the oil is allowed to become clear in settling tanks. These are built of boiler iron and large enough to contain one charge from the agitator. In some of the larger refineries they are 40 feet in diameter and 10 or 12 feet deep. Before being used they are frequently given two or three coats of white paint. They are provided with a coil of hot-water pipe for the purpose of gently warming the oil in very cold weather. This greatly facilitates the settling of any water which may be left in it, and also its clearing. These tanks are often entirely exposed on all sides, and are simply provided with a roof to keep the rain out of them. By this exposure the oil, in good weather, becomes in a short time beautifully clear and brilliant. The tanks are also provided with a pipe connected with the steam pump, which admits of the oil being transferred from one tank to another used for the same purpose. This pipe runs from the circumference to the centre on the bottom of the tank, and then straight up three or four feet along the rim; from the latter project a number of radiating pipes, all of which are perforated with holes, to admit of what is technically known as the

Spraying process. It sometimes happens that after the oil is in the form of finished product, perfect in color, brilliant and sparkling as could be desired, upon submitting it to inspection to ascertain the "fire-test," it falls short perhaps two or three degrees. A greater discrepancy than this manifests neglect of duty on the part of the distiller, or mismanagement somewhere. Where the difference is not greater than this the difficulty is easily remedied by pumping the oil from one tank to another and allowing it to pass through the *sprayer* shown in Fig. 99. As every particle of the oil is thus exposed to the air in small streams, the small percentage of benzine it may contain is quickly volatilized and the fire test correspondingly

FIG. 99.

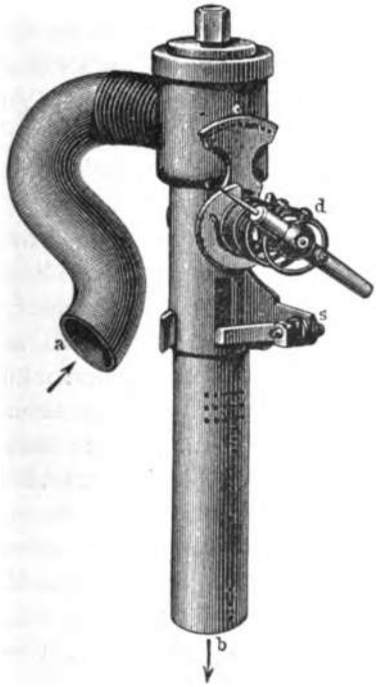


elevated. It is again tested, and if found satisfactory, it is ready for barrelling.

Barrelling.

The oil is seldom barrelled from the settling tanks, the latter being usually connected with the warehouse and sheds on the wharf by means of a pipe-line; this pipe-line may empty into what may be called a reservoir pipe, or a pipe of much larger capacity closed at both ends, with a number of small pipes inserted. To these are adjusted short sections of flexible gum hose supplied with a patented barrel-faucet.

FIG. 100.



An apparatus for filling barrels, which works automatically and requires no attention, is shown in Fig. 100. The petroleum coming from the tank enters at *a* and passes out at *b*. A valve *c* in the interior of the apparatus regulates the flow, the lever *d* opening and closing the valves. At the moment of filling, the valve is opened by the lever *d* being suspended in a slit in the float *s*, which is also in the interior of the apparatus.

When the level of the oil reaches the float *s*, the latter is raised, whereby the lever *d* is released and forced back by the spiral spring into the position shown in the illustration, thus closing the valve.

On account of its shape, capacity and weight, the American barrel has been almost universally accepted as the commercial standard. It is made of American oak, all other varieties of wood, for instance European oak and beech, being inferior to it on account of their greater porosity and smaller weight. An excellent description of the manufacture and preparation of barrels was given a few years ago by Mr. Boverton Redwood, in his Cantor lectures before the Society of Arts, London, from which we quote as follows:

"The oak staves are purchased ready jointed and seasoned in Michigan, and the barrel heads are brought to the works ready glued up. The first operation in barrel making consists in fitting the necessary number of staves together in a thick wrought iron ring or hoop circling their lower ends. This is an operation requiring some experience and judgment. The embryo barrel is then placed in an iron cylinder and steamed, whereby the wood is softened. The staves are next encircled by a wire rope connected with an engine, and are thus bent into shape and drawn together, a second strong iron hoop being slipped over their upper ends to hold them in position. The barrel is then "fired" by burning some readily combustible material in the interior, and the curvature of the staves thus rendered permanent. A number of extra temporary iron hoops of great thickness are next slipped on, and drawn towards the bulge of the barrel by means of an ingeneous arrangement of iron hooks or claws actuated by steam power. The final operation performed upon the staves consists in placing the barrel in a lathe, paring off the rough ends, and cutting the grooves for the heads.

"The barrel is then ready to receive the heads and to be hooped. The hoops weigh collectively about twelve pounds, and the total length of iron required for a set is 443½ inches, so that putting the out-turn of finished barrels from one factory at 10,000 per day, we have a length of about 70 miles of hoop iron (weighing about 55½ tons) used daily.

"In order to render the barrels capable of holding their fluid contents without leakage, they are coated internally with glue, about one pound of glue to three barrels being required. The glue solution is poured into the barrels hot, the barrels bunged up, and rotated so that the solution coats the entire surface, the surplus being afterwards drained out. There is some pressure of steam in the barrel during the operation, and a leak is thus at once shown. The barrels finally receive a coating of the well-known blue paint on the staves and white paint on the heads. Oil barrels returned to be refilled are often cleaned externally by an arrangement of rapidly revolving wire brushes, are steamed out, reglued and repainted.

"Before the barrels are filled, the hoops require 'driving' to take up the shrinkage of the wood. This was formerly done exclusively by hand; but Mr. Hopper has invented a successful machine for doing this by steam power. In this apparatus the barrel stands on a platform arranged like an inverted steam hammer, and on turning on the steam it is brought, with a succession of blows, against a number of hinged stops which closely encircle the barrel, and on which the hoops strike. With one such machine the hoops of 2000 barrels can be driven in ten hours by one man and two boys—an amount of work which formerly entailed the hand labor of ten men."

Attention has recently been drawn to the use of iron barrels, the advantages claimed for them being that they require less repairing and do not require treatment with glue solution.

At the present time shipment in barrels has to some extent, though not altogether, been superseded by transportation of oil in bulk.

Shipments of oil to warm climates are made exclusively in cans packed in cases,[1] as barrels, though cheaper per gallon, are liable to develop leaks when exposed to decided changes in temperature. Deliveries to the more distant ports of China, Japan, India, Australia and South America are still, and probably will for many years continue to be, made in those packages, as bulk vessels cannot afford to engage in that trade because no return cargoes can be secured, so that the whole expense of the round trip would have to be borne by the load of oil carried out, the steamer returning empty. Cases can be packed close together, making a solid mass, with no loss of space in a ship's hold. In this respect they have a decided advantage over barrels.

The cans are of rectangular form, holding five American (or four English imperial) gallons, and are put by twos into wooden rectangular boxes. The outside dimensions of a case are about 20¾ inches long by 15 inches high and 10½ inches wide. This makes a very convenient package for handling, the weight of the case with the cans full of oil being about eighty pounds. The manufacture of the can and of the case are distinct industries, the former requiring delicate and expensive machinery and a large force of skilled mechanics. Most of the raw material used in making the cans, including the tin plate, is imported from England, the major part of the heavy duty imposed being returned as drawback by the government when the package of oil is exported. This is also true of the case, much of the lumber used coming from Canada, a duty being paid when it is brought into this country, and refunded on such portion of the lumber as is made up into the case and shipped abroad. Each can is fitted with a handle of wire or tin, and a screw top from which the oil may be poured when the consumer wishes to use it.

Continuous Distillation.

The chief advantages of continuous distillation consist in a

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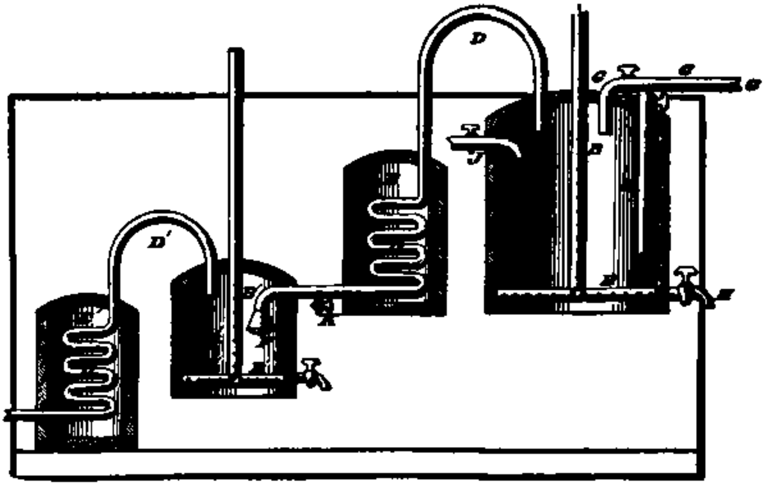
[1] Annual Report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania. Part III. Industrial Statistics, 1892.

great saving of fuel and of labor and time. The boilers are continuously kept at a nearly constant temperature, whereby waste of fuel is prevented and the plates of the boilers do not suffer from rapid heating and cooling, which in periodical distillation can scarcely be avoided. Singular to say, in the United States the system of continuous distillation is but seldom used, a fact which is very likely due to the greater content of illuminating oil in the crude oil worked, continuous distillation being based upon the attainment of larger yields from crude oil poor in illuminating oil, as is the case with the Russian product, The first experiments in continuous distillation were made by Samuel van Sycles, of Titusville, Pa. His patent bears date May 22, 1877, and suggests "a series of stills in which the oil is maintained at a constant level by means of a tank, in which a float on the surface of the oil as it rises or falls automatically controls the flow of oil." An apparatus constructed upon this principle of continuous distillation was put in operation in Buffalo, and the products actually placed on the market.

Fig. 101 shows a still constructed upon the same principle, designed by James Cole, Jr., of Cleveland, Ohio. The following description of its mode of operation is sufficiently explicit:

The still *A* being charged with the liquid, such as petroleum or any of its distillates, or the residual part left after a partial distillation of petroleum, steam is passed through the pipes *BB*, which we will suppose to be perforated as shown. As the liquid warms, the lighter and more volatile portions will be volatilized and pass over, the very lighest passing over with a very moderate heat, and, as the heat is increased, the heavier and more condensable products successively vaporize and pass over. If steam or air blast through the pipe *G* is employed, these volatized products, as soon as they separate from the liquid, are instantly caught up and carried out of the still. As these products pass forward through the pipe *D*, the heaviest of them are condensed in the condenser *E*, and fall as a liquid into the second still, while the lighter portions pass on through the pipes *D'*, etc. That which falls into the still *A'* may pass through a rose *F*, so as to drop in form of spray through an atmosphere which has been sufficiently heated to vaporize and drive out all except the very heaviest of the liquid product, which will remain in the still *A'*. The volatilized products continue on forward through the pipe *D'* and the condenser *E'*, of more power than the first, and here the next heaviest grade is condensed and falls in like manner, preferably through a rose into the third still, where a still greater heat is applied, or may be, leaving a certain grade of liquid, and passing the vaporized or lighter products still further forward, and so on. The result is that in the still *A'* a heavy oil is left suitable for illuminating and for other purposes, where the oil is required to stand a high fire-test, being entirely devoid of those very light and highly volatile and inflammable products that will vaporize when a very slight heat is applied, and may cause explosion.

FIG. 101.



In the still *A'* is a lighter oil of lower fire test, but still devoid of the lighter and more explosive and more highly volatile products. The still A_2 contains a still lighter product, and so on, as far as the process is carried.

By carefully grading the successive degrees of heat in the successive stills, this process may be carried to any extent desired, and the original oil may be separated into a large number of slightly different grades; or, in the same set of stills, any one of the grades that has been collected above may be treated in like manner, and be separated into separate and distinct grades.

By faucet *H* the products remaining in the several stills may be drawn off as collected, and by a feed-pipe *J*, the still *A* may be supplied with fresh liquid as rapidly as distilled and thus the process may be made continuous, and all the different grades may be produced and collected simultaneously, and by a single operation.

Faucets *K* may be located at suitable points for drawing off and testing the products at any point.

In the Caucasus considerable progress has been made in the direction of continuous distillation, Nobel's system being shown in Fig. 102. The plant consists of a battery of stills, there being, as a rule, four stills for preparatory heating and fourteen actual distilling stills. These fourteen stills are placed alongside each other, the total length of the row of stills being from 157 to 160 feet. The stills are arranged in the form of steps, the difference in level of the entire series being about 4¾ feet.

The stills are of a horizontal cylindrical form. Each still is about 20 feet long and 8 feet in diameter. It is provided with a dome *G* from which the products of distillation enter the condenser *SS*, the supply of cooling water being regulated by the pipe *l*. The condensed oils are conducted by a pipe-system to a building in which the production of the different varieties of oil is effected in accordance with the specific gravity of the separate fractions. Each still is provided with discharge pipe *e*, furnished with faucet *h*. By this faucet the residues heated to 572° F. are discharged and run in coils of pipes through

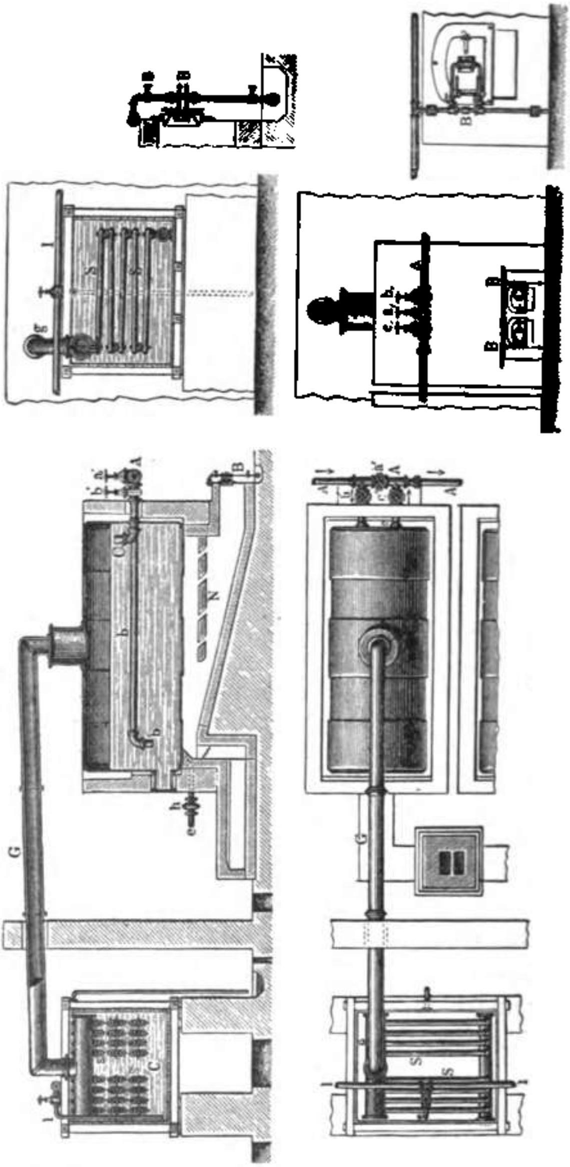


FIG. 102.

large preparatory heating tanks filled with naphtha to be distilled later on, which is thereby heated to between 230° and 266° F.[1]

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[1] Engler. Erdoel von Baku.

The lightest oils, at the utmost one-third per cent., volatilizing thereby, are condensed in special condensers connected with the covers of the tank, while the preparatorily heated naphtha is raised to the filling reservoir. From the latter, after the naphtha has cooled off to about 194° F., the first benzine still is uninterruptedly fed with the use of a regulator. The residues are discharged into large brick tanks.

By the preparatory heating of the naphtha not only fuel is saved, but also sand and mud are deposited.

All the stills are fired with residuum by means of Brandt's "forfunca" *B* (see "Utilization of crude oil and crude oil-products for heating purposes" later on.) The arch *N* protects the still from the pointed flame. The operation is carried on as follows: The first four stills, which are somewhat larger than the other fourteen, serve for separating the benzine and are, therefore, also called benzine stills, the other fourteen being the actual kerosene stills. Along the front side of the entire battery runs the principal conduit *A*, which is a pipe about 7¾ inches in diameter and a fall of one inch for the entire length. From this conduit the pipes *b* and *c* branch off in front of each still. The pipe *b* serves for filling the still. From the principal conduit *A*, the naphtha passes through the opened valve b_1 into the pipe *b* which extends to the rear end of the still and terminates in a joint pointed downward. From the still the naphtha returns through the pipe *c* and the opened valve c_1, to the principal conduit *A*, to flow in a similar manner into the next still. In this case the valve at a_1 is always closed, so that the naphtha is forced to pass through the still. From this arrangement it will be readily understood that any still of the battery may be excluded by simply shutting the valves b_1 and c_1, and opening the valve at a_1 in the principal conduit *A*. Distillation is effected in all stills with superheated steam, which is produced in a pipe-superheater and enters the steam-space through branch-pipes below and over the oil.

The following table shows the progress of some distillations.

	Preparatory heating stills.				First series of distillation.													
	48	49	50	51	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Temperature ° C.	131	153	175	194	195	211	227	234	248	250	256	......	......	......	273	275	285	294
Specific gravity at 17.5° C.	......	......	......	......	0.784	0.792	0.801	0.809	0.814	0.822	0.827	0.832	......	......	0.834	0.836	0.842	0.847
Temperature ° C.	129	159	177	200	206	221	230	238	257	259	......	......	......	280	285	288	297	307
Specific gravity at 17.5° C.	......	......	......	0.783	0.788	0.798	0.804	0.812	0.818	0.826	......	0.832	......	0.835	0.842	0.846	0.849	0.855
Temperature ° C.	133	157	175	......	193	207	218	228	246	247	......	......	267	272	278	283	297	304
Specific gravity at 17.5° C.	......	......	......	......	0.777	0.785	0.795	0.814	0.811	0.821	......	0.827	0.833	0.834	0.841	0.845	0.849	0.856
Temperature ° C.	126	150	179	192	195	219	228	233	243	247	256	......	275	286	294	300	310	315
Specific gravity at 17.5° C.	......	......	......	0.780	0.786	0.792	0.798	0.805	0.814	0.820	0.827	......	0.837	0.835	0.840	0.845	0.850	0.855

The stills Nos. 48, 49, 50, 51 are the preparatory heating stills, to which are joined the actual kerosene stills 1 to 14. In the horizontal column the temperature of a distillation and, below it, the specific gravities of the products are given. It will be seen that the distillation of Russian crude naphtha commences at 130° C (266° F.) and goes to 300° C. (572° F.), and that the specific gravity of the heaviest products used for petroleum is between 0.855 and 0.860. The result of working each still is nearly constant, the naphtha flowing through the stills yielding in each of them fractions corresponding to the temperature of the still. The difference in temperature of two adjoining stills amounts on an average to 7° or 8° C. The difference in the specific gravities is also uniform, it being between 0.007 to 0.010 degrees.

Besides the general advantages of continuous distillation, the result of the operation is a greater yield, amounting to about 36 per cent.[1]

This greater yield is due to the large vaporizing surface which in Nobel's system is attained by the number of stills and the constantly high level.

With this system of distillation the use of dephlegmators is indispensable, otherwise heavy oils may be readily carried along in consequence of the continuous supply of naphtha, the danger being especially great in the last stills.[2] Hence the vapors of the last five stills are passed through separators, the last three stills (Nos. 12, 13 and 14 of the table) being each provided with two, one after the other, and the two preceding stills (Nos. 10 and 11 of the table) each with one. Nearly 25 per cent. of the vapors are condensed, and the heavy oil thus obtained either runs directly back into the kerosene still, or what is the usual process, is caught in a special tank and worked for lower grade solar oils.

A continuously working distilling apparatus patented by Schuchow Intschik and Bary has recently been introduced in some refineries.

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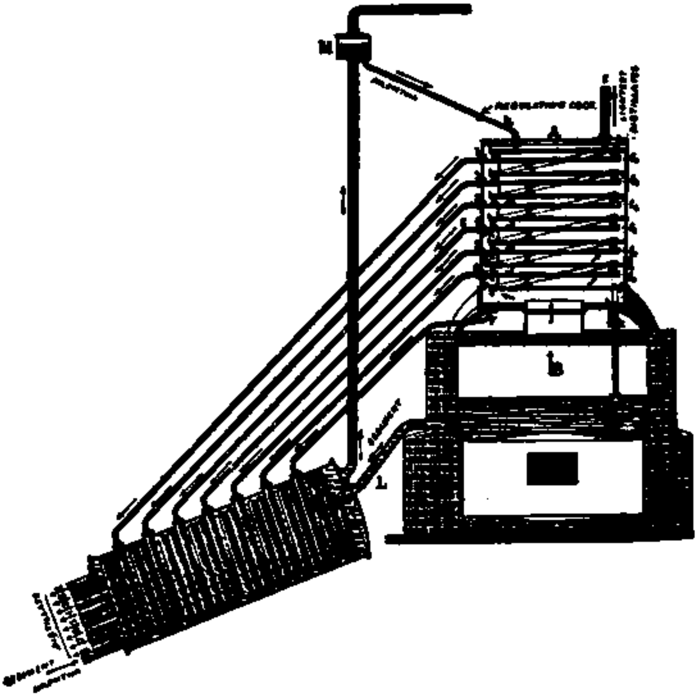
[1] Memoiren der Kaiserl. russisch. techn. Gesellsch., 1889, Mai.

[2] Engler. Erdoele von Baku.

The apparatus, Fig. 103 consists of a metallic box *A* which is placed upon the still *B*, or in its neighborhood. This box as seen from the illustration contains any desired number (generally nine) of shallow pans, which in combination with the sides of the box form a series of chambers and maintain in them a constant temperature. They collect at the same time upon their surfaces the condensed vapors according to their temperature. The progress of the distillation is as follows:

FIG. 103.



From the still *B* the vapors of the distilling fluid enter the box *A*, in which they circulate in the direction of the arrows and touch the surface of the pan *e f* filled with naphtha, thus heating the pan and consequently also the naphtha.

By yielding latent heat to the pans a portion of the vapors is partially condensed and falls in form of a fluid upon the plane *a b*. The vapors which have not been condensed in this chamber penetrate further through the hydraulic seal *p* into the oil masses and stir them up, whereby a portion of the heavier vapors is condensed, while the other portion is mixed with the vapors escaping from the naphtha of the pan, and enters through the slit *d* the second chamber. Here the entering vapors touch the plane $e' f'$ with less heated naphtha and heat the latter, whereby they are partially condensed, while the non-condensed portion passes through the hydraulic seal p' to act in the above described manner, the process being repeated in each chamber of the apparatus. The latent heat of the vapors ascending from below to above serves for heating the naphtha, which moves in the opposite direction from above to below to the still *B*. The closer the naphtha gets to the still the hotter the vapors which it meets; it becomes heated, whereby the portions corresponding to the degree of heating vaporize, so that only the heavy portion of the naphtha which cannot be volatilized in the apparatus runs into the still. The direction of the passage of the naphtha is readily understood from the illustration. It enters through the pipe K_7 the apparatus *A*, spreads out upon the planes e_6 f_6, and is heated by the vapors which circulate in the second chamber and pass into the fluid through *p*. The naphtha then pours through the pipe K_6 upon the plane $c_5 f_5$ which is heated by vapors possessing a higher temperature, and hence a proportion of the heavier fractions is here vaporized, while the other portion passes through K_5 to $e_4 f_4$, and so on. The portion which does not vaporize upon the plane *e f* passes through the pipe *K* into the still *B*.

The distillates formed by the condensation of the vapors flow upon the plane *a b* and through the pipes g_1 to g_7 into tanks. The pipes g_1 to g_7, before entering the tanks, pass an inclined cylinder which plays the role of a preparatory heater; the naphtha in going to the distilling apparatus passes this cylinder and is thus preparatorily heated by the distillate.

According to the statements of the inventors,[1] the apparatus possesses the following properties: It has a very small volume, consumes little fuel and cooling water, and the separation of the products of distillation is as complete as possible.

The still has a capacity of 400 pood crude oil, and with a continuous supply works up 8000 to 10000 pood crude oil in 24 hours. The specific gravity of the distillate upon the first pan is 0.872, and that of the residum 0.920; 57 per cent. of distillate is obtained. The difference in temperature between every two pans is 30° C., which for an apparatus with seven pans would make a total difference of 210° C.

The excess of the naptha residuum runs off from the still through the pipe *L*. It also passes the inclined cylinder filled with naphtha and yields heat to it. The crude naphtha is forced from a tank placed at a higher level through this cylinder into the reservoir *M*.

The apparatus is claimed to be in successful operation in the Schibajeff refinery at Baku. It has, however, undergone material improvements, such as the construction of a cast-iron rectifying column, so that scarcely more than the idea is left of the original apparatus. In the refinery above mentioned there are five such stills. The apparatus is provided with dephlegmation and fractional cooling, and is claimed to give a beautiful, light product, the yield being several per cent. larger than with ordinary stills. Thus far the apparatus has not been used for lubricating oils.

Less satisfactory results, it is said, have been obtained in the Rothschild refinery.

Experiments have recently been made in some refineries with an apparatus for continuous distillation devised by Alexejew, but the results thus far obtained are not sufficiently definite for its practical introduction.

In this apparatus distillation of the naphtha is effected with the assistance of light hydrocarbons instead of superheated steam. The hydrocarbons used for this purpose may be formed in dis-

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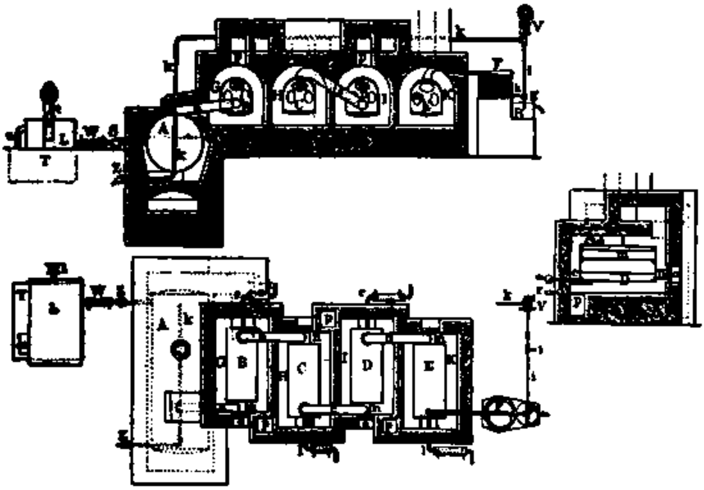
[1] Memoiren der Kaiserlich russisch. techn. Gesellsch., 1889, Mai.

tilling the naphtha or naphtha residuum, or may be produced in gas retorts of special construction. The light hydrocarbons formed during distillation pass with the distillate into the condenser, where they are separated from the oil and pumped back into the still. This mode of distillation is used for periodical as well as for continuous working. Fig. 104 shows a plant for continuous distillation.

From the still *A*, the vapors of the distillates and the light hydrocarbons pass through the pipe *a* into the first condenser

FIG. 104.



B, the distillate not condensing in the latter passing over into the second condenser *C*, from which the non-condensed portion enters through the pipe *c* the third condenser *D*. The non-condensed distillate passes from *D* through the pipe *d* into the fourth condenser *E*, and the portion which is not condensed there enters through the pipe *e* the coil *s* of the cooler *F*. On the lower end of the coil, as seen in the illustration, is a three-way cock *g*, one pipe of which is turned downward and dips into fluid 1¾ to 3 inches deep. Another pipe *i* turned upwards is connected with a gas (air) pump *V* which pumps the light hydrocarbons through the pipe *k* back into the still *A*. The pipe *k* is furnished with fine tubes and lies like a steam coil upon the bottom of the still.

The condensers *B*, *C*, *D* and *E*, lie in the chambers *G*, *H*, *I* and *K*. These chambers, and hence also the condensers, are heated to various temperatures corresponding to the distillate desired. The closer the condensers and the chambers are to the still, the higher their temperature. Thus the first condenser *B* is heated to between 680° and 752° F., the product obtained being vaseline. The second condenser, *C*, is heated to between 572° and 680° F., machine oil being obtained; the third, *D*, to between 392° and 572° F., the result being heavy oils, and the fourth, *E*, to between 212° and 392° F., the product being kerosene, while the vapors of benzine pass into the cooler.

The hot heating gases from the still *A* are conducted through the flues *p* into the chambers, and are regulated by the dampers *r*. On the bottom of each condenser is a discharge pipe *e*, which is connected with a special cooler *l*. The mouth of this discharge pipe lies somewhat higher than the bottom of the condenser, so that the fluid can run off only after having attained a certain depth, the object being to give the vapors of the lighter hydrocarbons, which may have been mechanically carried along, a chance to revaporize. To obtain greater dephlegmation (a larger cooling surface), the condensers are provided with pipes. On the opposite end of the discharge pipe *e* is placed, slightly above the bottom of each condenser, a shoulder *n*, which is provided with a man-hole *o* and the channel *p*, and is also connected with the pipes *b*, *c*, *d*. The still *A* is continuously fed through the pipe *S* with crude oil from the reservoir *L*, the crude oil being pumped into the latter from the reservoir *T*, which is located at a lower level. The pump sucks up somewhat more oil than required for feeding the still *A*; the superfluous crude oil flows back through the overflow-pipe *u* into the lower reservoir *T*.

To prevent the naphtha in the reservoir from becoming heated by the pipe *S*, the latter lies in the cooler *W*. The cock *Z* serves for discharging the fluid from the still *A*.

If the apparatus is to be used for the fractional distillation of residuum only two condensers are required.

The apparatus above described is said to be in use in the Zollikofer refinery at St. Petersburg, and to yield good results; this statement being confirmed by experiments made by Alexejew in the presence of a commission of experts. However, according to private information, an apparatus in a Baku refinery has not yielded satisfactory results.

It is claimed that from naphtha residuum the apparatus yields about 80 per cent. crude kerosene of 0.824 specific gravity. With one distillation only about 30 per cent. of the crude material are obtained as kerosene in the condenser *E*, but if the oils condensing in the condensers *B*, *C*, *D*, are again subjected to distillation in the apparatus, the above mentioned 80 per cent. is obtained. This crude kerosene is then subjected to distillation in ordinary stills. The product is a good illuminating oil of 0.821 specific gravity, and amounts to about 67 per cent. of the crude material.

The Alexejew apparatus is said to work very quietly and require no attention. However, as dephlegmating chambers are required, it is much more expensive than ordinary stills, and distillation having to be repeated three times, the consumption of fuel is necessarily large. Hence it could only be introduced in regions where naphtha is expensive and fuel cheap. That the apparatus did not yield satisfactory results at Baku is very likely due to the low price of crude naphtha prevailing there, it differing but little from that of residuum, so that there is no necessity of working residuum for illuminating oil, which is the actual principle of this apparatus.

The yield of about 67 per cent. kerosene from residuum is due, however, not only to the distillation being effected with the assistance of the light hydrocarbons, but also to the quite high temperature (about 717° to 735° F.) prevailing in the still. At this temperature the heavier portions undergo a decomposition whereby the lighter portions formed are carried away with the volatile hydrocarbons flowing in, the latter by constantly stirring up the fluid preventing also the very heavy portion from burning to the sides of the still.

In 1889, Mr. Dolinin constructed a continuous still for petroleum and solar oils, but as it has not been introduced in practice, a description of it is unnecessary.

Lissento's method is based upon splitting the naphtha residues between 812° and 934° F. with a yield of 64 per cent. kerosene of 0.805 specific gravity, and 30 per cent. of 0.860 specific grauity. According to Glasenapp this method, however, is not practicable, because, 1, distillation is too slow on account of the splitting of the hydrocarbons, so that twenty times less oil can be worked than with the ordinary process; 2, the kerosene obtained is of a dark color; 3, 20 per cent. of acid are required instead of 0.5 to 2 per cent. for ordinary petroleum, and 4, crude naphtha is too cheap.

Utilization of Residuum.

The residuum obtained in the distillation of petroleum forms the crude material for the production of valuable oils, fats, etc. It represents, as a rule, a thickly fluid mass of a dark green to black-brown color, and frequently congeals at the ordinary temperature. It has an empyreumatic odor, frequently reminding one of creosote. Its specific gravity, as a rule, varies between 0.880 and 1.0, but sometimes exceeds the latter. It generally floats upon water, and is distinguished by particular fatness, especially if derived from Russian oils. After the thinly-fluid oils have been separated, it shows a high burning point, and its boiling point is generally above 572° F.

Thickly-fluid residuum, which congeals readily, generally contains paraffine, though the congelation may also be due to tarry admixtures; residuum remaining fluid at the normal temperature contains very little paraffine. After distillation the residuum is too hot to be immediately discharged without previous cooling. Besides injury to every connection of the conduits in transferring the residuum by means of pipes, there is also to a certain extent danger of spontaneous ignition. This phenomenon of spontaneous ignition has not yet been sufficiently explained, and fortunately has been confirmed by a few cases only. It is very likely that at such a high temperature the oil vapors form with the oxygen of the air a mixture which readily ignites and explodes.

The residuum is generally cooled by means of water, a small reservoir provided with a contrivance for a constant supply of water being, as a rule, placed in the vicinity of the discharge pipe of the still. In this reservoir lies a large coil through which the residuum runs off, whereby it is sufficiently cooled to be subjected to further treatment without danger. This cooling arrangement may also be recommended for other reasons; with periodically working stills the residuum can be rapidly discharged and no time is wasted in cooling the residuum in the still itself, as is the case where no provision for cooling has been made.

In a crude state residuum is used for firing, and in a filtered and refined state as a lubricator and for the production of wagon grease and oil gas. Its use for fuel will be discussed in another chapter, while its employment for the manufacture of wagon grease and oil-gas does not strictly come within the scope of this work.

Oil residuum is also largely employed in the manufacture of asphaltic cement for street paving, which in the District of Columbia is carried out according to a method strictly prescribed. This method, in brief, is to melt the asphalt at a temperature not exceeding 325° F., and then to add the oil residuum previously heated to at least 150° F., and by continued agitation to bring the mixture to the condition of "a homogeneous cement." The specifications of the Department of Public Works of Philadelphia state that "the refined asphalt and oil residuum will be mixed in the following proportions by weight: asphalt, 100; petroleum, 16 to 22."[1]

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[1] **Asphalt Paving. Reports of Experts appointed by Special Sub-Committees of**

Not every residuum is suitable for the manufacture of lubricating oils, sufficient fluidity, which is a special advantage of Russian oils, being the first requirement, and next viscosity and purity. Russian residuum with an average specific gravity of between 0.910 and 0.920 forms an excellent lubricating material when free from water and freed by filtration from suspended tarry and coke-like constituents. Every residuum, if otherwise suitable, must as a rule be subjected to treatment with chemicals. The process is comparatively simple, and the results attained are frequently surprising. The residuum suitable for the manufacture of lubricating oil is generally treated as follows: It is brought into small agitators lined with lead and completely freed from water by means of indirect steam. It is then treated with vigorous agitation at a temperature of from 176° to 212° F. with sulphuric acid. When the acid has for a sufficient time acted upon the residuum, agitation is discontinued, and the product allowed to stand for a short time, when the sludge acid is drawn off as rapidly as possible, the latter becoming solid at the ordinary temperature. The oil is allowed to stand for some time longer to allow particles of tar held in suspension to deposit, when it is drawn off, immediately treated with lye and boiled bright in broad shallow pans. By this treatment a green fluid of slight odor, transparent in thin layers, and of great lubricating power, is obtained from the disagreeably smelling black-brown residuum. The expense of producing such oil is however considerable, since by the treatment with acid (generally from 5 to 10 per cent.) a large portion of the residuum, frequently one-half, resinifies with the acid. According to the consistency of the residuum, thinly or thickly fluid oil is obtained, the latter being generally used as cylinder oil, while the former is brought into commerce as "vulcan oil." According to the derivation of the residuum, oils of quite a good quality may also be obtained by simple filtration; thus the American

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the Citizens' Municipal Association of Philadelphia and of the Trades League of Philadelphia to investigate Asphaltic Materials available for Street Pavements in Philadelphia. 1894.

and Galician vulcan oils (filtered vulcan oils) are filtered warm with self-pressure through filters heated by steam. A vulcan oil is supposed to be pure if a sample leaves very little or no residue upon a paper filter.

The use of residuum as such, filtered or refined, for lubricating purposes is limited, it being employed only for subordinate parts of machines, for wagon axles, etc., where special stress is laid upon a high burning point, viscosity and low price. Its use for machinery, especially steam engines and tools, cannot be recommended on account of its large content of tar, which readily causes gumming. Oils obtained from the residuum by distillation with superheated steam are almost everywhere used as a substitute for the expensive vegetable oils.

The employment of lubricating oils of mineral origin is of recent date, it having attained its present importance only within the last two or three decades. Prior to the use of superheated steam, mineral lubricating oils were prepared from the residuum by simple distillation, *i. e.*, by vaporizing the product and condensing the vapors. Distillation was at first effected in cast-iron retorts and later on in sheet-iron stills. Although with careful distillation a product of a beautiful color and sufficiently high specific gravity was obtained, it did not possess the principal requisites of a good lubricating oil, it losing much of its lubricating power by the manner of distillation. Very high temperatures were required for vaporization, and the oil-vapors coming in contact with the over-heated sides of the still suffered partial decomposition, with the formation of lighter hydrocarbons, which decreased the fatness of the oil and imparted to it a disagreeable odor. To avoid these evils it was endeavored to destroy, or at least decrease the odor by the use of more chemicals, and to convert the oil into a tolerably useful commercial article by the addition of vegetable and animal oils. These endeavors led of necessity to improvements, and superheated steam to assist distillation was first introduced, as far as known, in Austria-Hungary by Mr. von Matscheko towards the end of the sixties or in the beginning of the seventies. The introduction of superheated steam and other improvements to be mentioned later on gave rise to an industry which has at present assumed great proportions. This applies especially to the Baku district, the residuum of the kerosene distillation offering a material that is especially suitable for the production of lubricating oils. The development of this branch of industry is largely due to the labors of V. J. Ragosin, the brothers Nobel, Messrs. Schibajeff, Oehbrich, Tagieff and Sarkisow.

The oils obtained from Russian residuum are distinguished by great viscosity, capacity of resisting cold and fire, and by a minimum content of paraffine. Like the manufacture of petroleum, the fabrication of lubricating oil consists in distillation and subsequent refining of the distillate, the difference, however, being that distillation cannot be effected with the use of fire alone, but superheated steam has to be employed because the vapors formed are so heavy that they can rise only with difficulty from the still. The superheated steam acts mechanically, the object of using it being not so much to effect vaporization, which it is not capable of accomplishing on account of its comparatively low temperature, as to carry along particles of oil and by enveloping them to protect them from suffering decomposition on the hot walls of the still. The oil thus retains its lubricating power, and there is no inducement for the formation of pyrogenous products with a bad odor. The steam may be used either directly from the boiler as saturated steam with a pressure and temperature corresponding with those of the boiler, or as superheated steam.

For the distillation of crude oil saturated steam may be used under limited conditions, but only for the vaporization of the light hydrocarbons and for assisting kerosene distillation in general. For complete distillation and the distillation of residuum it is, however, entirely useless, because to attain these comparatively high temperatures it would have to be produced under a pressure which iron could not well resist, and besides, the consumption of fuel would be enormous. Hence, in the practice, superheated steam only is used for this mode of distilling, because steam can be readily superheated to between 752° and 932° F. without the necessity of increasing the pressure.

Besides the above-mentioned advantages superheated steam facilitates the operation for the following reasons:

1. The temperature of the superheated steam is not dependent on the steam pressure, *i. e.*, with the same steam pressure the temperature of the steam can be raised at will.

2. Superheated steam as regards its thermal properties closely resembles permanent gases, it remaining gaseous even when heat is withdrawn and condensing gradually to water only when cooled off very much.

3. The relation of the temperature, pressure and volume of superheated steam to one another is as follows:

$$p.\ V = 0.0051\ T - 0.193\ p\ \tfrac{1}{4},$$

T meaning the absolute temperature, V the volume in cubic meters, and p the pressure in kilogrammes upon the square meter.

That is, the volume of the superheated steam is greater than that of the saturated steam with the same pressure from which it has been produced, and the difference in the volumes is proportional to the superheating.

The heating capacity of superheated steam is according to Hirn 0.45, and according to Regnault 0.48. To obtain saturated steam of, for instance, 392° F., a pressure of 16 atmospheres would have to prevail in the boiler. On entering the still so much water is condensed by the yielding of heat that, on the one hand, the operation would be constantly disturbed by the large quantities of condensed water, and, on the other, the steam would no longer be effective in consequence of yielding heat. But superheated steam remains gaseous, and is even capable of vaporizing quantities of water and carrying them along.

The steam after having been produced in the boiler is raised to the desired temperature in the so-called steam superheater.

In arranging the latter the superheating surface consisting of the sides of the superheater has to be calculated; it must be sufficiently large to allow of a certain weight of steam being heated to a certain temperature. The diameter of the pipes is determined by the velocity of the steam, which in its turn is dependent on the quantity of steam.

If, for instance, 100 kilogrammes of steam are to be superheated in one hour to 200° C. (392° F.) with a pressure in the boiler of 2 atmospheres, the quantity of heat required for the purpose may be calculated as follows: The temperature of saturated steam at 2 atmospheres is 120.6° C. (249° F.) and its heating capacity, according to Regnault, 0.48. Hence the quantity of heat required for superheating is 100 (250–120.6) 0.48=6240 calories. From this quantity of heat the surface of the superheater per square meter can be calculated according to Peclet's well known formula:

$$V=v+v_1=124.72\ K_a\ \vartheta(a^t-t)+0.552\ K_1 t^b,$$

V representing the total yield of heat.

$$v=124.12\ K_a\ \vartheta(a^t-1).$$

$$v_1=0.552\ K_1 t^b,$$

v the heat yielded by radiation per hour and m^2.

v_1 the heat-yielded by conduction per hour and m^2.

ϑ the temperature of the surrounding medium.

t the excess of temperature of the heat-yielding surface over the temperature of the medium.

K a coefficient dependent on the condition of the surface of the body.

K_1 a coefficient dependent on the shape and extent of the surface.

a a constant=1.0077.

b a constant=1.233.

From this formula the quantity of heat that is transferred by one square meter superheating surface may be calculated.

However, in the practice an excess of steam is always used.

The superheater consists of a system of pipes in a suitable furnace. In choosing a superheater care should be taken that the material of which it is constructed does not suffer from the heat and that the temperature of the steam remains constant and is not subject to variations. The pipes leading from the superheater to the still should be insulated up to the point where they enter the latter; furthermore the pressure in the boiler, and hence also in the superheater, should be constant.

Fig. 105 a and Fig. 105 b show a superheater of simple construction. It consists of straight pipes with the connecting pieces placed outside the furnace. It produces the same effect as a superheater of pipes bent in the most artistic manner, and has the advantage that a defective pipe can be removed with great ease and replaced by a new one. The joints outside the furnace can be readily protected from cooling off. The last pipe of the superheater is connected with the conduit leading to the still, and is provided with a branch to allow the steam to escape into the open air while it is being heated, and also with a cock for the discharge of condensed water and for the determination of the temperature of the superheated steam.

FIG. 105 A.

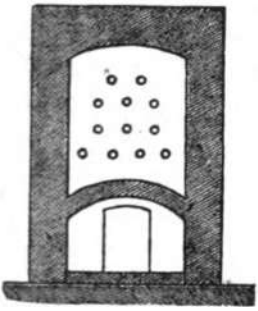
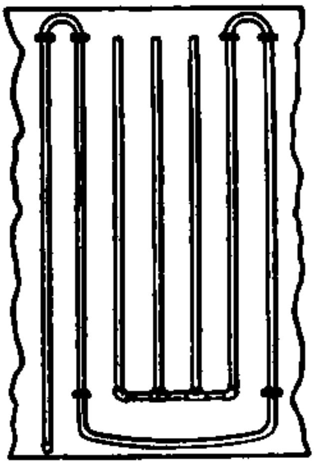


FIG. 105 B.



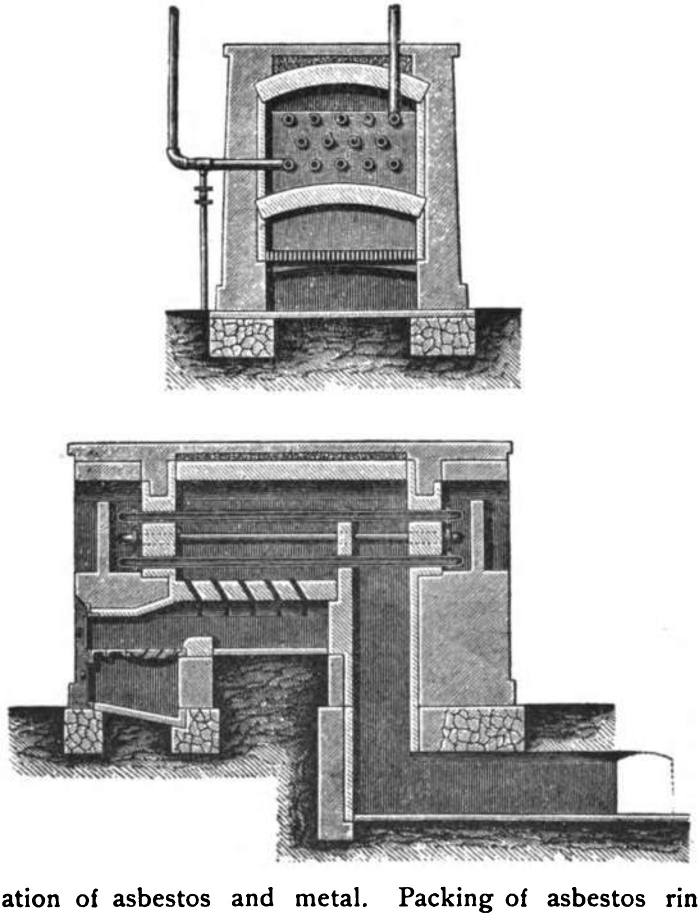
For the distillation of residuum it is necessary to superheat the steam to three different degrees, namely, approximately to 302°, 464° and 572° F. The first degree is recognized by the hand which, when passed through the steam escaping from the test-cock, should remain perfectly dry. Steam superheated to the second degree has no longer the dense, white, nebulous appearance of ordinary steam, but is bluish and thin like the smoke of a good cigar. When the third degree is reached, the steam escaping from the test-cock is not visible, though the ordinary whistling noise of escaping steam is heard. As it is very important not to superheat steam to above 572° F., and the steam itself furnishes no guide, the proper temperature is recognized when a piece of paper pressed with a stick against the pipe turns dark yellow. If it turns brown, or carbonizes, the temperature is too high. The above-mentioned device of a testing-cock for determining the temperature of the superheated steam is preferable to a pyrometer, which is expensive, and at the same time so unreliable, that after having been used for a short time it is apt to lead one astray.

Regarding the choice of material for the superheater, the following may be said: In many cases cast iron pipes are used. However, if not made of the best material they crack readily and require frequent repairs. Wrought iron pipes, though not possessing these disadvantages, are not durable, as they burn through very readily and become useless. Superheaters consisting of a combination of cast and wrought iron have recently been constructed and have given general satisfaction where introduced. They are constructed of wrought iron pipes coated with cast iron, this device answering the purpose, because the outer cast iron envelope does not burn through very readily and, being cast upon the wrought iron pipe, is held together in case of cracking, while the wrought iron pipe being protected from the flame cannot burn through.

Fig. 106 shows such a superheater. It is so arranged that the steam enters at a place furthest from the fire-box and to reach the still passes out at a place close to the fire-box. The portion of the heater outside of the brick work is, up to the still, protected by an insulating mass. The separate pipes rest free in the superheater and can expand at will. They are connected by joints outside the superheater.

The best packing for the joints of the superheater is a com-

Fig 106.



bination of asbestos and metal. Packing of asbestos rings, metallic sieves, etc., is not suitable, it being unable to resist the high temperature and comparatively high pressure.

Stills for Lubricating Oils.

As regards their shape, stills for lubricating oils have in the course of time undergone many modifications. Upright cylindrical cast iron stills with bellied or semi-circular bottoms were generally used. The steam was heated in cast iron pipes and introduced into the still, a simple branch-pipe being, as a rule, used for the purpose. The oil vapors mixed, with the steam, ascended, passed through a tall head, then through a cooling coil, and after condensation were refined in the usual manner. However, the products obtained by this process did not answer all demands. Hence it was endeavored to obtain good and faultless products by modifying the shape of the still, by selecting the proper material, the perfect superheating and introduction of the steam, and finally by the proper condensation of the vapors.

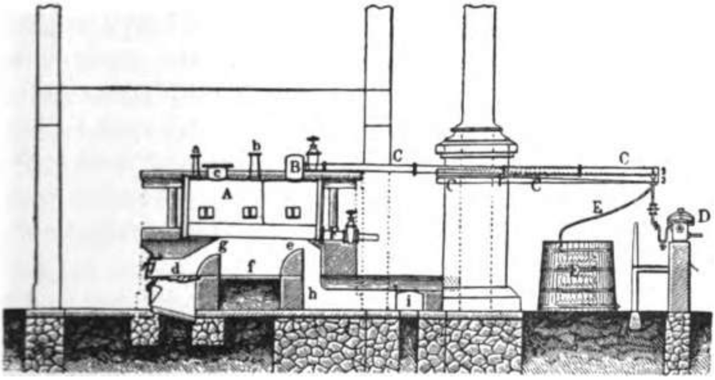
The separate modifications may be described as follows:

First it was learned from experience that cast iron stills did not answer the purpose, it being very difficult, in consequence of the thickness of the material and its slight capacity of conducting heat, to bring the still to a temperature at which, on the one hand, the oil would be properly heated, and, on the other, the introduced superheated steam would not condense. The oil remained cold and a considerable portion of the steam condensed, which frequently caused the oil to run over and produced irregularities in the process of distillation. If in the course of the operation the still became sufficiently heated it was very difficult to cool it off and regulate the temperature—a circumstance of great importance in this mode of distillation. Sheet iron stills were then successfully introduced; they being thinner, all the above described evils could be avoided. The oils obtained were fatter and lighter, but not free from odor. The principal reason for the latter defect was the use of upright stills, the distance the oil vapor had to ascend being disproportionately large to the vaporizing surface. The oil vapors carried along with the steam were forced to traverse a great portion of their way in the still itself, and becoming partially condensed on account of their high boiling point, they flowed back generally on the strongly heated sides of the still, where they suffered decomposition, though to a limited degree. This was the case especially towards the end of distillation, when the heaviest and fattest oils were obtained. This led to the adoption of horizontal cylindrical stills, a form which with slight modifications (oval cross-section) is now in general use in all Russian and modern European factories. When the importance of rapidly carrying away the oil was recognized, it was provided for by low domes and discharge-pipes with considerable fall.

In modern times distillation with superheated steam is assisted by a vacuum.

Fig. 107 shows the arrangement of a distilling plant without the use of a vacuum, together with the condensing apparatus. *A* is the oval still; *B*, the dome; *C* the pipe for the oil-vapor. The pipe *C* has the form of a coil with a constant fall; its diameter at the initial point is 15¾ inches, but is graduaHy reduced. At the points 1, 2 and 3, are pipes for the condensed oils, which run into the three pots *D*, and from there into the reservoirs. *E* is the cooling coil for the lightest products, *F* the discharge pipe for the residues no longer fit for distillation; *a* and *b* are openings for the introduction of steam and oil; *c* is the man-hole, and *d*, *e*, *f*, *g*, *h*, *i*, the heating arrangement together with the smoke flue.

FIG. 107.



Distillation is carried on as follows: When the residuum is sufficiently heated, which is recognized by its boiling uniformly and the appearance of drops of the lightest oil, steam is immediately introduced.

The superheater is heated a few hours before commencing operations, and the steam allowed to pass continuously through it. The steam is sufficiently heated to allow of its introduction into the still when it loses its white-gray color, and appears at the test cock blue and transparent. It should be introduced slowly and gradually, otherwise it might carry along not only oil but also residuum. Its admission is regulated by partially opening the steam-valve in front of the still and closing to the same extent the valve on the pipe which allows the steam to escape into the open air. Distillation commences immediately, and opening and closing of the two valves is continued until distillation proceeds quietly and vigorously. The steam enters the still through a forked pipe, the holes in which should be so arranged that while a portion of the steam passing out is forced to flow along the bottom of the still to prevent scorching of the oil and to expel the last heavy remnants, another portion flows partially in a lateral and partially in an upward direction. In the beginning of distillation the temperature of the steam varies between 266° and 390° F., but as distillation progresses it is raised to between 482° and 572° F., but never above the latter point. Many factories work with an average temperature of 392° F., it being slightly raised only in winter.

The quantity of superheated steam used varies, but as a rule it suffices when in the product of condensation, the quantity of water is in the proportion of 1 : 2, or at the utmost of 1 : 1 to the quantity of oil.

The next important operation is condensation, the good quality of the oil largely depending on it, because notwithstanding the use of horizontal stills and sufficiently and properly superheated steam, the oils were formerly not entirely satisfactory. In Russia, especially in the Nobel and Ragosin factories, a system has been introduced which is based upon the proper conception of the physical elements of distillation. While in nearly all the older refineries condensation of the oil vapors and steam is effected in the old method by allowing them to pass through one or at the utmost two pipes and then cooling them by water, the modern process is based upon separate cooling by air and water.

The action of the steam being purely mechanical, since it vaporizes the lighter portions of the oil and carries along the heavier portions, it is evident that with the old process of condensation, these vapors and particles of oil condense and combine in the pipe and the resulting oil does not possess a great degree of viscosity and a high igniting point. By allowing, however, this mixture of oil vapors and steam to circulate in properly constructed pipes, and providing discharge pipes at suitable places, the heaviest oils will first separate and run off, next those which condense with greater difficulty, and so on. Thus with a proper apparatus oils with different specific gravities. of varying degrees of viscosity and with different boiling points, can be obtained at the same time and alongside one another. The idea of aërial condensation, especially for light oils, is, however, not new.

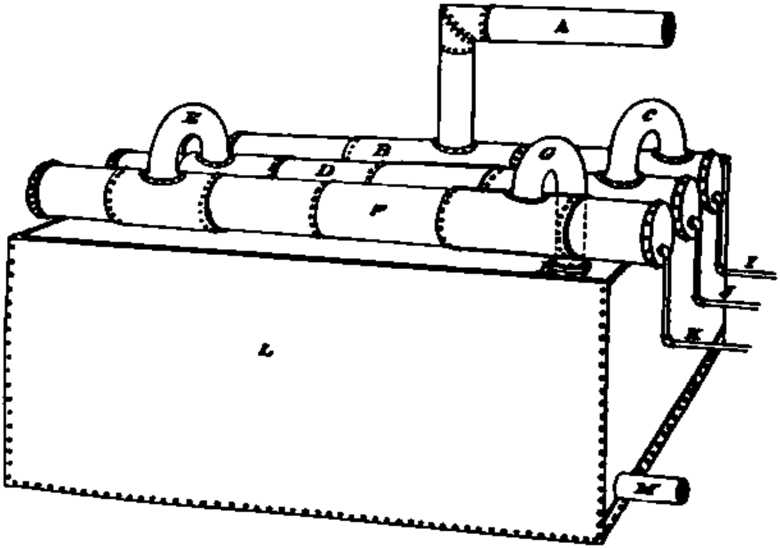
Every well arranged refinery has now introduced separate condensation, whereby the vapors are separated according to their volatility into fractions by dephlegmators cooled by air. M. Albrecht's aërial condenser, seen in Fig. 105, is much used. It consists of patent welded sheet-iron pipes about 7¾ inches or more in diameter, which gradually taper to 3¼ or 4 inches. Each pipe is from 20 to 23 feet long, the total length of the pipes varying between 131 and 164 feet.

The oil vapors condense in such a manner that in the beginning of the operation light oils appear at the first discharge pipe, but in a few hours the flow regulates itself, so that a natural separation of the oils is maintained up to the end of distillation. The difference in the specific gravities of the fractions varies between 0.005 and 0.015, according to the length of the condenser. By this method of condensation the oils running off at the first places of discharge are obtained almost free from water, a larger quantity of water condensing only with the lightest oil, while pure steam passes out from the terminal point of the coil. Hence the oil does not require much time for settling and can in a short time be used for refining.

Mr. Benjamin J. Crew describes a condenser in which water condensation is supplemented by an arrangement for aërial condensation. The apparatus is rigged immediately above the water tank and rests upon it. In the winter season it adds very materially to the condensing surface, besides affording an easy, rapid method of dividing the products of distillation at one operation into at least three distinct gravities of oil or benzine.

Fig. 108 will illustrate this form of aërial condensation:

Fig. 108.



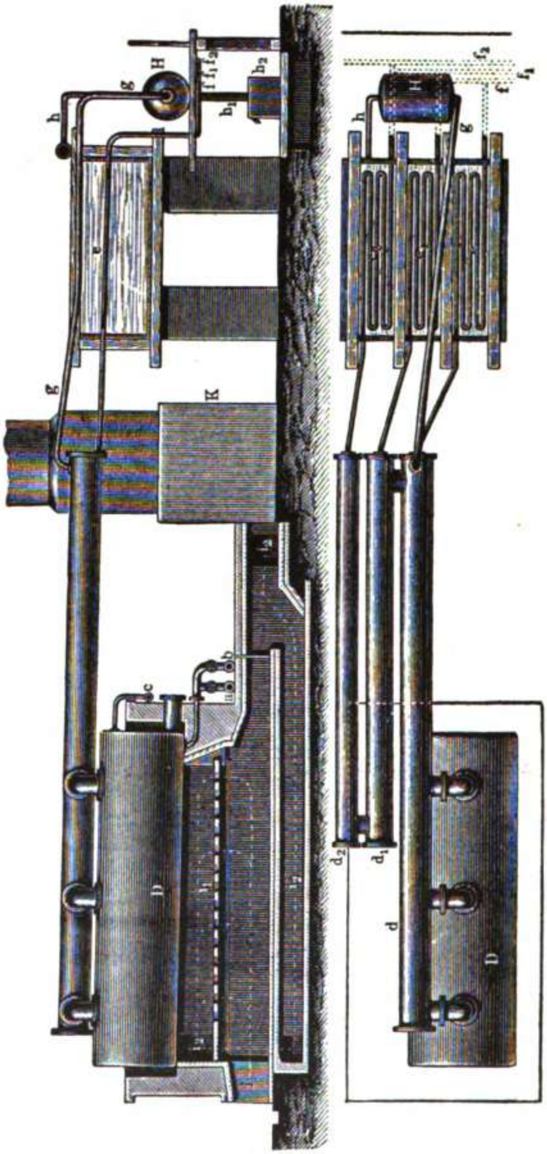
A represents the large pipe leading direct from the still and connecting this with the condenser. *B*, the first air condenser, is an iron cylinder of three-sixteenth iron, 30 feet in length, 24 inches in diameter. *C*, is an elbow connection between *B* and the second condenser *D*, of same diameter as the first. *E* is an elbow connection between the second condenser *D* and the third condenser *F*. *G* is an elbow connection between the third air condenser *F*, and the usual condensing pipe *H*, which here enters the water in the tank *I*.

Any light benzine which admits of condensation by simple exposure to the air of the condenser B, passes through the pipe *I* into the appropriate tank. A heavier grade of benzine requiring a still greater degree of cold, is subjected to this in the second cylinder and runs off through the pipe *T*. A still heavier grade of the lighter products, which will not admit of condensation, passes into the third air condenser and passes off through the pipe *K*. Any product which requires a greater degree of cold than the air will supply passes into the regular condensing worm at *H* and is graded subsequently at the receiving house in the usual manner. In the working of the apparatus in the early part of the operation, three grades of benzine are running at the same time, and also during the "cracking" process, a portion of light product the result of the decomposition of the heavier oils may also be received through the medium of the air condensers.

Distillation of lubricating oil with the assistance of a vacuum is now much carried on, especially for the production of very heavy oils. The apparatuses used for the purpose vary in construction so that no general rules can be laid down.

Fig. 109 shows an apparatus with vacuum for the distillation of lubricating oil as used in Nobel's refineries. *a b* are pipes for introducing and discharging the residuum; the superheated steam enters at *c*. The distillates are conducted from the still *D* into the dephlegmators d, d_1, d_2, the diameter of the pipe *d* being 24 inches, that of d_1 20 inches and that of d_2 15 inches. At all lower points are discharge pipes leading to the condensing coils e, e_1, e_2, from which the oils run through the pipes f f_1, f_2, into the tanks. The vacuum apparatus *H* serves to assist distillation, the necessary vacuum in the dephlegmators being produced by the exhaust pipe *g*. *h* is the water pipe for the vacuum apparatus, h_1 the outlet pipe from the vacuum still, while h_2 forms the hydraulic seal for the vacuum still; the water pipe is provided with a sieve through which the cold water is injected into the apparatus. With this arrangement special condensers can be dispensed with, and on the other

FIG. 109.



hand, in consequence of the constant rarefaction of the air in the still, distillation proceeds much more rapidly; besides, the yields of oil are greater and their quality better. The fire-place is separated from the still by the arch i_1; i_2 is the smoke-flue leading to the chimney *K*. The still itself is 24 feet long, with a diameter of from 5 to 6½ feet. In place of this vacuum apparatus of simple construction, pulsometers and directly acting exhaustors and ejectors are also used. With this separate condensation, a great difference between the first and second condensing pipes cannot be well determined, and they are generally taken together. The lightest oils condensing with steam are as a rule worked into illuminating oils (solar oils) of an inferior quality. In working Russian residuum, the specific gravity of the oil increases from 0.860 to 0.925, while the specific gravity of the black-brown residuum, which in the cold is viscous and almost solid, is 0.950 or more. There are, of course, variations according to the nature of the residuum and the manner of distillation and condensation.

The yield and specific gravity of the separate fractions are, according to experience gained in one of the largest factories, as follows:[1]

	Per cent.	Specific gravity.	Limits of the specific gravity.
First run	10 to 15	0.870	to 0.890
Spindle oil	9	0.896	0.890 " 0.900
Machine oil	40 to 42	0.911	0.900 " 0.918 to 0.920
Cylinder oil	3 " 4	0.915	0.925

In another large refinery the results were as follows:

	Per cent.	Specific gravity.
Solar oil	10	—
Spindle oil	10	0.897
Machine oil	25	0.908 to 0.910
Cylinder oil	3	0.915 " 0.918

Hence the total yield of non-refined lubricating oil varies between 38 and 54 per cent. of the weight of residuum, and with a yield of 56 per cent. of residuum between 20 and 30 per cent. of the weight of crude naphtha. From the light Bibicybat

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[1] C. Engler. "Erdöl von Baku."

naphtha worked near Tagieff and Sarkisoff only 14 or 15 per cent. is obtained.

By further subdivisions in the aërial condensers the number of fractions can, of course, be increased, but, as a rule, not more than two or three fractions of lubricating oil are worked for. A considerable loss amounting to 2 or 3 per cent. is always incurred.

The subjoined table shows the gradual increase, counted from the commencement of distillation, in the specific gravity of the distillates obtained with separate condensation from Caucasian petroleum residuum.

After hours.	1st Pot.	2d Pot.	3d Pot.
1	0.870	0.865	0.861
2	0.872	0.867	0.863
3	0.875	0.870	0.866
4	0.877	0.873	0.869
5	0.880	0.876	0.871
6	0.884	0.879	0.874
7	0.887	0.882	0.877
8	0.890	0.885	0.880
9	0.894	0.891	0.884
10	0.896	0.893	0.886
11	0.898	0.895	0.888
12	0.899	0.897	0.890
13	0.901	0.899	0.892
14	0.903	0.901	0.894
15	0.905	0.903	0.896
16	0.907	0.905	0.898
17	0.909	0.907	0.902
18	0.911	0.909	0.904
19	0.912	0.910	0.906
20	0.912	0.911	0.907
21	0.915	0.913	0.909
22	0.916	0.914	0.910
23	0.918	0.916	0.912
24	0.918	0.916	0.913
25	0.920	0.917	0.914
26	0.922	0.918	0.915
27	0.923	0.919	0.916
28	0.924	0.920	0.917
29	0.925	0.922	0.019
30	(Congeals at the ordinary temperature.)		

By working residuum of sufficient fatness a series of products, that answer all demands of the industry, may be obtained. Thus, besides specifically light oil of 0.880 to 0.890, which can be used only for mixing purposes, there can be produced from fat Russian residuum oils with specific gravity 0.895 to 0.915, that answer in every respect the requirements of a good lubricant. On the other hand, specifically heavy Galician residuum, distilled in the same manner, yields oils only suitable for mixing and subordinate lubricating purposes. The distillates, especially the heavy and fat ones, are advantageously used as lubricants, because it cannot be denied that by the chemical purification, to be described later on, the distillates lose a portion of their viscosity, the fattest constituents of the oil being withdrawn by the sulphuric acid, and perhaps also readily oxidizable by-constituents.

The chemical purification of lubricating oils is effected in a manner similar to that of petroleum, but is much more difficult and requires greater care, the conditions differing for every variety of oil, and the correct mode of refining can only be learned from experience. Hence it is difficult to lay down general rules regarding the purification of lubricating oil, every refinery keeping its process secret, though this applies only to some portions of the operation.

Before bringing the distillates into the refining apparatus it is recommended to free them as much as possible from water, which is usually effected in the distillate-tank itself, or in special tanks heated by steam circulating in a coil. After removal of the mechanically separated water, the water held in suspension by the oil is evaporated, the oil being dried in this manner. In some refineries it is then filtered before being subjected to treatment with sulphuric acid. The distillate thus freed from water can of course be refined much better and more rapidly, the preparatory acidulation for the removal of water not being necessary, and besides less acid is required. In older refineries, the oils are treated with sulphuric acid, then neutralized with lime and rectified; this method has, however, been abandoned in modern refineries.

Purification is generally effected in double agitators like those previously described. The acid-agitator is lined with lead and provided with steam, and stands at a higher level than the lye-agitator. The latter has a steam-jacket and is heated by direct steam and steam circulating in the jacket and in a coil. The oil is always treated with highly concentrated acid at as low a temperature as possible, since at a higher temperature the acid exerts a strongly oxidizing effect, and the oil turns out darker. The temperature for the treatment with acid is dependent on the degree of fluidity of the oil, but 104° to 140° F. may be considered the maximum, while as low a temperature as 86° suffices in some cases.

The oil and acid are mixed either by means of air or a stirring apparatus. The acid is allowed to run slowly into the strongly agitated oil, the mixing being continued until the product acquires a very dark color which, in thin layers, must, however, be transparent wine-red, while with the light falling upon it the oil should show a violet velvety lustre.

The quantity of acid varies, according to the specific gravity and quality, between 4 and 12 per cent., and is generally used in three portions. The settling of the acid requires several hours and has to be carefully attended to; the acid resin settles and balls together very slowly, and has to be frequently removed. It often takes 24 to 36 hours before the oil is sufficiently pure to be treated with lye. While the upper layers are nearly pure and may be allowed to run through a faucet in the side of the acid tank into the lye-agitator, the oil in the conical part requires much more time for settling. These acid resins have recently been successfully removed by means of centrifugals. The acidulated oil runs in a slow stream into a centrifugal placed between the acid-agitator and the lye-agitator, and having been purified by the removal of the resins, flows into the lye-agitator.

The treatment with lye is more difficult and requires special attention, there being no other process in the manufacture of lubricating oils which has to be so carefully controlled, because by simply working according to routine entirely different results may be obtained with the same oils. The quantities of lye and their concentration, the temperature of the oil, and the duration of time the lye is allowed to act, must be carefully considered. Most refineries treat this portion of the process as a special secret. A few general rules, which may however be modified as required, will here be given. The oil should be as free as possible from acid and resins, since in treating it with lye the latter dissolve and give it a dark color. The acidulated oil is, as a rule, immediately treated with lye, the preparatory washing with ordinary water used in the refining of petroleum being not only superfluous but even injurious, since emulsions difficult to separate and not acted upon by the lye are immediately formed. In many refineries dilute soda lye of 2° to 4° Bé. is used in such a manner that by the addition of water and lye the proportion between oil and lye is so maintained that soaps are formed which completely separate without carrying along much oil. In other refineries the treatment with lye is successfully effected as follows: With vigorous agitation 1½ per cent. of 33° to 35° lye is brought through a fine rose into the oil. The color of the latter, at first dark, becomes lighter, and samples are constantly taken from the appearance of which the process is judged. If flakes which rapidly settle appear in the oil, the agitation and addition of lye must be immediately stopped; further agitation or continued addition of lye would cause the formation of soaps difficult to separate. When the proper moment has arrived the oil is allowed to settle quietly, the process being assisted by the circulation of steam in the jacket. The temperature of the oil before treating it with lye is, in many cases, kept as low as possible, at least not higher than the temperature during the treatment with acid. On the other hand, some factories claim to work successfully with hot lyes, but the results differ very much. To be sure the soaps separate rapidly and there is less danger of the formation of emulsions, but the color frequently suffers, it becoming rapidly dark. When the treatment with lye is finished and the separated lye has been removed, the oil is carefully washed with warm water, it being advisable to keep the oil at a temperature of from 140° to 176° F. and to wash with hot water without agitation. Fourteen times the quantity of water is frequently required, especially with specifically heavy oils, to remove the lye. When the wash-water is perfectly neutral the oil is boiled bright. This is effected in shallow open pans, with double sides and provided with coils. It is also advisable to provide them with depressed bottoms for the removal of deposited water and to heat the room in which the pans are located with direct steam, so that the oil may clear at as high a temperature as possible. The boiling of the oil, assisted by air, must be done very carefully, since, when heated too strongly, it becomes dark later on.

When the oil is nearly clear or only slightly turbid from water held in suspension, it is, in many refineries, rendered entirely clear by conducting it over filters heated by steam. However, when sufficient pans are on hand, it is best to clear the oil in them at a uniform temperature, because there is no danger of the oil becoming turbid after some time, as is frequently the case with filtered and apparently entirely clear oil. This phenomenon is caused by the gradual separation of organic salts and sodium sulphate, and can only be avoided by carefully washing out the lye and allowing the oil to clear for a long time.

The "Cracking" Process.

The importance of the process which has been technically termed "cracking" cannot be over-estimated, because the idea of producing by a peculiar process of distillation more volatile products from heavy oils or even residuum must be of great interest. Professor B. Silliman was the first to notice the uncertainty of the boiling points of the hydrocarbons of petroleum and to come to the conclusion that a portion of the hydrocarbons could not be considered as *educts* (*i. e.*, bodies previously existing and simply separated by the process of distillation), but were produced by splitting during the process of distillation. The following account of the circumstances leading to the discovery of the cracking process is given by Mr. Allen Norton Leet in his work on Petroleum Distillation:

"One cold afternoon in the winter of 1861–62, a sixteen barrel upright wrought-iron still in a refinery at Newark, New Jersey, was about half emptied of its contents and the distillate indicated 43° gravity with rapid tendencies towards lower figures and darker color, and the still-man intended in half an hour's time to cut off the remaining portion of the outflow into the heavy oil tank. Having built a strong fire under the still, which supposably would keep the distillate in rapid motion for a time, the attendant locked up the refinery and went to dinner. It happened that after finishing his meal, he was taken with a fit, and when he was sufficiently restored to resume work, darkness had settled down upon the city. He had been away from the refinery for four hours. When he had struck a light, to his surprise and amazement he found a small stream of oil still running into the distillate tank, quite cool, light in color and 48° in gravity. Failing to comprehend how the gravity and color could both lighten up after a large portion of the contents of the still had run off and after a much lower gravity had been reached, and fearing something was wrong with the still, the still-man drew the fire, awaiting the coming of the proprietor. When the latter arrived a thin stream still issued from the end of the worm, and to the surprise of both the specific gravity had risen to 52°. In order to study the effects of the internal operations of the still, the proprietor had a heavy glass retort constructed, and then by experiment discovered that after the distillation of the heart of the crude oil, and when the gravity of the distillate had reached 44° with descending graduation, by reducing the temperature of the fire, the lighter vapors of what remained in the still would be carried over. By close observation of the motion of these vapors he discovered that a portions of the product would be condensed by the cooler upper portions of the retort, and were returned to the oil of the retort.

Here they were exposed to a higher temperature than was necessary simply for volatilization and were decomposed, giving rise to an increased yield of that grade of oil sought for. The theory was tested upon a larger scale in the iron retort, which was adapted for the new mode of distillation by removing the brick work from the upper portion of the still. The experiment was a success, to the delight and profit of the manufacturer."

The discovery, of course, did not remain a secret, and came rapidly into use in most refineries, especially in regions with a limited occurrence of oil (Germany), and where the residuum did not furnish a sufficiently good raw material for the manufacture of lubricating oil (Galicia and America.)

The fact that notwithstanding careful fractional separation of the hydrocarbons of the petroleum, light products boiling at a low temperature constantly occur in the remaining portions boiling at a high temperature, and the above-mentioned observations by Prof. Silliman regarding the irregularity of the boiling point of petroleum, must lead to the conclusion that in the process of distillation the hydrocarbons originally present in the petroleum are decomposed, and specifically lighter hydrocarbons are formed. Besides the light hydrocarbons formed by decomposition, there is also produced a corresponding quantity of heavy hydrocarbons not originally present in the petroleum. The proportion between the lighter and heavier hydrocarbons formed by decomposition is quite constant, and the more of the former are formed, the more also of the latter are produced. Thus in a distillation which yields many volatile, gaseous hydrocarbons (methane, ethane, ethyls) there will always be observed a large quantity of heavy tarry and even coke-like residuum, and *vice versa*.

Hence it is in the power of the distiller to regulate the cracking process so that but few parts condensable with difficulty and just as few coke-like parts are formed, and that mostly only good products suitable for illuminating purposes are obtained. The attainment of this object in the best possible manner depends on the kind of distilling apparatus used.

To be decomposed the hydrocarbons of the petroleum or their vapors must come in contact with the hot sides of the distilling apparatus. Hence the latter has to be so arranged that the heavy portions and their vapors come in contact for as long a time as possible with a large portion of the overheated surface. The hotter the sides of the still are, the more rapidly decomposition proceeds and the more light and correspondingly heavy parts are formed. Hence it is of great importance to be able to regulate the temperature so that distillates suitable for illuminating purposes are obtained with the cracking stills to be described later on.

Although the nature of the decomposition the heavy oils undergo by this operation is not yet thoroughly explained, it may be supposed to be based upon dissociation and polymerism. The distillates obtained by cracking have unfortunately not yet been subjected to examination, but it would seem to be incorrect to consider them as consisting of the same hydrocarbons as those obtained from crude petroleum, they being very likely richer in aromatic and non-saturated hydrocarbons.

The cracking process based upon decomposition with the assistance of hot iron may be explained by experiments of Letny, Ragosin and others. They conducted petroleum residuum through iron pipes heated to a slight red heat and obtained distillates with 15 to 20 per cent. of benzol and its homologue (anthracene). A similar process must take place in cracking heavy oils. The cracking still heated to a gentle red heat may be considered a large pipe in which the heavy oils suffer decomposition by coming in contact with it, and form, though not to the same extent as in the above-mentioned experiment, a considerable percentage of aromatic hydrocarbons. That the hydrocarbons formed by the cracking process have a different chemical composition from those occurring in crude oil is also proved by their behavior when subjected to treatment with sulphuric acid and lye. The consumption of acid and lye is incomparably larger, the action of the chemicals far more intimate, and the refined product more changeable and inferior in quality notwithstanding the most careful treatment. Petroleum prepared from such oil has a stronger odor, becomes dark very rapidly and possesses but little burning power. Nevertheless the cracking process is an indispensable part of the manufacture of petroleum, because it offers the means of realizing in a lucrative manner from residuum otherwise difficult to utilize, and of increasing the yield of petroleum. However, the process is not cheap, and its employment is rendered possible only by the small value of the crude material. In working residuum by the cracking process the consumption of fuel is very large; thus, for instance, while for the distillation of illuminating oil from crude oil about 22 pounds of coal are used for 220 pounds of crude oil, for the same quantity of residuum about 50 per cent. of coal is required, and it must further be considered that the product of distillation obtained cannot be utilized as such, but has to be subjected to further rectification, whereby residuum is formed that must again be cracked. The process of cracking also causes losses by the unavoidable formation of permanent gases (about 6 to 8 per cent.) which in well arranged refineries are caught and used for illuminating and firing purposes, but as a rule are allowed to escape. The separation of the heaviest hydrocarbons, asphalt and finally coke as the principal quantity, must also be taken into consideration; it generally amounts to from 10 to 25 per cent. or more of the residuum worked.

The cracking process is carried on in stills especially constructed for the purpose. The upright form of still is most suitable because the oil vapors, having to traverse a long distance in the still itself, have a chance to condense partially and in flowing back on the overheated sides to suffer decomposition and vaporization. The still should be provided with a large condensing dome and with suitable dephlegmators, the use of the latter being absolutely necessary to increase the yield. They should be so arranged that the oil-vapors meet large condensing surfaces, that the heavy liquid oils can flow back into the still, and that only the most volatile oils are caught in the distillate-distributor. The still is best provided with a convex bottom; a flat or inward bulging bottom is not suitable, because the first, if of wrought iron, burns through very readily, and if of cast-iron cracks easily, and besides the superheating of the oil and the separation of the coke are more difficult to effect. The same objections apply to the inward bulging bottom, to which must be added the filling space lost by its shape. The still is generally constructed of cast-iron, the temperature of the sides of the still being with this material more constant and the durability of the still itself greater. Where for economical reasons the still has to be constructed of wrought-iron, the most exposed part of it, the bottom, should be of cast-iron. The use of a wrought-iron bottom is objectionable, because it loses its shape and is destroyed in a short time by the high temperatures prevailing in the still and the separation of coke. The only advantage of a wrought-iron bottom is that the still can be more rapidly heated. Wrought-iron stills with bottoms which have been made especially resistant by the addition of ferro-manganese have recently been introduced, but whether successfully or not, is not yet known.

Figs. 110a and 110b show the construction and bricking-in of a cast-iron still. It consists of an upright cylindrical body and a hemisphere of cast-iron. Only very small stills are cast in one piece; larger stills are cast in two parts and joined by bolts and nuts, or during casting the cylinder is cast upon the hot hemisphere. As seen in the illustration, the hemisphere is provided with a shoulder *a* by means of which the still rests upon the brick work. On the hemisphere is the beak *S* which projects from the brick work; it is provided with the valve *V* and serves for the discharge of the hot asphalt. On the lid of the still are a conduit for filling the still, a conduit for direct steam, and finally the condensing pipes *cc*. The lid is screwed to the flange of the still. The man-hole *D* serves for removing the coke and cleaning the still. The arrangement for firing is as follows: The flame from the fire-place *A* passes the fire-bridge

FIG. 110a.

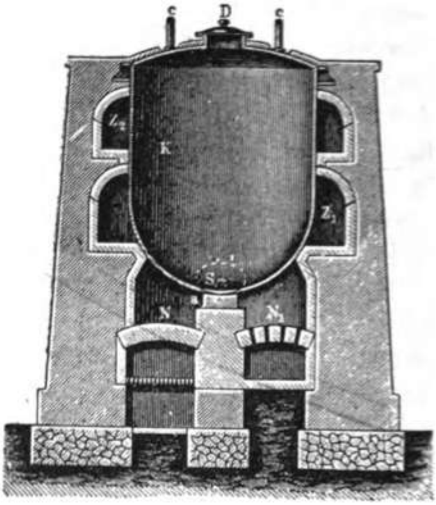
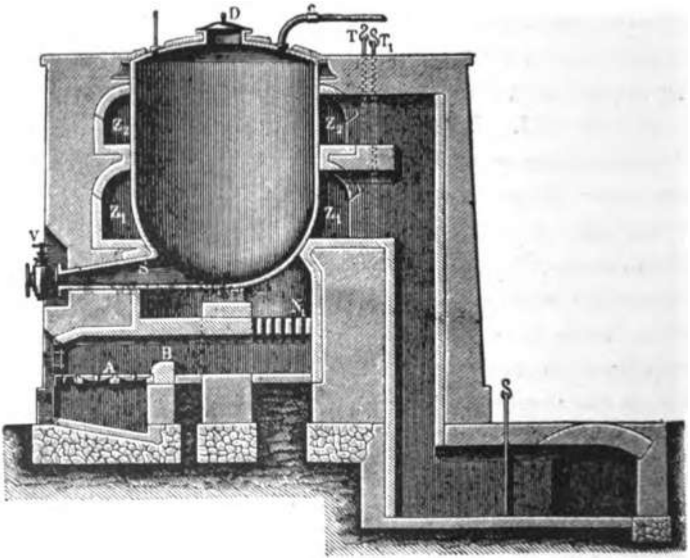


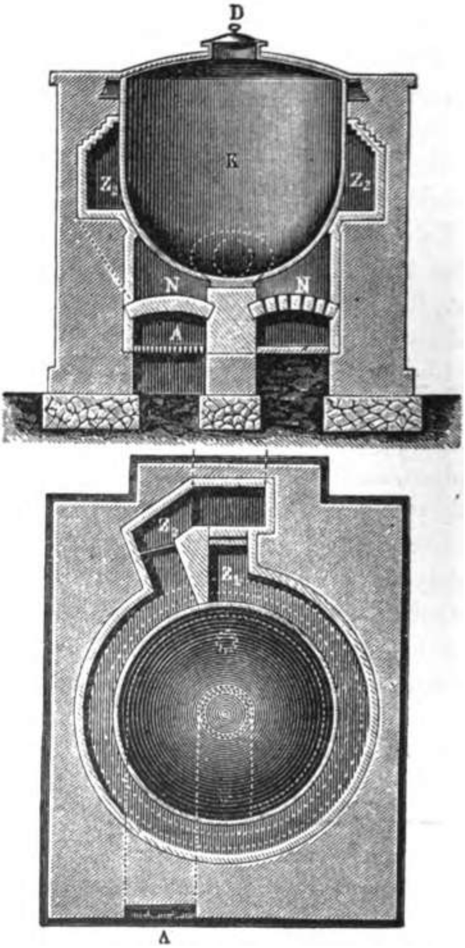
FIG. 110b.



B, ascends at N through the arch, washes the bottom of the still, ascends laterally, and through the flue Z_1 passes round the still. When the slide T_1 is closed, the flame ascends laterally, again washes the still at Z_2, superheats the sides, and on opening the slide T passes into the smoke-flue. If the work requires it, the slide T_1 is opened and the slide T closed; the heating gases then wash the still only once and pass immediately into the smoke-flue. With this mode of operation the still is filled with residuum or the oil to be decomposed. A gentle fire is then started to evaporate any water which may have been carried along. When the more volatile oils have been driven off the actual cracking process commences, whereby the fire must be kept in accordance with the products of condensation, *i. e.*, it must be decreased or increased according to whether heavier or lighter products are formed. The distillates when thoroughly dephlegmated are condensed in the manner previously described. However, by this distillation paraffine or paraffine-like products are formed which readily clog the condensing pipes, and hence the cooling water must be kept warm and frequently boiling hot.

Regarding the capacity of the stills no general rule can be laid down; they should, however, be of sufficient capacity to hold all the crude oil residuum. To save room and to avoid repeated firing and heating, the still may once or twice be refilled to the original depth towards the end of distillation. Further refilling is, however, inadmissible, because the products obtained are not light enough and the quantities of coke separated so large, that the operation and the still would positively suffer. The height of the still is generally 2 to 2½ times greater than its diameter. The thickness of the sides varies. While according to some the sides should be cast as thin as possible and the bottom portion thicker, there are many stills with sides from 2.36 to 3.15 inches thick, and bottoms up to 5.51 inches thick. Both of these extremes should be avoided, because, in the first case, the stills are not durable, and in the latter, the consumption of iron used in their construction, and of fuel for heating them, is unnecessarily large. It is recommended to cast the stills with bottoms 2.36 to 3.15 inches thick (and if of specially tough cast iron only 1.57 inches thick), and

Fig 111a.

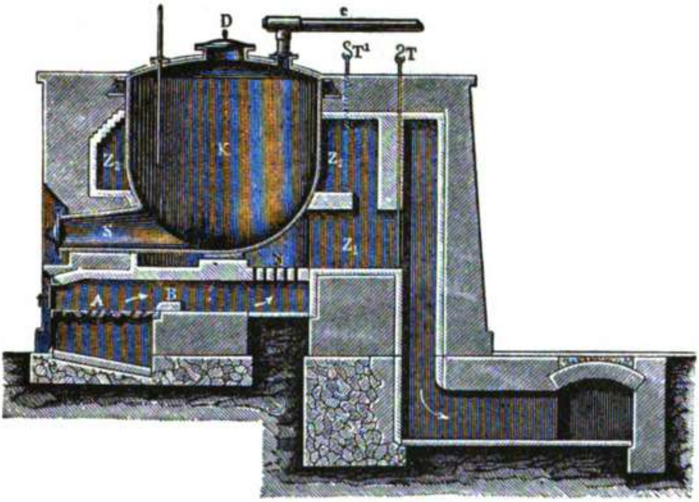


with walls 1.57 to 2.36 inches thick. Such stills answer all demands and show no cracks or other defects even after continuous use for a long time.

Figs. 111a and 111b show a form of a still *K* much used for working readily decomposable residuum. It consists of a somewhat lower cylindrical upper portion and a hemispherical bottom to which is cast the discharge aperture *S*. The latter projects from the brick work and is closed by a lid screwed on. All other arrangements are similar to those of the previously described still.

The mode of firing is, however different, the heating gases coming in contact with a far greater surface of still. The flame passes from the fire place *A* through the arch *N*, washes the bottom of the still and, if necessary, passes through the flue Z_1 into the smoke-flue. If the slide *T* be closed and T_1 opened, the flame passes into the flue Z_2 and into the smoke-flue only after washing the sides of the still.

Fig. 111b.



From the dimensions of the flues it will be seen that much larger surfaces are swept by the heating gases and that the temperature of the latter is much higher..

The mode of operating is nearly the same as with the still previously described, but in most cases the work is carried on to complete coking, to avoid as much as possible the opening and closing of the man-hole *D*.

The essential portion of the cracking process is the production of specifically lighter oils, the formation of which is effected, as previously mentioned, by overheating the heavy oils on the sides of the still, which presupposes their vaporization. A portion of the heavy oils is unavoidably carried along with the more volatile oils, whereby the yield of the latter and their quality are influenced. More intensely acting dephlegmation is therefore absolutely necessary, so that by as large a condensing surface as possible of the dephlegmator the specifically heavy oils are completely condensed and can flow back into the still, where they again suffer decomposition on the overheated sides.

Fig. 112.

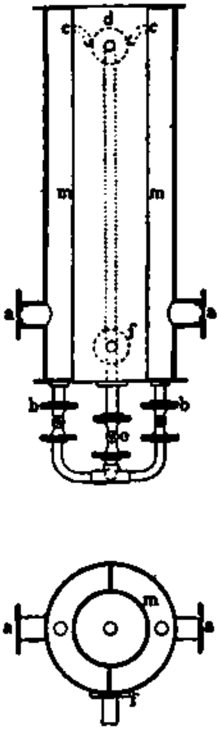
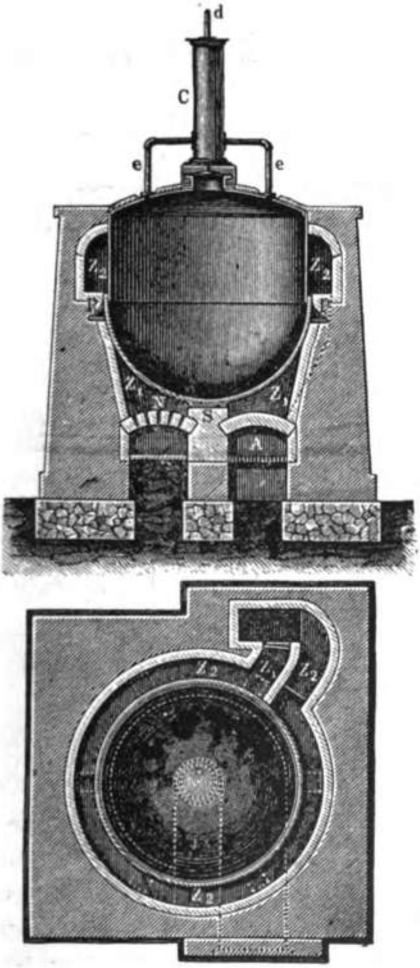


Fig. 112 shows the arrangement of a dephlegmator which has been used with great success. The oil vapors enter the apparatus at *a*, are partially condensed and flow back into the

Fig. 113a.

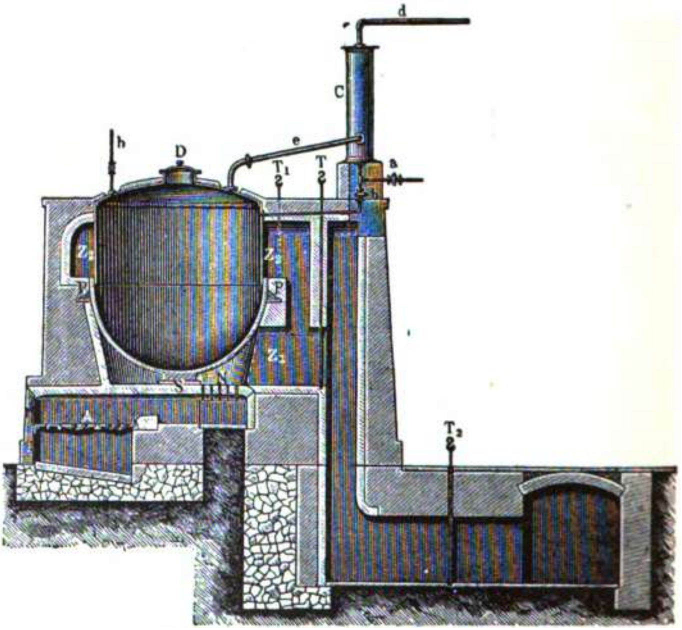


still at *b*, while the non-condensable vapors ascend at *c* into the space inside the jacket *m*, where they are also condensed, the condensed products also running back into the still at *e* and only the lightest portion flowing at *d* into the condensing apparatus. When towards the end distillation has proceeded so far that no oils appear at *d*, the distillate is discharged by simply turning the cock at *f*.

There are a number of other condensing drums, which, however, need not be described.

Figs. 113a and 113b show a form of still which may be recommended, it consisting of a wrought iron upper portion with cast-iron hemispherical bottom. Such a combination is advisable for several reasons. A still of the same capacity constructed entirely of cast iron is more expensive and less durable. In case the bottom from one cause or another becomes defective it can be readily removed and replaced by a new one. Besides, the wrought iron portion is much more rapidly overheated than is the case with cast iron.

Fig. 113b.



The still rests upon the claws *P* cast to the hemispherical portion, which is of importance, since experience has shown that a still not thus supported but rested upon the base *S* is subject to more rapid destruction, because tensions produced in the cast iron by overheating cause different expansions in the hemispherical cast iron and upper wrought iron portions, and when no provision is made for this, cracks in the casting and leakages at the joints are unavoidable. It is therefore best to leave a small space between the lowest portion and the base *S*. The thickness of the hemisperical portion varies, but should not be less than from 1.57 to 2.75 inches. The wrought iron portion is made in the usual manner of plates 0.23 to 0.39 inch thick. The mode of joining the upper and lower portions is of importance, it being frequently the source of great annoyance. In many cases the joint is effected by riveting a flange to the upper portion, a flange being also cast to the lower portion. These two flanges are then either riveted or screwed together and to make the joint especially tight copper rings and even iron cement are used. Such a joint, however, is not durable, the simplest and most effective joint being that shown in the illustration. The wrought iron and cast iron portions, are simply pushed one into the other and secured by rivets driven through holes in the edges. To make the joint tight a wrought iron ring is inserted between the upper and lower portions, which in case of leakage can be hammered down on both sides. The still is bricked in as follows: At *A* is the fireplace. The flames before passing out at the arches *N* and washing around the bottom pass a closed passage. When the slide *T* is open and T_1 closed, the heating gases, after heating the bottom, pass directly into the smoke-flue. If the sides are to be overheated, the slide *T* is closed and T_1 opened; the heating gases then pass through the flue Z_2 round the still and then through a lateral flue into the smoke-flue. The heating can thus be regulated in the most simple manner. The slide T_2 is only used when several stills are arranged in a battery and one or the other still is to be put out of operation, for instance, in case of fire.

The process of distillation is similar to that previously described. By inserting the dephlegmator *C* condensation is effected as follows. The vapors pass through the gas-pipes *ee* into the dephlegmator. The lightest portions which are not condensed there pass at *d* into the condensing apparatus. The condensed oils run at *b* back into the still, *b* being the position of the cock when closed and *a* when open. Towards the end of distillation the heavy oils run at *a* into the condensing apparatus. To assist distillation steam, usually superheated, is used in some refineries, the object being to carry along the oil vapors ascending with difficulty. It is also claimed that the use of steam increases the durability of the still, the separation of a much softer coke, which does not adhere firmly to the sides of the still, being thereby effected.

In conclusion the result in working on a large scale may be given. According to H. Deutsch ("Le Petrole et ses applications, Paris ancien maison Quantin"), the loss after entirely working the crude oil is as follows:

0.5	per cent.	loss	in the form of water and mud,
0.17	"	"	by evaporation in the storage tanks,
0.50	"	"	by pumping in the pipe conduits (?),
2.25	"	"	in the first distillation—non-condensed gases,
0.90	"	"	in the second distillation—non-condensed gases (?),
2.25	"	"	in the distillation of heavy oils,
0.65	"	"	in the rectification of benzine,
1.78	"	"	in refining.

9.00 per cent.
2.00 " coke.

11.00 per cent.—total loss.

CHAPTER X.

MANUFACTURE OF PARAFFINE.

WHILE paraffine in a fossil state, under the names of earth-wax or ozokerite, has been known in Europe from the earliest times, the modern discovery that it is a product of distillation of several organic bodies under high temperature belongs fairly to the chemist Karl Reichenbach, who gave to the strange compound its present name from *parum* and *affinis*, because it appeared to him wholly destitute of chemical affinity. His discovery and its peculiar behavior in this respect was published in the year 1830. The following year its presence in the petroleum of Rangoon was noticed by Christison of Edinburgh. He called it *petroline*, but hearing subsequently of Reichenbach's discovery, he was satisfied of the identity of the two substances and withdrew the name given by himself. In 1833, 1834 and 1835 we have records of the separate discoveries by the three chemists, Laurent, Gregory and Viobel, the former showing that the oil distilled from shale contained paraffin.

From this time on organic chemistry was making rapid advances, and we have frequent allusions to its presence in a number of compounds as a result of destructive distillation. To no one person does the credit more properly belong of founding the commercial industry based upon the manufacture of paraffine and its allied products than to Seligne of France, the many improvements made in the manufacture of oil from bituminous shale belonging largely to his genius and indefatigable industry.

The minerals used for the production of paraffine oils are shales and cannel coals. They are mined and brought to the surface much in the same way as coal.

G. T. Beilby, in the Transactions of the Insurance and

Actuarial Society of Glasgow, No. 7, describes the manufacture of paraffine oils as follows:

The paraffine oil industry is based upon destructive distillation; so is the illuminating gas industry. The specialty of the former is its low red heats, of the latter its bright red heats. The distilling vessels, in which the destructive distillation of shale and coal is carried on, are called retorts—they are made of iron, or of fire-clay, or fire-bricks. They generally take the form of vertical tubes, into the top of which the raw material is fed by a valve or door. The bodies or tubes are arranged in ovens heated by furnaces. The material, as it passes slowly through the hot retort or tube, is subjected to the distilling process, the vapors which come off are carried away by a pipe on the side of the retort to a series of cooling pipes or condensers in which the water and oil vapors are condensed and run into tanks. The spent shale, *i. e.*, the material from which all the oil vapors have been driven, passes away through a valve or lute at the bottom of the retort, and is removed as waste material.

By the destructive distillation of shale we obtain two crude products—crude paraffine oil and ammonia liquor. The latter is water containing 2 to 5 per cent. of carbonate and sulphide of ammonium. It is used for the manufacture of sulphate of ammonia.

The other product, the crude oil, is a green or brownish solid at temperatures below 80° F. Chemically it is very complex, containing a very large number of distinct substances. From the oil-refiner's point of view it contains roughly two classes of substances—products and impurities. The products constitute about 70 per cent. of its bulk, the impurities account for the remaining 30 per cent.

All the valuable products of crude oil, viz., burning oil, lubricating oil and solid paraffine, are hydrocarbons or compounds of the two elements, carbon and hydrogen. These various products differ from each other in many essential qualities. In appearance alone each is clearly distinguishable from the others. Naphtha is a colorless, thin, bright liquid, with a keen, persistent smell; burning oil is colorless or slightly yellow, more oily than naphtha, but still thinner than water, its smell is less pungent; lubricating oils are yellow, oily and have very little smell. Paraffine is a white solid.

These products may be arranged in a series according to their boiling points—naphtha boiling at from 90° to 212° F.; burning oils from 212° to 450° F., lubricating oils from 450° to 800° F., and solid paraffines from 600° to 800° F.

The impurities in crude oil consist chiefly of acid and basic tars, and certain resinous or gummy bodies of high boiling point.

The purposes of refining crude shale oils are: 1. To separate the impurities from the products; 2. To separate the various products from each other. This double purpose is the key to the several processes employed.

PROCESSES OF REFINING: *1. Chemical treatment to separate impurities from products.* The princiqal impurities present in crude oil are basic tars, acid tars and resinous or gummy bodies of high boiling point. The first and last mentioned, the basic tars and resinous bodies, unite with oil of vitriol or sulphuric acid to form heavy black tars, which readily separate from the pure oil. The oil to be purified is thoroughly agitated with a small percentage of oil of vitriol, so that every particle of oil is brought into contact with the vitriol. The basic tars combine with the vitriol, and separate from the oil in black globules. If now the mixture be allowed to stand quietly for a few hours, the separated tar settles to the bottom of its vessel, and can be run off, leaving the oil clear. In addition to removing basic tars, the vitriol also makes into tar and removes the resinous impurities. After the oil has been perfectly freed from the tar separated by vitriol, it is run off into another agitating tank, and thoroughly stirred or mixed with a strong solution of caustic soda. This combines with the other class of impurities—viz., the acid tars—which are substances nearly allied to creosote or carbolic acid; these also separate as a brown or black tar, which in turn is allowed to fall to the bottom of the vessel, and is drawn off.

If the preceding processes are very carefully carried out, the oil at this stage is nearly pure—*i. e.*, it consists almost entirely of pure products. But they are all mixed together, each spoiling the other, and preventing its being employed for its own special use. The naphtha present renders the whole mixture as unsafe as naphtha itself is; the burning oil is unfit for burning by reason of the mixture with it of lubricating oil and paraffine scale; which are in their turn useless for the purposes of lubrication and candle making, because of their mixture with the burning oil and with each other.

2. The first step towards separation of the products from each other is made by *fractional distillation*. Naphtha boils at from 90° to 212° F., burning oil from 212° to 450° F., lubricating oils boil together at from 440° to 800° F. If, therefore, we place our purified crude oil in a still, boil off first the naphtha up to 212°, and collect it, then the burning oils and collect them, we shall have the lubricating oil and paraffine coming over together.

This, roughly, is the process of fractional distillation as carried on in shale-oil refining; and is nearly in every respect the same as in petroleum refining.

We have seen how naphtha and burning oil have been separated from each other, and from the lubricating oil and paraffine, which are still mixed. For their separation the third process is necessary, viz.:

3. *Crystallization*. If solid paraffine is mixed with burning oil or naphtha, and warmed, the paraffine dissolves and disappears. If the solution be cooled down again to the atmospheric temperature, or, better still, if it be frozen artificially, the solid paraffine separates in crystals from the oil; and if the mixture of oil and crystals of paraffine be placed in canvas bags and pressed, the oil passes through the canvas, leaving a cake of paraffine crystal in the bag.

This is the crystallization process as applied in the oil-work.

The lubricating oils and paraffine, which have been separated at the stills, are cooled, so that the crystals of paraffine separate from the oil. The cooled magma is then drained in canvas bags, or, better still, is forced against canvas sheets in filter frames. The oil passes through the frames, and the paraffine is left in solid cakes. These cakes of paraffine are more perfectly freed from oil by being wrapped in canvas sheets and pressed between iron plates in a hydraulic press, being subjected to a pressure of about 300 pounds per square inch. These cakes of paraffine scale still contain coloring matter and some oil. To make the scale fit for the candlemaker, it must be further refined. With this object it is melted and mixed with a percentage of specially prepared naphtha. The hot solution of paraffin and naphtha is run into shallow tins in which it slowly cools. The cakes are then turned out, wrapped in canvas and again pressed between iron-plates in a hydraulic press. These operations are repeated twice or three times until the paraffine assumes the necessary degree of whiteness, after which it is melted up in a still, and steam is blown freely through it to carry off the traces of naphtha, which, if left in it, would give the wax an unpleasant smell. The melted paraffine is finally stirred with bone black, filtered through paper, and run into cooling tins or candle moulds.

In this country paraffine is wholly a by-product in the manufacture of lubricating oils or in the treatment of the heavy oils proceeding from the distillation of petroleum towards the last of the process.

In treating this subject from the standpoint of the American refiner, the preparation of lubricating oils and the manufacture of paraffine wax run so closely together, that in some points at least they touch, and must be treated as though they belonged to one subject. The manufacture of either or both begins when the residuum is placed in the still. The first products of this distillation down to about 320 Bé. (which when they are received into one tank, constitute an oil of 38°) are returned as crude oil.

After the separation of this first part, the products of the still are either again subdivided into at least two runnings, or run into one tank, according to the peculiar views of the refiner and the wants of his customers. If received into one tank, the oil is pumped into the "paraffine agitator." This apparatus is constructed upon the same general principles as the agitator used for illuminating oil, excepting that it is provided with special arrangements for heating its contents and retaining the dense easily-congealed oil in a liquid condition. This is readily accomplished by surrounding the agitator with a steam jacket, which not only supplies the facilities for applying the heat when required, but also affords a protection to the sides of the tank from the chilling effects of the cold during the winter. In the absence of this, in very cold weather, it would be almost impossible to treat paraffine oil on account of the solidification of the paraffine upon the internal surface of the tank; no more heat should be employed than is actually necessary to maintain the contents in a fluid state, and the paraffine entirely melted. The same general principles of chemical treatment followed in the case of illuminating oil are observed here. The amount of acid used is much larger, and is regulated by the gravity and color of the distillate. Three, four, or even five per cent. in volume is employed. Its action upon the oil is very energetic, accompanied by the disengagement of an abundance of sulphurous acid vapor, and the subsidence of a heavy "acid sludge," requiring exit pipes and stop-cocks for drawing it off to be of larger diameter than those ordinarily employed. The sludge upon standing becomes quite solid, and is entirely a waste product. This treatment is followed by the usual water and alkali washing. Care should be taken throughout that the proper temperature be preserved, so that the paraffine shall be maintained in perfect solution. When this operation is completed, the oil is either allowed to flow by gravity, or it is pumped into tanks, provided with a steam coil, in order that its contents may be preserved in a perfectly limpid condition to permit of the settling of the water. This being withdrawn through a stop-cock at the bottom of the tank, the contents are removed to another apartment, the temperature of which has been artifically lowered by a freezing machine, where it is subjected to the chilling process.

In the winter the ordinary temperature is sufficient to crystallize the paraffine. If the process is to be carried on during the warm weather, the contents of the tank are barreled, and the temperature of such a room may be reduced by a good apparatus to 10° or 15° F., even in very hot weather. An exposure of the paraffine oil for forty-eight hours to this temperature chills the whole mass to a complete solid. From the barrels the contents are shoveled out into small bags of strong cotton material and subjected to powerful pressure by means of a hydraulic press. This pressure is slowly applied and gradually increased, the operation being one requiring skill and experience. If the pressure be too rapid and too severe, especially at the commencement, a notable percentage of paraffine crystals will be forced through the interstices of the bagging, attended also, probably, with a rupture of the same, and a serious contamination of the oil that has already passed through. Unless this operation be skilfully conducted, enough crystallized paraffine, it may be in very fine particles, will pass through the bagging to interfere materially with the "cold test" of the oil. In the event of a difficulty of this kind, simple straining through coarse muslin will frequently remove these coarse particles of floating crystals.

From the refined paraffine oil, prepared and chilled as above described, there should be obtained about three-quarters of a pound of crude paraffine to each gallon of oil. The color and appearance of this will of course depend greatly upon the character of oil the from which it has been separated. When removed from the bags in which it has been pressed, it is somewhat variegated in color, some portions being of a light lemon, others presenting quite a greenish hue; the crystalline appearance is thorougly broken down by the immense pressure to which it has been subjected. The contents of the bag are thrown into a steam-tank, where they are melted by live steam, one per cent. of soda lye is added, and the whole thoroughly steamed, the condensed water withdrawn, and when sufficiently cool to admit of the process, about 25 per cent. of benzine is added and the whole vigorously stirred until a homogeneous mixture is obtained. The contents of this tank are ladled out into shallow tin pans holding about 5 or 10 gallons each, which are allowed to remain in the cold-air room for 3 or 4 days. This product is again expressed in clean bags. The paraffine thus obtained is in large crystals with a slight tinge remaining, and having a much higher melting poiut (about 130° F.) than the crude article first described. The expressed "mother liquor" from this second operation, is either run into the "stop-tank" (which is a convenient receptacle for a variety of wastings, small residues of sundry distillations, etc.) or thrown back into the benzine tank for use a second time. The contents of the "stop-tank," when sufficient stock has accumulated, are pumped into a still, which is generally kept for the special purpose, and the distillates proceeding from this are distributed according to their character. If the density should admit of it, a large percentage may be thrown down direct into the tank containing illuminating oil.

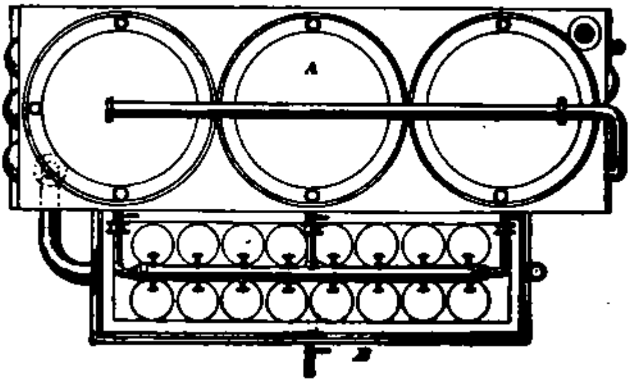
Another process for the purfication of crude paraffine consists in grinding together benzine and paraffine into a magma, which is submitted to the usual pressure. This process is repeated until the pressed mass is white enough for ordinary purposes. For the further purfication of the paraffine obtained either by this or the former process, the wax is placed in a suitabie tank and gently heated, with the addition of three to five per cent. animal charcoal. The whole is thoroughly agitated by an air-blower for several hours. The coarser particles of charcoal are allowed to subside, and the melted wax filtered through a wire-gauze filter, which is lined with flannel, the filtrate passing as colorless as distilled water.

Other refineries rely largely upon the purifying action of oil of vitriol for obtaining a white product. For this purpose a wax partially purified by re-crystallization from benzine and pressure is selected. The same is gently heated to its melting point, when about five per cent. of sulphuric acid is gradually added while brisk agitation is sustained. The action of the acid upon the melted wax is even more violent than upon the paraffine oil, and some arrangement is necessary to carry off the abundant vapors of sulphurous acid which are disengaged. This can be accomplished by covering the agitator with a hood, which will conduct these suffocating vapors into a chimney-stack. The same arrangements for keeping the contents of the vessel warm, which were needed in treating heavy oil, are required here. After half an hour's treatment, the heavy acid is drawn off at the bottom, a hot solution of soda-lye (five per cent. of a solution 12° B.) is added. The agitator is again put in motion, and the melted wax thoroughly treated, the soda-washing is withdrawn from the bottom of the tank, which is kept warm until it has completely settled, and the contents are bright and clear. The wax is run into large flat cakes, which when cool have a fine pearly lustre and are nearly colorless.

Decolorization through this agency appears to offer the most perfect results. This process, however, is only employed upon paraffine which has been partially whitened either by repeated crystallization or by acid process, or by a combination of both processes. To accomplish this upon a manufacturing scale commensurate with the demand, a number of plans have been suggested. One of the most complete of these is Ramdohr's filtering apparatus, which is constructed to filter about 2,500 lbs. per day. The apparatus has the following peculiarities in its arrangement: 1. The mixing of the paraffine with bone black does not take place by the hand or through a mechanical stirring device, but through a warm current of air previously blown into the apparatus. 2. The paraffine treated with bone-black flows of itself into the filter paper placed in a glass funnel, and, after the influx has once been regulated, the operation proceeds without demanding special attention on the part of the workman. Even if, at times, less permeable paper should be accidentally placed in the filter, this, with some attention on the part of the workman, cannot easily cause an overflow of the paraffine, since the greater or less permeability of the paper is easily observable during the first half hour and the feed-cocks can be regulated accordingly by the workman. 3. The whole apparatus is heated by waste-steam. 4. The mixing and filtering apparatus occupy little space.

The mixing apparatus *A*, Fig. 114, consists of a wrought iron chest, with cast iron lid secured by screws, and made tight with iron cement In this lid are three openings for the reception of three cast iron mixing kettles. These kettles are fastened to the lid of the steam-chest by a few screws in order to prevent any displacement which might cause the outflow tubes to become leaky. The connections of the kettles with the steam-chest are rendered steam-tight in the simplest manner by a band of rubber, placed beneath the rim of each kettle. About 3 inches above the deepest part of the bottom is cast a tube about 1 inch in diameter, of such a length that its forward end provided with screw threads projects about 1 inch through the side of the steam-chest. At this point the plate of the steam-chest, which

FIG. 114.



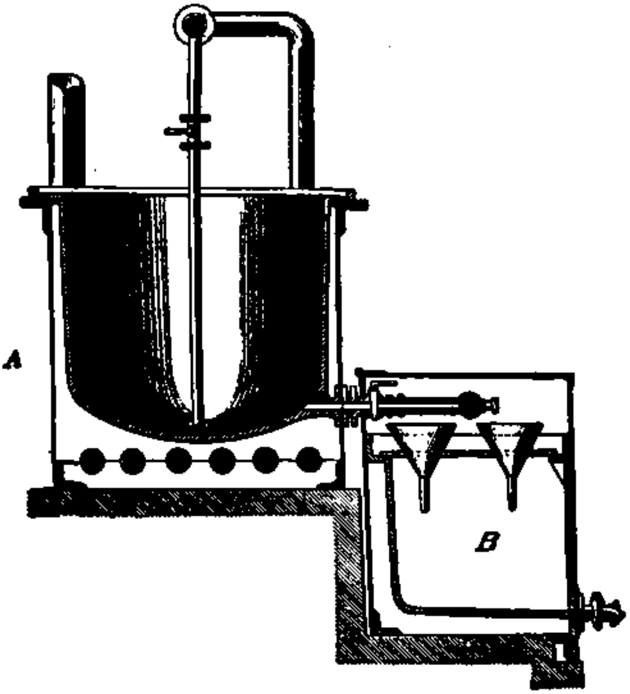
FILTERING APPARATUS—HORIZONTAL SECTION.

A, Mixing Apparatus; *B*, Filtering Apparatus.

is about 0.079 inch thick, is strengthened on the inside by a cast iron disk 0.59 inch thick, which is secured by means of sunken rivets, and provided with four holes for the reception of screw-bolts. From the outside a flange is screwed upon the end of the above-mentioned tube and solidly packed against the side of the steam-chest with chopped hemp intimately mixed with red lead cement, so that the four screw-holes in this flange exactly correspond to those of the inner disk. When the flange has been firmly secured, the end of the kettle, which is turned or planed level, should project about 0.079 to 0.118 inch above the flange. Four screw-bolts, each furnished in the centre with a six-cornered swelling, are now placed in the four holes provided for them and firmly and steam-tight drawn against the outer flange; each of the above-mentioned tubes is furnished with a cock for the passage of steam. A tight connection is effected here as well as on the pipe distributing the paraffine, and everywhere where finished paraffine has to pass, by several layers of soft, unsized paper, with the avoidance of all kinds of cement. It is advisable to provide the surfaces turned upon the lathe with fine circular grooves. In the lower portion of the steam-chest are placed six drawn copper pipes with thin sides, packed in the manner of the tubes of locomotive boilers, and connected by cast-iron joints outside the steam-chest so that they form a coil, heated by steam in which the air for mixing the bone-black and paraffine is heated. The outlet of this coil is connected with a pipe running obliquely over the mixing kettle. From this pipe narrower blast pipes furnished with cocks run towards the centre of the kettle and extend nearly to the bottom. The principal pipe for the heated air, is, of course, to be protected from cooling by a jacket.

The filtering apparatus *B*, Fig. 115, consists of two chests, one inserted partially into the other with a common front side. Hence the latter is not touched by the steam, this arrangement having been made to prevent having a strongly-heated surface on the side where the workman is mostly occupied, and to render access to the actual filtering apparatus as convenient as possible. If here were a double wall filled with steam it would absolutely have to be protected from too strong a radiation of heat by a brick wall in front of it, which would render attendance of the filtering apparatus more difficult. Besides, the arrangement chosen secures a cheaper and simpler construction, larger surfaces being made tight with difficulty against the action of melted and hot paraffine; and as any loss of paraffine should be avoided, the inner filtering chest serving for its reception is cast in one piece. The attachment of the steam jacket is simple and plainly shown in the illustration. The bottom of the cast iron filtering chest inclines towards the front and at the same time towards the centre from both sides.

Fig. 115.



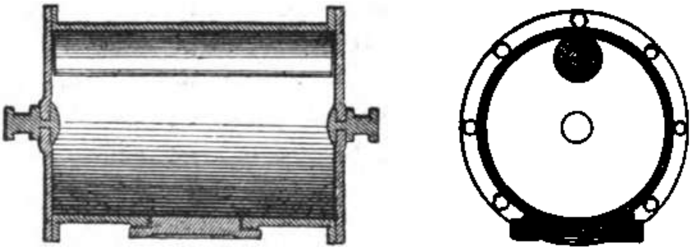
FILTERING APPARATUS—VERTICAL SECTION.
A, Mixing Apparatus; *B*, Filtering Apparatus.

At the lowest point is an exit tube with stop-cock for the discharge of the filtered paraffine. The interior of the filtering chest is provided with an edge projecting about 2 inches, which on the rear wall and at the same time on both sides serves for the formation of a steam-space. Upon this edge rest 8 wrought-iron funnel supports, each of which is capable of holding two glass funnels; thus there are 16 filters arranged in two rows always in operation. The funnels are made of glass, this material securing better control over the absolutely necessary cleanliness than if they were made of tin. In the centre of the filtering chest, running along its entire length and about 2 to 2½ inches above the glass funnels, is the paraffine distributing pipe. It is of wrought iron 1½ inches in diameter, closed on both ends, connected by three tubes with the corresponding stop-cocks of the mixing kettles, and furnished on each side with 8 cast iron cocks 0.15 inch in diameter. These small cocks are screwed in, small pieces of wrought iron being for this purpose fastened with hard solder in the proper places on the distributing pipe. The mouths of the small cocks do not lie perpendicularly over the centres of the filters, but are about in the middle of one of their side walls, to prefent perforation of the filter-points by droppings. The paper used for filtering is a thin, but tolerably firm, unsized printing paper. A sheet 1.57x1.57 inches gives one filter, and suffices for the passage of about 88 lbs. of paraffine; one filter is thus in use for 12 hours. But little paraffine remains in the filter and can be recovered by steam.

It being well known that the fresher bone-black is, the more energetically it acts, it is recommended that large paraffine factories prepare their own bone-black. In a business of less extext, powdered bone-black has to be procured from factories. Ramdohr recommends to reduce freshly-prepared, granulated and dust-free bone-black to a fine powder in a simple pulverizing drum, shown in Fig. 116. It is of cast-iron, 29½ inches long, 19½ inches in diameter, and revolves with two wrought-iron arbors riveted to the front-plates in metallic bearings.

The drum is provided with an opening for filling and emptying it, which is made tight by rubber. The drum is slowly revolved, at most two turns per minute. In the interior of the drum lies a massive cast-iron roller, 4¾ inches in diameter, of the same length as the drum. In 12 hours an apparatus of this size will pulverize in the finest manner about 55 lbs. of bone-black. The quantity of bone-black used does not exceed 3 per cent. by weight, and the paraffine retained by it amounts to about the same weight. This mixture of bone-black and paraffine is first collected in a double-walled kettle heated by waste steam, whereby the greater portion of the paraffine is separated as a clear fluid, which is scooped up with shallow ladles and placed directly upon the paper filter. The mixture, which is now thin, is brought into a large iron kettle in which it is vigorously boiled with at least six to eight times the quantity of water and the occasional use of a jet of steam. By the cooling of the mass nearly all the paraffine separates upon the surface of the water as a solid layer of a gray color, which is lifted off, melted and filtered through paper, together with the other product. A repeated boiling of the mixture of bone-black and paraffine is seldom necessary; the paraffine obtained in such second operation scarcely ever covers the cost of the fuel used. However, the bone-black retains a small percentage of paraffine so tenaciously that it has to be driven off by heating the bone-black if the latter is to be again used as a decolorizer, or even if

FIG. 116.



PULVERIZING DRUM.

it is to be employed in the preparation of fertilizers—superphosphate.

The dried bone-black is heated in a horizontal cast-iron retort about 7½ feet long and 31½ inches in diameter with a nearly elliptic cross section, and provided with a suitable receiver for the condensation of the paraffine vapors. However, even with the lowest possible melting temperature, these vapors never consist of undecomposed paraffine but of paraffine with a lower melting point and of oils as products of decomposition.

The bone-black in shallow wrought iron boxes each about 3 feet long and 1.47 inches wide is brought into the retort and after the evaporation of all the paraffine, is allowed to partially cool off for four to six hours. The boxes are then taken from the retort, covered immediately with suitable lids, which are luted with clay, and allowed to become cold.

The paraffine in the filtering box is occasionally drawn off into moulds or boxes of various sizes and allowed to cool slowly.

Paraffine is a colorless, waxy, or foliated crystalline, alabaster-like, semi-transparent mass without odor or taste, and resembles spermaceti. It is slippery but not greasy to the touch, and is softened by the warmth of the hand so that it can be kneaded.

American paraffine occurs in commerce chiefly in three qualities—*A*, *B*, *C*-paraffine, melting at 135°, 128° and 125° F. Paraffines from Pennsylvania and Rangoon petroleum have an average specific gravity of 0.869 to 0.873. Hot absolute alcohol dissolves about 3 per cent. of paraffine; it is readily soluble in ether, bisulphide of carbon, chloroform, benzine and volatile oils. From ether and photogene it separates in the form of a jelly, and from the other fluids as a crystalline mass. By heating paraffine for some time in the air to 302° F., it assumes a brown color by the absorption of oxygen.

The oil obtained after the crystallization of the paraffine from the heavy petroleum by pressure and decolorization is known as *paraffine oil* or *liquid paraffine* and is officinal. It is a clear oily liquid, having a specific gravity of not less than 0.840 and boiling not below 680° F. It should be free from colored, fluorescing and odorous compounds. When heated for a day with sulphuric acid by means of a water bath, it should not become dark colored, and the sulphuric acid should become only slightly brownish. Metallic sodium placed in the oil should retain its metallic lustre; if it becomes tarnished it is an indication of the presence of combinations of sulphur or oxygen. Alcohol boiled with officinal liquid paraffine should not have an acid reaction.

Fossil paraffine or *ozocerite* occurs generally in fissures and cavities in the neighborhood of coal fields and deposits of rock salt, or under sandstone pervaded with bitumen. The principal deposits are in

AFRICA: Egypt.

AMERICA: Texas, Arizona, Utah, Canada.

ASIA: *Caucasus:* Caspian Sea near Darbent. Baku; the islands of Swjatoi, Ostrow and Tachalkäu; Ekaterinodon; Station Kalachinsky. *Persia:* Truchmenia.

EUROPE: *England:* Newcastle. *Roumania:* near Plajesti in Wallachia, and Stanik, on the mountain Zietriska in Moldavia. *Austria:* Lower Austria near Gaming; in East Galicia near Boryslaw, Drohobycz, Dzwiniarz, Starunia, and near Solotwina, besides on the northern slope of the Carpathians. *Germany:* Wettin on the Saale; East Friesland.

The deposit in East Galicia is the most interesting. The ozocerite occurs there in a saliferous clay belonging to the miocene of the more recent tertiary period, and forming a narrow, almost continuous, strip on the northern edge of the Carpathians, which runs from Silesia into Galicia and Bukowina, and from there can be traced into Moldavia and Wallachia. This miocene group of saliferous clay consists chiefly of bluish and variegated clays, sands and sandstone, with numerous occurrences of gypsum, rock salt and salt springs. In Boryslaw the strata of saliferous clay form a perceptible saddle as they sink on the south below the so-called menilite shales, which are very bituminous and foliated, and form here the most northern of the Carpathians. The principal deposit of ozocerite converges with the axis of this saddle.

The ozocerite as obtained from the mines in Galicia is not a commercial article, being contaminated by adhering earthy and stony parts, and varying very much in appearance and consistency. The crude product is therefore subjected to several processes. The large pieces are picked out, while the small ones are recovered by washing with water, the particles of ozocerite floating on the surface and the specifically heavier contaminations sinking to the bottom. The two varieties of ozocerite called respectively "Claub- und Wasch–Wachs" (hand-picked and wash ozocerite) are then melted with a little water in large open boilers over an open fire, so arranged that only the sides of the boilers are heated. The earthy portion called "Schmelzlep (smelted clay) forms a deposit on the bottom of the boiler, while the melted pure ozocerite is ladled into moulds of a capacity of 110 to 220 lbs. The "Schmelzlep" retains 6 to 12 per cent. of ozocerite so tenaciously that it can be obtained only by extraction. The moulds, generally of iron, have the shape of a truncated cone, the inside being painted with milk of lime to prevent the adhering of the block of ozocerite. The ozocerite thus obtained forms the commercial article; its melting point lies between 133° and 158° F. Its price is governed by the melting point, and also to some extent by the color, which should be quite pale, but varies from pale green to brown. A good commercial article should be plastic when kneaded between the fingers, and plainly show every pressure; when cut with a knife the surface should not show a smooth, cheese-like appearance, but some of the ozocerite should adhere to the knife-blade. Notwithstanding these general tests by which a good commercial article may be recognized, there still remains to be decided the question whether the ozocerite is best adapted for the manufacture of paraffine or ceresin; for the former the article with the lowest congealing point is the best.

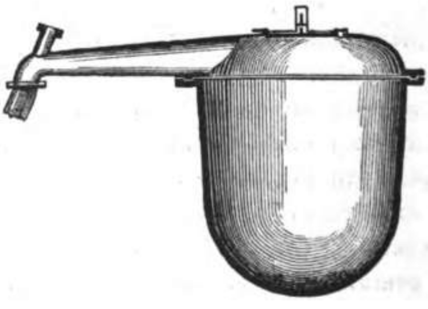
The structure and melting point of ozocerite depend, according to E. Sauerlandt, on its principal constituents, paraffine and "waxy resin," because with the distillation of ozocerite conducted with superheated steam and the avoidance of decomposition, he distinguishes the following constituents:

1. Liquid hydrocarbons with a low boiling point.
2. Paraffines, chiefly with a melting point of from 140° to 158° F.
3. Resinous bodies called "waxy resins."
4. Bituminous resins.
5. Coke.

Paraffine and waxy resins are solid bodies, the latter, however, having a higher melting point than the former.

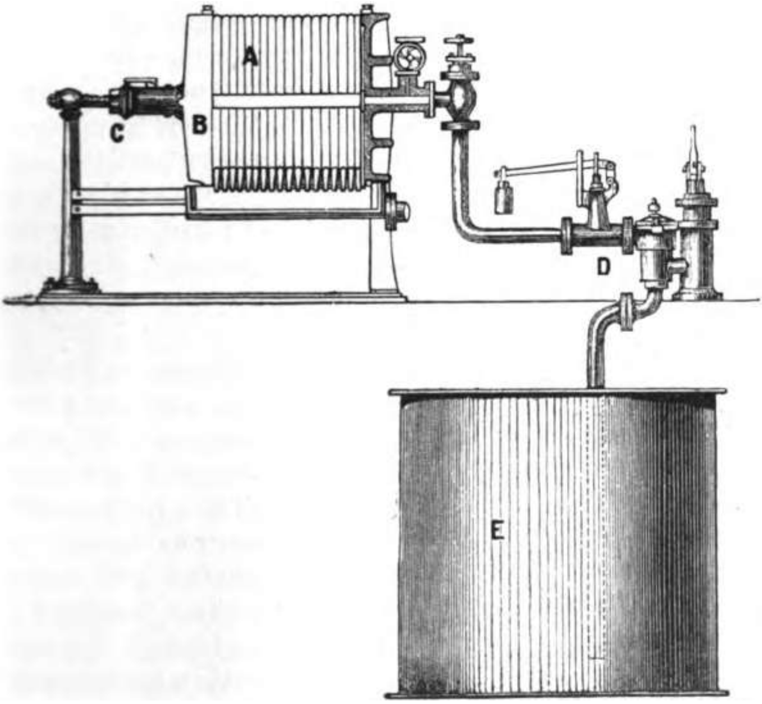
Ozocerite was first worked on a large scale in Galicia, in about 1860, and up to about 1875, was extensively used for the manufacture of paraffine. Distillation was at first carried on only over an open fire. To prevent too strong heating and the vapors of paraffine from rising too high, a still with quite a flat helmet, Fig. 117, similar to a tar-still, was used. The product of distillation was about 5 per cent. of benzine, 15 to 20 per cent. of illuminating oil, 15 per cent. of "blue oil," and 50 per cent. of paraffine mass or paraffine butter.

FIG. 117.



The paraffine mass obtained by distillation over any open fire has a melting point of from 113° to 122° F., and is treated in the same manner as paraffine obtained from petroleum, *i. e.*, after complete crystallization, the paraffine scales are separated from the oil by pressure. In the distillation the color of the distillate must be taken into consideration; the pale distillates should be separated, as they can be more easily purified and directly decolorized, and yield the finest qualities of paraffine.

FIG. 118.



A, press plates; *B*, head plate; *C*, screw; *D*, pump; *E*, paraffine reservoir.

Dehne's filtering press, Fig. 118, consists of a number of grooved plates which form a system of filtering chambers. The plates are of iron and are so constructed that the grooved portion stands back on both sides about ½ to ¾ inch from the outer frame. Over the grooved portion is screwed a perforated sheet-iron plate, upon which is placed the filtering cloth. The grooved plates are placed upon a solid frame in such a manner that they can be readily pushed apart. By means of two strong head plates, one stationary and the other movable, and two screws, the filtering plates with the filtering cloths between them can be firmly pressed together, whereby the entire apparatus is made tight. The paraffine butter previously rendered pasty in a mixing apparatus is conducted to the filtering box system by the sucking and forcing pump, *D*, driven by steam. In the tight filtering chamber the paraffine is immediately separated from the oil, the latter running off clear from the separate filtering chambers into a common gutter. The filtering chambers, when filled with paraffine, which is indicated by the pump becoming disengaged, are emptied by screwing back the screw *C*, which gives sufficient space to allow of the separate press plates being pushed apart; the scales of paraffine suspended between the cloths then fall down by themselves. The operation of emptying and reconstructing the apparatus requires 5 to 10 minutes.

The scales of paraffine thus obtained still contain 20 to 25 per cent. of oil. To obtain this the paraffine is packed in stout bags and subjected to pressure in a hydraulic press with heated plates. The expressed oils are purified like crude oils, and by rectification yield a heavy illuminating oil and fresh paraffine masses, which are treated in the same manner as the first.

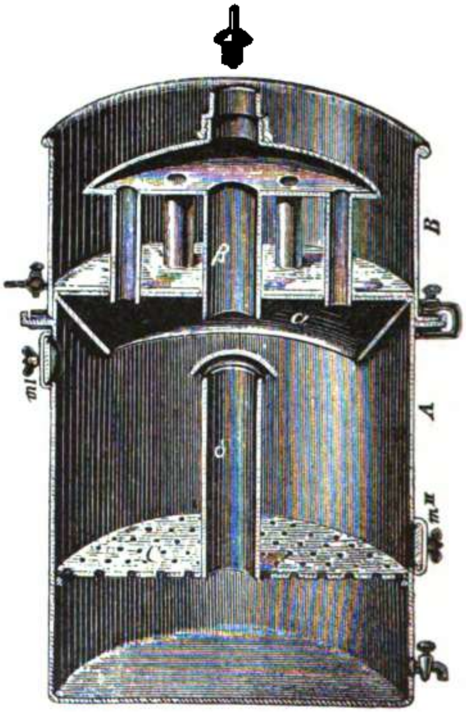
The method of purifying the crude paraffine with concentrated sulphuric acid has been almost entirely abandoned, as also the distillation over lime or chloride of lime. The crude paraffine, after melting, is at present treated in a similar manner to petroleum paraffine, with about 15 to 25 per cent. of benzine of not over 0.785 specific gravity, and then subjected to pressure in a hydraulic press. The operation is repeated several times according to the desired degree of fineness, and the benzine adhering to the paraffine after pressing expelled by treating with steam for 10 to 12 hours. The paraffine is then fined by digesting with bone-black in the manner already described. The paraffine thus obtained shows a melting point of about 144° F.

It is self-evident that no matter how well the distillation of ozocerite over an open fire may be conducted, losses of paraffine will occur on account of the formation of a large quantity of fluid products and gases. The yield under the most favorable circumstances will not exceed 40 per cent. The most rational method of distillation is, therefore, that with superheated steam, introduced in 1875, whereby a good quality of ozocerite will yield over 80 per cent. of paraffine, and others, according to quality, 55 to 70 per cent. Two methods are in use, viz., the introduction of direct steam into the fluid to be distilled, or distillation in *vacuo*. The operation is conducted in the same manner as with petroleum. About 3000 to 4000 pounds of the raw material are worked at one time, requiring about twelve hours for distillation.

The decolorizing material retains a sufficient quantity of paraffine to make its extraction a paying operation. A very simple apparatus for this purpose is that constructed by Thorn, Fig. 119, which can also be utilized for other purposes, for instance, for the extraction of "Schmelzlep," etc.

In the interior of the extractor *A* is suspended the perforated bottom *C* with the steam pipe *S*, for the reception of the material to be extracted. Through the bottom of the cooler *B* run the pipes for condensing the steam, and pass above into the cupola. The centre pipe *B* alone passes through this cupola; it is provided with a valve, and, when it is to be used as a distilling pipe for recovering the solvent, is connected with a cooling pipe. *a* is a gutter fastened to the bottom of the refrigerator, and serves to catch the solvent, which is condensed here, and to distribute it over the material. The flanges are so constructed that the gutter can be made air-tight by a fluid and also by a rubber cord and clamps. m' and m'', are man-holes for the introduction and removal of the material. The perforated bottom *C*, covered with a straining cloth, is placed in the extractor and charged with the material to be extracted, over which is poured as much of the solvent as it can absorb. A further quantity of solvent is then poured into the extractor, so as to fill the space between the true and perforated bottoms about half-full. After closing the apparatus air-tight, the solvent is brought nearly to the boiling point by a steam pipe. The vapors ascend in the pipe in the refrigerator, where they are condensed, and extract the material by falling down upon it as a fluid on the points of the pipe and the gutter *a*. The extract collects under the perforated bottom, where, after disengaging the refrigerator and making connection with a cooling worm, it is concentrated by distilling off the solvent.

FIG. 119.



A, extractor; *B*, cooler; *C*, perforated bottom; *m'*, *m''*, man-holes; *a*, bottom of the refrigerator; *B*, condensing pipe; *S*, steam-pipe.

CHAPTER XI.

METHODS OF TESTING OILS.

TESTS of illuminating and lubricating oils refer to the determination of their physical and chemical properties with the assistance of various contrivances and apparatuses. In the practice an examination of the physical properties is, as a rule, considered sufficient for the determination of the value of an oil. However, the chemical properties, for instance the determination of resin and sulphur, the behavior towards sulphuric acid and lye, are not less conclusive, especially with more exact tests, they together with the physical constitution giving a true picture of the character and nature of the oil to be tested.

In determining the physical properties of the oils the following methods of testing have to be executed: Determination of the specific gravity; fractional distillation; inflammability; combustion; viscosity (power of rising in the wick); color (colorimetric determination); photometric measurements (intensity of light), etc.

Specific Gravity.

This is of great importance for judging oils, because the specific gravities of the latter are, generally speaking, proportionally inverse to their volatility, and their determination furnishes a guide for proving the inflammability or dangerousness as regards fire, of illuminating oils. Since oils boiling at a lower temperature have a lower specific gravity than medium oils, an admixture of such oils—consequently danger of fire—is indicated by a lower specific gravity. On the other hand, too high a specific gravity indicates the presence of a larger quantity of heavy oils boiling at a higher temperature, which causes a loss of illuminating power by the oil not rising with sufficient force in the wicks of the lamps. However, the determination of the specific gravity alone is not sufficient for judging an oil, because by mixing very heavy portions with light essences an oil of medium specific gravity may be prepared, which, notwithstanding its medium specific gravity, is unfit for burning in lamps.

In the practice the specific gravity is ascertained by means of hydrometers, densimeters, etc., according to the scales of Baumé, Fleischner, Brix and others. For the determination of exact figures—five or six decimals—the picnometer, the specific gravity balances of Mohr and Westphal, or the so-called aerometer-balance of Reimann is used.

Baumé's hydrometer is the oldest and is largely used, it being employed, besides densimeters, in the United States, Russia, and Austria. In Germany Brix's hydrometer is occasionally used, and in France, Gay-Lussac's.

FIG. 120.

FIG. 121.

FIG. 122.

Fig. 120 represents the ordinary hydrometer graduated according to the Baumé scale for liquids lighter than water. Fig.

121 represents the combined hydrometer and thermometer, and Fig. 122 the vessel usually employed for holding the oil.

The use of the hydrometers of Baumé, as well as of Brix, requiring reduction tables, which is somewhat troublesome in practice, densimeters from which the specific gravity can be directly read off are recently more and more employed.

Fleischner's densimeter consists simply of a spindle graduated from 0.600 to 1.000 or from 0.750 to 1.000, each degree being divided into quarters.

Stelling's densimeter, also called *Stelling's oil balance*, can only be used for heavy mineral oils or vegetable oils with a specific gravity of from 0.900 to 1.000. It is provided with a thermometer, the tube of which passes through the hollow body and the tube for the scale.

Greiner's densimeter has four spindles giving the specific gravity respectively from 0.600 to 0.700, from 0.700 to 0.800, from 0.800 to 0.900, and from 0.900 to 1.000.

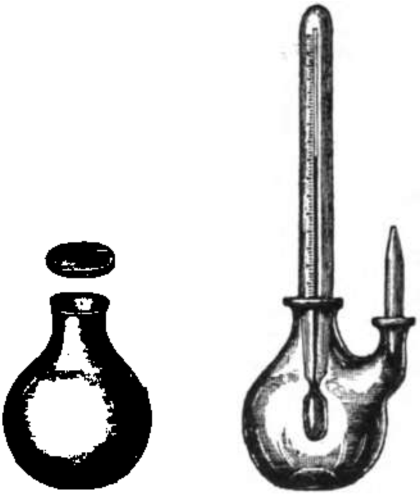
In the hollow space of the densimeter is a thermometer on which a normal temperature of 14° R. = 17.5° C. = 63.5° F. is especially marked.

The tables for correcting the specific gravity and its computation to the normal temperature have been given in Chapter iii., p. 43.

The picnometer, Fig. 123, is one of the instruments used for the more accurate determination of the specific gravity. It is a small glass flask holding from 5 to 20 cubic centimeters. It is provided with a glass stopper made of a piece of thermometer tube so that, in case of heating, a portion of the fluid can escape through the small orifice without lifting the stopper or endangering the flask. A thermometer may also be used as a substitute for the glass stopper, but the flask must then be provided with a lateral tube for the escape of fluid.

The flask is filled with water, closed with the stopper, and weighed. It is then emptied, thoroughly dried, filled up to the stopper with the oil to be examined, and again weighed. The volumes of water and oil used being equal, it is only necessary

Fig. 123.



to divide the weight of the oil by that of the water to obtain the specific gravity of the oil. For example:

Weight of the empty picnometer....................11.532 grammes
Weight of the picnometer filled with distilled water...24.832 grammes

24.832
Subtract 11.532

13.300

Weight of the picnometer with oil...................23.668 grammes
Weight of the picnometer without oil...............11.532 grammes

12.136

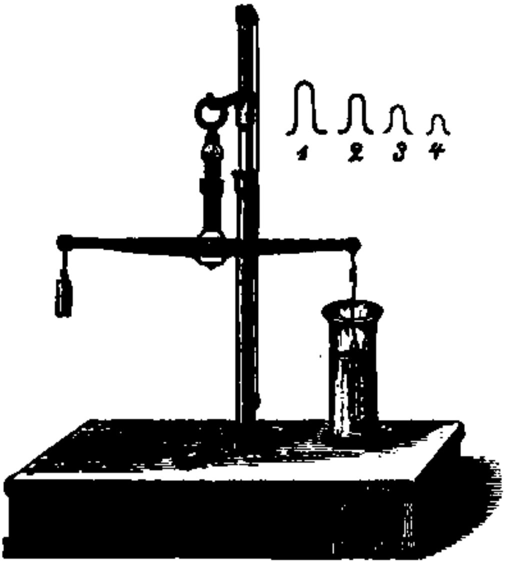
We have now the proportion:—

13.300 : 12.136 = 1 (specific gravity of water) : X. Consequently X =

$\frac{12.136.1}{13.300} = 0.91250$ = specific gravity of the oil.

Another exact method of determining the specific gravity is based on the well known theorem of Archimedes, which may be thus expressed: When a body is immersed in a fluid, it loses a portion of its weight; and this portion is equal to the weight of the fluid which it displaces; that is, to the weight of its own bulk of that fluid. The oldest specific gravity balance based upon this principle is Mohr's, shown in Fig. 124. One arm of the balance is divided into ten equal parts, and upon it is suspended by means of a fine platinum wire a glass-vessel embracing a thermometer, which is balanced by a weight

FIG. 124.



affixed to the other arm. The equilibrium caused by loss of weight of the glass-vessel when immersed in water of 4° C. (39.2° F.) is restored by appending an adjusted weight. There are four weights (riders) No. 2 being equal, to $\frac{1}{10}$, No. 3 to $\frac{1}{100}$ and No. 4 to $\frac{1}{1000}$ of No. 1. If now after immersing the glass-vessel in an oil, the riders are placed in the division marks, the first indicates the tenths, the second the hundredths, the third the thousandths, and so on.

Westphal's balance is constructed in a similar manner. Reimann's aerometer-balance has the advantage of the division marks on the arm of the balance being omitted, which contributes to the accuracy of the determination.

Fractional Distillation.

This offers the only means of determining the quantities of oils (heavy oils) which exert an injurious influence upon the illuminating power of petroleum.

Distillation is of less importance in regard to testing the oil as to its content of light essences, because the latter burn in our lamps with excellent illuminating effect, and the determination of the flashing point suffices as a protection against too large a content of them. If the flashing point lies above the permitted minimum, it does not matter whether many or few essences are present. This applies especially to Baku oils.

In making the experiment, fractional distillation cannot be executed in the ordinary manner, but in order to obtain reliable results, certain precautions have to be observed.

According to Beilstein's[1] directions a retort provided with a Glinsky dephlegmator is used. The entire apparatus (including the dephlegmator) is weighed; the petroleum is then poured in and the apparatus again weighed. A glass-tube about 2½ feet long for cooling the vapors is fitted to the dephlegmator, and distillation is so conducted that about 2 grammes per minute pass over. Distillation is carried on first up to 302° F., and then from 302° to 518° F., the apparatus being weighed each time. Three fractions—boiling below 302°, from 302° to 518°, and above 518° F.—are thus obtained. Beilstein also suggests that a petroleum should be required to contain less than 5 per cent. light oil and less than 15 per cent. heavy oil. Such requirement, however, could apply only to Baku oils. For Pennsylvania oils, for instance, it would be of no great advantage as it would enhance the price of the product. Therefore, in view of the American heavy oils burning with greater ease a standard permitting a maximum content of 15 per cent. of oils boiling above 572° F. would suffice, this being generally done in the practice.

For the above mentioned reasons it is also unnecessary to

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[1] Fresenius Zeitschrift, 22, 313.

fix a lower limit. Besides it is advisable, in order to obtain a complete picture of the nature of a petroleum, to divide the distillation into sub-fractions of from 25° to 25° or from 50° to 50° and determine these according to volume or weight. If, for instance, an oil contains 60 per cent. of constituents boiling between 302° and 572° F., it is by no means unimportant whether this quantity consists of 30 per cent. from 302° to 392°, 20 per cent. from 392° to 482° and 10 per cent. from 482° to 572° F., or *vice versa* of 10 per cent. from 302° to 392° F., 20 per cent. 392° to 482°, and 30 per cent. 482° to 572° F., an oil of the former constitution burning much better in a lamp than one of the latter. In short, a sufficient decision regarding the quality of an oil can only be obtained by dividing it into separate parts.

For the execution of such distillation the arrangement and method prescribed by Engler, which has been given in Chapter viii., p. 248, is recommended.

That the values obtained by this method do not entirely agree with the results of Beilstein's process is natural, but in executing the distillation according to Engler's method the results obtained by different experimenters are likely to agree better than with the use of special boiling tubes, particularly if the dimensions of the latter are not accurately determined and controlled.

The results given in the appended table were obtained by fractional distillation of different commercial varieties of Caucasian (Nobel's) and Pennsylvania oils according to Engler's method. The fractions were caught from 20° to 20°. It is still better, according to Engler's later proposition, to divide the fractions from 50° to 50° or from 25° to 25°, because the principal fraction from 150° to 300° C., (302°-572° F.), which may be designated standard illuminating oil, is more readily reduced to the latter sub-divisions.

	No.	Cubic centimeters or grammes.	Flashing point ° C.	Specific gravity.	Commencement of boiling ° C.	Up to 130° C.	130° to 150° C.	150° to 170° C.	170° to 190° C.	190° to 210° C.	210° to 230° C.	230° to 250° C.	250° to 270° C.	270° to 290° C.	290° to 310° C.	To 310° C.	Over 290° C.
Caucasian illuminating petroleum.	I	ccm	31	0.820	129°	—	6	16	16	16.25	14.75	13.5	8.5	4.5	3	98	5
		g					5.23	11.94	13.33	13.1	12.17	10.66	6.37	3.27	2.32	78.39	
	II	ccm	32	0.820	117°	2.25	8.75	15	11.5	13	15.75	11	9	7	5	98.25	6.75
		g				1.69	6.37	11.55	8.97	10.42	13.15	10.28	7.83	5.74	4.6	80.6	
	III	ccm	34	0.8205	118°	2	6.75	13	14	18.25	15	14	7	4.75	2.5	96.25	5
		g				1.43	5.06	10.01	10.92	14.6	12.45	12.84	6.09	3.89	2	79.35	
	IV	ccm	36	0.820	119°	2	4.25	14	19	13.75	23.25	10	6	3	1	96	5
		g				1.32	3.1	11.3	14.8	10.33	18.09	9.3	5.23	2.46	0.91	76.84	
American illuminating petroleum.	I	ccm	25.5	0.809	115°	6.5	7.5	7	8	6	9	7.75	9.25	11	5	77	28
		g				4.49	5.37	5.37	7.32	4.58	5.98	6.03	7.49	9.91	3.18	59.72	
	II	ccm	24.5	0.800	100°	6.9	8.9	9	11	8.25	9	7.8	8	7	2	77.85	24.15
		g				4.83	6.31	6.9	8.58	6.41	8.07	6.47	6.96	5.74	1.89	62.19	
	III	ccm	25.5	0.805	102°	8.5	6.5	11	12.5	10.5	9.5	6.5	6.5	8	7	86.5	20.5
		g				5.81	4.65	9.36	9.93	8.01	7.8	4.83	5.3	6.8	6	68.49	
	IV	ccm	24.5	0.805	110°	7.75	7.5	8	7	5.75	6.25	11.5	9.75	9.25	4.75	78	26.75
		g				5.21	5.95	5.95	5.35	4.75	5.23	9.24	8.14	8.15	4	61.97	
	V	ccm	23.5	0.800	105°	9.25	11.25	8	9.25	5	7	5.25	7.25	6.25	5	74.25	30.75
		g				6.51	9.29	6.03	5.73	4.38	5.11	5.08	5.5	5.78	4	57.41	
	VI	ccm	27.5	0.805	115°	4	8.5	12.5	11.5	8.75	9.5	9.25	10.5	4.75	4	83.25	20.75
		g				2.78	6.79	9.08	8.61	7.04	7.55	7.08	8.49	3.86	3.97	66	
	VII	ccm	24	0.800	95°	10.25	9.5	8	8	6	6.5	4.5	10.25	9	6.5	78.5	28
		g				7.19	7	6.45	5.89	4.88	5.08	3.58	9.8	7.89	5.5	63.13	
	VIII	ccm	25.5	0.805	110°	8	8.75	9	7.75	6	6.25	8.75	5.75	10.75	7.75	78.75	29.25
		g				5.2	6.53	6.83	6.02	4.89	4.96	7.07	4.83	9.1	6.4	61.86	
	IX	ccm	26.5	0.800	108°	7.25	9.75	9	7.75	8.75	5.75	5.25	9.75	8.75	10	82	18
		g				5.18	7.45	6.86	5.61	6.51	4.38	4.96	8.31	7.43	7.91	64.74	
	X	ccm	23	0.800	100°	8	14.5	12.5	7.75	5.75	6.5	5.75	9.75	6.25	4.25	81	23.25
		g				5.18	11.22	9.22	6.38	4.3	5.15	4.68	8.15	5.21	3.69	63.18	

For distillation 100 cubic centimeters of each of the petroleum varieties were used.

On an average there were obtained from the separate portions of the four Caucasian and the ten American kinds of petroleum:

	Below 150° C. (302° F.)	Between 150 and 190° C. (302° and 554° F.)	Above 190° C. (554° F.)
Caucasian petroleum	8.0	86.6	5.4 per cent. by volume.
American petroleum	16.9	57.1	26.0

However, as previously mentioned, it must not be supposed that Pennsylvania oils burn worse in proportion to their content of heavy oils than Caucasian oils, because experiments have shown that the heavy portions in American oil injure the illuminating power somewhat less than corresponding quantities of Caucasian heavy oils of the same boiling point, which very likely is connected with the considerably higher specific gravity of the latter.

Below are given the results of distillation made by Engler and C. Schestopal, of Alsace petroleum known in commerce as "brilliant petroleum," as compared with Kaiserœl (Imperial oil) and ordinary Pennsylvania petroleum.

The specific gravities of the oils are:

Alsace brilliant petroleum	0.801
Kaiserœl	0.795
Ordinary Pennsylvania petroleum	0.800

For distillation 100 cubic centimeters of each were used; the experiments were made with Engler's apparatus.

Varieties of oil.	Commencement of boiling.	Up to 302° F.	302° to 347° F.	347° to 392° F.	392° to 437° F.	437° to 482° F.	482° to 527° F.	527° to 572° F.	Above 572° F.
	°F.								
Alsace brilliant petroleum	296.6	0.8	10.5	20.0	24.7	20.0	15.4	4.8	3.8 cubic centimeters.
		—	8.2	15.9	20.9	16.2	12.5	3.9 gr.	—
Kaiserœl.........	212	—	12.5	17.2	16.9	15.4	14.5	11.8	11.7 cubic centimeters.
		—	9.6	13.3	13.5	12.5	12.0	9.6 gr.	—
Ordinary Pennsylvania petroleum.	212	15.8	10.0	12.0	8.25	11.0	7.8	9.0	26.15 cubic centimeters.
		5.1	7.7	9.42	6.42	8.96	6.8	7.5 gr.	—

From the table it will be seen that brilliant oil as well as Kaiserœl are within the limits of a normal petroleum, while ordinary Pennsylvania petroleum is far outside of them and consequently is inferior.

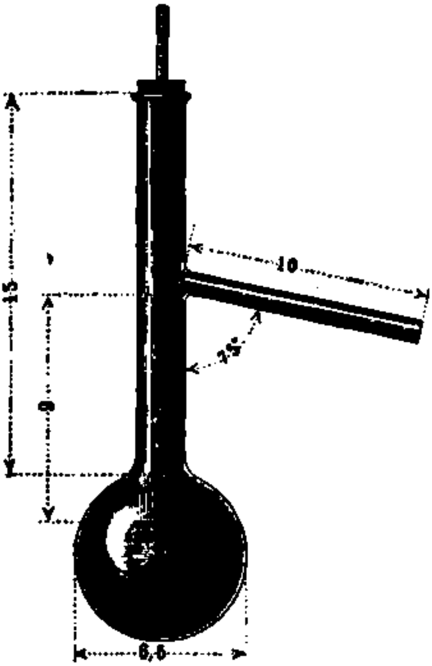
The content of "normal burning oil" in thoroughly purified varieties of petroleum, for instance, in American astral oil, Kaiserœl, etc., exceeds 80 and even 90 per cent., this being the principal reason for the safety as regards fire and the excellent illuminating value of these varieties of oil.

As regards the examination of lubricating oils and their fractions, the determination of their content of readily volatile oils is, as a rule, sufficient, a distilling test, similar to that for illuminating oil, being made according to Engler's method. Engler in his laboratory uses a small glass retort of the form and size shown in Fig. 125 and distils in it 100 cubic centimeters of oil so that about 2½ cubic centimeters per minute pass over. With properly prepared lubricating oil by far the greater portion should boil above 590° F. Hence distillation is interrupted at this temperature and the distillate measured in the measuring apparatus, when distillation is continued.

If the asphaltum-like residuum, which cannot be distilled, is also to be determined, distillation is continued, after removing the thermometer, as long as anything passes over, and the residuum determined by weighing the retort. Properly distilled lubricating oils do not leave behind over three per cent. of coke, and lubricating oils, not distilled but simply chemically purified, not over 7 per cent., according to their derivation.

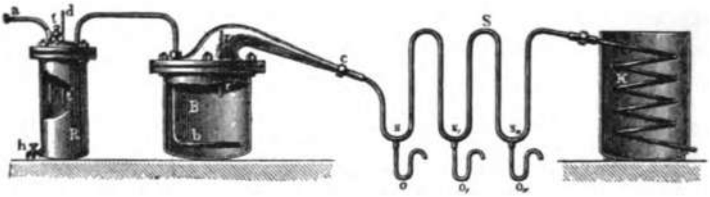
However, by direct distillation, the lubricating oils are decomposed, thinly-fluid (light) oils being formed, and consequently show more light constituents than they actually contain. Hence a true picture of the content of more or less volatile, and especially of heavy oils, is not obtained by this mode of distillation, and it is therefore recommended to execute distillation either in vacuum or, still better, with superheated steam.

FIG. 125.



The latter method, which also serves for determining the value of petroleum residuum (the portions boiling above 572° F.) for working into lubricating oils, is carried on by means of an apparatus, Fig. 126, constructed by Engler,* which is based upon the principle as the apparatus used in the lubricating oil factories at Baku.

FIG. 126.



Steam generated in a small boiler is superheated in pipes to about 572° F., and to maintain it at uniform temperature is conducted into the copper receiver *R*, which is provided with a screw-lid made tight by an asbestos ring. In this lid are screwed the tube *t'* for the reception of the thermometer *d*, also the small cock *t*, through which in the beginning of the operation the air is discharged, and the steam when the operation is finished. The cock *h* serves for discharging the condensed water. By heating upon a small gas-stove the temperature of the steam passing through *R* is maintained at 572° F. The steam passes through a pipe covered with asbestos paper to *B*, and from there into the oil through the pipe *b*, which is provided with numerous small holes directed downward at an angle of 45°. The copper still *B* is about 7¾ inches deep and 7¾ inches in diameter, and holds about 6.6 to 8.8 lbs. of oil (it may be made of any size desired). Upon it is screwed a helmet, also rendered tight by means of an asbestos ring. The temperature in the still is indicated by the thermometer *v* in the tube *v'*. The still *B* being filled with oil, it is slowly heated upon a gas stove. With too rapid heating the oil, if water is present, runs over very readily, and strong bumping takes place. A more energetic heat should be applied only after the thermometer *v* shows a temperature of 266° F. When a tem-

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* Engler. "Die deutschen Erdöle."

perature of 572° F. has been attained, the steam heated to 572° F. is introduced from *R* into the still by closing the cock *t*, and the vapors are conducted into the separatory condenser *S* joined to the helmet by the connection *c*. This condenser consists of copper pipe bent three times. It has a diameter of about ½ inch and a total length of about 5 feet, each bend being about 9¾ inches long. Into the bottom of each bend is screwed a small discharge-pipe o, $o_{,}$, $o_{,,}$, which to cool the distillates are placed in a vessel filled with cold water. With the separatory condenser is connected a condensing coil *K* cooled by water. This serves for condensing the rest of the vapors, especially the steam. The neck of the helmet and the separatory tubes should be covered with asbestos paper to prevent the condensation of light oils and water in them.

In the commencement of distillation light oils and a small quantity of water condense at s, $s_{,}$, $s_{,,}$. These are removed and combined with the distillate from *K*. However, in the course of 15 to 25 minutes distillation progresses regularly and the heaviest and thickest oils condense in the leg s and thinner oils in $s_{,}$ and $s_{,,}$, while the lightest oils together with steam pass into *K*. It is a characteristic feature of this process that thick oils immediately separate in the commencement at s, which is a clear proof that a sufficient separation can never be effected by the ordinary method of fractional distillation, in which in the beginning light oils and then oils becoming constantly heavier are caught; besides, the first so-called light distillate contains a considerable quantity of heavy oils, which in Engler's apparatus are separated in s or $s_{,}$.

By this method four fractions are thus obtained, which are weighed, whereby the content of the different light and other parts is established.

Flashing Point.

Petroleum consists of a mixture of hydrocarbons and with a preponderance of light volatile oils its use is dangerous. When the readily volatile oils are not sufficiently separated by distillation, petroleum frequently evolves vapors even at the ordinary temperature of a room, which form, with the air in the oil-holder of the lamp, explosive gas mixtures. According to Chandler's experiments the most violent explosion occurs with a mixture of 1 part petroleum vapor and 8 to 9 parts air; 1 part air and 3 parts petroleum vapor give a slight report, while a mixture of 1 part air and 1 part petroleum vapor does not explode. According to Thörner, the explosive mixtures contain at least 1.9 to 3.2 per cent. by volume of petroleum hydrocarbons. To what degree a few per cent. of naphtha reduce the degree of temperature at which the oil evolves inflammable vapors, is shown by the following experiments of Dr. C. B. White, of New Orleans, Louisiana. With an oil which originally yielded inflammable gases at 113° F., the respective degrees of temperature fell with the addition of 1 per cent. naphtha to 103° F.; with the addition of 2 per cent. naphtha to 92° F.; with the addition of 5 per cent. naphtha to 83° F.; with the addition of 10 per cent. naphtha to 59° F.; with the addition of 20 per cent. naphtha to 40° F.

The property of petroleum to evolve on heating inflammable vapors which explode when mixed with air is called *inflammability*, and the degree of temperature at which vapors are evolved in sufficient quantity to allow of their ignition, the *flashing* point. The lower the latter is, the greater the danger in using the oil in lamps or stoves.

By *combustion* is understood the property of petroleum to take fire and continue burning when heated to a certain temperature, and the lowest temperature at which it will take fire is called the *burning point.* Hence, a distinction has to be made between the flashing test and the burning test. These two tests are often confounded. In the first case, only the vapor over the oil burns or explodes, the combustion not extending to the oil itself; in the latter case, the ignition of the vapor is transferred to the oil itself, the latter continuing to burn on the surface. The burning point and flashing point, therefore, can never agree, and, in fact, the burning point of an oil may be from 10° to 70° F. higher than the flashing point. In ordinary petroleum the burning point is, as a rule, from 41° to 53° F. higher than the flashing point.

The flashing test is the most important test, as it is the inflammable vapor evolved at atmospheric temperature that causes most of the accidents. Moreover, an oil having a high flashing test is sure to have a high burning test, while the reverse is not true. In most countries regulations regarding the minimum flashing point permissible have been established. In making such regulations the degree to which the oil in the burning lamps is heated above the surrounding air must, of course, be taken into consideration. Chandler, in his experiments with 23 lamps and 72 varieties of petroleum, found that during seven hours, with the air of the room at from 73° to 74° F., the temperature of the oil in the burning lamps ranged from 76° to 100° F., the highest temperature of 100° having been reached in a metal lamp at the end of one hour. That this was an exceptionally high temperature is shown by the fact that the highest temperature reached in any other lamp was 92° F. With the air of the room at from 82° to 84° F., the temperature of the oil in the burning lamps ranged from 82° to 120° F. The temperature 120° was exceptional, being confined to one lamp. With the air of the room at from 90° to 92° F. the temperature of the oil in the burning lamps ranged from 84° to 129° F., the highest temperature being exceptional.

From these results it appears that the temperature of the oil in burning lamps often rises much above 100° F., thus reaching a temperature at which oil which does not emit a combustible vapor below 100° F. would be dangerous.

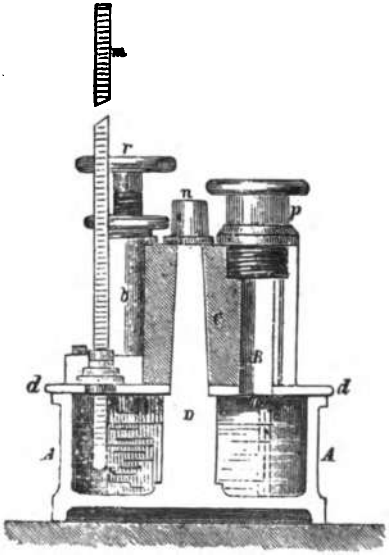
Apparatuses.

The large number of apparatuses constructed for determining the flashing point may be divided into two groups, those of the first group being based upon the principle according to which the expansion of the vapor which the petroleum shows at fixed temperatures is measured. In the apparatuses of the second group the petroleum is heated in a vessel to the point at which the gases accumulated over the oil can be ignited or exploded by bringing them in contact with a small flame.

1. *Apparatuses in which the expansion of the vapor is measured.*

The Salleron-Urbaine apparatus may be designated the most complete of this kind. It consists of a brass or copper vessel *A*, Fig. 127, in which is fixed the conical pillar *D*, and which is covered by the plate *d d*, fitting on its upper edge. *C* is a movable plate turning on the pillar *D*, and held in place by the screw *n*. In this movable plate is the cylindrical chamber *B*, closed at the top by the screw-plug *p*, while its lower opening can be placed in communication with the vessel *A*, by means of the opening *o*, or, by turning the plate *c*, it can be sealed by the upper surface of *d*. There are also in the plate *d*, a thermometer, a graduated tube *m*, 35 centimeters (13.78 inches) long, and the regulating apparatus *l*, which consists of the

FIG. 127.



screw *r*, so arranged that by raising or lowering it, the water level in *m* is made to stand at zero.

Fifty cubic centimeters of water are put in the vessel *A*. *B* is nearly filled with the petroleum to be tested, the screw *p* replaced, and the whole placed in warm water until the temperature has become constant. The water level in *m* is placed at zero, and the plate *C* is moved until the opening of *B* comes over the opening *o*. The petroleum spreads upon the surface of the water in *A*, and by the expansion of its vapor causes the water to rise in the tube *m*, when its height is read. By a comparison of this number with the known expansion of the vapor of normal petroleum at a corresponding temperature, the combustibility of the oil is determined. For this purpose a table accompanies the apparatus, which gives the obtained vapor expansion of normal petroleum in *m*, for different temperatures sought.

This method depends upon the supposition that the numbers which express the expansion of the petroleum vapor run parallel with the temperature of the inflammability of all kinds of petroleum. It has been found, however, that this supposition is not correct for all cases, inasmuch as the presence of a small quantity of a very volatile hydrocarbon occasions, by increased temperature, a correspondingly greater pressure in the tube *m*, without it being sufficient to form an explosive mixture with air. Experiments made by Engler, on samples of petroleum, prepared by mixing in varying proportions oils of low and high boiling points, showed that a small percentage of a volatile constituent, notwithstanding the equal inflammability of the oils, occasions an uncorresponding increase of the vapor expansion. A similar conclusion may be drawn from Biel's investigations, recently published, as will be seen from the appended table showing the results obtained with various oils.

Name of oil.	Vapor expansion at 35° C. in millimeters of water-column.	Flashing point ° C.
Standard oil	160	26
Astral oil	5	48
Kaiser oel	13	44
Russian Kerosene	201	26
" " *A*	73	28
" " *B*	45	30
" " *C*	95	25

While, according to the above, vapor expansion may be considered a valuable criterion for judging in general the properties of an oil, it does not allow of drawing a direct and exact conclusion as to its inflammability. The researches of Arthur H. Elliot[1] also lead to the conclusion that the vapor expansions obtained in this apparatus are very irregular.

II. *Apparatuses in which the inflammability is directly observed by igniting the vapors evolved at a certain temperature.*

Extraordinary difficulties have been found to attend the construction of exact apparatuses for heating petroleum and determining thereby the degree of temperature at which a small flame brought over the level of the oil may effect the ignition of the accumulated vapors. The execution of such experiments also requires great attention, because rapidity of heating, motion, quantity of oil, form of the oil-holder, size and intensity of the igniting flame, etc., are factors which may considerably impair the results of the determination of the flashing point. The results to be obtained are largely influenced by the construction of the petroleum-holder. In this respect a distinction is made between apparatuses with open or closed petroleum-holder.

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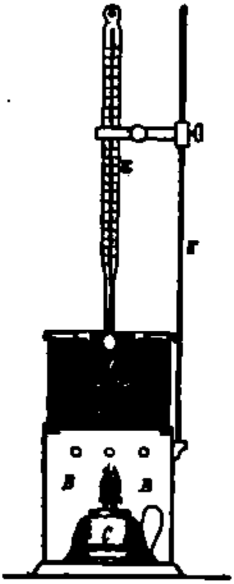
[1] Report on the Methods and Apparatus for Testing Inflammable Oils.

A. *Apparatuses with open petroleum-holders.*

Of the different petroleum testers of this kind, those of Tagliabue and Saybolt will here be described.

Tagliabue's open tester. This apparatus, Fig. 128, was employed in the official testing of petroleum in this country until 1879. It consists of a brass water-bath, *A*, upon the stand, *B*, heated by the lamp, *C*. *D* is the glass petroleum-holder, in which is immersed the thermometer *E*. The bath is nearly filled with cold water, allowing for the displacement by the oil-holder. *D* is filled to the top with the petroleum to be tested, care being taken not to wet the rim, the thermometer placed in position and the lamp lighted. The heating should be gradual, and if necessary, the lamp be occasionally removed. When the oil has reached the temperature at which the operator wishes to begin testing, a small flame, either from a wooden splinter or a gas-jet, is slowly and carefully passed over the petroleum,

FIG. 128.

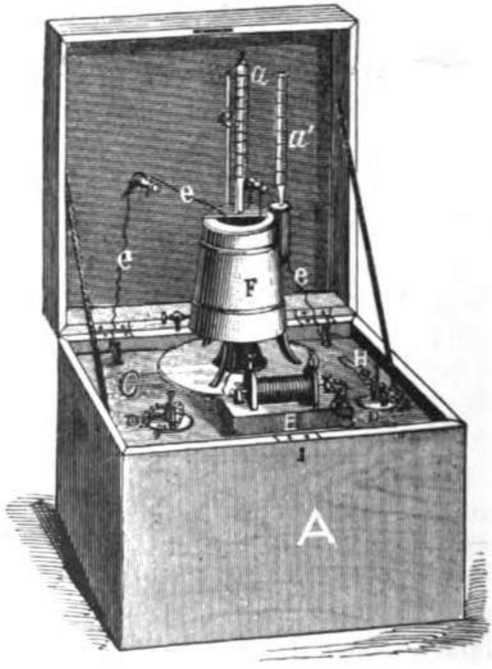


about half an inch from the surface. If no flashing takes place, this is repeated as the temperature rises until the flashing point is reached. During the testing the apparatus should be protected from draughts of air.

To the group of open testers belong also the apparatuses of Ernecke-Hannemann and of Lenoir, as well as the Saybolt tester which was formerly used in England and the United States, it having been adopted in the latter country, in 1879, by the Produce Exchange of New York, in testing refined petroleum.

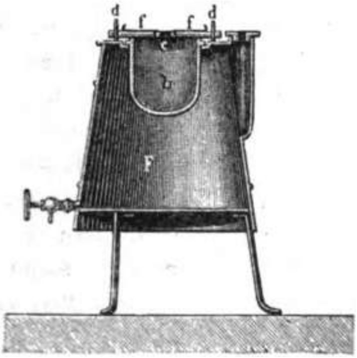
Saybolt electric tester. This apparatus resembles the open tester of Tagliabue, differing chiefly in the use of the electric spark in place of the burning splinter. It is shown in Fig. 129, and consists of the copper water-bath *F*, containing the petro-

Fig. 129.



leum-holder, which, with the other parts of the apparatus, are placed on the tray *C*, and, for transportation, can be enclosed in the box *A*. *D D* are the covers of two battery elements. *H* is a current-breaker, *E* an induction coil, and *e e* the conducting wires for producing the spark over the surface of the petroleum; *a* is the thermometer of the oil-holder, and *a′* that of the water-bath. The further details of the water-bath *F* may be seen from Fig. 130. *b* is the glass petroleum holder, *c* a

FIG. 130.



small ebonite beam secured by the brass pins *d d*; *f f* are two strips of brass ending towards the centre in platinum wires which pass through the ebonite beam, and below the latter are placed opposite to one another so that the spark can leap across.

In using this apparatus the bath is filled with water, and heated to 100° F., after which the lamp is removed, the oil cup, filled to within an eighth of an inch of the top with the petroleum to be tested, is placed in the bath, and the thermometer is immersed in the oil until the bulb is just covered. When the temperature of the oil is raised to 90° F. a spark is produced by the key *H*, and after replacing the lamp the operation is repeated every two or three degrees until the flashing point is reached. The temperature of the oil when brought into the water bath should not be below 55° F. and not above

70° F. Oil with a flashing point of 110° F. or above is tested at 90°, 95°, 100°, 104°, 108°, 110°, 112° and 115° F. Oils with a flashing point of 120° F. or above are tested at 100°, 105°, 110°, 115°, 118°, 120°, 122° and 125° F.

The easy supervision of this apparatus renders it possible to execute several tests alongside of one another, and by supplying the necessary connections and contrivances for breaking the current the sparks from several apparatuses in use at the same time can be produced by means of an induction-apparatus.

Like all petroleum testers with open oil-holder, the otherwise very exact Saybolt tester has the defect of giving the flashing point too high. This is readily explained by the escape of vapors, by the warm current of air ascending from the apparatus, and by other accidental movements of the air. A too high flashing point is also obtained if the level of the oil is kept a few millimeters lower. But even by strictly observing the rules accompanying the apparatus, there is a considerable difference in the results with one and the same oil, they amounting according to numerous experiments by Engler to as much as about 35.6° F.

B. *Apparatuses with closed oil-holders.*

These apparatuses yield more corresponding results, their construction approaching more closely the plan of a lamp. The petroleum is under similiar conditions as in the holder of a lamp, inflammable vapors being gradually evolved which accumulate in the empty portion of the vessel, become mixed with air, and explode when ignited. The results obtained in these apparatuses also correspond better one with another, since the oil vapors are not carried away by the warm current of air. As examples the apparatuses of Tagliabue, Abel, Bernstein, Braun, Engler, Heumann, Victor-Meyer, Haas and Beilstein will here be described.

Tagliabue's closed tester. This tester, Fig. 131, consists of the water-bath *A* and the petroleum-holder *B*, both of brass. The latter is provided with a cover, upon which are fixed the hood

C, containing a rectangular opening *a*, the sliding bar *b*, for opening or closing the aperture beneath it, and lastly, the thermometer *D*. There is also an improved form of this tester differing from the first in the arrangement of the cover, which is shown in Fig. 132. In this *a a* is the cover, with openings under the movable bar *b b*, by which they are closed; *f f* are small openings in *b b*, closed by the piece *e*, held up by the spring beneath it. By pressing upon the knob *c*, the apertures *f f* are opened, and the bar *b b* can be moved by the handle *g*.

FIG. 131.

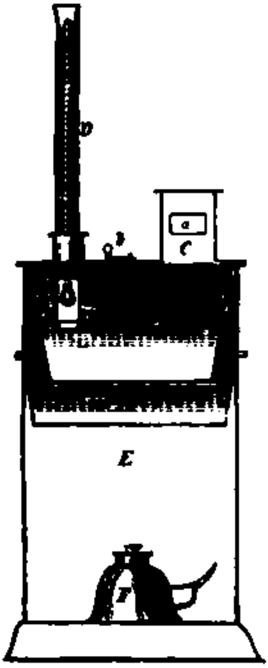
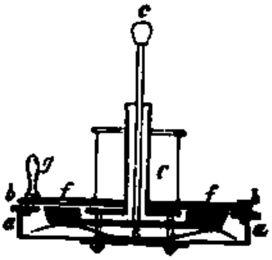


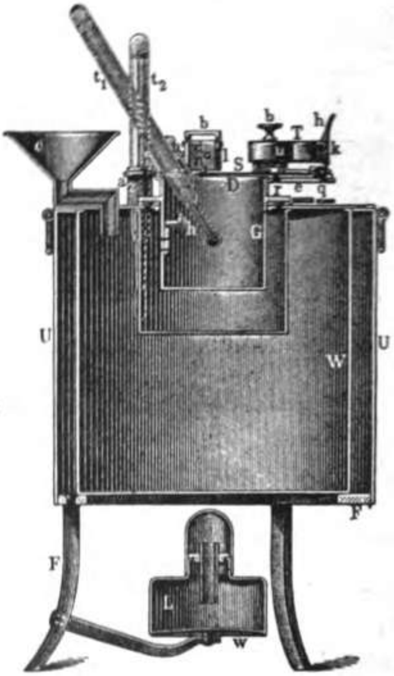
FIG. 132.



In using this apparatus, the water-bath as well as the oil-holder is filled, and the bath is gradually heated by the spirit lamp. When the thermometer reaches a definite temperature, a small flame is introduced through the opening *a*, into the hood *C*: and at the same time the bar *b*, in Fig. 131, is moved to one side, or, as represented in Fig. 132, the knob *e* is pressed down in order to establish communication with the air by openings *b*, or *f f*. The testing is repeated as the temperature rises until the flashing point is reached.

Abel's tester. This apparatus is used in England and, since 1882, has been employed in the official testing of petroleum in Germany. It is shown in Figs. 133, 134, 135, and 136.

FIG. 133.



It consists of a petroleum holder closed by a cover. This holder is filled with petroleum up to a fixed mark. Through the cover a thermometer passes into the oil. The cover is also provided with openings which can be opened and closed by a sliding bar. The movement of the sliding bar is effected by means of a small mechanism, the flame of a small lamp being, by the same movement, so tipped that it comes opposite to the opening in the middle of the cover when the sliding bar is drawn back. The flame thus comes each time in contact with the petroleum vapors, but retreats after each contact, while the openings in the cover are at the same time closed by the sliding bar. This is repeated until the flashing point is reached. *G* is the brass petroleum-holder with the brass ring *r*; *K* are two knobs for lifting *G*, and *h* the mark to which the holder is filled with petroleum. *D* is the cover, the arrangement of which is shown in Figs. 134, 135, and 136. The circu-

FIG. 134.

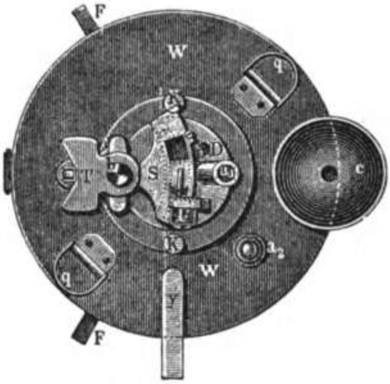


FIG. 135.

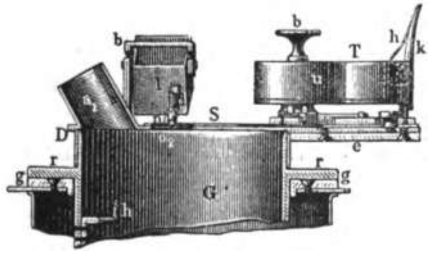
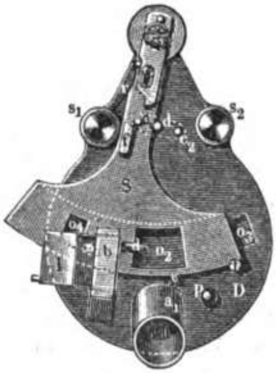


FIG. 136.



lar cover has a prolongation with a pivot for the sliding bar *S*; below are two small pillars s_1 and s_2 for securing the mechanism. As a protection from radiating heat, the prolongation is covered below with ebonite *e*. Opposite to the prolongation are the opening a_1 for the reception of the thermometer t_1 and alongside of it the strap *b* for the reception of the small lamp *l* suspended in two pivots; also a white bead *p*, 3.75 millimeters in diameter, which serves as a measure for the size of the flame. In the cover *D* are three rectangular openings o_2, o_3, o_4, which can be brought into correspondence with two openings in the sliding bar *S* by turning the latter.

The object of the mechanism *T* is to effect a slow and uniform movement of the sliding-bar *D* so that the gradual opening of the apertures o_2, o_3, o_4 lasts exactly two seconds, and that the slide-bar *S* finally returns to its initial position and closes the apertures. *W* is the water-holder, consisting of two metallic cylinders with flat bottom; the inner cylinder must be of copper, while the outer cylinder, as well as the bottom, may be of brass. The annular space between the two cylinders is closed on top by a copper plate. Hence, the inner cylinder alone remains open on top, so that the petroleum holder *G* can be placed in it. *g* is an ebonite ring to prevent the conduction of heat. The cover of the holder *W* is further provided with the tubulure a_2 for the reception of the thermometer t_2, further the funnel *c* for filling *W* and two brass rings *gg*. The excess of water is discharged through the pipe *y*.

F is the trevet upon which the holder *W* rests; *U* a copper or brass jacket open below and closed above; and *L* a spirit lamp secured upon the plate *w* to one leg of *F*. The scale of the thermometer t_1 for measuring the temperature of the petroleum, is graduated in ½ degrees from + 10° to + 35°, while the thermometer t_2 for the water bath is graduated only in whole degrees from + 50° to + 60°, the mark 55° being indicated by a red line. Finally, the tester is provided with a glass pipette for filling the oil-holder with petroleum, and a gauge for controlling the dimensions of the apparatus. The whole is enclosed in a wooden box, in the cover of which a metallic barometer may be placed.

In executing the test the apparatus is to be placed in a medium warm room, as free from draughts as possible, the petroleum in a closed bottle being allowed to stand in the same room until it has acquired the temperature of the latter. The water is heated by means of the spirit lamp to from 44.5° to 55° C. (red mark). *G* is then filled by means of the pipette to the mark *h* with the petroleum to be tested. The cover *D* is then immediately placed in position and the petroleum-holder *G*, without shaking the petroleum, brought into the holder *W*. The spirit lamp is then removed, and, in case the temperature of the water has risen to above 55° C., it is brought to that degree by the addition of cold water. When the temperature of the petroleum approaches the supposed flashing point the wick of the small lamp *l* is ignited and arranged to give a flame of the size of the bead *p*. The mechanism *T* is, at the same time, wound up by turning the knob *b*. When the petroleum has acquired the degree of heat prescribed for the commencement of the test, the sliding-bar is set in motion by pressing with the hand against the lever *h*, and by the movements of the sliding-bar the lamp is so tipped that its nose comes opposite to the opening in the middle of the cover. This operation is repeated every half degree until the flashing point is reached. The experiment is then repeated with a fresh portion of petroleum; the petroleum holder, thermometer and cover being first wiped and dried with a cloth and the petroleum-holder cooled off, if necessary, by placing it in cold water. If there be a difference of more than 1° C. a third test has to be made, and the average of these three determinations is taken. Before commencing the test the marking of a suitable barometer in the work-room is read off in whole millimeters, and based upon this the degree of heat at which testing has to be commenced is ascertained from the following table:

With the barometer	Testing commences
at from 685 to 695 Mm	at + 14° C.
at over 695 to 705 Mm	at + 14.5 C.
" 705 to 715 Mm	at + 15 C.
" 715 to 725 Mm	at + 15.5 C.
" 725 to 735 Mm	at + 16 C.
" 735 to 745 Mm	at + 16 C.
" 745 to 755 Mm	at + 16.5 C.
" 755 to 765 Mm	at + 17 C.
" 765 to 775 Mm	at + 17 C.
" 775 to 785 Mm	at + 17.5 C.

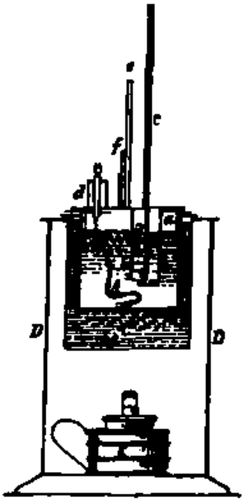
The arrangement of Abel's apparatus as introduced in England is, generally speaking, the same as that of the apparatus described above. However, it is not provided with a mechanism for setting the sliding bar in motion, the petroleum-holder, *A*, as shown in Fig. 137, being simply moved forward and backward by means of the handle, *d*. By the backward movement a pin strikes the lamp *c*, and the latter is so tipped that its nose comes opposite to the opening in the middle of the cover.

Parrish naphthometer. This instrument is used chiefly in Holland, and differs from those already described in that the inflammable mixture is carried out of the petroleum-holder to a stationary flame. It is shown in Fig. 138. *A* represents the oil-holder, *C* the water-bath, *D* the support, and *E* the lamp. The holder is provided with a projecting cover, in which is the cylinder, *d*, having in its axis a small tube with a wick running into the petroleum; *e* is a screw, against whose base rests the glass plate, *f*, for protecting the thermometer from the heat of the wick-flame, and lastly, *B* is a chamber communicating with the air, in which are the openings *a* and *b*, the former for the circulation of the air through the petroleum-holder, and the latter to allow the oil to pass from *B* into *A*. The thermometer, *c*, is placed in the vessel *B*. The bath is filled with cold water, and the oil-holder with the petroleum to be tested, to a point one centimeter below the rim. The heating must be slow and is effected by the spirit lamp, whose flame is only 1 to 1½ centimeters high. The small wick in *d* is then lighted.

FIG. 137.

care being taken that the flame is not more than 6 to 7 millimeters high. The heat of this flame produces a current of air, which, coming in through the opening *a*, spreads over the sur-

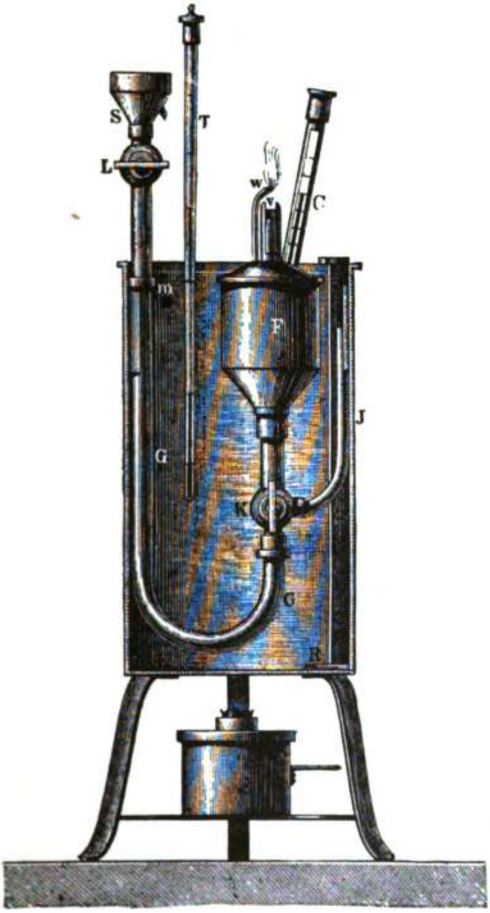
Fig. 138.



face of the oil and passes out by the tube *d*, taking with it the vapors evolved from the heated oil. When the oil vapors are sufficient in amount to produce an inflammable mixture, they are ignited by the flame in *d*, the flame being extinguished by the sudden motion of the air. At this moment the flashing temperature is read.

Bernstein's tester. In this apparatus, Fig. 139, the petroleum is contained in a closed holder *F*, which is heated by a water bath and from which the vapors evolved are displaced by water pressure. In the cover of the petroleum-holder are two wicks, *w* and *v*, placed vertically one above the other and fed by the petroleum to be tested; the upper wick is ignited after the oil has been heated. In the cover is also the thermometer *C*, the mercury bulb of which dips into the oil. The funnel-shaped bottom of the petroleum-holder communicates by the bent pipe *G G*, and the cocks *K* and *L* with the funnel *S*; the latter, by shifting the doubly perforated cock *K* can also be brought into communication with the pipe *J*. *R* is a stirrer, *T* a thermometer for the water bath, and *m* the mark up to

FIG. 139.



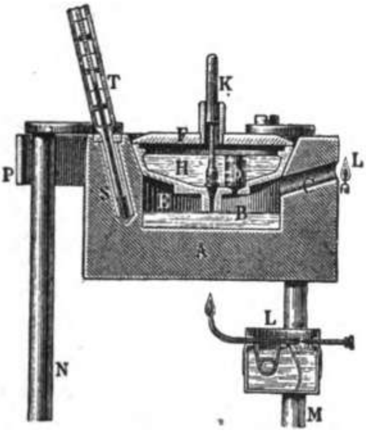
which the bath is filled with water. In executing the test the petroleum-holder is taken from the water-bath, the latter filled with water up to the mark and heated to the temperature, for instance, 35° C., which corresponds to the minimum flashing point. By using the stirrer the water is kept at a uniform temperature. In the meanwhile the lid is removed from the petroleum-holder and the cock *K* placed in a horizontal, and the cock *L* in a vertical, position. By means of a measuring flask accompanying the apparatus, the proper quantity of petroleum is brought into *F*, and, after replacing the lid, water is poured in through *S* until it flows out from the top of *J*. The cock *K* is now placed vertically and the cock *L* horizontally, when the entire apparatus is placed in the water-bath and the funnel *S* filled with water up to the lateral discharge-pipe. The petroleum becomes heated and the water cooled off thereby is reheated to 35° C. until water and petroleum have acquired the same temperature. The wick *w* is now ignited and the cock *L* opened (placed vertically). The water from the funnel *S* now presses towards *F*, and from there forces the petroleum vapors evolved through the small pipe below the lower wick. If the latter is thereby ignited from the upper wick the minimum flashing point lies below 35° C. and the petroleum is not admissible. After each test the petroleum-holder is rinsed out with cold water.

With careful manipulation this apparatus gives, according to Engler's experiments with it, very satisfactory results. It has, however, the disadvantage that for every determination of the flashing point it has to be refilled, which is troublesome and time-consuming. But for simply testing an oil as to whether it is admissible or not, this apparatus is very useful and reliable.

O. Braun's tester. This apparatus is based upon a principle similar to the preceding. It is shown in Fig. 140. *A* is a cast-iron or copper block, weighing about 13 lbs. In this block is a cavity *B E*, 2.95 inches in diameter and 1.77 inches deep. In this cavity sits the bronze vessel *H* provided with a glass-cover, *F*, in which is a small opening which can be closed by a cork, *K*. In the bottom of *H* a small hollow cylinder, *b*, is secured. *L* is a lamp secured to the leg, *m*; it can be turned and screwed up so high that its flame is brought directly in front of the opening, *C*. The thermometer, *T*, sits in a bore-hole, *S*, filled with petroleum. *P* and *N* form the stand for the apparatus.

For the execution of a test the glass cover, *F*, is removed and 25 cubic centimeters petroleum are poured into *H*, until a small quantity of oil enters the small overflow cylinder *b*, from which it is removed by means of a pipette. The cork, *K*, is now lifted and the first 25 cubic centimeters of oil run into *B*, when 25 cubic centimeters more are poured into *H*, and the glass cover is placed in position. In three to five minutes the oil in *B* has acquired the temperature of the block, *A*. In about 10 minutes the flame is brought in front of *C*, and the cork, *K*, is removed, the oil now running from *H* to *B*; the vapors in the latter are displaced and brought to the flame. If an explosive mixture has been formed the flame is extinguished by the sudden combustion. This apparatus, like Bernstein's, also permits only of a test at a definite temperature.

FIG. 140.



Braun has also constructed a glass apparatus based upon the same principle in which the vapors are displaced by the water of the water-bath.

Engler's tester. The apparatus devised by Engler is of the closed form, to which is added an electric mechanism similar to that of the Saybolt tester. It is shown in Figs. 141 and 142. It consists of the copper water-bath, *A*, heated by the spirit-lamp, *B*. *CC* is a glass vessel for water, which has a filling mark etched upon it. *mm* is the cover, and *n*, the thermometer. In the cover is the glass petroleum-vessel, *D*, also provided with a filling mark, and to which is fitted the brass cover, *oo*. The latter is shown in Fig. 142, in which will be noticed the following details: *ss* are two movable covers, *tt* the conducting wires insulated by the ebonite rings *uu*, *r* the thermometer and *q* the handle of the stirrer *p*, seen in Fig. 141. The conducting wires terminate in platinum points in the vessel *D*, from ½ to ⅔ centimeter above the surface of the oil and at a distance of 1 millimeter from each other. For the production of the electric spark, a chromate cell is used with an induction apparatus, which gives a spark at least 2 to 3 millimeters long. The electric apparatus of the Saybolt tester answers very well. In using this tester the baths *A* and *C* are filled with water, and *D* is filled to the mark with the oil to be tested. When the petroleum vessel is in place, the water in *C* should stand one centimeter below the rim. The wires are connected with the induction coil and the lamp is lighted. As the temperature rises to the testing point, the electric spark is allowed to leap

FIG. 141.

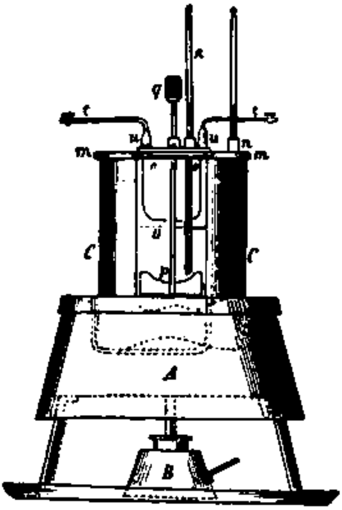
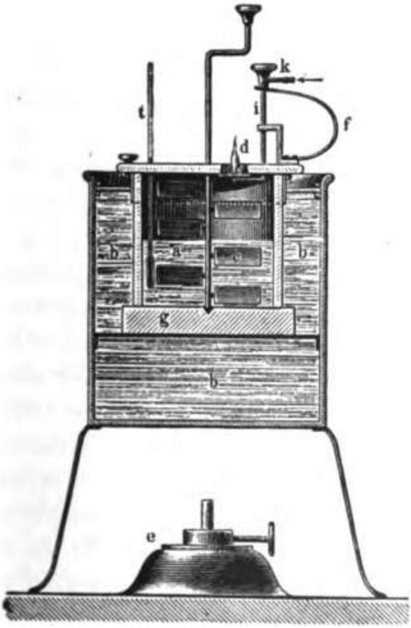


FIG. 142.

across from degree to degree, care being taken that the spark continues from one-half to one second. After each passage of the spark the oil is gently agitated by the stirrer. The operation is continued in this way until an explosion occurs, by which the covers, *ss*, are thrown open.

K. Heumann has improved Engler's apparatus by continuing the stirrer into the upper portion of the petroleum-holder in order to produce there a homogeneous mixture by mixing the oil vapors evolved with air. In other apparatuses the specifically heavier oil vapors remain lying on the surface of the oil, so that the closer the flame is approached to the latter the lower the flashing point is found. Heumann has also simplified the means of igniting. In Fig. 143 *a* is the glass petroleum-holder, *b* a brass water bath resting upon *g*, *c* the stirrer, *d* the igniting flame which is fed with gas from *k* through the

FIG. 143.



pipe *f*. By pressing upon the spring *i* the flame can be lowered into the vapor-space of the petroleum-holder *a*; it afterwards rises by itself and closes the opening *d*. A thermometer *t* passes through the hard-rubber cover into the petroleum.

In executing an experiment the necessary quantity of petroleum is brought by means of a marked funnel provided with a cock into *a*, and water up to the mark into *b*. The water, as in Engler's apparatus, surrounds the petroleum-holder so that the result is not influenced by the temperature of the room. The lamp *e* is lighted and at the suitable moment the igniting experiments are made by depressing *k*. The throwing open of the cover indicates the flashing point.

Victor Meyer's method of determining the flashing temperature. Meyer designates the temperature at which petroleum agitated with a quantity of air flashes by the introduction of a small flame as the true or absolute flashing temperature of petroleum. To determine the flashing point about 40 cubic centimeters of the oil to be tested are brought into a glass cylinder of about 300 cubic centimeters capacity (according to experiments by Hörler the results are independent of the size of the cylinder or the quantity of oil used). The mouth of the cylinder is closed with a doubly perforated cork. Through the perforations pass two thermometers, one reaching nearly to the bottom of the cylinder and the other but a few centimeters below the cork. The cylinder is then placed up to its upper rim in warm water. When the oil and air above it have acquired the temperature at which the oil is to be tested, the cylinder is taken from the water, vigorously shaken, and allowed to stand until the bubbles have disappeared, when it is opened. A small gas flame is then introduced through a pointed glass tube to see whether the vapor ignites. If the latter is not the case the experiment is repeated from degree to degree until ignition takes place.

Hörler uses a somewhat different method for determining the flashing point. He mixes, after the first ignition, some cold water with the warm water, allows the open petroleum-holder to cool off somewhat, and repeats the same experiment at a lower temperature. This is continued until the limit at which no ignition takes place is reached. In using this method it is necessary to allow the cylinder to stand quietly at least one minute after shaking before introducing the flame, otherwise the results will evidently be too low on account of the spray formed by shaking, which is suspended in the gas mixture and vaporized by the introduction of the flame. The result is also, to a considerable extent, influenced by the size and intensity of the flame, a stronger flame giving a lower flashing point than a weak one. Hence, in making comparative experiments, it is necessary to use an igniting flame of the same size and intensity.

Haass' tester. This apparatus is based upon Victor Meyer's principle of agitation with the use of the method of igniting the vapors by an electric spark in a closed glass vessel employed in Engler's apparatus. The apparatus is shown in Figs. 144 and 145. A glass cylinder with a foot is provided on top with a brass edging, to which is secured, by means of a hinge-joint, the hermetically closing cover *d*. For the convenient pouring out of the oil, the edging *f* is also furnished with a lip *e*. It also carries the brass socket *h* in which the thermometer in the interior of the glass cylinder is so secured that it hangs free at a distance of about ½ centimeter from the sides. The ends of the poles in the form of platinum wires are screwed in brass mountings at *m m*, and, after entering the glass cylinder, turn upward so that the oil can run off. They end at a distance of 1 millimeter from each other. The platinum wires are further connected with the copper wires *K K*, which pass through holes in the glass foot and communicate by their lower ends with the brass plate *n n*. The object of the glass jacket *S S* of the cylinder is to form a layer of air between the two cylinders, so that after removing the entire apparatus from an air-bath which serves for heating, the temperature of the petroleum is for some time kept constant. This protective cylinder is also provided on top with an edging, the arrangement of which will be seen from Fig. 145, which gives a view of the apparatus from above. *r r r* are three pins provided with knobs, and serve as a guide for the movable disk furnished with corresponding slits. By turning the disk in one direction the three pins are pushed forward (as can be readily seen in the illustration) so that they serve as carriers of the inner cylinder, while by turning the disk in the opposite direction they are pushed aside and permit the jacket to be removed from the inner cylinder. A copper air-bath serves for heating the apparatus. To prevent radiation of heat the bath is covered with a clay plate, and is heated by a spirit-lamp. On both sides, over the clay plate, a glass cylinder, open on both ends, 8 to 9 centimeters in diameter and 18 centimeters high, is secured in a brass frame. By means of a binding screw it can be raised and lowered so that, corresponding to the lower slit, which remains free, the warm air may pass more rapidly or slowly through it. By suspending the apparatus, shown in Fig. 144, in such a glass cylinder, and shifting the latter as well as the lamp under the air-bath, one is

FIG. 144.

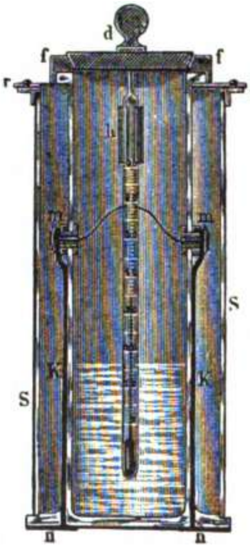
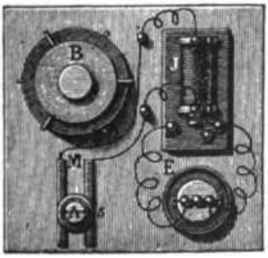


FIG. 145.

enabled to effect the heating of the oil in the inner cylinder as slowly as desired. The temperature is observed by a second thermometer placed in the outer glass jacket.

For the production of the electric spark an apparatus similar to that of the Saybolt tester is used. Instead of two chromate cells there is but one, and in place of the special current-breaker the zinc plate is arranged like a spring-balance to dip for a moment in the chromic acid. After each pressure the zinc is again lifted from the fluid by the spring. The wires of the induction-apparatus terminate in two brass strips set in a board, as otherwise, every time before the spark leaps across, the apparatus has to be taken from the digester and then brought into connection with the pole ends of the induction-apparatus, which would require repeated screwing in and unscrewing of the pole-wires. By placing the test cylinder upon these brass strips so that the brass plate on the foot of the cylinder comes in contact with them, conduction is established, and on dipping the zinc plate the spark leaps across. Fig. 146 shows the complete arrangement of the apparatus

FIG. 146.



with its auxiliary contrivances, seen from above. *A* is the testing apparatus shown in Fig. 144, *B* the air-bath, *E* the chromate cell, *J* the induction-apparatus, while at *M* are indicated the brass strips set in the board and connected with the induction-apparatus.

In using the apparatus the inner cylinder is filled up to the mark with the petroleum to be tested; the protective jacket *S S* is then placed in position and the whole suspended in the digester *B*, Fig. 146, and heated so slowly that the two thermometers never show more than 5° difference. When the temperature, at which the test is to be made, has been attained, *a* is taken from the digestor and vigorously shaken. The apparatus is then placed upon *M* so that conduction is established. It is permitted to stand quietly for one minute to allow the oil-spray to settle. The temperature is then noted and the spark allowed to leap across for one second by pressing down the knob on the cell *E*. If no ignition, by which the cover is thrown open, takes place, heating is repeated and continued from 1° to 1° or 2° to 2° until ignition takes place. Before re-using the apparatus, the oil-holder must, of course, be completely cooled off.

Pease's tester. This apparatus, shown in Fig. 147, consists of the usual water-bath *A*, an oil-holder *B*, and a spirit-lamp for heating the water-bath. The oil-holder has many modifications not found in other testers. To maintain a constant level it is furnished with an overflow-pipe. Further the cover *C* is readily movable backward in a horizontal direction, is slightly convex, and has in the centre a short pipe on which are the screws that yield the electric current. In the cover is also an opening for the thermometer.

In the apparatuses of Stoddard, Liebermann and Beilstein, air is conducted into the petroleum to be heated and igniting experiments are executed with the mixture of vapor and air over the surface of the petroleum. Stoddard conducts air continuously through the oil, which gives less accurate results, while Liebermann and Beilstein from time to time conduct air through it. Beilstein's apparatus, being the most complete, shall here be described. It is shown in Fig. 148. *A* is a glass cylinder 1.37 inches in diameter and 6.89 inches high; at 2.36 and 2.75 inches above the bottom it is provided with marks, it being filled with petroleum up to the lower mark. *B* is a brass pipe through which air is conducted, and it terminates below in a small rose *c*; *t* is a thermometer whose mercury bulb reaches into the centre of the petroleum. The apparatus is placed in a water-bath which is slowly heated (a rise of about 1° every 2 or 3 minutes) and at each rise of 1° air is forced through for 5 seconds so that the foam rises to the upper mark, a small flame being at the same time held near the mouth of the apparatus.

FIG. 147.

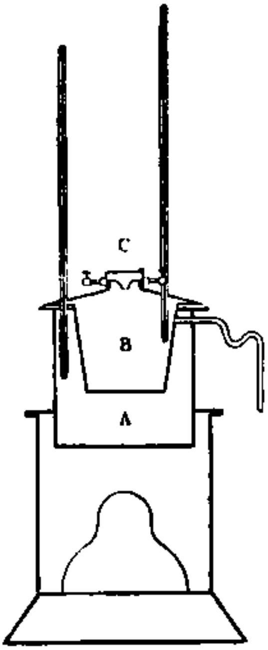
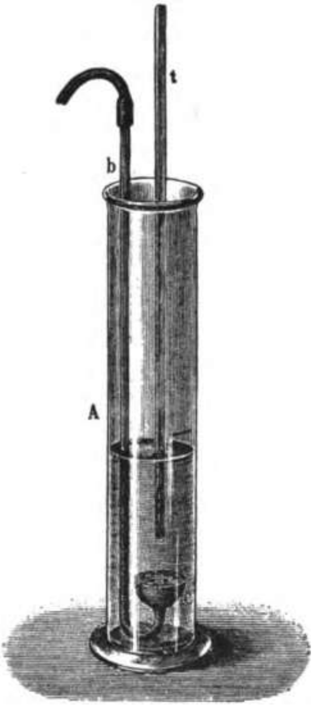


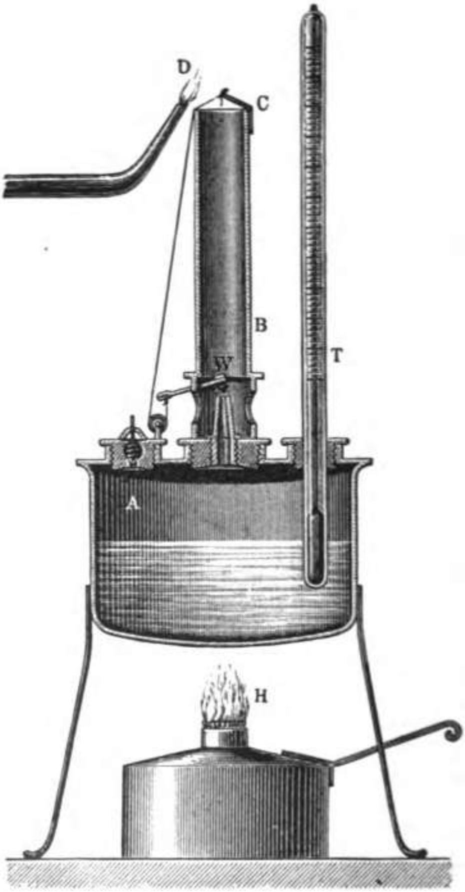
FIG. 148.



The first experiment is always a preparatory experiment only, and has to be repeated with the introduction of air at the flashing temperature first determined. With sufficiently slow heating the results vary at the utmost ¼ degree.

A. Gawalowski of Brünn has recently constructed an apparatus for determining the explosive power of petroleum in lamps, which, as he claims, renders it possible to establish the degree of danger from fire which a commercial petroleum possesses at the moment of lighting an improperly constructed lamp. The apparatus is shown in Fig. 149. *A* contains the petroleum to be tested. In the centre of the cover is screwed

FIG. 149.



in a Bunsen burner *B*, further a safety-valve and a thermometer *T*. *C* is a small hook soldered to the opening of the Bunsen burner, by means of which a valve *W* is held suspended in the burner by a cotton-thread impregnated with ammonium nitrate.

By heating the petroleum in *A* and placing a small flame at *D*, the thread is consumed at the moment the gas mixture flashes at *C*, and *W* is automatically closed. The flames at *D* and *H* are extinguished and the temperature is read off on *T*.

Extensive experiments made by Engler in co-operation with Haass have shown that one and the same petroleum gives very varying flashing points when tested in different petroleum testers. Of all the apparatuses in use Abel's gives the lowest flashing points, those indicated by Engler's electric apparatus being from 5° to 7° C. higher, by Parrish's naphthometer 5°, by Tagliabue's closed apparatus 9°, by his open apparatus from 14° to 20°, and by Saybolt's apparatus also from 14° to 20°.

Even when one and the same oil is repeatedly tested with the same apparatus, results which entirely agree are never obtained, and with the present state of petroleum testing one has to be satisfied if such testers as Abel's, Beilstein's, Bernstein's, Engler's, Haass's and Heumann's yield results within the limit of 1° C.

Flashing Point of Lubricating Oils.

For determining the flashing point of lubricating oils the old method is still largely employed. It consists in heating the oil to be tested in a porcelain dish or crucible in a sand bath, and, when a slight evolution of vapor appears, to pass from time to time, a small flame, either from a wooden splinter or a gas jet, slowly and carefully over the surface of the oil. A thermometer dipping with the mercury bulb in the oil indicates the temperature of the latter. The flashing point is the temperature at which the vapors on the surface of the oil flash with detonation.

This method has many defects, the principal one being that the free access of currents of air to the surface does not permit a uniform accumulation of inflammable vapors, so that, with the air in motion, the results obtained with one and the same oil may be entirely different. The flashing point is also influenced by the vessels in which it is determined, as well as by the depth of oil in them, and even by the manner in which the flame is passed by the hand over the surface of the oil.

This defective method led to the construction of apparatuses similar to petroleum testers for the determination of the flashing point. Pensky's apparatus for the purpose is shown in Figs. 150 and 151; it is arranged similar to Abel's tester.

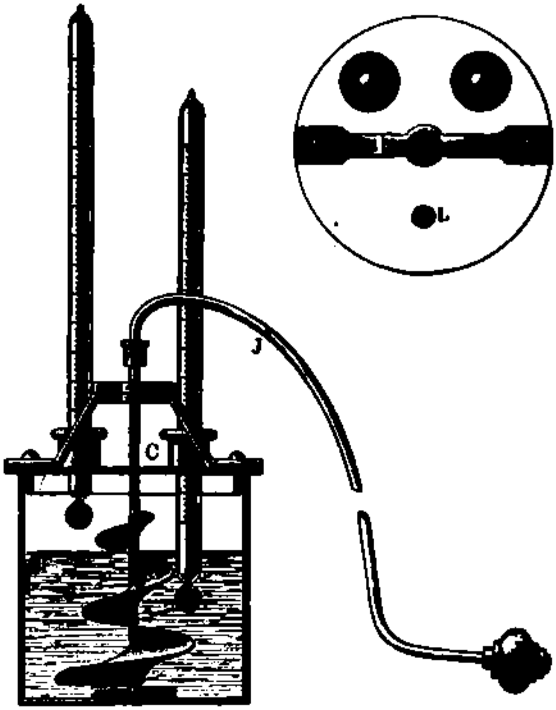


FIG. 150. FIG. 151.

In using the apparatus the oil-holder of cast brass is filled to the point of the filling mark with petroleum. The cover containing the thermometer, etc., is then placed in position, and the oil-holder is suspended by the projecting edges in a suitable vessel, which may serve as a water bath, calcium chloride bath, etc. For oils boiling at higher temperatures direct heating by wire nets or sand baths is employed; however, still better are hot-air baths which allow of a uniform temperature of 400° C. (754° F.). No matter what source of heat may be used, a uniform temperature in the interior of the oil is produced by the movable shaft *J* with the stirrer *C*. However, according to the manner of heating, whether over a free fire, sand bath, etc. (but not in an air bath), a difference in temperature shows itself above the oil, and, for this reason, the apparatus is furnished with two thermometers, one dipping in the oil and the other being placed above the oil near the opening *L*. The most uniform heat for all temperatures is best obtained in a hot air bath.

All preparations for heating, etc., having been made, the fluid is agitated by turning the shaft *J* to allow of the escape of the readily volatile bodies and the distribution of heat. For testing the flashing point a small gas flame is from time to time passed over the opening *L*. The flashing point is recognized by a quick flash which goes out again, and the burning point by the flame continuing to burn quietly. Both points are read off on the thermometer. If there is a difference between the temperatures of the oil and in the vapor-space, which may happen by too rapid heating over an open fire or in the sand bath, the mean of the two temperatures is taken.

To obtain uniform results a testing apparatus should answer the following requirements:[1]

1. The measurements of the apparatus to be used must be exactly prescribed, and only accurately compared apparatuses should be employed for testing.

2. The oil-holder must have a mark up to which it is to be filled with oil.

3. The access of air-currents to the surface of the oil must be accurately regulated.

4. The igniting flame must always be passed (best by a mechanism) in the same manner over the surface of the oil.

---

[1] Holde. "Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin." 1889. Heft 2.

5. Heating must be effected as uniformly as possible and overheating of any parts of the oil be prevented by a stirring apparatus.

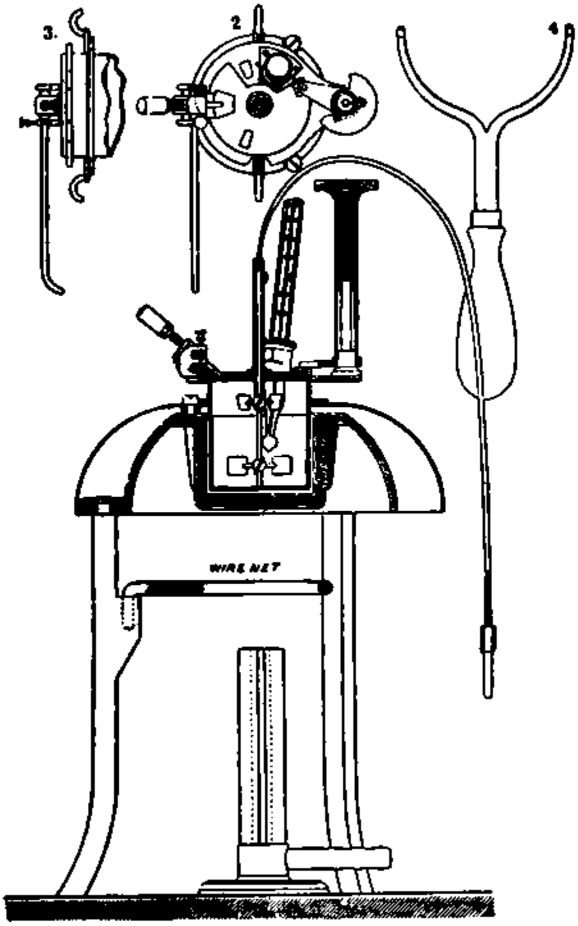
6. The apparatus must allow of easy and convenient cleaning.

7. The test must everywhere be executed in accordance with accurately stated regulations.

Pensky's apparatus, above described, does not answer in a sufficiently satisfactory manner requirements 5 and 6. The results vary frequently in consequence of slight overheating and the apparatus, especially the cover-parts, is difficult to clean. These defects were overcome by A. Martens, who gave the apparatus the form shown in Figs. 152 to 155.

Holde found that the oil to be tested has first to be examined as to a content of water, and if such is found, it is freed from it by shaking with calcium chloride and allowing it to stand one day. Oils which foam but slightly, or not at all, can be directly used, as well as oils in which foaming is due to air-bubbles. After filling the oil-holder up to the mark, the cover with the stirring apparatus and thermometer is placed in position and the triple burner brought under the apparatus. If the flashing point of the oil is supposed to lie above 140° C., heating with the full flame is continued up to 120° C., when the flame is removed, the stirring apparatus vigorously worked and the igniting flame set the size of a pea. When the temperature of the oil shows 140° C., igniting experiments are commenced and repeated every 2° C. The flame should not be held more than two seconds over the oil. When the flame becomes perceptibly disturbed and larger, testing is continued from degree to degree until flashing with or without extinguishment of the igniting flame takes place in the vessel. The degree of heat read off at that moment on the thermometer is noted down as the flashing point. Towards the end of the experiment the thermometer may rise as much as 12° C. per minute. Should flashing not take place at 160° C., the flame of the triple burner is again brought under the apparatus, the wire net being interposed between the bottom of the latter and the flame. If flashing has been observed at 140° C., the flame, in a second experiment, has to be removed at 100° or 80° C. The stirring apparatus is then set in motion and igniting experiments commenced at 120° or 100° C., as the case may be. If the flashing point lies

FIG. 154. FIG. 153. FIG. 155.



near the admissible limit it is advisable to control the determination by a second test. In all other cases one test suffices if executed carefully and in accordance with the directions given above.

The size of the igniting flame has no perceptible influence upon the results, but it is recommended to be set in all experiments the size of a pea, since the appearance of flashing is more clearly perceptible with a small flame. Filling the oil holder up to the mark must be strictly adhered to.

To obtain a picture of the reliability of the method, repeated experiments were made with the same oils and the results tabulated in Table I, together with those obtained by slow heating without stirring. It will be seen that with constant stirring of the oil and rapid heating the same results are obtained as with slow heating, and hence that by agitation overheating of some parts of the oil is avoided. The table also shows the faulty determinations obtained by too rapid heating without the use of a stirring apparatus.

TABLE I.

Preparatory Experiments for the determination of the flashing Points with Pensky's improved Apparatus.

Variety and Mark of the Sample.	Number of the experiment.	Flashing point in ° C.		
		Slow heating. Rise of the thermometer towards the end of the experiment 2° per minute.	Rapid heating. Rise of the thermometer towards the end of the experiment about 10° per minute.	
		without stirring.	without stirring.	with continuous vigorous stirring.
Mineral oil I^{28}	1	164	156	165
	2	165	160*	164
	3	163	—	164
	4	164	—	—
	5	163	—	—
	Mean.	164	—	164
	Difference between maximum and minimum.	2	—	1
Mineral oil 27°	1	164	159	167
	2	164	167	168
	3	167		167
	4	164		166
	5	167		—
	Mean.	165	—	167
	Difference between maximum and minimum.	3	—	2
Mineral oil 27*	1	121	117	121
	2	122	110	122
	3	122	113	119
	4	123	—	122
	5	—	—	(125)
	6	—	—	119
	7	—	—	122
	Mean.	122	—	121
	Difference between maximum and minimum.	2	—	3 (6)
Mineral oil I^{29}	1	175	—	172
	2	—	—	174
	3	—	—	174
	Mean.	175	—	173
	Difference between maximum and minimum.	—	—	2

* Rose 6° per minute.

Table II treats of the influence of the size of the igniting flame, as well as of the depth of the oil in the holder. It shows that the results are not, to any extent, influenced by the first factor, while filling the oil-holder below the mark considerably raises the flashing point. Hence, filling the oil-holder up to the mark has to be strictly adhered to.

TABLE II.

Variety and Mark of the Sample.	Number of the experiment.	Flashing point in ° C.			
		Normal experiment. Flame the size of a pea. Oil-holder filled up to the mark.	Flame double the size of a pea.	Oil-holder filled to about 1 centimeter below the mark.	Oil-holder filled to about 1 centimeter above the mark.
Mineral oil I^{a}.	1	156	155	158	154
	2	156	157	159	155
	3	—	155	—	—
	Mean.	156	156	158.5	154.5
Mineral oil I^{b}.	1	174	173	176	174
	2	—	173	176	174
	3	—	173	—	—
	Mean.	174	173	176	174
Mixture of I^{b} and petroleum.	1	110	108	110	109
	2	110	113	115	110
	3	—	110	—	—
	4	—	111	—	—
	Mean.	110	110.5	112.5	109.5

Since oils containing water yield faulty results, they have to be freed from it before subjecting them to the test.

In Table III, the results of experiments made by Holde with 40 varieties of oil, are tabulated and show the great variations in the determination of the flashing point by Pensky's improved apparatus and by open dishes. The magnitude of these variations obtained by the use of different methods shows the necessity of a uniform method.

TABLE III.

Comparative Tests Between the Older and more Recent Methods.

Apparatus.	Number of the Experiment.	Flashing point in ° C.																									
		a. Pure mineral oils (arranged according to rising flashing points).																									
		Marks of the samples.																									
		27^{e}	47^{a}	47^{r}	47^{u}	47^{e}	47^{d}	47^{o}	47^{q}	47^{h}	47^{t}	47^{p}	47^{s}	47^{l}	I^{60}	47^{f}	47^{i}	I^{61}	32	47^{m}	47^{k}	41^{f}	I^{28}	27^{c}	I^{29}	41^{e}	33^{a}
a. Improved Pensky Apparatus.	1.	121	131	144	150	149	152	153	153	153	154	155	152	153	156	156	157	156	158	158	163	164	164	167	172	(173)	176
	2.	122	....	146	148	....	....	....	153	....	151	153	155	156	156	....	....	158	159	160	160	163	165	168	174	175	177
	3.	119	....	144	....	....	....	....	....	....	....	....	....	....	....	....	....	....	159	....	....	....	164	167	174	177	176
	4.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	159	.. .	....	....	....	166	....	....	....
	Mean	121	131	145'	149	149	152	153	153	153	153	154	154	155	156	156	157	157	159	159	162	164	164	167	173	175	176
	Difference between maximum and minimum	3	....	2	2	....	....	....	0	....	3	2	3	3	0	....	....	2	1	2	3	1	1	2	2	4	1
b. Porcelain Crucible.	1.	140	140	173	155	170	165	164	164	164	164	(157)	163	169	177	167	169	176	170	167	170	184	191	186	192	195	190
	2.	141	141	174	158	170	167	164	161	165	163	163	161	167	178	168	170	173	171	164	169	187	188	191	191	190	197
	3.	140	....	173	....	....	....	....	162	....	164	162	....	....	174	165	....	176	172	....	172	185	190	192	190	191	192
	4.	....	....	....	....	....	....	....	....	....	....	163	....	....	....	....	....	....	....	....	....	....	....	....	195	....	....
	Mean	140	141	173	157	170	166	164	162	165	164	162	162	168	176	167	170	175	171	166	171	185	190	190	192	192	193
	Difference between maximum and minimum	1	1	1	3	0	2	0	3	1	1	6	2	2	4	3	1	3	2	3	3	3	3	6	5	5	7
Difference *a* to *b*.		19	10	28	18	21	14	11	9	12	10	8	8	13	20	11	13	18	12	7	11	21	26	23	19	17	17

TABLE III.—(*Continuation*).

Apparatus	Number of the Experiment.	Flashing point in ° C.													
		b. Mineral lubricating oils with an addition of petroleum.										*c*. Mixtures of mineral lubricating oils with fat oils.			
		Marks of the Samples.													
		O_1^{29}	O_1^{29} With 0.5 per cent. petroleum.	O_1^{29} With 1 per cent. petroleum.	O_1^{29} With 1.5 per cent. petroleum.	O_1^{29} With 2 per cent. petroleum.	O_1^{28} With 0 per cent. petroleum.	O_1^{28} With 0.25 per cent. petroleum.	O_1^{28} With 0.5 per cent. petroleum.	O_1^{78} With 0.75 per cent. petroleum.	O_1^{28} With 1 per cent. petroleum.	8^b	8^c	8^d	8^e
a. Improved Pensky Apparatus.	1	172	152	140	124	110	164	154	146	139	135	123	121	118	118
	2	174	151	140	125	110	165	154	147	140	133	123	118	120	120
	3	174	......	......	......	......	164	......	......	......	132	......	120	......	......
	4	......	......	......	......	......	......	......	......	......	......	......	......	......	......
	Mean	173	152	140	125	110	164	154	147	140	133	123	120	119	119
	Difference between maximum and minimum	2	1	0	1	0	1	0	1	1	3	0	3	2	2
b. Porcelain Crucible.	1	195	182	174	168	145	191	184	178	173	168	142	157	162	153
	2	191	181	177	167	147	188	182	184	171	165	139	158	150	156
	3	192	178	174	164	......	190	184	179	173	171	143	162	155	153
	4	190	......	......	......	......	......	......	......	......	......	......	161	......	......
	Mean	192	180	175	166	146	190	183	181	172	168	141	160	156	154
	Difference between maximum and minimum	5	4	3	4	2	3	2	5	2	6	4	5	12	3
Difference *a* to *b*	......	19	28	35	41	36	26	29	34	32	45	18	40	37	35

From these tables it will be seen that there is not only a considerable difference between the flashing points of one and the same oil obtained with Pensky's improved apparatus, but also that according to the variety of oil this difference may vary between 7° and 45° C.

The experiments also show that by testing in an open crucible, small quantities of readily volatile constituents flashing at a low temperature are not established, since, on account of their great volatility, they cannot accumulate on the surface of the oil in a sufficient quantity to produce an explosion. Hence, in all cases where a high flashing point is the principal requirement, for instance, in machines working with compressed air, testing in an open crucible has to be absolutely rejected, because by this method the actually dangerous constituents are not with perfect certainty recognized.

Holde finally draws attention to a source of error which has been observed in an apparatus provided with an oil-flame for igniting the vapor. The oil-flame when brought to the surface of the oil to be tested was frequently extinguished by the evolving vapors, in consequence of which flashing, in several experiments, took place 5° to 10° C. later than in an apparatus provided with a gas-flame. By the use of a better wick-material and a regular supply of oil this defect was remedied, and the flashing point was the same as in the apparatus provided with a gas-flame. Hence to avoid errors care should be taken to have in all apparatuses the igniting flame of sufficient intensity to prevent its being extinguished before the appearance of flashing.

The appended table[1] gives the flashing and burning points, as well as the constitution and other properties of machine oils found in commerce.

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[1] S. Lamansky. Dingler's polytech. Jour., 1883, 248.

Names of the Oils.	Specific gravity at 15° C.	Specific viscosity at 19° C.	Content of carbon. per cent.	Content of hydrogen. per cent.	Flashing point. ° C.	Burning point. ° C.
Cylinder oil G	0.917	191	86.27	12.71	227	274
Machine oil I*G	0.914	102	86.03	12.92	213	260
Wagon oil *G	0.914	80	86.43	12.71	148	182
Wagon oil *R	0.911	70	86.45	12.76	157	187
Naphtha residuum N	0.910	55	86.96	12.82	134	162
Oleonaphtha OR	0.910	121	86.53	12.83	219	253
Wagon oil* OG	0.907	60	86.03	12.96	158	183
Machine oil 1 CG	0.907	59	86.29	12.92	203	254
Oleonaphtha 1 R	0.904	66	86.55	12.99	201	242
Machine oil 2 G	0.898	20	86.33	13.09	171	201
Oleonaphtha 2 R	0.894	20	86.49	13.05	184	222
Oleonid 16 R	0.884	28	86.19	13.62	185	217
Oleonid 12 R	0.881	24	86.20	13.53	187	214
Oleonid R, best quality	0.881	26	86.14	13.73	188	224
Huile vierge	0.916	23	76.70	12.03	—	—
Oil prov. opt. rect. I	0.916	22	76.71	11.96	—	—
Oil prov. opt. rect. II	0.916	22	76.66	11.84	—	—
Winter oil	0.879	9	79.16	12.59	—	—
Summer oil	0.875	8	79.43	12.63	—	—

* Railroad carriage oil.

Viscosity.

By viscosity is generally understood the degree of fluidity an oil posseses, or the resistance opposed by its smallest particles to their separation. The viscosity of oils is not proportional to their specific gravities, but to their internal friction, and hence oils of the same specific gravities may possess entirely different degrees of viscosity.

The viscosity of *illuminating oil* stands, according to experiments by C. Engler and J. Levin, in direct relation to the rapidity with which the oil rises in the wick, and is a very important feature for judging the qualitity of an oil. If the oil cannot rise in the wick with sufficient rapidity to feed the flame, the wick becomes carbonized and the flame retrogrades. Engler and Levin have also shown that the rapidity of rising in the wick is not dependent on the actual capillarity and the specific gravity, but only on the viscosity of the oil, and the more viscous an oil is the more slowly it rises in the wick, and *vice versa.* To recognize the capacity of an oil to rise in the wick special lamps have been constructed, the oil holder of which consists of a graduated cylindrical vessel on which the distance of the oil-level from the upper burning edge of the wick *i. e.*, the height of rising, can be read off. The oil holder is first filled up to the uppermost mark and by a tap placed near the bottom the oil can be discharged so as to test its behavior in burning (intensity of light, carbonization, etc.,) at various levels.

The rapidity with which the oil rises in the wick may also be ascertained by dipping a wick provided with lead pencil marks in the oil to be tested and noting the time required for the oil to rise to certain marks on the wick (10 centimeters, 15 centimeters above the level of the oil). The lower end of the wick is allowed to dip 5 centimeters deep in the oil, the experiment being best made in a dark room and placing a light behind the wick. For comparison an approved variety of petroleum is used.

For the determination of the viscosity, viscosimeters, which will be described later on, may also be used.

A few experiments by Engler and Levin from which the relations between the viscosities and the rising in the wick will be readily seen, may here be given. The viscosity was determined by the velocity of its flow in Engler's viscosimeter described below (Temperature 20° C. and water=1), and the rapidity of rising by a wick especially cleaned and dried, which dipped to a mark into the oil. The end of the wick projecting perpendicularly was provided with lead pencil marks at 5 centimeters distance from each other, so that the time required by the oil to rise to a mark at the height of 10 and 15 centimeters was shown.

	Specific gravity.	Viscosity.	Time of rising in minutes, up to 10 cm.	up to 15 cm.
Caucasian illuminating oil	0.8205	1.04	3.50	8.5
American " "	0.800	1.08	4.00	11.0
Saxony solar oil	0.830	1.09	3.50	8.5
Oelheim illuminating oil	0.819	1.13	3.75	9.5
Pechelbronn " "	0.809	1.17	4.00	11.5
American petroleum	0.800	1.12	4.00	11.0
Caucasian "		1.00	3.00	8.0
Saxony "		0.98	2.50	7.0
American petroleum	0.825	1.32	6.00	15.0
Caucasian "		1.08	3.50	8.5
Saxony "		1.04	3.00	7.5
American petroleum	0.830	1.40	6.50	16.5
Caucasian "		1.11	4.00	10.5
Saxony "		1.09	3.50	8.5

Although the results of the viscosity degrees above given are not entirely in the inverse ratio to the time of rising in the wick, it will nevertheless be seen from them that generally speaking the viscous oils rise more slowly than the thinly-fluid oils, but above all that the rapidity of rising stands not in direct relation to the specific gravities of oils of different derivation. The illuminating oils from American and Alsace (Pechelbronn) crude oils, for instance, notwithstanding their relatively low specific gravity (0.800 and 0.809) rise more slowly than the specifically heaviest—the Baku oil and Saxony solar oil, with 0.8205 and 0.830 specific gravities.

The rapidity of rising in the wick or the capillarity of illuminating oils is also determined by small glass capillaries, the capillary tubes being provided with a millimeter-graduation etched in and their diameters accurately measured. The tubes, which may also be of different diameters, are placed at the same temperature with their zero point upon the surface of the fluid and the capillarities read off.[1]

If *h* represents the capillarity, *s* the specific gravity of the oil,

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[1] Engler. "Das Erdöl von Baku."

r the radius of the capillary tube and *a* the capillary constant then :

$$hr = \frac{2a}{s} \text{ or } a = \frac{hrs}{2}$$

The *viscosity* of *lubricating* oils and their behavior when used for lubricating machines are of the utmost importance. A lubricating oil should be so viscous as to prevent the direct contact of the rubbing parts, so that, for instance, between the bearing and axle, a thin layer is constantly maintained. Hence the oil must to a certain degree be thickly-fluid, because the less the viscosity, the thinner the layer of oil becomes and the greater the possibility of the direct contact of the rubbing surfaces is.

Since the oil is to serve the purpose of reducing friction, it should be as thinly-fluid as possible. However, the thinner the layer of oil between the rubbing surfaces is, the more firmly it must adhere to them, if the oil, at a greater friction and reduced power, is to resist the same pressure as a thickly fluid oil. If, however, an oil is too thinly-fluid and possesses but slight lubricity so that it does not adhere with sufficient tenacity, it is squeezed out and the rubbing surfaces come in contact with each other; if it is too thickly-fluid it may unnecessarily increase friction. Hence heavy machines require a somewhat thicker oil than light. The temperature acquired by the lubricant is also of considerable influence. The warmer an axle runs and the more the oil in the cylinder of a steam-engine is heated, the more thickly-fluid it must be at the ordinary temperature. The determination of the degree of viscosity of an oil at different temperatures is therefore of great importance.

The velocity with which the oil flows from an orifice is generally used for the determination of its viscosity, it being supposed that the more slowly an oil flows from a small tube the more viscous it is.

Most of the apparatuses used for this purpose consist of a holder with a discharge tube, which can be closed. To maintain the oil at a fixed, uniform heat, the apparatus is surrounded by another vessel, which serves as heat-reservoir.

If the friction-constant, *i. e.*, the viscosity (z) of an oil is to be determined by means of the flow from a capillary tube, independent of the size and form of the respective apparatus, we have, according to Poiseuille:

$$z = \frac{\pi . r^4 p t,}{8 . v . l.}$$

Wherein r represents the radius and l the length of the outflow tube, p the difference in pressure at the beginning and end of the capillary tube, and v the quantity of fluid.

The formula given above,[1] however, holds good only so long as the tube may be considered capillary, and the proportion $\frac{1}{2r}$ attains a certain value which is different for various radii of out-flow tubes and various fluids and degrees of heat.

Magenbach[2] has given Poiseuille's experiments, and by theoretical development has shown that by not keeping within the imit of values for Poiseuille's law, correcting terms have to be appended to the formula above given, which is inconvenient in making experiments.

The reason for Poiseuille's law being of limited validity only, has been found by Magenbach, and recently also by Petroff, in the fact that in very narrow tubes only the movement of fluids takes place in such a manner that the separate layers, which must be imagined concentric, move with a rapidity increasing towards the centre without their cylindrical form being changed by a vortical or oscillatory motion. Hence, the path of each drop of fluid is strictly a straight line. Under these conditions Poisseuille's law, as shown by both authors, may be theoretically deduced.

In N. Petroff's work, "Neue Theorie der Reibung," the limits of value $\frac{1}{2r}$ are given, for which Poiseuille's law loses its

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[1] A. Martens. "Schmieröluntersuchungen." 1888.

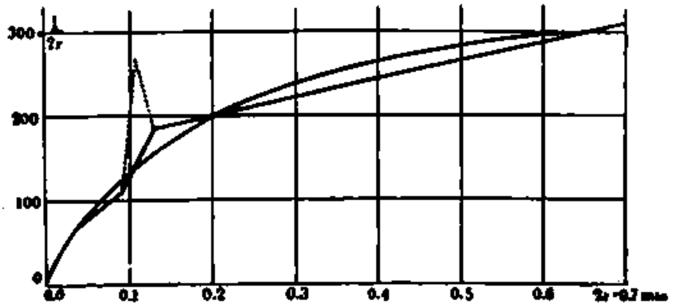
[2] Ueber die Bestimmung der Zähigkeit einer Flüssigkeit durch den Ausfluss aus Röhren. Poggend. Ann., 1860. S. 385.

validity. There being no sharp limit, the figures are only approximate values; if the law is to be valid the proportion $\frac{l}{2r}$ must have greater values than given in the table.

Medium diameter of tube.	Proportion $\frac{l}{2r}$
0.03 millimeter	70
0.04 "	80
0.09 "	120
0.11 "	170
0.14 "	180
0.65 "	360

The law represented by these figures will be readily recognized from the accompanying illustration, Fig. 156.

FIG. 156.



It will be seen that to allow of the determination of z by the above mentioned formula for water of a lower degree of heat, an outflow tube of 0.6 millimeter diameter must have a length of 300x0.6=180 millimeters.

However, since in all the apparatuses mentioned below, the diameter of the outflow tubes is considerably greater than 0.6 millimeter and their length considerably shorter than 180 millimeters, it is evident that Poiseuille's formula cannot be applied to them. This is also the reason why the "specific viscosity," the relation of the internal friction of an oil to that of water, cannot be determined, and why under otherwise equal conditions entirely different values for the "specific viscosity" are obtained with the various apparatuses.

There are a large number of apparatuses, so-called viscosimeters, for determining the viscosity of an oil, *i. e.*, the velocity with which it flows from an orifice. In such apparatuses the outflow-orifice should not be a hole in an infinitely thin partion (Mason's apparatus), nor should the outflow take place from a capillary tube, because in the former case the viscosity is not sufficiently marked in the velocity of the outflow, and, in the latter, thick oils stick fast in the capillary tube or run out too slowly. Further it is absolutely necessary that the dimensions of the outflow tube as well as those of the oil-holder are accurately regulated up to the filling marks; and finally it is advisable to give the oil-holder as shallow a form as possible, in order to reduce hydrostatic pressure to a minimum.

In the apparatuses described later on, the time required by equal volumes of the oil to be tested and of water or of rape oil at the same temperature is taken as the unit. The mode of executing the experiment presents a series of sources of error,[1] and hence it must be considered how to reduce these errors to a minimum. The errors in the determination depend, on the one hand, on the time-measures used and on the skill of the experimenter. On the other hand, and this applies to the determinations according to directions by Fischer, Lamansky and Engler, the error has to be sought in the fact that at higher degrees of temperature the jet flowing out is more strongly cooled off and flows into a cold vessel, so that the measured volume cannot be considered a correct measure for the quantity of flow corresponding to the experimental heat, and, hence, in order to obtain correct figures the volume has to be calculated to this temperature or to zero. This, however, is only possible when the quantity of flow is measured at a fixed degree of heat or determined by weight.

Apparatuses for determining the Viscosity.

Vogel's viscosimeter. This consists of a glass tube 34 centimeters (13.38 inches) long and 4 cm., (1.57 inches) internal

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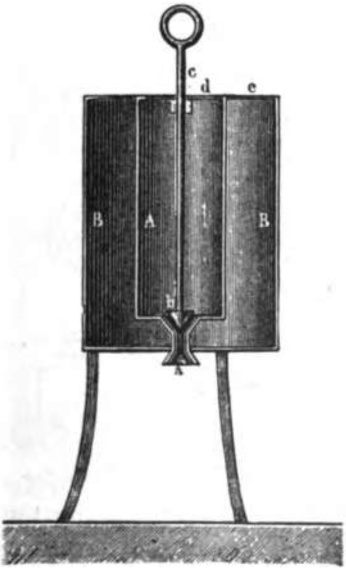
[1] A. Martens. "Schmieröluntersuchungen."

diameter. It is graduated in cubic centimeters, and is closed on top with a well-fitting glass-rod. The orifice has a diameter of 35 millimeters (0.13 inch). By lifting the glass rod the tube can be emptied. For measuring the time a sand-glass running exactly ½ minute is used.

Coleman's viscosimeter. This apparatus differs from Vogel's in that the glass tube provided with a thermometer and filled with oil is surrounded by a glass cylinder for heating the oil by steam. Since the temperature obtained by this means is not uniform, this apparatus has no essential advantages over Vogel's.

Fischer's viscosimeter. This is similar in principle to the apparatuses of Vogel and Coleman, but the oil-holder is so placed that to heat the oil the orifice through which the latter passes stands in a bath. This is of importance, as otherwise the oil is considerably cooled off during its passage through the orifice. Fig. 157 shows the apparatus. The copper cylinder *A* serves for the reception of the oil and *B B* for the reception of the

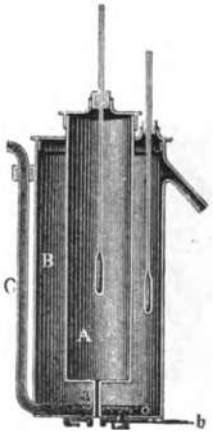
FIG. 157.



water used for heating. The outflow-tube *a* consists of a platinum tube 5 millimeters (0.19 inch) long and from 1 to 2 millimeters (0.039 to 0.078 inch) in diameter. This platinum tube is enclosed by a thicker copper tube; it expands conically above and below and can be closed by means of the small cone *b* and the handle *c*. The handle is guided by three arms *d* on the vessel *A*, the latter being secured in a similar manner by the arms *e* to the vessel *B*.

For making the test, fill *A* up to the mark with 65 cubic centimeters of oil and *B* with water. Heat the water, stirring the oil with the thermometer until the oil has exactly acquired the temperature desired. Now place a narrow-necked bottle of 50 cubic centimeters capacity under the orifice, raise the cone and determine the time required by 50 cubic centimeters of oil to run out.

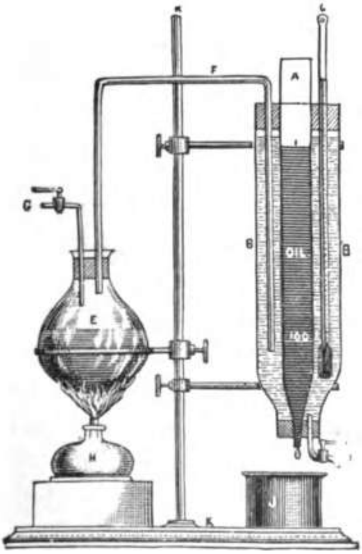
FIG. 158.



Lamansky's viscosimeter. The arrangement of this apparatus is shown in Fig. 158. *A* is a brass cylinder for the reception of the oil to be tested, and *B* the jacket for the reception of the water, which is heated to the desired temperature by the introduction of steam from *C*. The oil flows out through the tube *a*, 1 millimeter (0.039 inch) in diameter, which is closed by the slide *b*. With this apparatus the time is determined which is required by 100 cubic centimeters of oil to flow into a flask placed under the orifice. The figure found for the time is referred to that for 100 cubic centimeters of water as unit. With the narrow outflow-tube, many thick mineral oils might flow out too slowly or not at all.

J. V. Wilson's viscosimeter. This apparatus is represented in Fig. 159, and is thus described by Prof. Thurston: *A* is a glass tube about 1 inch in diameter, graduated from 1 to 100, to contain about 100 cubic centimeters of oil. *BB* is a glass jacket about 3 inches in diameter, filled with water, as shown. *C* is a thermometer indicating temperature in jacket. *D* a small brass cock for withdrawing water from jacket. *E* a glass flask for generating steam to heat water in jacket. *F* a glass tube connecting the steam flask *E* with jacket *B*, delivering at bottom of jacket. *G* is a small cock for permitting an escape of steam in order to regulate the amount sent into jacket. *H*

FIG. 159.



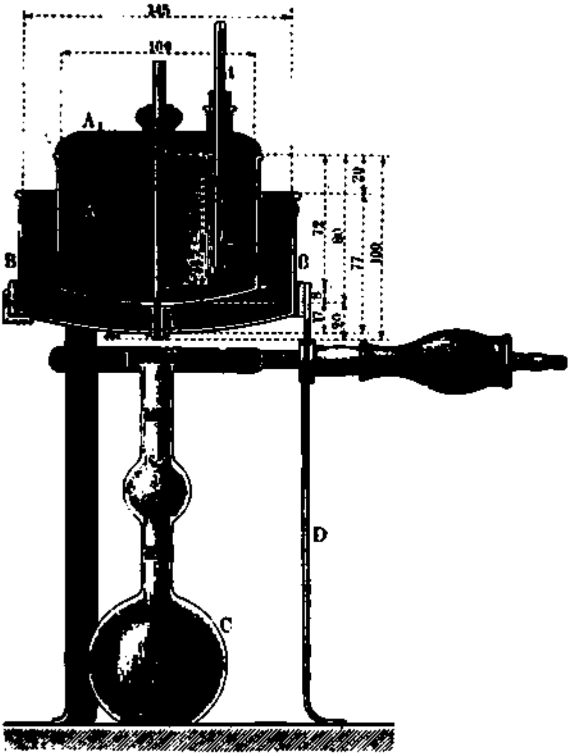
is a spirit lamp on a stand. *J* a glass beaker to contain oil, and *K* a cast-iron stand, with adjustable arms, for carrying the apparatus.

The following table gives the time required by each of the several oils to flow through the orifice of the above-described apparatus and the temperature observed in the same oils when used on a journal 3 inches in diameter making 1500 revolutions per minute, the average being noted for an hour and a half. It is seen that, as a rule, the more viscous the oil, the more heat is developed by friction.

Name of Material.	Specific Gravity at 60° F.	Rate of Flow.			Temperature Developed by Test °F.
		60° F.	120° F.	180° F.	
Water	1000	....	....	....	....
Castor Oil	960	....	132	41	158°
Rosin Oil	990	....	....	....	155
Engine Tallow	....	solid	41	26	....
Tallow, or American Oil	....	143	37	25	141
Neat's Foot Oil	....	112	40	29	....
Rape Oil	916	108	41	30	148
Lard Oil	916	96	38	28	146
Olive Oil	915	92	37	28	143
Sperm Oil	880	47	30	25	133
Mineral Oil, No. 1	905	45	....	....	121
Mineral Oil, No. 2	875	30	....	....	117

Engler's viscosimeter. This apparatus is employed by all railroads in Germany, Austria-Hungary and Russia, as well as by most experimental stations, and has recently been introduced for custom-house purposes in Italy. It differs from the previously described apparatuses in that the oil-holder is shallow, in order to reduce hydrostatic pressure to a minimum. The dimensions are also accurately fixed throughout, and the outflow orifice is of such diameter that not too much time is required in testing very thick oils. Fig. 160 represents the latest improved form of the apparatus. *A* is a shallow brass vessel for the reception of the oil, which can be closed by the cover A_1. The form and dimensions of *A* will be seen from the illustration. To the conical bottom of *A* is fitted the outflow-tube *a*, exactly 20 millimeters (0.78 inch) long with a diameter on top of 2.9 millimeters (0.1142 inch) and on the bottom of 2.8 millimeters (0.1102 inch). For exact normal determinations the tube is made of platinum, and for ordinary purposes, of brass. It can be closed by the pointed, hard-wood stopper *b*, and opened by withdrawing the latter. Three marks *c* are

FIG. 160.



placed at equal distances from the bottom and serve for measuring the oil, as well as for judging whether the vessel *A* stands level. Up to the marks *c* the vessel *A* must hold 240 cubic centimeters, which, with the slightly conical bottom and the dimensions given in the illustration, is actually the case. The thermometer *t* serves for reading off the temperature of the oil to be tested. The vessel *A* is surrounded by a brass jacket *BB*, open on top, and serves for the reception of a heavy mineral oil for heating the contents of *A* up to 150° C. (302° F.) To prevent the oil from cooling off too much while passing through the tube *a*, the latter projects only about 3 millimeters (0.118 inch) from the jacket *B*. For observing the temperature of the oil in *B*, a thermometer is fixed in the latter. A trevet *D* serves as a support for the whole, and besides carries the gas-pipe *d*, with four burners, by means of which the oil is brought to and maintained at the proper temperature. Under the outflow tube stands the measuring flask *C* with two marks, one at 200 cubic centimeters and the other at 240 cubic centimeters, on the neck. To obviate a too great length of the neck, which would also affect the outflowing jet and impair the accuracy of the experiment, the neck is bellied.

To work with this apparatus the time must first be determined which is required by water of 20° C (68° F.) running from it to fill the measuring flask *C* to the lower mark. The viscosity of the various oils at different temperatures is then determined in proportion to that of water of 20° C. (68° F.), and the figure obtained is called the specific viscosity—*viscosity degree*—of the oils. To determine the specific viscosity of the oils at different temperatures, as proposed by Lamansky, is not advisable; it being better to refer it, as is done in determining specific gravities, to water of one and the same temperature.

To test the apparatus as to its accuracy, the time in seconds is determined which is required by 200 cubic centimeters of water of 20° C. (68° F.) to flow from the vessel *A* filled up to the marks *c*. For this purpose the vessel *A* is rinsed out successively with small quantities of ether, alcohol and finally of water, the outflow tube being at the same time cleaned with a feather and a small paper-wad and the hard wood stopper *b* inserted. Exactly 240 cubic centimeters of water are then measured off in the measuring flask *C* and poured into the vessel *A*, which thereby should be filled exactly up to the marks *c*. The temperature of the water is then brought to 20° C. (68° F.), this being done by maintaining the water or heavy mineral oil in the jacket *BB* at a uniform temperature until the thermometer *t* shows exactly 20° C. (68° F.) and the thermometer fixed in *B* differs but slightly from it. The measuring flask *C* having in the meanwhile been allowed to drain off for at least one minute, is then placed under the orifice, the hard wood stopper *b* withdrawn, and the time in seconds noted by a watch or chronometer which is required for the measuring flask *C* to be filled up to the 200 cubic centimeter mark. Before allowing the water to flow care must be taken that it is perfectly still and especially not in a rotatory motion due to previous stirring. If the apparatus is properly constructed 50 to 55 seconds are required by the water to run out. The mean of at least three determinations, which should not vary more than 0.5 second from each other, is however taken as the correct figure and placed = 1. Very exact determinations should be executed in a room having as nearly as possible a temperature of 20° C. (68° F.).

In *testing oils* care must be taken to remove every trace of moisture from the vessel *A*, this being effected by drying and rinsing in succession with alcohol, ether and petroleum. The apparatus is finally rinsed with the oil to be tested and then filled with the latter up to the marks *c* (only thin oils can be measured like water in the measuring flask *C*). By heating the mineral oil-bath the temperature is then brought to the degree desired, and maintained at that degree for at least three minutes before allowing the oil to be tested to run out. The time required for the oil to run out is determined in the same manner as described above for testing the apparatus. The figure obtained, for instance, 270 seconds, is divided by the figure of the flow of water of 20° C. (68° F.) in the same apparatus, for instance, 52 seconds, which gives the so-called specific viscosity or degree of viscosity, hence, in this case, $\frac{270}{52}=5.2$.

Oils containing particles or water in suspension have to be passed, before testing, through a dry filter. Instead of water, rape oil may be taken as the unit in testing lubricating oils, but water only in testing petroleum.

After a number of experiments with Engler's viscosimeter in the technical experimental station at Berlin, the conclusion of this being the most suitable apparatus has been reached.

Lepenau's leptometer. This apparatus, shown in Figs. 161 and 162, allows of a direct comparison of the viscosity of the oil to be tested with a standard oil, generally rape oil, under the same conditions, two oil-holders, one of which is filled with the standard oil and the other with the oil to be tested, being combined in one bath, and the oils passing out simultaneously through two tubes of the same shape. *A* is the bath in which the two oil-holders *B B* are so placed as to be surrounded on

FIG. 161.

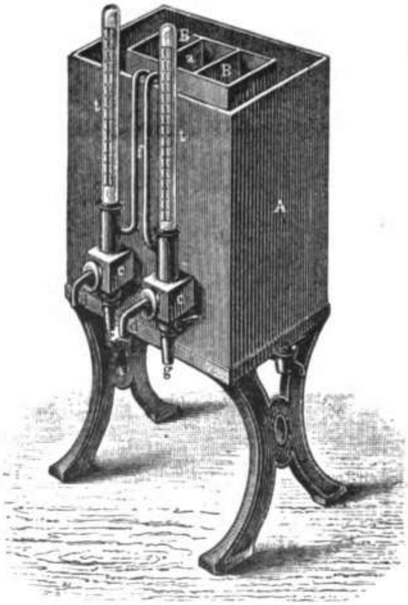
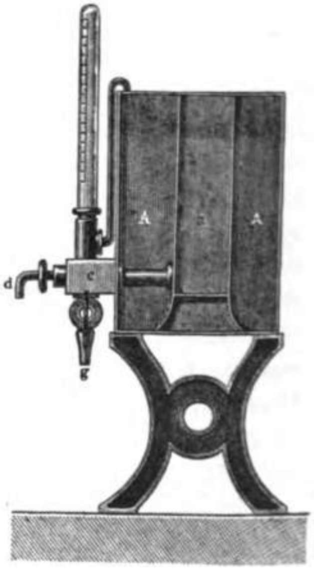


FIG. 162.



all sides by the fluid in the bath. For this purpose the partition between *B* and *B* is open on top and below, so that the fluid can circulate in it from *a*. The two oil-holders *B B* are connected below by means of pipes with *c c*, whence the oil, by three-way cocks, passes into a pipe in which outflow-orifices *d d* of different diameters, according to the consistency of the oil, are inserted; *t t* are thermometers, the bulbs of which dip into the oil passing through *c*, and *f* are rising pipes for the removal of air bubbles. Through *g* the oil can be directly discharged from *B B*, and by adjusting the three-way cock the oil can be run off through *d* or through *g;* or finally *B* can be shut off. In making experiments, *a* is filled with a fluid for heating purposes. One of the vessels *B* is filled with standard oil and the other with the oil to be tested, and after heating to the desired temperature, both oils are allowed to run off simultaneously through the orifices *d d*. The relative viscosity of the oil to be tested, as related to the standard oil, is then directly found from the volumes or weights of the oils run off.

At the ordinary temperature this apparatus gives very good results; it has, however, the defect that in consequence of the outflow-orifices not being in the heating bath, the oils in them will cool off several degrees, according to the surrounding temperature. The construction of the different outflow-orifices with perfectly uniform internal dimensions might also prove difficult; the outflow-orifices should at least not be bent as in the most recent constructions, they being difficult to clean and keep in order.

Prof. Stefano Pagliani's viscosimeter "for the determination of the internal friction of very viscous fluids." The apparatus consists chiefly of two parts, a pressure-reservoir for the production of the pressure required for the flow, and the outflow-vessel.

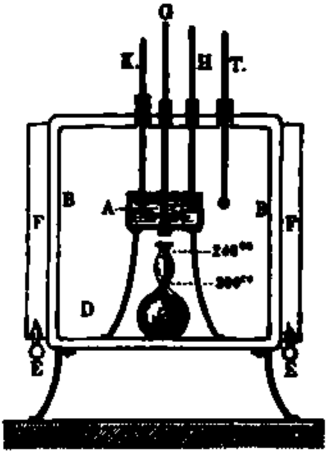
A metallic stand carries on its lower end a metallic receiver which is connected with the outflow-vessel, while the necessary pressure in the latter is produced by a vessel filled with water placed at a higher level. The outflow-vessel, the actual viscosimeter, consists of three parts, two graduated vertical glass tubes of special shape and a horizontal tube which connects the two vertical tubes. The vessel stands in a box which is heated.

One of the vertical tubes is filled with the oil to be tested, and after the temperature desired has been reached, air is forced upon the oil, whereby the latter rises in the other vertical tube. After establishing the outflow-time T, the pressure p and the volume v of the oil run out, the viscosity is determined according to the formula.

$\eta = K \frac{p}{v} T$ (K being the constant). The apparatus is said to be successfully used by the "Societa delle ferovie delle Rete Mediterranea."

A. Marten's viscosimeter. This apparatus is shown in Fig. 163. The vessel A is placed upon a trevet in the air-bath formed by the double-sided box B with a solid back glass wall

FIG. 163.

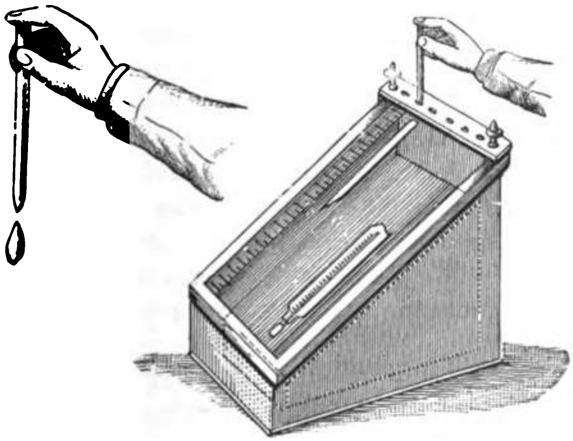


D and a movable front glass disk. The air-bath can be heated by the burners E by means of the side-chambers F. The thermometers T and H indicate the temperatures of the air-bath and the oil. The stirrer K of platinum wire serves for agitating the oil in order to uniformly distribute the heat. The vessel *A* and the flask *C* are provided with marks for measuring the oil. The stopper *G* of the flask *C* reaches through the cover of the air-bath so that it can be withdrawn from the outside. The heat can be readily regulated by the flame and by from time to time opening the glass wall. This arrangement has the advantage over an apparatus with oil-bath that the oil which has run out is not cooled off and that the apparatus can be readily cleaned.

B. Redwood's viscosimeter. This apparatus has been adopted by the Scotch Mineral Oil Association. The result is expressed in minutes and seconds required by 50 cubic centimeters of oil to pass through the tube of the apparatus at 21° C. (69.8° F.)

Testing the viscosity by means of the inclined plane. An apparatus for thus testing oils is illustrated in Fig. 164. It consists of a piece of plate-glass set with considerable inclination and heated by means of a vessel of boiling water to about 200° F., and held at a uniform temperature as indicated by the thermometer attached. A drop of oil placed at the top will flow down. A scale on the side affords a convenient means of

FIG. 164.



measuring the track of the oil. The length of time consumed in its descent is the measure of its viscosity. This form of apparatus also allows of observing any tendency of the oil to "gumming," which is here permitted by the oxidizing properties of the air.

Besides the determination of the velocity of the flow of an oil, there have recently been constructed viscoscineters based upon different principles, of which J. C. Stahl's apparatus may be taken as a representative. It consists of a glass tube which can be closed on both ends by glass-stoppers. A short distance below these stoppers the tube is provided with marks so that when the tube closed at one end is filled with the oil to be tested and the other glass stopper is inserted, there remains an air-bubble of a fixed size between the stopper and the mark. By holding the tube in a perpendicular position and then turning it 180° so that the glass stopper previously on top comes below, the viscosity can be measured by the time required by the air-bubble to ascend in the oil. The more thickly-fluid the oil is, the more slowly the bubble ascends.

Manufacturers who are close observers have a variety of simpler tests, such as timing a ball falling through an oil column of known height; rubbing a portion of the oil between the thumb and forefinger; letting drops of the oil fall upon the surface of the same oil in bulk; exposing the oil for a few hours, or a day, upon the surface of a piece of glass. These tests (except perhaps the first) are not accurate, and oils are not bought or sold upon their indications.

Tests as to frictional resistance.

Besides testing lubricating oils as to their viscosity, it is also of importance to determine, by direct lubricating experiments, their frictional resistance. The power of oils to decrease friction depends, under all conditions, on their degree of fluidity—their viscosity. The more thinly-fluid an oil is, the slighter its frictional resistance. Hence, a good oil should be as thinly-fluid as possible, but at the same time possess as much adhesion as possible to form a sufficient layer between the rubbing parts.

The extent to which friction is decreased by a lubricant may be established either directly by determining the co-efficient of friction, or indirectly by the heating which a bearing lubricated with the oil to be tested shows in a determined number of revolutions.

Many apparatuses serving for the determination of the co-efficient of friction admit also of forming a judgment regarding the chemical behavior (thickening, gumming) of a lubricant under the influence of strong friction; of the consumption of material, as well as of the lubricating power at various degrees of temperature. In the absence of an absolute measurement of the lubricating power all results are only relative, *i. e.*, they only show the extent to which the material tested deviates from a lubricant of noted good quality, which serves as a standard.

The experiments may be executed in accordance with two different principles. The rubbing surfaces (plates, bearings and axles) may be provided with a quantity of oil just sufficient for lubrication, and, besides the co-efficient of friction or increase in the temperature of the rubbing parts, the time may be determined, which, with a minimum quantity of oil used in the experiment, is required for the total consumption of the oil; or, an excess of oil may be employed and the co-efficient of friction or increase in temperature which shows itself within a certain space of time may be determined.

Up to the present time no apparatus for determining the lubricating power of oils has been constructed, which answers all requirements. The defects inherent in almost all such apparatus are due to the technical difficulty of constructing rubbing surfaces unalterable under great pressure and strong heating, and which remain constant, especially when thick and thin oils are to be successively treated. There is the further difficulty of uniformly distributing the oil to be tested between the rubbing surfaces without a portion of it being forced out, and the losses of heat in consequence of the conduction of the metallic parts, and partially of radiation.

The best results are obtained by always using the apparatus on hand under as nearly equal conditions as possible, that is, by testing oils not differing too much in consistency at a not too varying pressure of the rubbing surfaces, and at a nearly equal revolving velocity of the axles, etc., as well as at nearly the same temperature of the air. Of the separate apparatuses some, in consequence of their construction, are more suitable for light, and others for heavy, oils.

It may here be remarked that in regard to the results obtained by testing the same oils with different apparatuses no standard can be set up, the construction of the apparatuses varying too much, and the conditions under which the experiments are made being never almost alike, so that a standard has to be established for each apparatus, *i. e.*, the results obtained with the oils tested have to be referred to those obtained with an oil selected as a standard.

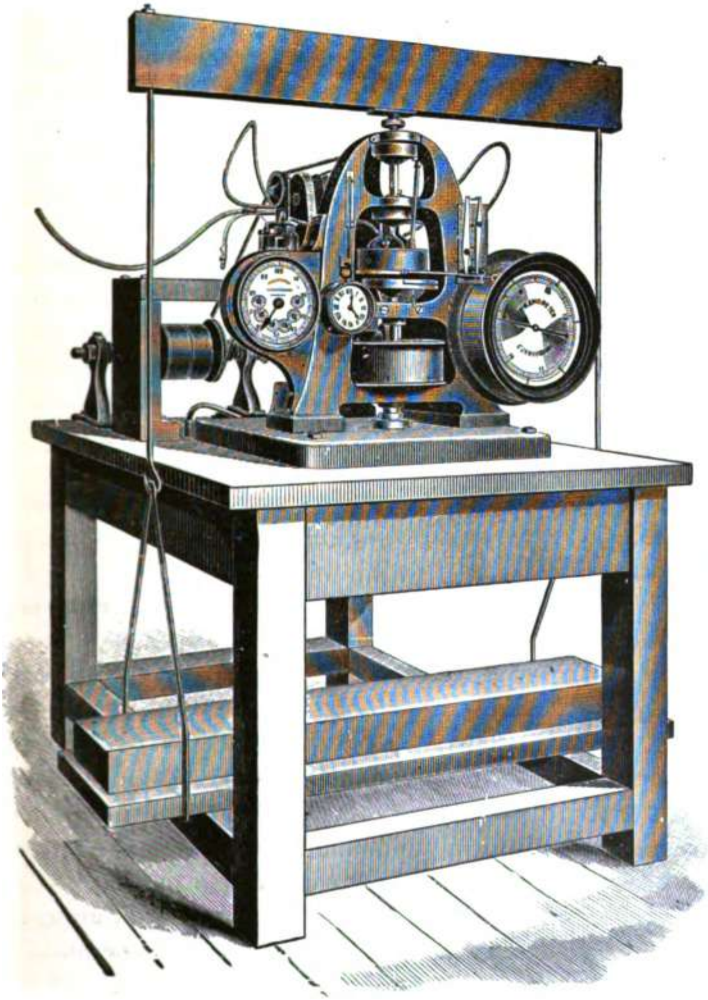
The most important apparatuses for testing the lubricating power of the oils will here be described:

To the oldest completely arranged machines of this kind belong the oil-testing apparatus of *MacNaught* of Glasgow, and that of *M. Hogson*. Both machines are based upon the same principle, and differ only in size and in the execution of measuring the magnitude of friction. The oils are tested as follows:

The oil to be tested is interposed between two horizontal disks, the lower one of which sits fast upon a vertical shaft and revolves with it, while the upper one is loose and revolves only by the friction caused between the two disks. The motion of the upper disk is checked by a special contrivance, and the resistance which it opposes to this checking is equal to the friction between the two disks. With Mac Naught's machine the friction is measured by allowing the resistance to act upon a T lever. A movable weight slides on the arm, on which is a scale to note its position. A counterweight is attached to the opposite end of the lever so as to afford the means of a more delicate adjustment.

With Hogson's machine the resistance of the disk is kept in equilibrium by a spring balance, and the friction is measured

Fig. 165.



by the tension of the latter. This machine is so arranged that the pressure to which the lubricant between the two disks is exposed, can be increased to within certain limits, and that the velocity of revolution can be changed at will.

Woodbury's apparatus for testing lubricants.[1] This machine is shown in perspective in Fig. 165, and in elevations in Figs. 166 and 167. The lower disk is secured upon the top of an upright shaft, its top being an annulus, ground to a true plane surface. Upon this rests the upper disk, which is in the form of a hollow ring, based upon a flat plate, and is made of a very hard composition cast in one piece. The bottom of this disk is scraped to a true plane surface, so that the contact between these two disks is uniform.

A partition divides the interior of the hollow ring, forming the upper disk, so that water can be introduced through the connecting tubes to control the temperature of the disks or to retain the heat of friction. The sides and top of the upper disk are surrounded by a case of hard rubber, and the space is filled in with eider down.

Ice water is generally used to reduce the temperature of the disks nearly to the freezing point of water, and the friction is noted at each degree of the rise in temperature due to the heat of friction.

A tube of thin copper, closed at the bottom, reaches through the bottom of the disk, and a thermometer with its bulb placed within this tube, indicates the temperature of the frictional surface. A tube leading through the upper disk conducts the lubricant under trial to a recess in the middle of the lower disk. The upper end of this tube being of glass, indicates the supply and rate of feeding of the oil. As the friction of a journal depends quite largely upon the method of lubrication, uniformity in the manner of supply is of the utmost importance.

Over the upper disk a yoke with four arms rests upon four columns, which extend through the upper disk to the middle of the frictional surfaces, these columns being cast as a portion of the disk. In the centre of this yoke is a hole with hemispherical

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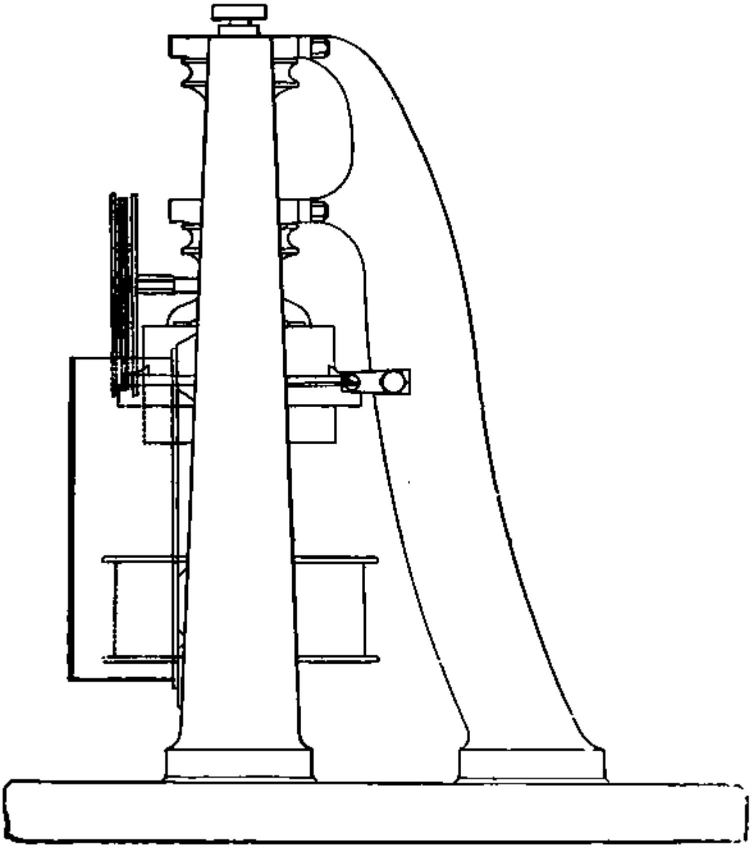
[1] Trans. of Am. Soc. Mech. Engineers, vol. vi., p. 136, Nov., 1884.

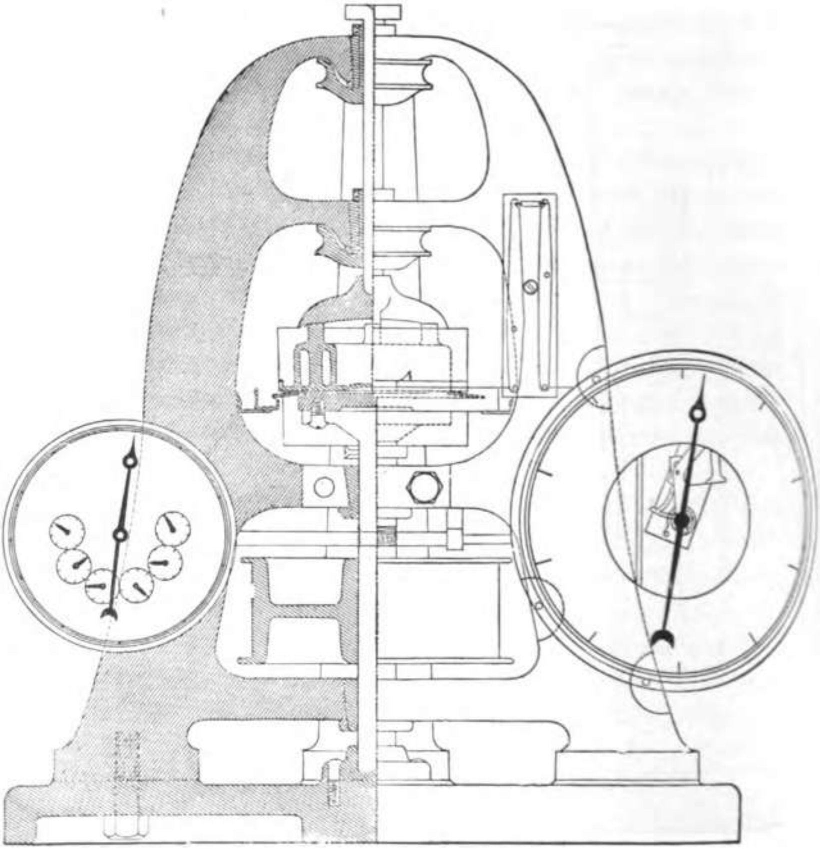
bottom. The lower end of the upper spindle is round, and fitting into this hole makes a ball-and-socket joint. This construction transmits the stress due to the weight applied upon the spindle to four points in the middle line of the frictional surfaces, and the strains due to excessive loads will not distort the disks so as to interfere with the uniformity of the thickness of the film of oil between the surfaces, while the ball-and socket joint allows the surfaces to meet without any cramp or binding due to imperfection or wear, which would prevent the surfaces from revolving in a true plane.

FIG. 166.



The axes of the upper and lower spindle do not coincide, but are on parallel lines about one-eighth of an inch from each other. This prevents the surfaces from wearing in rings, because the same points are not continuously brought in contact with each other.

FIG. 167.



At the left of the machine a counter records the number of revolutions made during any given time. A lever at the top controls a small friction clutch, in order to stop or start the counter at any time during an experiment.

The dynamometer, shown on the right hand of the machine, consists of a mechanism of segments and pinions for multiplying the deflection of a steel bar and indicating the stress necessary to produce such deflection, by the position on the hand of a dial. An arm which ends in the arc of a circle projects from the lower surface of the upper disk and is connected to the dynamometer by a flexible brass tape. When the machine is in operation the lower disk is revolved and tends to carry the upper disk around with it, by a force equal to the friction due to the lubricant between the disks.

The frictional resistance is obtained from the dynamometer by the principle of couples of equal moments. The reading on the dynamometer indicates a force of a couple whose arm is the length of the lever projecting from the upper disk, and this couple is opposed by a couple of equal moment, of which the dimensions of the frictional surface form the data for computing the arm, and the frictional resistance of the lubricant is the unknown quantity.

The co-efficient of friction is deduced from the data of observation in the following manner: Let

P = weight on disks, pounds;
R = outer radius of frictional contact, feet;
r = inner;
ρ = radius of any infinitesimal ring or band of the frictional surface, feet;
N = number of revolutions per minute;
W = reading on dynamometer, pounds;
l = length of arm on upper disk, feet;
ϕ = co-efficient of friction.

Suppose that the annular surfaces of the disk be divided into an infinite number of elementary areas by equidistant circles and radial lines, then will

Width of band $= d\rho$ .... (1)
Angle between two successive radial lines $= d\theta$ .... (2)
Length of arc between two radii $= \rho\, d\theta$ .... (3)

Elementary area $=\rho\, d\rho\, d\theta$ ……(4)

Area of annulus $=\pi(R^2-r^2)$ ……(5)

Pressure per unit of area $=\frac{P}{\pi(R^2-r^2)}$ ……(6)

Pressure on elementary area $=\frac{P\rho\, d\rho\, d\theta}{\pi(R^2-r^2)}$ ……(7)

Friction on elementary area $=\frac{\phi P\rho\, d\rho\, d\theta}{\pi(R^2-r^2)}$ ……(8)

Moment of friction on elementary area $=\frac{\phi P\rho^2 d\rho d\theta}{\pi(R^2-r^2)}$ ……(9)

Moment of friction on entire disk $=\frac{\phi P}{\pi(R^2-r^2)}\int_r^R\int_0^{2\pi}\rho^2 d\rho d\theta$ ……(10)

Integrating $=\frac{2\pi\phi P}{\pi(R^2-r^2)}\left\{\frac{\rho^3}{3}\right\}_r^R$ ……(11)

Substituting the limits $=\frac{2\phi P(R^3-r^3)}{3(R^2-r^2)}$ ……(12)

Work of friction per minute $=\frac{4\phi\pi PN(R^3-r^3)}{3(R^2-r^2)}$ ……(13)

Resistance of the dynamometer $=2\pi lWN$ ……(14)

The friction equals the resistance, hence $4\frac{\phi\pi PN(R^3-r^3)}{2(R^2-r^2)}=2\pi lWN$ ……(15)

$\phi=\frac{3Wl(R^2-r^2)}{2\pi(R^3-r^3)}$ ……(16)

This is not in a form convenient for continual use, and is susceptible of much simplification, if the proper dimensions are used for the various parts in connection with the frictional surfaces, and the dynamometer arm. It is also important for the sake of simplicity, that the length of the line of mean area of the disk be one foot, so that the number of revolutions per minute is equivalent to the frictional velocity in feet per minute. For convenience, it was desirable that the area of the disk be ten square inches.

If c=radius of circle, whose circumference is 12 inches, then

$2\pi c=12$ ……(17)

$c=\frac{12}{2\pi}=1.909$ inches ……(18)

Area within this circumference,

$$\pi r^2 = 11.46 \text{ square inches} \ldots\ldots\ldots\ldots (19)$$

If this circumference divide the annulus of 10 square inches area into two equal parts, then the outer rim of the annulus will circumscribe an area of 11.46+5=16.46 square inches. The radii corresponding to these circles are

$$R=\sqrt{\frac{A}{\pi}}=2.289 \text{ inches}=.1907 \text{ feet} \ldots\ldots\ldots\ldots (20)$$

$$r=\sqrt{\frac{a}{\pi}}=1.434 \text{ inches}=.1195 \text{ feet} \ldots\ldots\ldots\ldots (21)$$

$$R^2-r^2=.0221 \text{ feet};\ R^3-r^3=.00523 \text{ feet} \ldots\ldots\ldots\ldots (22)$$

Substituting these values in equation . . . . (16)

$$\phi=\frac{6.338\,Wl}{P} \ldots\ldots\ldots\ldots (23)$$

This equation can be made still more simple if the length of the arm l is of such length that

$$\phi=\frac{2W}{P} \ldots\ldots\ldots\ldots (24)$$

Substituting this value of ϕ in equation (23) we have

$$l=.3156 \text{ feet}=.3787 \text{ inches.}$$

Generally the weight on the disks is referred to in pounds to the square inch, then

$$\phi=\frac{W}{5p} \ldots\ldots\ldots\ldots (25)$$

If the reducing levers which have been referred to are used, the reading of the dynamometer is one-fifth of the pull on the arm, and when the machine is used with this attachment,

$$\phi=\frac{W}{p} \ldots\ldots\ldots\ldots (26)$$

After the temperature of the disks has been reduced by a current of ice water, the circulation of the water is stopped, the machine started, and the reading of the dynamometer noted at each degree of temperature.

As the machine is generally used without the compound levers, the column of coefficient of friction is obtained by dividing the dynamometer reading by five times the pressure in pounds per square inch.

Ingham and Stapfer's lubricant testing machine, in use in this country as well as in Europe, consists of a horizontal shaft running in two bearings in the vertical uprights of a cast-iron frame. The shaft carries a third journal with adjustable bearings, which are set to any desired pressure by weighted levers. By a thermometer inserted in the top brass the temperature is observed. The shaft carrying the test-arbor is revolved by a pulley keyed upon it. A counter records the number of revolutions. The oil to be tested is brought into a reservoir placed on the top brass, from whence it runs to the sliding surfaces of the test-arbor.

FIG. 168.

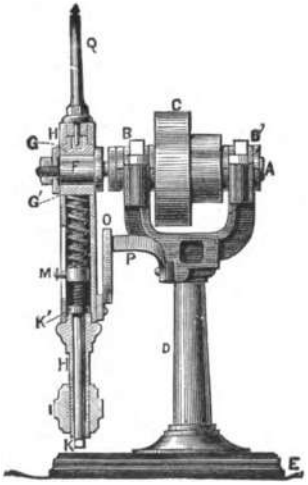
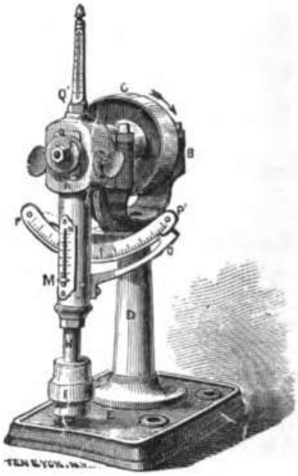


FIG. 169.



Professor R. H. Thurston's lubricant testing machine.[1] The construction of this machine is shown in Figs. 168 and 169.

At *F* is the journal on which the lubricating material is to be placed for test. This journal is carried on the overhung extremity of shaft *A*, which is sustained by the journals *B*, *B'*, on a standard *D*, mounted on base-plate *E*. The shaft is driven by

[1] "Treatise on Friction and Lost Work in Machinery and Millwork," by R. H. Thurston. 4th edition, 1891.

the pulley *C* at any desired speed. A counter is placed at the rear end of this shaft to indicate the number of revolutions. The shaft is usually driven at a fixed speed, corresponding to a velocity of rubbing surfaces approximating that of the journals on which it is proposed to use the oil. The testing journal *F* is grasped by bearings of bronze *G*, *G'*, and with a pressure which is adjusted by the compression of a helical spring *J*. This spring is carefully set, and the total pressure on the journal and the pressure per square inch are both shown on the index plate *N* by a pointer *M*. Above the journal is a thermometer *Q*, of which the bulb enters a cavity in the top "brass," and which indicates the rise in temperature as the test progresses.

The "brasses," thermometer, and spring are carried in a pendulum *H*, to which the ball *I* is fitted, and the weights are nicely adjusted and, as nearly as may be, in such a manner that the maximum friction of a dry but smooth bearing shall just swing it out into the horizontal line. The stem *K K'* of the screw, which compresses the spring, projects from the lower end of the pendulum and can be turned by a wrench. A pointer *O* traverses an arc *P P'* and indicates the angle assumed by the pendulum at any moment. This angle is large with great friction, and very small with good lubricating materials. This arc is carefully laid off in such divisions that dividing the reading by the pressure shown on the index *N* gives the corresponding coefficient of friction.

The figures on the arc are the measure of the actual resistance of friction on the surface of the journal. Dividing this frictional resistance by the total load gives the value of the coefficient. As there is no intermediate mechanism, this measure is obtained without possible error; and, as the resisting moment changes very rapidly at low angles, great precision of measurement is obtained. The machine can also be arranged to give readings of this coefficient directly.

The effect of the machine is found from the relations between the weight and dimensions of the pendulum to the dimensions of the testing journal and the pressure of the helical spring exerted upon the latter. Let

R = radius to centre of gravity of pendulum;
F = effort due to weight of arm;
l = length of journal;
r = radius of journal;
W = weight of pendulum complete;
P = total pressure on journal;
p = pressure per square inch of longitudinal section;
T = tension on spring;
O = angle between arm and a perpendicular through axis;
f = coefficient of friction;
Q = total friction.

When O is equal to 90°,

$$F R = Qr \quad \text{. . . . . (1)}$$

And when any other angle,

$$F R \sin. O = Qr \quad \text{. . . . . . . (2)}$$

Solving equation (2) with respect to Q,

$$Q = \frac{F R \sin. O}{r} \quad \text{. . . . . (3)}$$

The coefficient of friction is

$$f = \frac{Q}{p} = \frac{F R \sin. O}{r P} \quad \text{. . . . . . (4)}$$

The pressure per square inch is

$$p = \frac{P}{4 l r} = \frac{2 T + W}{4 l r} \quad \text{. . . . . . (5)}$$

From this last equation the graduations on the right-hand side of the index-plate are deduced.

From the equation

$$N = 4 p l r \quad \text{. . . . . (6)}$$

the numbers on the left-hand side are determined.

By substituting in equation (1) the value of Q, in terms of the co-efficient and total pressure from (4), it becomes

$$F R = f (p l r) r \quad \text{. . . . . (7)}$$

Solving with respect to f, equation (7) becomes

$$f = \frac{\frac{FR}{r}}{4plr} \quad \dots\dots \quad (8)$$

From the numerator of the second number of equation (8) the graduations of the arc are deduced.

In applying the foregoing equations to the machine shown in the engraving, the following numerical values may be given to the respective symbols: $F = 2.5$ pounds; $R = 10$ inches; $r = 0.625$ inches; $l = 1.5$ inches; $4\,l\,r = 3.75$ square inches; $W = 6$ pounds. Also a compression of $1\frac{3}{8}$ inches of the spring corresponds to a tension of 100 pounds; hence, for each pound's tension, the spring will be compressed 0.1375 of an inch.

The graduations on the right-hand side of the scale are obtained from equation (5):

$$p = \frac{2\,T + W}{4\,l\,r} \quad \dots\dots \quad (4)$$

The first graduation will naturally be that value of p when T is equal to O, which value is 1.6.

The speed of the machine when the belt is upon the largest pulley of the cone, C, should be that which will give at the surface of the testing-journal the least speed of rubbing, which is expected usually to be adopted.

The figures on the arc $P\,P'$, traversed by the pointer O attached to the pendulum, are such that the quotient of the reading on the arc $P\,P'$, by the total pressure read from the front of the pendulum at $M\,N$, gives the "co-efficient of friction;" *i. e.*, the proportion of that pressure which measures the resistance due to friction.

A printed table, furnished with every machine, gives these co-efficients for a wide range of pressure after readings.

To determine the lubricating quality of an oil with this machine, remove the pendulum $H\,H$ from the testing-journal

G G' and adjust the machine for the desired velocity. Then carefully slide the pendulum upon the testing-journal, oil the journal through the oil-cups, and set the machine in motion, running it a moment, until the oil is well distributed over the journal. At intervals of one or two minutes, observations and records are made of the temperature given by the thermometer Q and the reading indicated by the arc P P' of the machine by the pointer O. When both readings have ceased to vary, the experiment may be terminated.

If the test is to be made with a different pressure, or with another lubricant, remove the pendulum, clean the journal and brasses with great care, compress the helical spring to the desired pressure, and proceed as before. If the oil to be tested is to be used at a higher temperature heat the testing-journal to the desired temperature by means of a Bunsen lump.

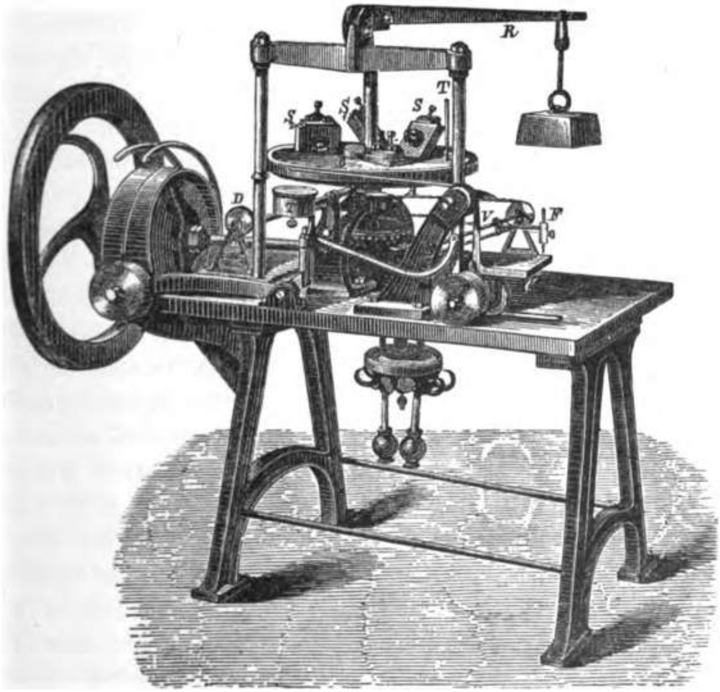
Professor Thurston has also designed a machine especially fitted for railroad work.

The journal of this last-named machine is of standard size, 3¼ inches diameter and 7 inches long. The speed is intended to be adjusted to velocities varying from that of a 26-inch engine-truck wheel at 60 miles an hour, down to a 42-inch wheel running 15 miles an hour. The pressure is adjustable from a minimum total pressure up to 400 pounds per square inch, or a load of nearly 10,000 pounds on the journal.

Friedrich Lux has in Germany improved Thurston's machine by the addition of an automatic recording apparatus. The pendulum of the machine carries an arm with a horizontal bolt on its extreme end. This bolt raises and depresses a slide at the right, which slide carries a pencil. A cylinder is mounted behind the pencil-slide, and connected with clock-work, by which it is made to revolve uniformly at a convenient rate. Paper wound on this cylinder is thus made to move under the pencil at a constant rate, and the rise and fall of the latter are proportional to the swing of the pendulum, and vary with the friction at the journal. The paper is ruled with a system of vertical and horizontal parallel lines at equidistances. The distances between the vertical lines correspond to a round number of revolutions of the shaft, so that the total number of tours the apparatus has made can be conveniently read. The distances between the horizontal lines are made equal to the sine value of 1°, so that the comparative review, as well as the calculation of the absolute values of friction, proceeds with simplicity and rapidity.

Duprez and Napoli's oil-testing machine. This machine, Fig. 170, is also provided with an automatic recording apparatus. It has, according to Lamansky, the advantage over the machines already mentioned that a determined quantity of the oil under trial can be subjected to the test, so that by comparison it can be ascertained which oil, in a determined quantity

FIG. 170.



and with a determined load and velocity, shows the greatest constancy of the co-efficient of friction. The machine can also be used for measuring the wear and tear of various materials caused by friction.

Upon the smoothly polished disk *A* sits a similar disk *B* by means of three cheeks fastened in *B* at an angle of 30°. Each of these cheeks presents to the disk *A* a contact-surface of exactly 10 square centimeters (1.55 square inches). The cheeks transmit the pressure exerted by the weighted lever *R* to the disk *A*, uniformly distributing it upon the latter. The disk *A* is revolved by the pulley *D*, the disk *B* being carried along by the friction between *A* and the cheeks S, S_1, S_2. To the circumference of the disk *B* is secured a thin steel ribbon, the other end of which is fastened to the circumference of a pulley readily movable between points. This pulley and the pendulum *P*, which in a state of repose hangs in a horizontal position, consist of one piece. The revolution of the disk *B* thus effects a stroke of the pendulum *P*, which is the greater, the stronger the friction between the cheeks S, S_1, S_2.

Upon the table of the machine the carriage *C* is carried horizontically and vertically to the axis of revolution of the pendulum. A projectionon *P*, which is guided in the vertical slit *V* of the carriage *C*. causes a displacement of the carriage proportional to the stroke of the pendulum and the frictional resistance. Perpendicularly to the direction of this displacement a pencil *F* is moved over a strip of paper upon the carriage *C*, with a velocity dependent on the number of revolutions of the disk *A*. By both motions, one of which is proportional to the frictional resistance on the disk *A*, and the other to the travel of *A*, a diagram is sketched, the area (product of force and travel) of which must be proportional to the frictional work. Under otherwise equal circumstances a poor lubricant consumes more work by friction and a good lubricant less, so that from the magnitude of the areas of the diagrams the value of the lubricants under trial may be deduced.

To avoid the necessity of calculating the areas of the diagrams the machine is provided with an apparatus which allows of the direct reading off of the proportional number of the frictional work consumed during a fixed time with the use of any lubricant. This apparatus consists of a cylinder *T* which is constantly pressed by a spring against the circumference of a disk placed concentrically with *A*. The axis of this cylinder can assume all possible inclinations in one and the same vertical plane, and is connected with the pendulum *P*, so that towards the horizontal it always incloses the same angle which the pendulum forms with the vertical. The number of revolutions of the cylinder indicated by this apparatus is proportional to the number of kilogrammeters consumed by friction, and may serve directly for judging the value of the lubricant under trial.

Of the oil to be tested 5 grammes (2.82 drachms) are interposed between the disk *A* and the cheeks S, S_1, S_2. To obtain comparable results the velocity of revolution must be maintained as uniform as possible, a special regulator seen under the table being supplied for that purpose.

With this apparatus Lamansky made experiments in Beilstein's laboratory. The apparatus was each time charged with 30 cubic centimeters of oil, this giving 1 cubic centimeter of oil per 1 square centimeter of rubbing surface. The experiment lasted 3 to 4 hours, the load with the same velocity of revolution rose from 5 to 33 kilogrammes per minute, or with the use of the same load the velocities of revolution were so varied that one revolution was made in 0.75, 0.50, 0.35 seconds.

After every 625 revolutions the temperature in the upper plate was observed, the variations in the temperature of the work-room being at the same time taken into consideration. By this the limits of the load and the velocity for the tested oils, and hence, also, the availability of the latter for definite purposes (for light or heavy machines, for machines running slowly or rapidly), were determined. The apparatus was finally allowed to run with one and the same (maximum) load and velocity for three to four hours with the oil, and the degree to which the friction remained the same and the temperature rose was determined, from which conclusions regarding the constancy of the oil may be drawn.

The appended table, p. 495, shows the results obtained in testing a series of vegetable and mineral oils, the numerator of the fraction in the column headed "duration of the experiment" indicating the total number of revolutions and the denominator the number of a revolution in hundredths of seconds. The specific viscosity was determined by Lamansky's apparatus.

Lamansky's experiments confirm the fact that the co-efficient of friction is dependent on the viscosity of the oil; fluid oils, *i. e.*, oils with the least viscosity, have the smallest co-efficient of friction, but cannot stand a great load; in other words, they cannot be used for lubricating heavy machinery.

Lubricant-testing apparatus of the Paris-Lyons Mediterranean Railway. This apparatus was exhibited, in 1878, at Paris. It has the great advantage of furnishing guiding points for judging lubricants for heavily loaded axles of railroad cars, locomotives, etc. It allows of observing the number of revolutions of the axle and the velocity of revolution, as well as the heating of the journal-boxes at varying velocities of the axles and with different loads. Finally the consumption of oil and the behavior of the oil upon the axle can also be judged. The apparatus is shown in Figs. 171 *a* and 171 *b*. Upon a solid stone foundation stands the cast-iron frame *A*, on both sides of which are guides for the shaft *B* which carries the friction-wheels *c c*. The tires of both wheels are at a distance from each other corresponding to the gauge of a railroad, and carry two ordinary railroad car wheels *D D* whose axle *E* is fitted laterally in the journal-boxes *m*. The boxes are arranged similarly to those of railroad cars and serve for the reception of the lubricant under trial. Resting upon the boxes there are on both sides strong springs *n n* on the ends of which the weights *f f* act by means of the levers *o o*. *E* can be loaded as desired by placing weights upon it or taking them off. In the centre of each of the two springs is fastened a screw *p* which can be lifted to-

Names of Oils.	Specific viscosity at 19° C.	Density at 15° C.	Co-efficient of friction with a load of kilogrammes per square centimeter. 5.				9.				15.				25.				29.			
			Mean co-efficient of friction.	Co-efficient of friction.	Duration of the experiment.	Increase in temperature.	Mean co-efficient of friction.	Co-efficient of friction.	Duration of the experiment.	Increase in temperature.	Mean co-efficient of friction.	Co-efficient of friction.	Duration of the experiment.	Increase in temperature.	Mean co efficient of friction.	Co-efficient of friction.	Duration of the experiment.	Increase in temperature.	Mean co-efficient of friction.	Co-efficient of friction.	Duration of the experiment.	Increase in temperature.
Organic Oils.																						
Sperm oil.........	8	0.879	0.104	0.0013	6875 0.73″	16.0—16.3 14.5—15.5	—	—	—	—	0.362	0.0016	6875 0.73″	13.2—16.2 14.0—15.2	—	—	—	—	—	—	—	—
Pale rape oil......	22	0.915	0.340	0.0045	13 750 0.69″	19.0—20.2 18.7—19.7	0.627	0.0046	17 500 0.69″	18.2—21.2 17.5—19.0	1.798	0.0079	18 125 0.71″	18.5—24.9 18.5—20.2	—	—	—	—	—	—	—	—
Rape oil mechanically purified...	22	0.915	0.517	0.0069	13 125 0.73″	16.4—18.4 15.5—16.2	1.250	0.0092	1250 0.63″	13.8—14.2 14.5—14.5	1.653	0.0173	8750 0.77″	19.0—23.0 19.5—18.0	2175	0.0058	1250 0.81″	17.2—18.2 16.0—16.0	—	—	—	—
Italian castor oil ..	250	0.962	1.850	0.0246	18 750 0.75″	20—26.2 19—21.2	2.790	0.0206	18 125 0.75″	20.4—28.8 19.0—21.2	—	—	—	—	—	—	—	—	—	—	—	—
Mineral Oils.																						
Machine oil 2 G...	20	0.898	0.107	0.0014	13 750 0.70″	19.6—21.2 19—20	0.281	0.0020	13 750 0.76″	18.6—21.8 18.1—19.6	1.240	0.0055	13 750 0.69″	19.2—24.2 18.5—21.5	—	—	—	—	—	—	—	—
Oleonid 12 R	24	0.881	0.574	0.0076	6875 0.70″	17.6—17.8 13.4—15.2	0.804	0.0059	6875 0.72″	15.6—17.8 18.0—14.6	1.622	0.0070	6875 0.77″	15.6—17.8 14.0—14.5	—	—	—	—	—	—	—	—
Mineral oil from Pastuchow	55	0.910	0.948	0.0126	20 000 0.70″	12.4—18.6 13.6—15.6	1.325	0.0097	1250 0.77″	14.8—15.3 15.2—15.4	1.325	0.0058	13 750 0.75″	14.8—20.9 16.0—16.2	2.721	0.0072	13 750 0.80″	15.4—24.2 16.5—16.4	—	—	—	—
Petroleum residuum from Nobel .	55	0.910	1.386	0.0180	18 125 0.70″	14.4—19.6 14.0—16.0	—	—	—	—	2.446	0.0126	18 750 0.75″	12.0—19.6 12.0—13.0	3.322	0.0086	13 750 0.75″	12.0—19.6 12.0—13.0	3.527	0.0081	17 500 0.74″	13.6—23.6 13.0—16.0
Waggon oil* Og ..	60	0.907	1.207	0.0160	16 875 0.75″	13.6—19.3 13.5—15.5	—	—	—	—	2.544	0.0113	12 500 0.75″	16.0—20.6 12.2—14.0	3.115	0.0083	16 875 0.74″	13.4—22.4 11.5—15.0	3.129	0.0072	16 250 0.74″	14.5—24.6 14.0—16.0
Oleonaphtha I R..	66	0.904	1.313	0.0175	16 875 0.75″	11.8—16.3 10.5—13.5	—	—	—	—	2.172	0.0096	16 875 0.78″	13.2—20.1 12.0—13.5	3.542	0.0094	16 250 0.75″	13.4—22.5 12.0—14.5	—	—	—	—
Waggon oil* R....	70	0.911	1.009	0.0135	16 875 0.75″	14.4—20.3 15.0—17.0	—	—	—	—	1.950	0.0087	18 750 0.75″	12.0—19.8 12.5—15.0	2.893	0.0074	18 750 0.75″	11.8—20.4 11.0—14.0	2.884	0.0066	16 250 0.74″	14.6—22.7 14.0—15.0
Machine oil I ag..	102	0.914	1.021	0.0136	10 000 0.69″	24.8—22.8 18.0—18.0	2.563	0.0189	9375 0.75″	16.2—21.6 16.0—17.0	—	—	—	—	—	—	—	—	—	—	—	—
Cylinder oil G	191	0.917	1.864	0.0248	17 500 0.77″	17.2—22.3 15.0—17.0	2.702	0.0200	13 750 0.77″	17.4—24.2 17.6—17.0	5.318	0.0236	6875 0.78″	17.8—26.0 17.8—18.9	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	4.000	0.0177	6875 0.75″	34.6—32.4 17.8—18.0	—	—	—	—	—	—	—	—

FIG. 171*a*.

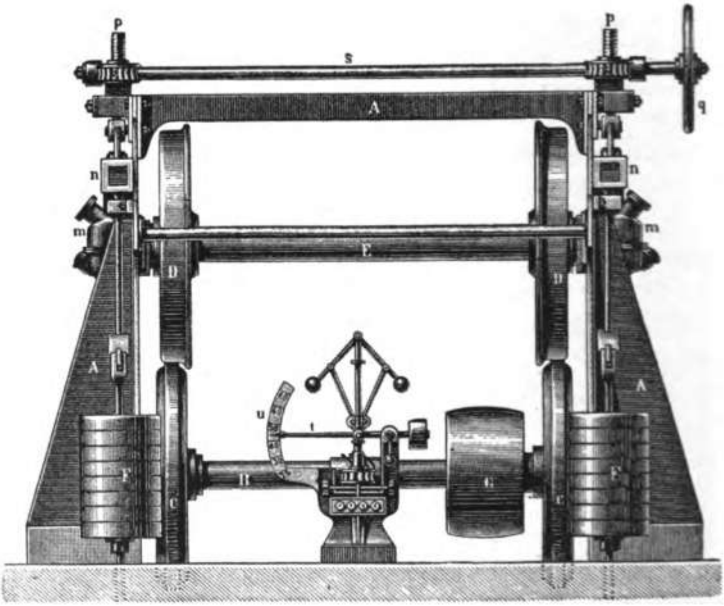
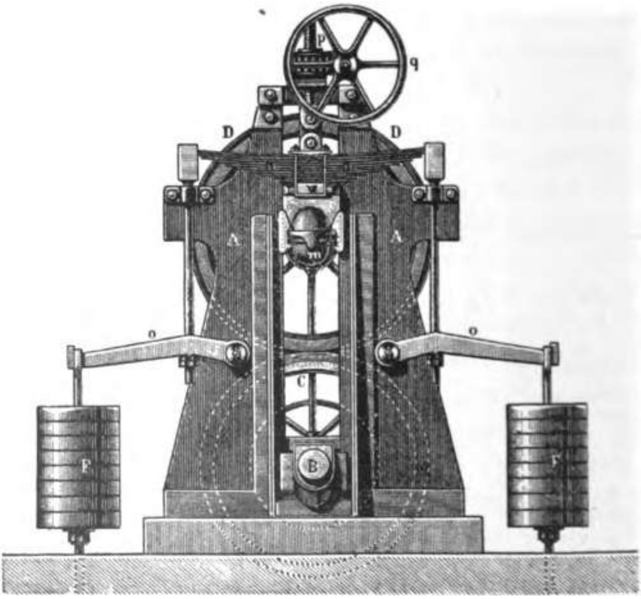


FIG. 171*b*.



gether with the springs from the driving wheel *q* by means of the female screws *z* forming a worm-wheel and the cross shaft *s* provided with screw-threads. By this means the load can be entirely removed from the journal-boxes. On the lower shaft there is further the driving wheel *G*, as well as a screw by means of which the motion of the shaft is transmitted to a counter. Besides the pointers, which indicate the number of revolutions, this counter also sets in motion the pointer *t*, which indicates upon the scale *u* the approximate velocity of the rim of the wheels in kilometers per hour. The two friction-wheels *c c* are turned eccentrically about 2.5 millimeters so that in revolving there is a slight vertical oscillation, which is transmitted to the upper wheels, thus imitating the jolting of the cars upon the track.

In executing the test the lubricant under trial is brought into the journal-boxes *m m*. The spring is then raised to remove the load as much as possible from the upper shaft, and the lower shaft set in motion. When the apparatus is running the springs are gradually lowered, and finally loaded with a weight corresponding to the intended use. The oil which with this test stands the heaviest load at the greatest velocity without heating the journal-boxes is to be considered the best.

Although the apparatus does not allow of accurately measuring the frictional resistance, the practical value of lubricants is fairly determined by it. It especially furnishes sure guiding points whether, with determined loads and velocities, hot running of the axles is to be feared or not, which is of great importance as regards the use of oils for railroad purposes.

Professor E. Willigk's oil-testing machine. This apparatus differs from the preceding chiefly in the choice of journals and in that during the experiments special regard is had to the temperatures. It consists of a vertical shaft bedded in the bottom plate of a cast-iron frame and revolved by a gearing. The shaft carries on its upper portion a hollow cup-shaped cone which forms the bearing of the test-arbor. The latter forms another hollow cone of tombac which is fitted to the first so that it sits exactly upon its bottom. By means of a weighted lever the test-arbor can be loaded at will within certain limits. The inner space of the test-arbor is filled with mercury into which dips the thermometer for observing the temperature.

A small portion of the oil to be tested is brought into the lower part of the cone forming the bearing, and the machine set in motion.

The quality of the lubricants is tested either by lubricating the test-bearing with a determined quantity of oil and counting the number of revolutions the machine makes until the bearing has acquired a certain temperature; or the machine is allowed to make the same number of revolutions and the temperature which the test-bearing acquires with the use of various oils is observed. With the first method the better lubricant is indicated by the greater number of revolutions, and with the latter, by the lower temperature.

The results yielded by the second method suffice for practical purposes, but it is better to use, instead of a counter, a watch with a second-hand, and determine the increase in the temperature by allowing the apparatus to revolve for the same length of time at the same velocity with each kind of lubricant.

The chief object of the use of a lubricant is to decrease friction by enveloping two metallic surfaces rubbing upon each other, in order to gain work as well as to preserve the surfaces in good working condition.

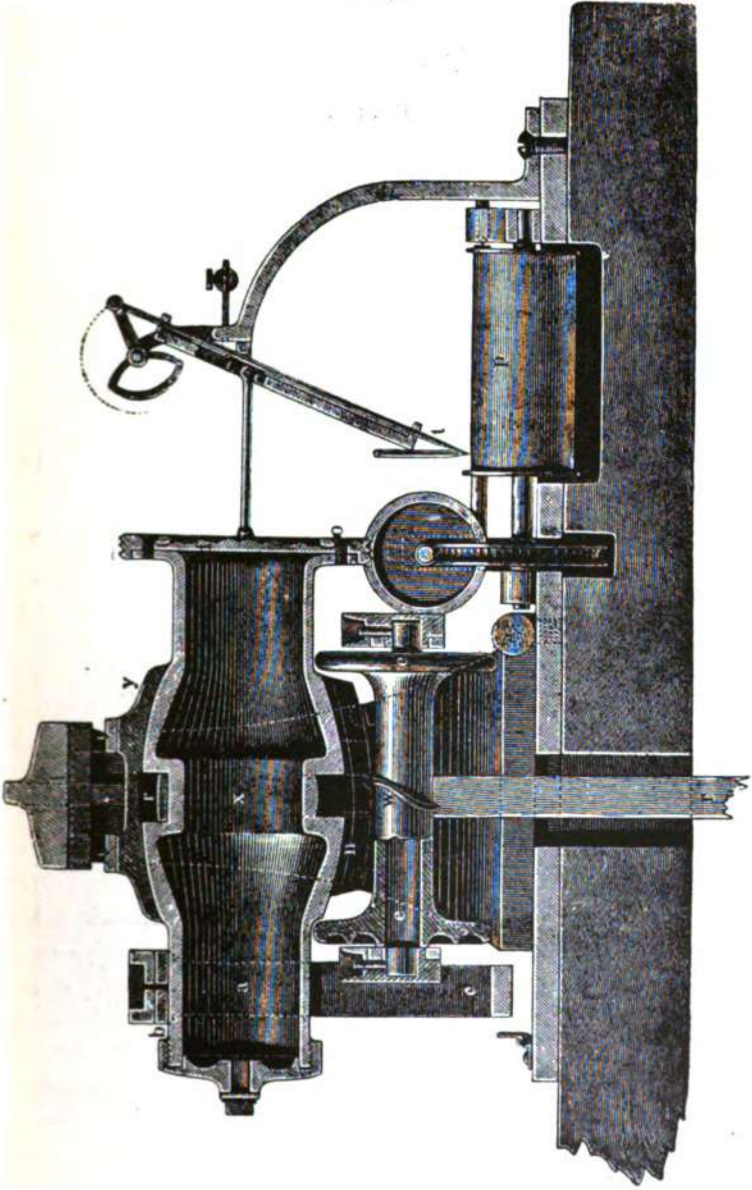
These general guides, on which depends the choice of a lubricant, also prescribe the course the examination or test has to take. Generally speaking, an examination will, therefore, have to deal with answering the following two principal questions:—

1. Does a lubricant intended for certain purposes possess in a sufficient degree the ability of decreasing friction between two metallic surfaces?

2. Has the respective lubricant the capacity of resisting, in a degree corresponding to a certain purpose and for a sufficient time, the effects of the work it has to perform?

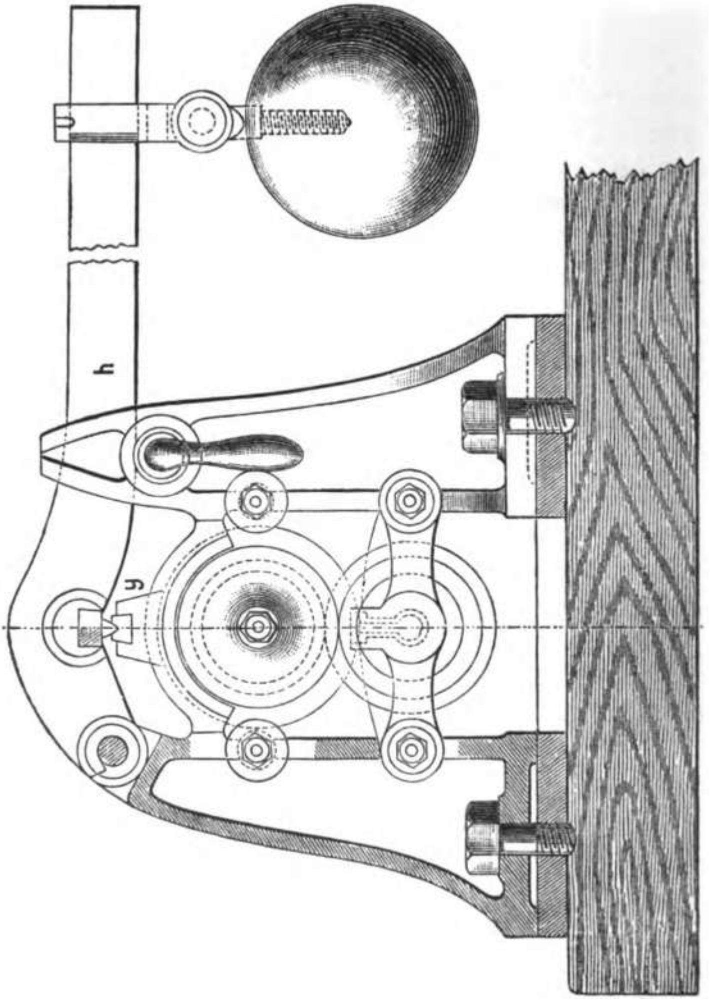
With these conditions in view, R. Jähns, inspector of ma-

Fig. 172.



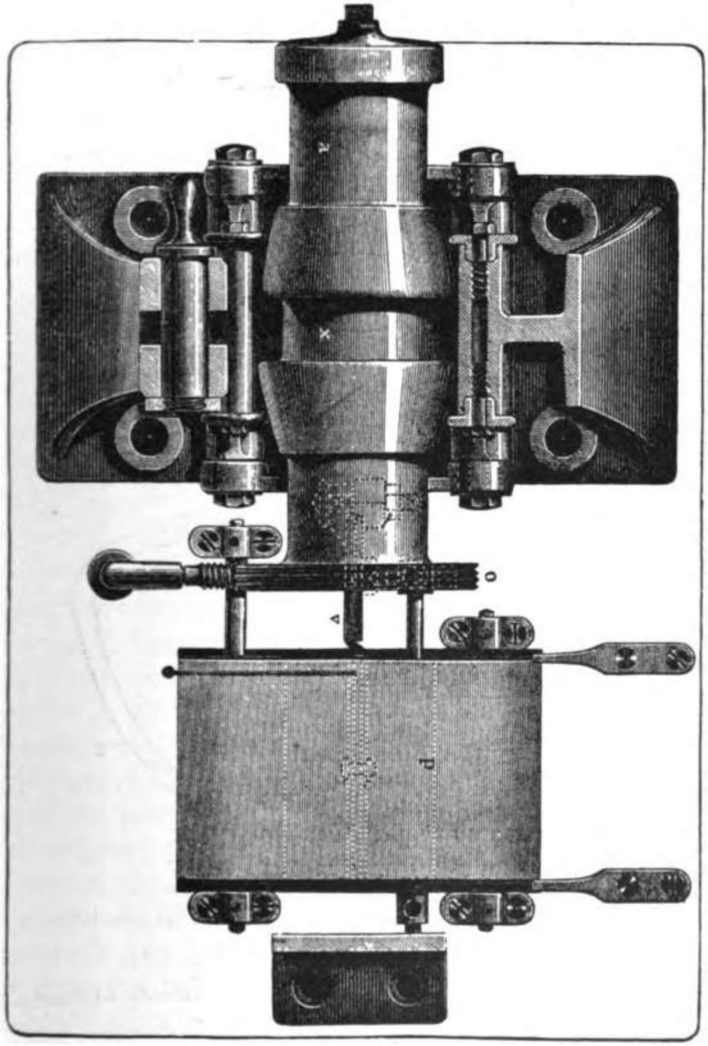
chinery of the railroad management at Cologne, has recently constructed and patented a very ingenious and useful apparatus, which is very likely to be introduced upon all German

FIG. 173.



railroads. Jähns calls his apparatus "*Testing machine for the examination and choice of lubricants.*" Its construction is shown in Figs. 172 to 181.

FIG. 174.

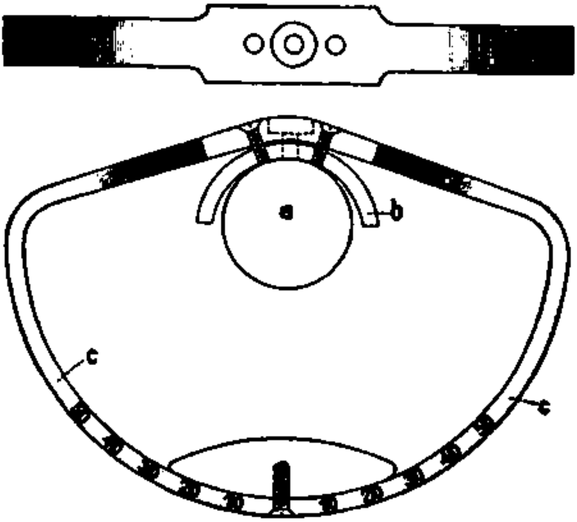


The part *a* of the hollow arbor *x*, Fig. 172, serves for the determination of the capacity of the lubricant to decrease the friction of two surfaces sliding upon each other.

To avoid as much as possible the influence exerted by the differences in the condition of the sliding surfaces, their width is reduced to a minimum by the interior radius of the bearing *b* sliding upon *a* being somewhat larger than the radius of the exterior surface of the arbor itself. By these means the contact of both surfaces takes place only in a line parallel to the revolving axis of the arbor, and, therefore, under always equal external conditions.

The sliding bearing *b*, Fig. 175, is of steel sufficiently hardened to make a change in the condition of the surfaces on the point of contact by cutting in or working in impossible. The bearing *b* is fitted to a strap-like piece *c*, Fig. 175, the mass of which is so distributed that the lower half has a greater moment of oscillation than the upper.

Fig. 175.



The test of the lubricant in the sense of question 1, page 498, is carried on as follows: The outer surface of the arbor *a* and the inner surface of the bearing *b* are sufficiently moistened with the oil to be tested, and thus kept during the experiment. The mechanical process which begins with the revolution of the pivot is illustrated by the schematic sketches Figs. 176, 177 and 178.

The vertical line passing through the centre of gravity *S* of the strap (Fig. 176) appears after the commencement of the revolution of the arbor as shown in Fig. 177, and after several oscillations forms an angle constant to the vertical line. This angle depends on the intensity of the friction created on the point of contact between arbor and bearing, and is always the same for the same material at the same temperature. The greater the total friction is, *i, e.*, the smaller the capacity of the respective lubricant to counteract the friction between the two lines of contact of the arbor and the bearing, the larger the inclination of the strap from its vertical position will be, because the component *y*, which represents the intensity of the friction on the periphery of the arbor, becomes greater. The inclination of the pendulum strap *d* indicates also the capacity of the lubricating material to decrease friction between the two points of contact, and is directly determined and read off in units of circumference on the periphery of the lower portion of the strap.

FIG. 176.

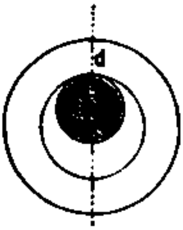


FIG. 177.

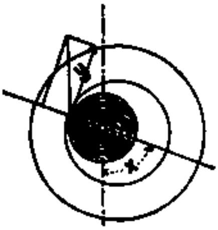
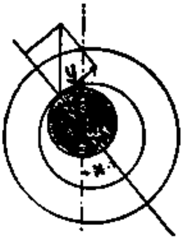


FIG. 178.



To test the lubricant in the sense of question 2, page 498, the apparatus is provided with the following arrangements:

As explained in the beginning, the judgment in question here must proceed from the heating produced by the internal work of the lubricant in the layer between the arbor *x* and bearing *y* (Figs. 173 and 174).

The construction must, therefore, be such as to offer a sufficient guaranty that the heating observed originates from this source alone, *i. e.*, from the layer itself, as only under this condition can it be observed entirely independent of foreign influences. To attain this object and to leave the working arbor, so to say, in a pendent position, the latter was given the form of a revolving body whose plane, set parallel to the axis of revolution, is curved according to the arc of a circle, the centre of which, however, lies outside the axis itself; moreover, the bearing used joints accurately to a portion of the upper surface. Upon the bearing itself rests by means of two points the lever *h*, Fig. 173, which is fastened in the frame, thus fixing the position of the bearing, and as this embraces the arbor, that of the latter also. Vertically downward the arbor is only sustained by the two rolls *e*.

In this manner the bearing, the running surface of which serves for the experimental plane, assumes at the same time the guidance of the arbor, the rolls *e* serving only for its support, but without the production of any material friction, there being no sliding between the circles of contact and the surface of the arbor.

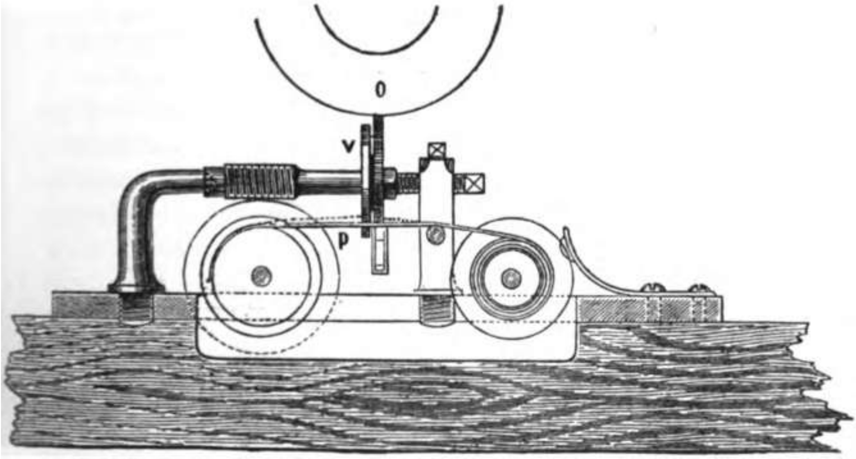
This arrangement fulfills the condition of an almost entire thermic insulation of the source of the development of heat, *i. e.*, the layer between the arbor and bearing, and of the latter themselves.

To test the lubricant about 12 drops of it are distributed upon the surface of the arbor and that of the bearing. The oil is kept uniformly distributed by the small strip of leather *n* moved to and fro during the revolution of the arbor by the oblique collar *w*.

The revolution of the arbor is effected at *x* by the belt *r*. The arbor itself is hollow and hermetically closed on one side by a spring-plate *f*, and is filled with vapors of sulphuric ether, the expansion of which, with the quantity used, amounts on an average to about ten times that of atmospheric air.

Now, when the arbor becomes heated by revolving and the heat yielded by the layer of lubricant, the heat developed is communicated to the vapors in the interior of the arbor, which causes an outward expansion of the spring-plate *f*. The movements of the latter with the required interpretation are communicated to the pencil *t*, whose different positions correspond, therefore, to the various temperatures of the arbor and of the layer of oil. In front of this pencil moves eccentrically a strip of paper *p*. Its motion is effected from the pivot at *o* (Fig. 172) by wheels and screws, so that a certain number of revolutions always correspond to a determined length of paper unrolled. The proportions are so chosen that the strip of paper only progresses 3.75 millimetres per minute, while the arbor makes 250 revolutions per minute.

FIG. 179.



In order that the pencil may mark its positions upon the paper without resistance, the arrangement is made (Figs. 179 and 180) that the strip of paper is lightly pressed against the pencil only every fifteenth second, and the latter is at once released, so that it may change its position without exerting a restraining effect upon the spring-plate *f*. The mechanism of the pencil is besides so arranged that its point moves in a straight line and parallel to the surface of the paper. Now, while the strip of paper, as soon as the pivot is made to revolve, moves in the direction of its length, the pencil changes its position, according to the heat produced in the arbor, at a right angle to the direction of the motion of the paper, and its markings, every fifteenth second, form points of a curve which gives a general picture (Fig. 181) of the development of heat in the layer of lubricant and in the bearing and arbor.

The curve marked by the pencil soon forms a straight line, running parallel to the direction of the motion of the paper, because the temperature of the arbor remains constant very soon after revolution begins, that is to say, when the effect of the cooling off of the surrounding air is just as large as that of the only slight development of heat in the still fresh layer of lubricant. This condition may suitably be called "*permanency*."

FIG. 180.

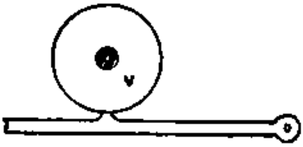
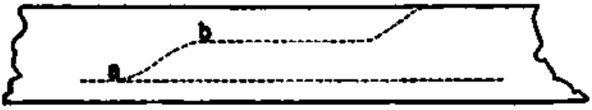


FIG. 181.



a, temperature of air; *b*, permanency.

The distance of the degrees designating this condition from the degrees corresponding to the temperature of the air is differently given by this apparatus for the various kinds of lubricants, but always exactly alike for the same kind. The curve thus formed has the shape as shown in Fig. 181.

Now, by allowing the arbor to revolve sufficiently long, the material adhering to it will be constantly reconveyed to the place between arbor and bearing, and repeatedly exposed to the work originating there. As the quantity of lubricant remains, however, the same, the effects of the work sum up so that the temperature of the arbor no longer remains constant, but rises proportionally to the internal resistances of work of the lubricant itself. The curve in its further course then takes an upward direction as indicated by dots.

The more quickly the lubricant changes its normal condition, the more resisting heat it develops; and the greater its consumption, the more rapidly the curve ascends.

From the previously explained mechanical combination of the machine it will be seen that the abscissa of the several points of this curve represent the revolution of the arbor, and consequently also the road traversed from the centre of gravity of the layer of lubricant between the bearing and arbor, while the ordinates of the changes in the condition of the layer express its heating and the magnitude of its injurious internal resistances according to quantities of heat in corresponding lengths of the ordinates.

The curve, therefore, represents a picture of the relations between the road and resistance within one and the same period, and the product of both consequently gives the magnitude of that work of resistance which the lubricant has developed in itself by the demand between arbor and bearing.

This product is directly represented by the area terminated by the curve itself and the abscissa—the line of the temperature of the air—passing through its point of beginning.

With different lubricants the internal work of resistance is, therefore, under otherwise equal circumstances, proportional to these areas, and their mechanical durability inversely proportional to them.

In this manner it is possible to express the mechanical effect of a lubricant as compared with another by a fixed value of figures which makes it also possible to answer the question under § 2, page 498.

It may here be remarked that experiments with the described testing machines are of value only within certain limits, and that a comparison of the results obtained with the different apparatuses is impossible. Even the results of two machines of the same construction cannot, according to Engler, be compared with each other, since the slightest variations in the constitution (shape, hardness, etc.,) of the rubbing surfaces give rise to considerable differences in testing one and the same oil. Even the results with the use of one and the same apparatus are not uniform and cannot be relied on, if the directions for making the experiments are not strictly observed.

It is impossible to obtain exact, useful results if the test-surfaces are not most accurately worked, for instance, if the axles are not almost absolutely round, or are not placed in a perfectly horizontal position and firmly secured; further, if the rubbing metal is not possessed of sufficient solidity and hardness to remain perfectly constant under the influence of friction. According to observations by Engler, no testing machine is entirely free from one or the other of the above-mentioned defects, and, in fact, a machine answering all requirements does not exist. By further taking into consideration that the absolutely necessary conditions in making experiments are freqently not observed with sufficient nicety, it is evident that the results of experiments regarding the lubricating power of different kinds of oil, which have from time to time been published, are of little or no value.

Experiments made with the various testing-machines always lead to the same results, viz., that the coefficient of friction stands in direct relation to the viscosity of the oils; thinly-fluid oils, *i. e.*, oils of slight viscosity, have a small coefficient of friction and will not bear a great load, while thick oils show, with a light load, a large coefficient of friction, but will also stand a heavy load. The latter, however, can be advantageously used for lubricating purposes only when the axle and bearing are warm enough to render them more thinly-fluid, this being the reason why thick oils at first yield a large coefficient of friction, which constantly becomes smaller as the axle and bearing become warmer, and finally remains quite constant.

From the results of Lamansky's experiments (see p. 493) it is evident that in consequence of more uniform viscosity at varying temperatures, vegetable oils also possess more uniform and constant lubricating power than mineral oils, whose viscosity rapidly decreases with a rising temperature. It has further been shown that the friction with one and the same oil is considerably increased with an increase in the velocity of the rubbing surface, and that when lubrication is effected by means of wick the co-efficient of friction is considerably greater than when there is a constant excess of oil between the axle and bearing.

In regard to directly testing oils as to their lubricating power, Engler arrived at the following conclusions, which are based upon numerous experiments made in the laboratory by himself and others:

1. To judge of the value of a lubricant for a definite purpose, it is advisable to use a testing machine whose construction and other conditions correspond as closely as possible with the intended practical use. Thus, for instance, for railroad purposes, the testing machine of the Paris-Lyons Mediterranean Railway might be recommended.

2. Generally speaking, testing machines give the most reliable results when they are used within narrow experimental limits (pressure and temperature). The execution of successive experiments under very extreme conditions of pressure and with oils varying very much in their degree of fluidity should be avoided.

3. The direction of the revolving surfaces should always be the same. If, for instance, with Thurston's apparatus, the axle is allowed to run in a direction reverse to the ordinary, considerably stronger frictional effects will result.

4. Testing machines whose rubbing surfaces become strongly heated give unreliable results for the direct measurement of the frictional resistance, and hence it follows that machines whose axles and bearings exhibit large surfaces of contact are also to be excluded. It would be best for the contact to take

place in one line only, or at least only from one side (above or below). Likewise, in case the co-efficient of friction alone is to be determined, to construct the rubbing test-portions hollow and to keep their temperature constant by a fluid.

5. Strong heating of the test-axles, bearings, etc., constitutes a defect, if for no other reason than that the oils are thereby tested under abnormal test-conditions. It is also a source of error, because with a varying temperature of the trial-room an unequal loss of heat is caused by radiation and conduction.

6. On the contrary, it is evident that oils whose lubricating power is demanded at a high temperature, must also be tested at a high temperature.

7. For the compensation of unavoidable construction-errors in the results of the experiments, the test-conditions (duration of the experiment, number of revolutions, load, temperature of the surrounding air, quantity of oil) should, for all comparative experiments, be as nearly the same as possible. These test-conditions have to be adapted as much as possible to the intended use (pressure and velocity of the rubbing surfaces).

8. If the co-efficient of friction alone is to be determined, and, in general, the heating which eventually takes place, the test has to be made with an excess of the oil under trial. Only in special cases is the supply of oil to be adapted as much as possible to the intended practical use, for instance, by supplying the oils by means of wick.

9. For the determination of the durability of a lubricant comparative tests have to be made always with the same quantities of oil, it being best to use no more than is necessary for once lubricating the rubbing surfaces.

10. The rubbing surfaces of the testing machines should be worked with the utmost accuracy, polished as smoothly as possible, and be of such hardness that they are not changed by the experiments.

11. The viscosity of oils is so closely related to their lubricating power that, if the determinations have been made at the respective temperatures, conclusions as to the usefulness and

value of a lubricating oil may be drawn from it and by comparison with other approved oils.

Photometric Tests.

The illuminating power of an oil is determined, with regard to the quantity consumed, by ascertaining the intensity of light emitted by a flame fed with the oil. The intensity of light is determined by a photometer and the quantity of oil consumed by weighing the experimental lamp before and after the experiment.

Photometers are based upon the principle that the intensities of two sources of light, which equally well illuminate different surfaces, are proportional to the squares of their distances.

Of the different photometers in use the most important shall here be described.

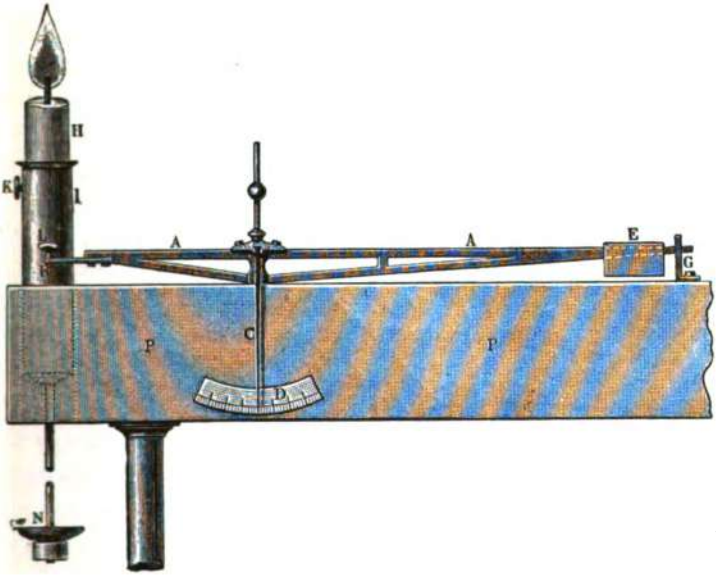
Bunsen's photometer. This instrument is almost exclusively used in Germany, partially so in Austria, and with slight modifications in England. In Bunsen's photometer, a vertical sheet of paper with a grease spot at its centre is exposed to the illumination of a standard candle on one side, and the light to be measured on the other. The sheet of paper is placed inside a dark box provided with two plane mirrors placed at such an angle to the paper that an observer can readily see both sides of the paper at the same time.

The box can be slid along a graduated horizontal scale, towards, or from, the light to be measured, and carries with it the standard candle mounted on it at a constant distance of 10 inches. If the box is too near the light to be measured, the grease spot appears brighter on the side of the sheet of paper nearest the candle. If too near the candle it appears brighter on the side of the sheet of paper nearest the light to be measured. The position in which the spot appears equally bright on both sides, is the position in which both sides of the paper are equally illuminated, and the relative intensities of the two lights are then directly as the squares of their distances from the sheet of paper.

Unit of light, or standard flame. All flames used up to the present time are more or less imperfect and do not sufficiently answer the requirements of a unit of light. The flame of a candle or of a carcel lamp is most frequently employed for the measurement of light, though under certain conditions the flame of illuminating gas is also used for the purpose. While in England but one kind of candle is used, which must be of definite composition, in Germany the regulations regarding the candle to be used vary very much and are frequently quite defective. However, candles, as well as carcel lamps, are not constant as regards their intensity of light and subject to variations of greater or smaller magnitude, so that the amyl acetate lamp recently introduced by von Hefner-Alteneck may shortly entirely supplant the candle, it answering best of all sources of light proposed, the requirements of constancy and of being readily produced.

London standard spermaceti candle. The light adopted in the United Kingdom, under the authority of the Legislature, and also in the colonies, as a standard whereby to estimate and express the illuminating value of substances used in artificial illumination, is that which is derived from a spermaceti candle burning at the rate of two grains of spermaceti per minute, or, as usually expressed, "sperm candles of six to the pound, each burning 120 grains per hour." Few candles burn at this exact rate, and in practice, "if the rate of consumption per candle shall not have exceeded 126 grains per hour or fallen short of 114 grains per hour," corrections by calculation are made for such variations from the standard rate. Hence, in England, the consumption of candle-material during the time of observation is also determined, Keates's candle-balance, Fig. 182, being most frequently used for the purpose. The candle-holder *T*, in which the standard candle is secured at the desired height by the screw *K*, is carried by the knife edge *F* of the beam *A* by means of the steel arm *L*. On the long arm of *A* is a shiftable weight *E*, which, when the candle is lighted and burns normally, is slowly shifted towards the centre until the indicator *C*, moving in front of the scale *D*, strikes toward the right. The attachment *G* on the end of the long arm of *A* prevents the latter from being raised too much. By the candle burning down its weight is decreased, and the indicator *C* again approaches the zero point of *D*. When the latter has been reached the time is noted by a watch, and observations regarding the consumption of candle and photometric measurements are commenced. After finishing the latter, the flame of the candle is extinguished, the time required for the measurements read off, and the consumption of candle during this time determined by placing weights in the pan *N* until the indicator *C* points again to zero. The weights used represent the consumption of candle-material during the time of observation. The entire apparatus is secured to one end of the photometer.

FIG. 182.



In making photometric experiments the flame of the standard candle should be 1¾ inches long. The standard candles are 8¾ inches long from base to shoulder, and according to F. W. Hartley are best prepared for making experiments as follows: Cut each candle in two parts at 4⅜ inches from its base. This is best done by laying the candle on a clean level surface and rolling it under the edge of a sharp knife. Cut away half an inch from the top of the *lower half*, and also cut away the spermaceti from the top half; reduce the projecting wick of the latter to half an inch in length. Take great care in cutting away the spermaceti, not to injure the wicks in the slightest degree. Burn the pieces of candles not too closely together in a place free from draughts, until the flames attain their maximum size, and each wick bends over and presents a red point through the flame, then touch it with a piece of spermaceti and blow out the flame. Always extinguish candles in the way described, and thus preserve their wicks in good condition.

For conveniently measuring the size of the flame a shiftable pin is connected with the candle holder, which is provided with two fine metallic points at the desired distance (1¾ inches) from each other. The lower point is so set as to accurately point at the lowest part of the flame. When the point of the flame touches the upper metallic point, the photometric measurements are commenced. Since it is of importance that the standard candles used should be as uniform in composition as possible, it is advisable to determine the melting or the congealing point of the candle material by the method proposed by Rüdorff. Fill a glass flask of 150 to 200 cubic centimeters capacity two-thirds full of the candle material and melt the latter by immersing the flask in water of from 140° to 176° F. When all is melted take the flask out of the water, dip a sensitive thermometer into the melted material and, while constantly stirring, observe the falling of the temperature. The temperature at which the thermometer remains constant for some time is considered the congealing point; with the spermacetic candle it lies at 43.5 to 44.5° C. (110.3° to 112.1° F.)

Munich stearin candle. This candle is to consume 10.2 to

10.6 grammes (157.41 to 163.58 grains) per hour with a flame of 52 millimeters (2.04 inches), and is to be composed of stearin with 76 to 76.6 per cent. carbon.

Paraffin candle of the Verein der Gas- und Wasserfachmänner. This candle is made of paraffin with a melting point not below 131° F. It is 20 millimeters (0.78 inches) in diameter and of such a length that six candles weigh 500 grammes (17.63 ozs.). The wick should be made as uniformly as possible of 24 cotton threads, and 1 meter (3 feet 3.37 inches) of it should, in a dry state, weigh 0.668 gramme (10.3 grains). In making measurements the size of the flame is to be 50 millimeters (1.96 inches); trimming the wick of the candle is permissible. According to experiments by Rüdorff, the intensity of light with this candle is not constant, it being in this respect inferior to the spermaceti candle and the Munich stearin candle.

Von Hefner-Alteneck's amyl acetate lamp. Amyl acetate is used for burning in this lamp. The influence of the wick is very slight, and, besides, the size of the flame, after the lamp has burned for a short while, remains constant for a considerable time.

According to von Hefner-Alteneck's proposition the unit of light is the illuminating power of a free burning flame ascending from the cross section of a wick saturated with amyl acetate, which completely fills a German silver wick-tube of 8 millimeters (0.31 inch) internal, and 8.3 millimeters (0.32 inch) external, diameter, and 15 millimeters (0.59 inch) in length. The size of the flame, measured, at least 10 minutes after lighting, from the edge of the wick tube, is to be 40 millimeters (1.57 inches).

A lamp constructed according to these directions is shown in vertical section in Fig. 183 and in ground plan in Fig. 184.

The height of flame is indicated by the line of sight over the two edges *a* and *b*. By sighting through the point of the flame to the brightly illuminated edges *a* and *b*, and by turning the disk *S*, the height of the flame is so regulated that the point of the bright nucleus of the flame which appears about ½ millimeter (0.19 inch) below the outermost point of a semi-luminous edge surrounding the nucleus, touches from below the line of sight. The two edges, *a* and *b*, turned towards the flame, are kept bright. The wick is made of coarse cotton thread; it should completely fill the wick-tube and be capable of absorbing amyl acetate in excess of the quantity consumed. For this reason it should not be pressed tight in the tube. It is best prepared from separate threads of wick-yarn, or of a corresponding number of ordinary soft and thick cotton threads. A cord of such thickness that it can be readily pressed together to the size of the diameter of the wick-tube is made by laying the separate threads parallel together without twisting. The quantity of amyl acetate in the lamp is immaterial as long as all the threads of the wick dip into it. The German silver wick-tube must be firmly placed upon the lamp, otherwise the size of the flame will be incorrect. The air-holes, *m* and *n*, on both sides of the wick-tube must be kept clear.

FIG. 183.

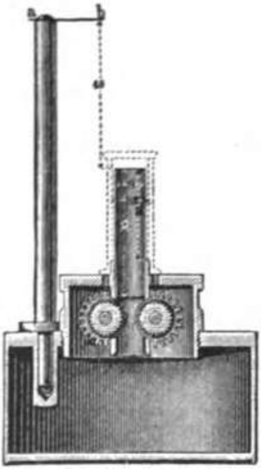
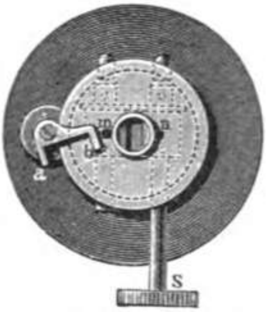


FIG. 184.



To what an extent the illuminating power is influenced by the pressure of the air has not yet been ascertained. The degree of purity of the air in the photometer room is, however, of considerable influence, and after each measurement the room should be aired. From the report of a committee of the German Association of Gas- und Wasserfachmaenner, the relation between the unit of light of the amyl acetate lamp, as above defined, the English spermaceti candle and the German paraffin candle may be seen. Six Bunsen photometers were used and six observers made several thousand observations. The results of these observations gave the following figures for the illuminating power:

One German paraffin candle	1.224	Hefner lamps
" long English spermaceti candle	1.145	" "
" short " " "	1.148	" "
" non-separated, tested English spermaceti candle	1.160	" "
" average English spermaceti candle	1.151	" "

Or vice versa:

One Hafner lamp is equal to:

0.808 German paraffin candle,
0.879 long English spermaceti candle,
0.875 short " " "
0.862 non-separated, tested English spermaceti candle,
0.870 average English spermaceti candle.

Hence the relation of the German paraffin candle to the average English spermaceti candle is 1.065 : 1. The size of the flame of the former was 50 millimeters (1.96 inches) and of the latter 45 millimeters (1.77 inches). The appended table from Schilling's "Handbuch für Gasbeleuchtung" gives the number of the different standard flames required for the production of the same illuminating power:

Candle of the German Association of Gasfachmaenner.	Munich candle.	English spermaceti candle.	Paris carcel lamp.
1000	887	977	102
1128	1000	1102	115
1023	907	1000	104
9826	8715	9600	1000

According to Schiele, a great difference in the readings is frequently effected by turning the paper in the photometer, and, according to Nichols, observations with one eye are much more accurate than with both.

Carcel lamp. This is an oil lamp employed in France as a photometric standard. It has a round wick and is fed with rape oil. Like the standard candle the carcel lamp is a standard only when it consumes a given weight of the light-producing substance in a given time. The intensity of light is considered standard when the lamp consumes exactly 42 grammes (648.15 grains) of oil per hour. If the consumption is not exactly 42 grammes, but between 40 and 44 grammes (617.29 and 679.02 grains) the relation between the consumption of oil and the light evolved is, according to experiments by Audouin and Berard, nearly constant and corrections by calculation are made. With a consumption outside of these limits, the observations are defective and have to be rejected.

The dimensions of the lamp and burner as prescribed by law are as follows:

Outside diameter of the wick-tube	23.5 mm.	(0.92 inch.)
Inside " " "	17.0 "	(0.66 ")
Diameter of the outside air-tube	45.5 "	(1.79 ")
Height of the glass chimney	290.0 "	(11.41 ")
Distance of the contracted part of the chimney from the base of the latter	61.0 "	(2.4 ")
Outside diameter of the chimney immediately below the contraction	47.0 "	(1.85 ")
Outside diameter of the chimney at the upper end	34.0 "	(1.33 ")
Average thickness of the glass	2.0 "	(0.079 ")

The wick used is what is known as light-house wick; it is plaited from 75 threads, and in a dry state weighs 3.6 grammes (55.55 grains) per decimeter. It is to be used in a dry state and hence must be kept in a dry place or in a box with a double bottom containing burnt lime for the absorption of moisture. A new wick is to be used for every experiment. It is trimmed close over the wick tube, and after filling the lamp with oil and raising the wick 5 to 6 millimeters (0.19 to 0.23 inch) above the wick-tube, the lamp is lighted and the chimney placed in position. To regulate the consumption of oil, the wick is then screwed up, and the chimney so placed that its contracted portion is 7 millimeters (0.27 inch) above the end of the wick.

Harcourt's pentane flame.[1] Harcourt employs as the unit of light the flame of a mixture of 210 volumes of pentane gas with 600 volumes of air which escapes with a velocity of ½ cubic foot per hour from a ¼-inch brass tube. At 60° F. and with a barometric pressure of 30 inches the length of such a flame is 2$\frac{5}{16}$ inches; its intensity is equal to that of the standard spermaceti candle and is said to be very constant, so that the pentane flame is frequently used in England for photometric measurements. When the mixture of pentane with air is not exactly composed according to the standard, it is claimed that for practical use it suffices to keep the flame at the above-mentioned length of 2$\frac{5}{16}$ inches in order to obtain the standard intensity defined as the unit of light.

Pentane is obtained by distilling American petroleum at 122° F. It is a colorless, mobile liquid of 0.6298 to 0.63 specific gravity. The mixture of pentane and air is prepared by pouring 1 volume of liquid pentane into 600 volumes of air contained in a gasometer immersed in water. The quantity of liquid pentane used vaporizes with great rapidity and corresponds to 210 volumes of pentane gas at 60° F.

The use of illuminating gas for the establishment of a unit of light has also been frequently proposed. Methven thus employed the flame of an argand burner, but numerous experiments showed it not to be suitable for the purpose. Giroud's photorheometer has, however, greater claims to accuracy.

Giroud's photorheometer serves for keeping constant for a longer time the volume of gas escaping from a burner, and consequently also the length of the gas flame produced. The

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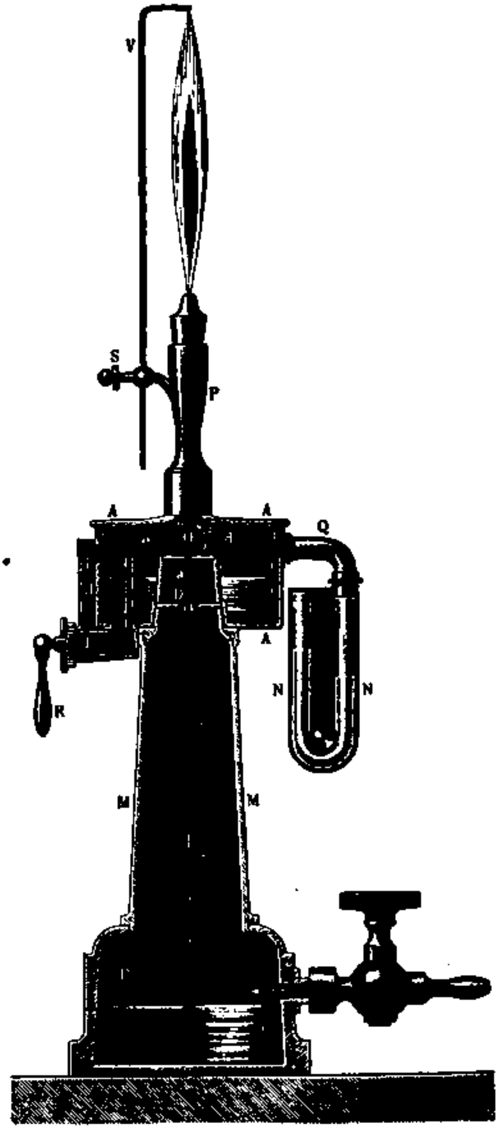
[1] Rep. of British Assoc. for the Adv. of Science, 1885, p. 426.

FIG. 185.



gas enters through the cock *L*, Fig. 185, the space *E*, next *M M*, washes around the pipe *a′*, passes the opening *D*, goes through another opening above it and arrives underneath a bell $d\ d$ of light copper-sheet, which floats in the box $A\ A$. The pipe a' passes through D and terminates above the bell d; its lower thinner portion, a, is firmly connected with d, the diameter of the joint being exactly the same as the inside diameter of a'. The diameter of the opening D is also the same as the clear diameter of a'. The bell d and the pipe a' dip into and float in glycerin. The bell $d\ d$ is provided on top with a small round aperture o, through which the gas escapes and finally reaches the burner. The velocity with which the gas escapes through o depends on the difference in the pressure of the gas below and above the bell. In the space E the varying pressure of the entering gas does not exert a moving influence upon the pipe a', it being apparent only by the rise or fall of the glycerin in a'. The level of the glycerin in E may be considered constant because the cross-section a' is infinitely small in proportion to that of E. If the pressure beneath the bell upon the unit of the surface S is designated P, and the plane s, which connects a with the bell d is equal to the clear width of a', then the force acting from below to above is $= P\ (S - s)$. From above to below the gas-pressure acts over the bell d. It is mostly dependent on the resistance of the flow of gas from the opening of the burner, and is transmitted through the bell D to the pipe a' and the column of glycerin in the latter. It is $= P'\ (S - s)$. Moreover, the weight π of the bell exerts a downward force. Q and $N\ N$ form a manometer. To vary at will the consumption of the burner P the U-pipe is provided with the cock T and the handle R. The leg H enters below the bell d, and the other leg communicates through the opening I with the space over the bell. When the cock T is opened, by turning it, a portion of the gas flows, without passing through the opening o, into the space above the bell, the effect produced thereby being the same as if the opening o in the bell d had been enlarged. Hence the consumption of the burner P is increased and may be varied at will by the cock T.

Giroud has proposed as a photometric standard a flame of

67.5 millimeters (2.65 inches) produced by a burner 1 millimeter (0.039 inch) wide. A flame of this length evolves a constant light equal to $\frac{1}{10}$ of that of a carcel lamp, and approximately equal (0.96) to that of the spermaceti candle. The height of the flame is marked by the wire *V*, secured by the screw *S*.

The room in which the photometric measurements are made should be entirely dark, and, for the sake of comfort and convenience, be of reasonable dimensions, that is about 12 feet square and 9 feet in height. It should be well ventilated, although *free from draughts*, not subject to vibrations, and should be maintained at a temperature as near to 60° F. as circumstances will permit. The walls of the room, as well as all apparatuses in it, should be painted dark to avoid disturbing reflections. Before commencing the measurements, the apparatus should be carefully examined to see that it, as well as the lamp used in the experiment, is in thorough order. The selection of a proper lamp is of great importance in judging the intensity of the light of an oil, because oils from different localities require, on account of the difference in their combustibility, the use of burners with a varying supply of air.

For specifically lighter oils which as a rule burn readily (for instance, Pennsylvania oil), ordinary burners will do, while for heavier oils (for instance, Caucasus kerosenes), burners with a greater supply of air have to be used. It may here be remarked that an effect similar to an increased supply of air may also be produced by contrivances which bring the air nearer to the flame; for instance, stronger contraction and deeper position of the glass chimney, introduction of air through a tube in the centre of the round burner, spreading the flame by means of a disk, etc. By increasing the supply of air corresponding to the specific gravity and combustibility of the oils, heavy oils also burn with a good illuminating effect, provided the distance from the level of the oil to the flame be not too great. But besides burning with difficulty, thick, heavy oils differ from light oils in that they rise but slowly in the wick. Hence for correct photometric measurements, burners have to be selected which by repeated trials have been found to yield the best illuminating effect.

To obtain a correct picture of the illuminating power and the illuminating value of a petroleum, the following points have to be stated or be determined by experiments: System and size of the burner, and the illuminating power in the commencement and at the end of the experiment, which should last at least 5 hours burning time. By testing for one or two hours only, a sufficient guide for judging the retrogression in the illuminating power during a longer period of burning is not obtained. Further, the mean illuminating power for the entire experimental time (obtained by reading off the statement every half hour) must be stated, as well as the consumption of oil per candle and hour. According to Engler, the illuminating effect of a good quality of oil with a ten line burner should not be much below eight candle powers. The proportion between the initial and final intensities should not be below three-quarters, and the hourly consumption per unit of light not amount to more than 3.5 grammes (54.01 grains) of oil.

Below some tests of the most common commercial varieties of oil, which were made by Engler, Lew, Kraemer and Böttcher, Zaloziecki, Schmelk and others, are given. Before discussing them, however, the effect of burning upon the flashing point and the specific gravity of the oil may be mentioned. The investigations of M. Albrecht, Junker, Thörner and Engler, show that neither the specific gravity nor the flashing point is essentially changed during and after burning, and that the opinion that first the lighter, and finally, the heavier constituents rise in the wick is fallacious, it having been proved that the oil rises and burns uniformly in the wick, the proportion of light to heavy constituents being thereby quite constant.

Photometric measurements executed by Engler and Lew, with the improved Bunsen photometer and a standard paraffine candle.

The appended experiments show: 1. That Caucasian oil burned in lamps constructed for the purpose gives as good a light as American oil. 2. Although the initial illuminating effect with American oil is greater than with Caucasian, there is also a correspondingly greater decrease in the intensity of the flame, so that towards the end of the experiment Caucasian oil shows throughout a brighter flame than American. 3. The consumption of oil for the production of equal quantities of light is about the same with both varieties of oil, it being, if anything, less with Caucasian than with American oil. 4. American oils burned in a lamp for Caucasian oils, and the latter burned in a lamp for American oils, produced as a rule a smaller illuminating effect. From the tables it will also be seen that with certain varieties of oil the intensity of light with reference to the consumption of oil is dependent on the lamp, so that each variety of oil requires a special burner and a special lamp.

The tables on pp. 527 and 528, show the fractions of commercial petroleum which under certain conditions as regards lamps yield the most light. The difference of behavior in burning between the same fractions of American and Caucasian oils will, in this case, also be noticed.

CAUCASIAN OIL.

Variety of Oil.	Kind of Burner.		No. of the oil.	Percentage of standard illuminating oil (302° to 554° F.).	Percentage of heavy oils boiling at over 590° F.	Intensity of light in the first hour.	Intensity of light at the end of the experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Consumption of oil in grammes per one standard candle and one hour.	Weight in grammes of the carbonized ring.
Caucasian Illuminating Oil from Nobel's Tank at Illowo.	Burner of Wild and Wessel.	10 lines.	I.	89	5	8.35	7.6	7.86	5	3.76	0.064
			II.	82.25	6.75	8.4	7.8	7.96	6	3.8	0.050
		14 lines.	I.	......	......	9.0	7.1	8.6	5	4.04	0.132
			II.	......	......	9.2	7.2	8.8	6.5	4.5	0.107
	Shuster & Baer's Improved	10 lines.	I.	......	......	10.1	9.4	9.72	6¼	3.8	0.020
	Cosmos Burner.	14 lines.	I.	......	......	11.65	10.7	11.0	5	4.1	0.024

AMERICAN OIL.

Variety of Oil.	Kind of Burner.		No. of the oil.	Percentage of standard illuminating oil (302° to 554° F.).	Percentage of heavy oils boiling at over 590° F.	Intensity of light in the first hour.	Intensity of light at the end of the experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Consumption of oil in grammes per one standard candle and one hour.	Weight in grammes of the carbonized ring.
American Illuminating Petroleum obtained in the City of Carlsruhe.	Small Burner of Wild and Wessel.	10 lines.	I.	58.	28.	8.65	7.0	7.6	7¼	4.1	0.0849
			II.	60.5	24.15	8.55	6.5	7.72	7½	3.7	0.062
			III.	64.5	26.5	9.15	6.8	7.8	5¼	4.0	0.0585
	Large Burner of Wild and Wessel.	14 lines.	I.	......	......	10.95	8.2	9.82	5	4.1	0.078
			II.	......	......	11.9	8.8	10.0	8¼	4.3	0.126
			III.	......	......	10.95	8.8	10.1	5½	4.6	0.100
	Schuster & Baer's Improved	10 lines.	I.	......	......	9.4	7.8	8.0	6	4.2	0.0832
	Cosmos Burner.	14 lines.	I.	......	......	11.3	8.6	9.4	5	5.7	0.104

Fractions.		No. of the oil.	Specific gravity.	Flashing point.	Intensity of light in the first hour.	Intensity of light at the end of the experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Consumption of oil in grammes per one normal candle and one hour.	Weight in grammes of the carbonized ring.
Experiments with a Ten Line Burner of Wild and Wessel.	302° to 392° F.	I.	0.805	31	9.7	9.4	9.5	5¼	4.0	not weighable.
	392° to 482° F.	I.	0.835	63	7.9	7.0	7.4	6½	4.0	0.073
	482° to 572° F.	I.	0.850	......	7.5	4.7	6.3	7	3.4	0.104
	302° to 572° F.	I.	0.825	45.5	8.65	7.9	8.1	5	4.0	0.053
	All oil exclusive of the portions boiling up to 302° F.	I.	0.830	46	8.0	7.1	7.4	5	4.0	0.072
	All oil exclusive of the portions boiling above 572° F.	I.	0.820	26.5	9.1	8.6	8.8	6	4.1	not weighable.
Experiments with the Improved Ten Line Cosmos Burner of Schuster & Baer.	302° to 392° F.	I.	......	......	10.85	10.45	10.6	9⅛	3.9	not weighable.
	392° to 482° F.	I.	......	......	9.95	9.25	9.5	6½	3.0	not weighable.
	482° to 572° F.	I.	......	......	9.4	6.8	7.5	9⅛	3.0	0.071
	302° to 572° F.	I.	......	......	10.3	9.7	9.9	6	3.7	0.024
	All oil exclusive of the portions boiling up to 302° F.	I.	......	......	10.1	9.3	9.7	5	3.8	0.042
	All oil exclusive of the portions boiling above 572° F.	I.	......	......	10.85	10.55	10.57	6½	3.9	not weighable.

AMERICAN PETROLEUM.

	Fractions.	No. of the oil.	Specific gravity.	Flashing point.	Intensity of light in the first hour.	Intensity of light at the end of the experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Consumption of oil in grammes per one normal candle and one hour.	Weight in grammes of the carbonized ring.
Experiments with a Ten Line Burner of Wild and Wessel.	302° to 392° F.	I.	0.795	27	9.35	8.6	8.8	6	3.9	not weighable.
		II.	0.7905	26.5	9.4	8.4	8.7	6⅓	3.8	not weighable.
	392° to 482° F.	I.	0.815	41.5	8.4	6.9	8.0	7¼	3.7	0.064
		II.	0.810	39.0	8.5	7.0	8.0	5	3.85	0.059
	482° to 572° F.	I.	0.825	......	7.5	6.3	7.1	6	3.7	0.103
		II.	0.825	......	7.6	6.0	6.9	6	3.7	0.102
	302° to 572° F.	I.	0.805	29	9.3	7.7	8.2	6½	3.8	0.023
		II.	0.800	28	9.2	7.9	8.3	6	3.9	0.020
	All oil exclusive of the portions boiling up to 302° F.	I.	0.810	32	8.1	5.0	6.5	6½	4.0	0.140
		II.	0.805	31	7.8	5.4	6.7	6	4.1	0.095
	All oil exclusive of the portions boiling above 572° F.	I.	0.800	19.5	8.7	7.8	8.4	6½	4.03	not weighable.
		II.	0.800	18.5	9.05	8.0	8.4	6⅓	4.2	not weighable.

The German varieties of petroleum have been tested by Engler as to their intensity of light, and compared with Caucasian and American illuminating oils occurring in commerce. The results of these investigations will be seen from the appended table, p. 530.

As regards the intensity of light, the Pechelbronn illuminating oil from the older bore-hole, when burned in an ordinary lamp, is, according to the results given in the above table, slightly inferior to Oelheim oil, and considerably so to illuminating oils from Baku and Pennsylvania. Like Oelheim oil, it burns best in lamps with an increased supply of air (Schuster & Baer). In its general behavior in burning in the lamp the Pechelbronn oil from the more recent bore-hole (No. 213) closely resembles Pennsylvania oil, but surpasses it as regards constancy of illuminating power after burning for five hours, as well as with respect to the smaller consumption of oil. Like American oil it burns to the best advantage in an ordinary lamp, without an increased supply of air, while the Pechelbronn oil from the older bore-hole (No. 146), as well as the Oelheim oil, agree in this respect with the Baku oil.

In the appended table, p. 531, photometric measurements, made by Engler and Schestopal, of Korff's *Kaiseroel* (*Imperial oil*) and *Brilliant petroleum* from Pechelbronn crude oil compared with Pennsylvania petroleum, are given. The improved Bunsen photometer and standard paraffin candle were used in making the experiments.

Variety of Oil.	Kind of Burner.	No. of the oil.	Percentage of standard illuminating oil (302° to 554° F.)	Intensity of light in the first hour.	Intensity of light at the end of the experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Consumption of oil per one normal candle and one hour.	Weight in grammes of the carbonized ring.	Percentage of portions boiling above 554° F.
Pechelbronn, Bore-hole No. 146.	Wild & Wessel.	......	92	8.5	7.5	8.0	5	4.32	0.102	8
	Schuster & Baer.	......	......	8.8	8.0	8.32	5	4.37	0.097	......
Pechelbronn, Bore-hole No. 213.	Wild & Wessel.	......	79	10.3	7.8	8.9	5	3.7	0.061	9.5
	Schuster & Baer.	......	......	10.1	7.6	8.9	5	4.1	0.043	......
Oelheim, German Petroleum Co.	Wild & Wessel.	......	87	9.0	7.2	7.95	5	3.86	0.117	9.5
	Schuster & Baer.	......	......	9.4	7.7	8.4	5	3.51	0.0985	......
	Helios.	......	......	10.2	8.7	9.53	5	3.4	0.048	......
American Illuminating Petroleum obtained in the City of Carlsruhe.	Wild & Wessel.	I.	58	8.65	7.0	7.6	7¼	4.1	0.0849	28
		II.	60.05	8.55	6.5	7.72	7½	3.7	0.062	24.15
		III.	64.5	9.15	6.8	7.8	5¾	4.0	0.0585	20.5
	Improved Cosmos Burner.	I.	......	9.4	7.8	8.0	6	4.2	0.0832	......
Caucasian Illuminating Petroleum from Nobel's Tank at Illawa.	Wild & Wessel.	I.	89	8.35	7.6	7.86	5	3.76	0.064	5
		II.	82.25	8.4	7.8	7.93	6	3.8	0.050	6.75
	Improved Cosmos Burner.	I.	......	10.1	9.4	9.72	6¾	3.8	0.020	......

Variety of Petroleum.	Kind of burner.	Mean intensity of light in the first hour.	Intensity of light at the end of experiment.	Mean intensity of light from ten readings.	Duration of the experiment in hours.	Mean consumption of oil per hour in grammes.	Consumption of oil in grammes per one standard candle and one hour.	Specific gravity.	Viscosity (water=1).
Kaiseroel.	Small (10-line) burner of Wild & Wessel.	8.8	8.1	8.4	6	27.0	3.2	0.795	1.08
Brilliant petroleum.		8.5	7.8	8.1	5	26.8	3.3	0.801	1.04
Ordinary Pennsylvania petroleum.		8.5	6.5	7.7	7	28.7	3.7	0.800	1.12
Kaiseroel.	Improved cosmos burner of Schuster & Baer.	9.1	8.2	8.6	6	24.0	2.8	0.795	1.08
Brilliant petroleum.		9.2	8.1	8.7	6½	25.1	2.8	0.801	1.04
Ordinary Pennsylvania petroleum.		9.4	7.8	8.0	6	39.8	4.2	0.800	1.12

From the above results it will be seen that Alsace brilliant petroleum closely approaches the well known and celebrated Kaiseroel, and like the latter is suitable for both kinds of burner.

The intensity of the light of an oil is seriously affected by lime and magnesia salts dissolved in the oil. According to Redwood, a content of iron of 0.1 gramme in 1000 grammes of oil is not injurious, while, on the other hand, by a content of 0.02 gramme of lime or magnesia salts in 1000 grammes of oil, the illuminating power is reduced 30 to 40 per cent. in 8 hours, and with a content of 0.1 gramme of lime salts in 1000 grammes of oil, 85.5 per cent., and with a content of the same quantity of magnesia salt, even 94 per cent. The different behavior of the iron salts, on the one hand, and of lime and magnesia salts, on the other, may be explained by the fact that the iron salts separate on the point of the wick, and even fall off or remain upon the wick without fusing, while the lime and magnesia salts slag to a solid mass, and thus prevent the access of the oil to the flame.

Colorimetry (*Measurement of Color.*)

Petroleum should show at the utmost a pale yellow color, and good qualities of it should be entirely colorless. A yellow color indicates insufficient purification or an addition of inferior, especially of heavier, varieties of oil. Moreover, most varieties of oil have a blue lustre, the cause of which has thus far not been explained. A noticeable difference between the American and Caucasian varieties of petroleum is found in the shade of color. Caucasian petroleum, even of specific gravity 0.824 to 0.826, is white or shows at the utmost a slight yellowish cast, while American commerical petroleum shows a stronger yellow-green cast and more fluorescence.

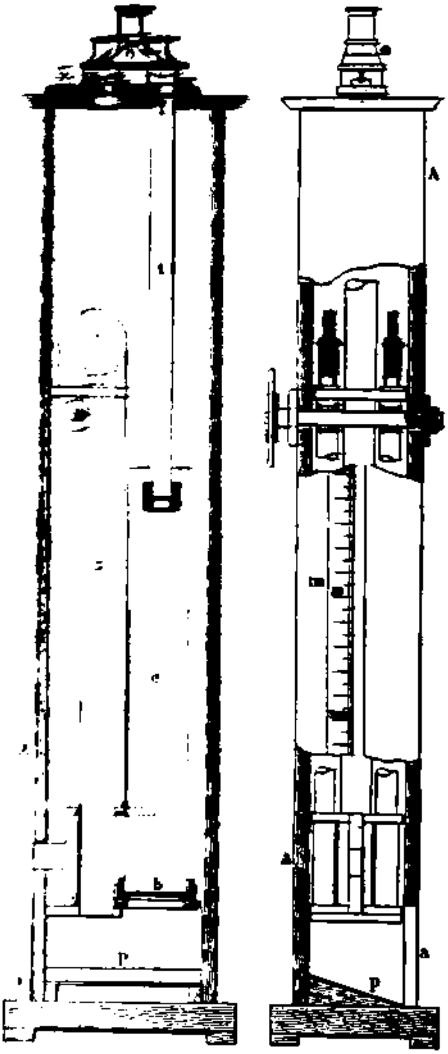
Since the color of varieties of petroleum and lubricating oils cannot be accurately determined by the naked eye, instruments (colorimeters, chromometers) have in recent times been constructed, by means of which the coloration permissible may be established. Stammer's improved colorimeter, Fig. 186, constructed by Schmidt and Hænsch of Berlin, is mostly used for this purpose, especially in Baku. The box *A* contains the metallic cylinder *c* which serves for the reception of the oil to be tested; the bottom *b* of the cylinder *c* consists of a ground-glass plate secured by means of a metallic mounting and screws. The cylinder *c* stands upon a slide which can be moved up or down by turning a button. By the same movement a pointer connected with the slide is set in motion, whereby the extent to which the cylinder *c* has been raised is indicated in millimeters on the scale *m*. In the cover of the box is suspended the plunger-tube *t* also terminating in a similar manner to *c* in a glass plate. The tube is secured in its position by a small hand-spring *f*. On the bottom of the box lies in an oblique position the bone-glass mirror *p*, through which, when the door *a* is open, diffused light is thrown into the apparatus. The light passes, on the one hand, through the oil in the cylinder *c* and the tube *t* above it, and, on the other, through the metal-tube *z*, blacked inside, which extends from the bottom of the apparatus to the ocular. Through this ocular the rays of light which have passed through *c* and *z* are, with the assistance of suitably arranged mirrors, combined upon a round field of view, so that upon one-half of it are seen the rays of light which have passed through *c* and upon the other half the rays of light which have passed through *z*, and both shades of color can thus be compared.

Instead of a colored fluid, a uranium-glass plate is used as standard color. It is placed at *u*, in the ocular. To allow of the convenient changing of the tube *t*, the ocular *o* can be turned around its axis at *x*, and can also be shifted laterally.

For testing lubricating oils, which are much darker, the apparatus is provided with a short cylinder for the reception of the oil.

The operation of testing the oil is as follows: The cylinder *c* having been brought to its lowest position, is taken from the apparatus, filled up to the mark with the oil to be tested, and

FIG. 186.



carefully replaced. The tube *t* is then placed in position, and the box *A* closed with the exception of the door *a*. The apparatus is then so placed that through a window as bright a light as possible falls upon it, when the cylinder *c* is shifted upwards until both halves of the field of view show the same tones of color. The higher the cylinder *c* is raised, the thinner the layer of oil between the bottom of the cylinder *c* and the bottom of the stationary tube *t* becomes, and the brighter also the field of view.

It is evident that this layer becomes thinner the more deeply colored the oil is, and the pointer indicates the thickness of the layer in millimeters on the scale *m*.

The tone of color and thickness of the standard glass are so selected that the readings of the scale give the following values for the customary commercial brands:

For standard white	50.0	millimeters.
" prime "	86.5	"
" superfine "	199.5	"
" water "	300 to 320	"

The apparatus allows of rapid work and convenient reading. For sharp determinations several readings have to be made and the mean of them is taken.

Although the coloration of the standard glass is an excellent imitation of the tone of color of petroleum, it is evident that with oils of different derivation there will be small differences in the tone of color as compared with the standard glass, so that it will not always be possible to arrange the cylinder so that the two halves of the field of view show exactly the same coloration. However, the error caused by this is very slight, it being within a few millimeters, and could not be avoided by the use of a standard oil or other standard fluid.

It having been shown that petroleum acts upon metals, it becoming thereby darker, though to a scarcely perceptible degree, the use of an apparatus with the oil cylinder *c* and the tube *t* made entirely of glass is recommended for testing the finest brands. Experiments made by Engler with such an apparatus yielded very satisfactory results.

An older form of colorimeter, which is still much used, is shown in Figs. 187 and 188. It consists of two tubes *A* and *B* secured to a frame. By means of the mirror *C* light is thrown into these tubes, and observed through *a*. The tube *B* contains a glass disk of a slightly yellowish color corresponding to the standard petroleum. The coloration of the glass disk corresponds to the figure 100 on the scale. The tube *A* is open on top and closed below by a colorless glass disk. In the outer tube moves, telescope-like, a second tube also open on top and closed below by a glass disk. At *a* is seen a circle divided by a line, one side of which receives the light from *A*, and the other from *B*, so that the coloration of both can be readily compared. The oil to be tested is poured through *c* into *A*, and after drawing up the inner tube as high as possible, the two pictures are compared. If that on the side of the petroleum is too strongly colored, the inner tube and the tube *B* connected therewith are screwed down to the point at which both halves appear of the same color. The degree of coloration as compared with the standard is then read off on the scale *b*.

FIG. 187.

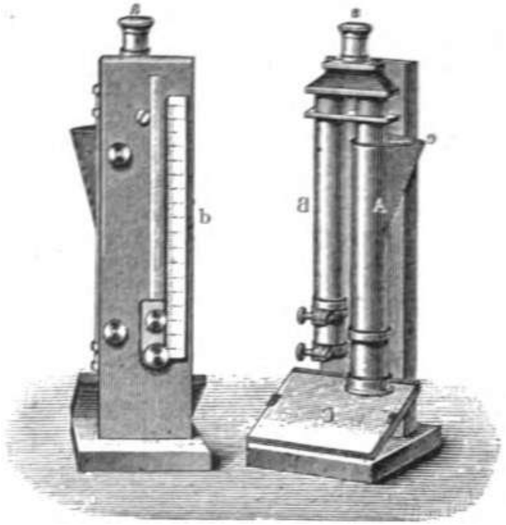
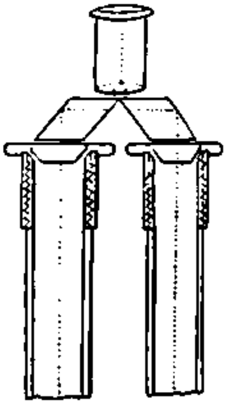


FIG. 188.



Wilson's colorimeter, which is used in England, closely resembles the preceding apparatus. In Bremen the instrument of Wilson-Ludolph is used.

At the various commercial exchanges petroleum is generally traded in according to definite colors, the oil being divided into several brands corresponding to its brightness. Thus at the London exchange four shades of color are recognized, viz: *Water white*, *prime white*, *standard white*, and *merchantable*, water white representing the brightest, and merchantable the darkest kind. In Bremen there are the following varieties: *Water white*, *prime white*, *standard white*, *prime light straw to white*, *prime light straw to standard white*, *light straw*, and *straw*.

In the determination of the value of *lubricating* oils, the color is in many cases decisive, though it is not, as with petroleum, a standard for its quality. In judging mineral lubricating oils it has to be taken into consideration whether they are to be used as a substitute for, or as an addition to, vegetable oils. This applies especially to commerce, in which case the utmost brightness to straw yellow is of great value.

As mentioned in Chapter IX on Manufacture, mineral lubricating oils may be divided into two groups, one embracing the oils directly prepared from the residuum by refining, and the other the distillates. In the first case the color is in so far of importance as it furnishes a guide for the purity of the oil; the lighter the oil and the more transparent or translucent it is in thicker layers, the purer it may be supposed to be. The second group of lubricating oils—the distillates—are in many cases advantageously used as such. They are distinguished from the refined product of the same derivation by greater viscosity, but refining the oils became necessary in consequence of the prejudice of consumers, who had been used to pale vegetable oils for lubricating. The color of the refined product becomes, as a rule, darker with an increase in the specific gravity. Thus the lightest solar and mixed oils are lemon-yellow, the heavier spindle oils orange to slightly wine-red, and the machine oils dark wine-yellow to dark wine-red, frequently transparent only in thin layers, while the cylinder oils are almost non-transparent or dark red. All oils show a green to blue-green fluorescence. Oils of the same derivation and the same specific gravity should show the same color, a darker color indicating, in this case, inferior refining.

Odor.

The odor of *illuminating oils* should be slight and not disagreeable, or still better, should be entirely absent.

A penetrating, disagreeable odor, such as is possessed by many varieties of commercial petroleum, is due to constituents of the crude oil, which have not been entirely removed in refining.

Lubricating oils should be odorless. A disagreeable odor of lubricating oils is due either to defective distillation or insufficient treatment with the customary chemicals, sulphuric acid and lye.[1]

Behavior towards Sulphuric Acid.

Petroleum mixed with an equal volume of sulphuric acid of 1.53 specific gravity and shaken, should, after the acid has settled, appear not darker, but rather lighter. The sulphuric acid should thereby not acquire a brown or brown-black color, but remain unchanged, or at the utmost show a slightly yellow color. Brown coloration of the acid indicates insufficient purification.

If the petroleum is adulterated with distillates of lignite, wood, resin, etc., the temperature of the mixture, when shaken with sulphuric acid, rises 20° to 50° C. (68° to 122° F.) When such petroleum is mixed with water, the petroleum separates very slowly, it appearing, frequently, also colored and dirty.

With pure petroleum the temperature rises at the utmost 5° C. (41° F.) and the petroleum separates rapidly from water.

To test *lubricating oils*, mix by frequent shaking equal

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[1] The disagreeable odor of many crude oils and illuminating oils is chiefly due to non-saturated hydrocarbons which are completely absorbed by the sulphuric acid, and hence remain behind with defective refining. (Kast and Lagai. Dingl. polyt. Jour., 284, 71.)

volumes of oil and sulphuric acid of 1.53 specific gravity and let the mixture stand. Heat another sample of the mixture in a water-bath, with frequent stirring, to 212° F. The sulphuric acid separated from both samples should at the utmost show a yellowish color; brown coloration indicating a separation of carbon, etc. A considerable increase in the temperature also indicates the presence of oxygenous admixtures.

Determination of acidity.

In the process of refining, both illuminating and lubricating oils are treated with concentrated sulphuric acid, which has to be removed by washing with lye and water in order to obtain the oils free from acid. If, in consequence of defective purification, any of the acid remains behind, the illuminating oil burns badly and evolves vapors containing sulphurous acid which are injurious to the health. Lubricating oils containing free acids attack the metals of the bearings and gradually destroy them.

To detect acid, shake the oil with water, separate the latter from the former and mix it with barium chloride solution. In the presence of sulphuric acid a white turbidity or precipitate is formed. In place of water, it is better to shake the oil with dilute solution of pure sodium carbonate, acidulate, after separating the oil, with hydrochloric acid; mix with barium chloride solution.

However, the simplest manner of testing lubricating oils as to the presence of acid, is as follows: Pour a few drops of the oil into shallow depressions in a brass or copper plate and heat the latter to 122° or 140° F., for a few hours. If the oil is acid a green lustre, especially perceptible on the edge of the oil, appears. By heating the oil for a longer time the tendency of the oil towards acidity may be recognized by the degree of the green coloration, which becomes constantly more pronounced.

The slightest traces of mineral acids may be established by shaking with methyl orange solution (1:1000).

For the quantitative determination of the content of acid, [illegible] sufficient quantity of a mixture of [illegible] alcohol and [illegible] ether, so that the fluid [illegible] to allow of the recognition of the [illegible] as indicator. Then [illegible] until the reddening of the [illegible] appears. The cubic centi[illegible] to Burstyn's degrees [illegible] potash lye [illegible]. The mixture of alcohol and ether [illegible] be mixed with sufficient [illegible] produces [illegible] of the oil which [illegible] acid.

If the oil is so dark that in titrating with potash lye the appearance of the reddening cannot be recognized, shake [illegible] cubic centimetres of the oil with [illegible] cubic centimetres of a mixture of equal parts of water and alcohol, take 50 cubic centimetres of the alcoholic and aqueous layer and determine the content of acid in the above described manner. Multiply the cubic centimetres found by 2.

By shaking the oil with a mixture of alcohol and water (1:1) the sulphuric acid remaining in it from the refining process may be determined. Take a portion of the alcoholic-aqueous layer and, after expelling the alcohol and acidulating with hydrochloric acid, precipitate the sulphuric acid with barium chloride, and weigh it as barium sulphate.

The presence of organic sulphocarbonic acids in mineral oils is determined by shaking the oil with soda lye of 1.2 specific gravity, allowing the lye to settle, then separating it from the oil, and acidulating it with hydrochloric or sulphuric acid. If flakes are separated or the fluid becomes very turbid, the oil contains, without doubt, the above mentioned acids.

Determinations of mineral salts.

Admixtures of iron, lime, and magnesium salts are determined as follows: Reduce by distillation 100 or more cubic centimeters of the illuminating or lubricating oil to about 20 cubic centimeters, evaporate the latter in a weighed porcelain dish, glow, and weigh the residue. In this manner the entire solid residue is obtained. The latter is then dissolved in dilute hydrochloric acid and tested in the ordinary manner as to its constituents.

Determination of paraffin.

With lubricating oils this test is best combined with the distilling test, the latter being executed in the same manner as in testing petroleum residuum, by collecting the fractions from about every 50° to 50° C., and determining by cooling them, which of them contain paraffin. The paraffin may also be determined quantitatively by filtering, etc., or by the ether-alcohol method (see Crude Oil).

Determination of resin and caoutchouc.

Many lubricating oils are adulterated with resin and caoutchouc to increase their specific gravity and viscosity. Such oils when exposed to the air are not constant, are injurious to the bearings, and offer greater frictional resistance.

For the determination of resin, boil a few cubic centimeters of the oil with twice or three times its volume of spirits of wine of specific gravity 0.88 to 0.90 in a test-tube for a few minutes, then shake vigorously, and allow to cool. Take a portion of the upper alcoholic layer and mix it with alcoholic solution of lead acetate. If a resin is present a thick, flaky to caseous precipitate is produced; otherwise the fluid only shows a milky turbidity.

Determination of rosin oil.

The best test for this purpose is that given by Valenta. It is based upon the rotation of the polarized ray of light by rosin oil and the optically inactive property of mineral oil. The oil is brought into a polarizing apparatus and observed whether it is dextorotatory or not. In the first case rosin oil is present. If the oil is colored, it is diluted with petroleum ether to make it lighter, or treated with decolorizing powder (residue from potassium ferrocyanide factories).

Although the quantity of rosin oil cannot be accurately determined by this method, its content in the mineral oil may be approximately established, and this suffices for most purposes.

Rosin oil may also be qualitatively determined, according to Hübl's method by titrating with iodine solution. The iodine solution is made by mixing a solution of 25 grammes of iodine in 500 cubic centimeters of 95 per cent. alcohol with a solution of 30 grammes of mercuric chloride in 500 cubic centimeters of alcohol; the mixture must stand 6 to 12 hours, and any precipitate which may form in that time must be filtered off. It is standardized by means of a solution of sodium hyposulphite (about 24 grammes to the liter). The test is then applied as follows: Dissolve 0.2 to 0.8 gramme of the oil in 10 cubic centimeters of chloroform. Add an excess of the above iodine solution, and after standing 1 to 1½ hours, determine the excess of iodine by the sodium hyposulphite solution, using starch as an indicator. By means of a simple calculation the amount of iodine absorbed by 100 grammes of the oil is then determined, and this is the "iodine number" for that oil.

The iodine number of rosin oil[1] being considerably higher than that of mineral oil, the presence or absence of rosin oil may be established by the amount of iodine absorbed. There, being, however, a considerable difference in the iodine number of the various mineral oils, this method is not suitable for more accurate quantitative determinations.

To detect rosin oil in mineral oils, glacial acetic acid may also be used, according to Valenta. Rosin oil dissolves in glacial acetic acid with ease at 122° F., but mineral oils very sparingly; 10 cubic centimeters of glacial acetic acid dissolve

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[1] 100 grammes of rosin oil absorb, according to Valenta, 43 to 48 grammes iodine, and 100 grammes of mineral oil seldom more than 14 grammes.

0.2823 to 0.6849 gramme of mineral oil and 1.7 to 2 grammes of rosin oil. In mixtures the solubility does not, however, increase proportionally to the content of rosin oil.

Mix 2 grammes of the oil to be tested with 10 cubic centimeters of glacial acetic acid, and heat, with constant shaking, in the water bath for 5 minutes. Filter through a slightly moistened filter, and in a weighed portion of the filtrate determine the glacial acetic acid by titration with soda lye. The quantity of oil dissolved is then calculated from the difference in weight between the total solution and the glacial acetic acid.

For the detection of rosin oil in mineral oil, Demsky and Morawski make use of the greater solubility of rosin oil in acetone.

Shake 50 cubic centimeters of the oil to be tested with 50 cubic centimeters of acetone, allow to settle, and then evaporate 10 cubic centimeters of the acetone layer. Weigh the residue and determine its specific gravity. The quantity of rosin oil which has to be added for the oil to dissolve in exactly one-half its volume of acetone is also determined. Demsky and Morawski have made experiments with mixtures of mineral oils of different origin with refined rosin oil. The results of these investigations show that when in Caucasian oil the content of rosin oil exceeds 50 per cent., and in American and Galician oils about 35 per cent., the oil dissolves completely in one-half its volume of acetone. In the absence of rosin oil, which may be determined by means of the polariscope, the derivation of the mineral oil may also be approximately determined by the acetone method.

Cold test.

The value of lubricating oils is in an inverse ratio to their tendency to thicken or even become solid at low temperatures, and they are rated accordingly. The test consists in exposing 5 to 8 cubic centimeters of the oil to be tested in an ordinary test-tube to chilling in a cold mixture or in a suitably constructed ice-chest fitted with thermometer.

For the exact determination of the congealing point of lubricating oils, Hoffmeister recommends the following method: The oil is brought successively into different salt solutions saturated at their freezing points, which are partially frozen by a mixture of ice and common salt. To avoid over-cooling the sample of oil is brought each time from a solution of a higher freezing point into one of a lower.

Another method is as follows:

Bring into a glass vessel four inches in depth and three inches in diameter the oil to be tested and place the vessel in an ice-chest. A thermometer is placed in the centre of the oil glass, and another thermometer outside of said vessel but in the ice-chest. When the two instruments reach the required point and indicate the same temperature, if the oil is still limpid, it shall be taken as the proper cold test.

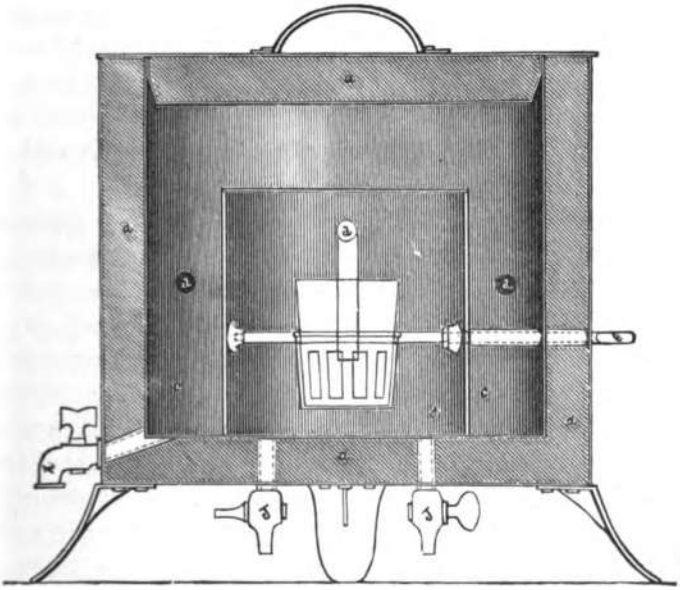
Tagliabue's standard oil-freezer. This apparatus is shown in sectional view in Fig. 189. The freezer is a semi-cylindrical metallic stand, divided into three compartments: The first, *f*, is the oil-cooling chamber in which is the receiver, adjusted to a rocking shaft, *g*, to facilitate the introduction of the regulation oil cup therein, and to show by its motion whether the oil is congealing or not. The second compartment, *c*, is the ice chamber, which is filled with ice and rock salt for the cooling process; a faucet, *h*, is connected with it, to allow the melted ice to flow out.

The third compartment, *a*, is a non-conducting jacket, lined with patent mineral wool filling, to maintain an even temperature in the cooling chamber, and to prevent a too rapid melting of the ice.

Three thermometers, *d*, are inserted in the freezer—one on each side of the cooling chamber, to denote its temperature; and a third one in the centre, so adjusted that its bulb, penetrating the middle of the oil, enables the expert to see through a glass door (without opening the same) at what temperature the oil commences to congeal.

Two stop-cocks, *j*, are attached to the bottom, communicating with the cooling chamber, to force therein (by either opening or blowing through them with a rubber tube) atmospheric or warm air, whenever it is desired to raise its temperature.

FIG. 189.



American lubricating oils congeal generally at 32° F., or somewhat below it, while Baku oils have to be cooled to 14° and even to 4° F.

Determination of fat oils and fats.

As is well known, fat oils are distinguished from mineral oils by the former being capable of saponification, while the latter are not. F. Lux has drawn attention to the fact that the soap formed by the presence of even 2 per cent. of fat oil in mineral oil suffices to effect congelation of the fluid on cooling.

The saponification of admixed fat oils takes place slowly below 392° F., and best at about that temperature; at a temperature much above this the soap formed is again decomposed.

Heating for 15 minutes is sufficient, and 2 to 5 minutes in the presence of more than 10 per cent. of fat oils.

For the determination of small quanities of fat oils in mineral oils containing a considerable quantity of hydrocarbons boiling below 662° F., it is best to use sodium, since the anhydrous soap formed dissolves with greater ease in the light hydrocarbons than the hydrous soap resulting from the use of sodium hydroxide, which at the previously mentioned temperature of 392° F., has the tendency of separating in flakes instead of dissolving in the oil. All stirring or shaking in heating and cooling must be avoided.

On heating oils with over 10 per cent. of fat oils a perceptible odor of soap makes its appearance, which remains after cooling. The bubbles of gas and air escaping from the sodium or sodium hydroxide disappear immediately with pure mineral oil, while, in the presence of fat oils they remain as a rule after cooling, the walls of the bubbles acquiring a certain coherence from the soap formed. With transparent oils this phenomenon can be recognized in the presence of ¼ of 1 per cent. of fat oil. By using for the experiments ordinary test-tubes of about 15 to 25 millimeters clear diameter, mineral oils compounded with fat oil form, on cooling, clearly perceptible funnel-like depressions on the surface.

Gelatination of mineral oils containing fat oils takes place at comparatively high temperatures, which, however, can be only approximately determined, the transition of a body from a fluid into a gelatinous condition taking place very gradually and not within such sharp limits as to make the method available for quantitative determination.

Although the limits of determination are not alike for all mineral oils, and perhaps not for all fat oils, 2 per cent. of fat oil in mineral oil can always be determined with certainty.

Preliminary test for the detection of larger quantities of fat oils. To about 5 cubic centimeters of the oil in a test-tube add a small piece of sodium hydroxide; heat the liquid directly over the flame to boiling, and keep it boiling for 1 or 2 minutes. The presence of larger quanities of fat oil is detected by the peculiar empyreumatic smell given off, and by the congealing of the liquid on cooling. There being seldom less than 10 per cent. of fat oil present this, in most cases, ends the test. If a negative result is, however, obtained, proceed as follows:—

Detection of smaller quantities of fat oils (*to 2 per cent.*) Take two medium-sized beakers, of which the one can be pushed into the other so as to leave a space of about 1 or 2 centimeters between the two. Into the larger beaker bring enough melted paraffine to bring its surface, when the narrower beaker is pushed into the larger, half way up between the sides of the two beakers. Then fill the inside beaker with paraffine to the same height. Fluids in test-tubes placed in a paraffine-bath thus constructed cannot be overheated. A thermometer hung in the inner beaker indicates the temperature, which is to be maintained at from 392° to 410° F.

Now supply two test-tubes with a few cubic centimeters of oil; add to the one some shavings of sodium, and to the other a small stick of sodium hydroxide so that the latter is covered by about 1 centimeter of oil.

Place the two test-tubes in the paraffine-bath and note the time; allow them to remain quietly for 15 minutes, then take them out, and, after freeing them from paraffine, let them cool.

In the presence of as much as 2 per cent. of fat oil, solidification takes place in one of the two test-tubes, or generally in both, to a tough jelly, which does not run out by turning the tubes upside down, and can only be detached from them by a smart tap.

Mineral oils and fat oils can be *quantitatively* determined as follows: Saponify 10 grammes of the oil in question with about 4 grammes of sodium hydroxide, 60 cubic centimeters of water, and 10 to 15 cubic centimeters of alcohol. When saponification is complete, expel the alcohol and slightly oversaturate the soap paste with dilute sulphuric or hydrochloric acid. Wash the fatty acids, including the mineral oil, very carefully, until the wash-water shows no acid reaction. Then dissolve the mixture in ether, fill it up to a determined volume, about 100 cubic centimeters, and titrate an aliquot part with standard alkali in the usual manner:

Standard Alkali.

1 cubic centimeter corresponds to 0.282 grammes oleic acid=0.884 olein.
1 " " " " 0.284 " stearic acid=0.890 stearin.
1 " " " " 0.256 " palmitic acid=0.806 palmitin.
1 " " " " 0.270 " fatty acids as mixture of margaric acid=0.848 margaric acid.
1 " " " " 0.258 " fatty acids=0.860 oil.

The difference between the quantity used for the examination and the calculated oil gives the corresponding quantity of mineral oil.

Test for creosote, carbolic acid, and allied substances.

For the determination of creosote, determined volumes of the oil are generally shaken with soda lye, and the decrease in volume which the oil suffers in consequence of yielding creosote, etc., is determined. Graduated cylinders which allow of the volumes being directly read off are used for the purpose. Lye of specific gravity 1.35 to 1.40 is usually employed.

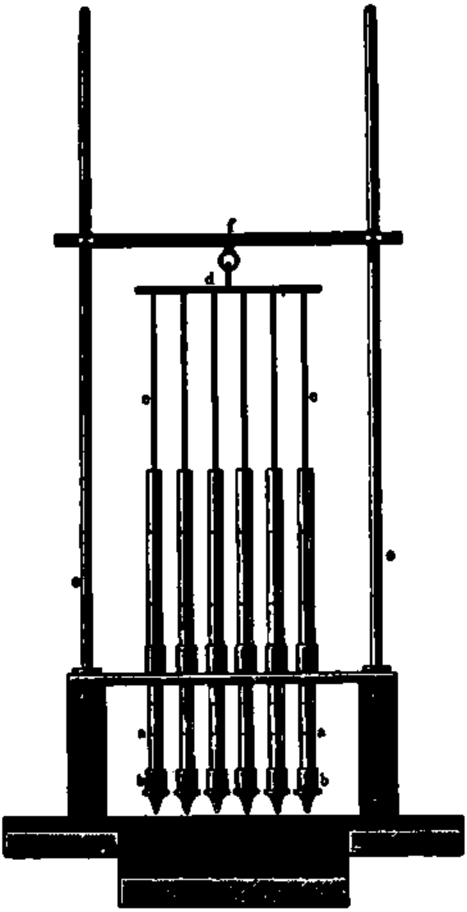
Brenken executes the reaction with soda lye as follows: Bring into a graduated test-tube about 5 cubic centimeters of soda lye of 1.4 specific gravity, add 10 cubic centimeters of oil, shake vigorously, place the tube in a water-bath, and heat. In a few minutes, the entire quantity of the soda lye separates clear. The hot fluid is again shaken and allowed to stand quietly in the water-bath, whereby the soda lye should again separate clear and without loss of volume.

The presence of heavy coal-tar oils in mineral oils may, according to Brenken, be recognized by the appearance of a strong reaction and heating on mixing equal volumes of oil and nitric acid of specific gravity 1.45. But an acid of this concentration attacks more or less every mineral oil and forms nitro-benzine products, so that this method cannot be recommended.

Determination of the constancy of lubricating oils.

It is of great importance that lubricating oils should retain their consistency and not become thickly-fluid when exposed to the air for a short time. The latter property is especially shown by rosin oils or mineral oils mixed with resin. Nasmyth's apparatus for testing the tendency of an oil towards thickening or gumming on exposure to the air is very simple.

FIG. 190.



It consists of an iron plate 4 inches wide by 6 feet long, in the upper surface of which six equal-sized grooves are planed. This plate is placed in an inclined position—say 1 inch in 6 feet. The apparatus is used as follows. Suppose that six kinds of oil are to be tested to determine which of them will for the longest time retain its fluidity when in contact with iron and exposed to the action of air. For this purpose pour out simultaneously at the upper end of each inclined groove an equal quantity of each of the oils under trial. The six oils now make a fair and even start on the race down-hill; some are ahead the first day, and others are still ahead the second and third day, but on the fourth or fifth day the bad oils begin to fall behind by gradual coagulation, while the good oil holds on its course. At the end of 8 or 10 days there remains no doubt as to which oil is the best.

To start simultaneously an equal quantity of each of the oils under trial, Albrecht uses the apparatus shown in Fig. 190. A frame secured to the sides of the iron plate carries six glass-tubes *a a*, one of these glass-tubes standing exactly in the centre over each of the six grooves. The lower end of each glass-tube is provided with a brass socket *b* with conical point and as narrow an opening as possible. These openings are closed by thin pointed brass wires *c* connected on top by the cross-rod *d*. In the centre of this cross-rod is a hook which can be hooked in the ring of the stem *f*. The latter can be raised by means of the rods *e e* and screws. In filling the glass-tubes the openings of the latter are closed by the brass wires. When the tubes have been filled up to a mark the wires are slowly withdrawn and hooked on to *f*.

Distinction of mineral lubricating oils of different derviation.

The determination of the characteristics of oils of different derivation is very difficult. For American and Caucasian mineral lubricating oils the following differences may be taken as a basis: 1. In cooling American oils to 32° F. or below, paraffine is separated and the oils become solid, while Caucasian oils cooled to the same temperature separate no paraffine, and only acquire gradually the consistency first of grease, next of butter, and finally of tallow. If this test leaves the question of derivation in doubt, it is advisable to execute a fractional distillation and to cool off the fractions 25° C. (77° F.) at a time, whereby American oils will be observed to separate paraffine. Galician oil and oil from Pechelbronn flowing wells, as well as oils from Scottish shale and Saxony coal, behave like American oils, while Oelheim and Pechelbronn pit oils correspond more with Caucasian oils. 2. The specific gravity of fractions boiling at the same temperature is higher with Caucasian than with American oils. 3. The refraction of light may also be used for distinguishing heavy mineral oils of different origin, as shown by the appended indices of refraction of separate fractions determined by Engler with an Abbe refractometer.

Variety of oil.	Index of refraction.	
	Fractions 464° to 500° F.	Fractions 554° to 590° F.
Pennsylvania	1.459	1.468
Alsace (Pechelbronn)	1.459	1.467
Caucasus	1.472	1.484
Oelheim	1.473	1.485

The method of distinguishing mineral oils by the absorption of iodine and their behavior towards nitric acid has proven not reliable.

CHAPTER XII.

USES AND PROPERTIES OF PETROLEUM.

Crude Oil.

In localities where crude oil abounds and where coal and wood are scarce, it is used for fuel; otherwise it occupies but a secondary position in this respect, only such oil as cannot be employed for the production of illuminating and lubricating oils being utilized in this manner. For metallurgical purposes it is advantageously used in some localities. A large number of processes have been invented and patented for employing crude oil in the manufacture of iron, amongst others the "Whipple and Dickerson," or "Ambler process" and the "Eames process." Of these the Eames process seems to have been most successful. It has been put in practical operation both in Titusville, Pa., and in Jersey City, opposite New York, and has been made the subject of a most careful and exhaustive examination by Professor Henry Wurtz and Professor R. H. Thurston.[1] The apparatus consists of an ordinary reheating furnace with "generator" and steam-boiler attached. The generator consists of a cast-iron vessel with alternate projecting shelves attached to its sides. The oil on entering the apparatus trickles over the shelves, from which it is swept by a jet of superheated steam. The amount of oil required for this furnace, which is capable of working charges of 3000 pounds, and making steam for the rollers besides, is a maximum of 30 gallons, or 200 pounds per hour. The trickling oil is met by a jet of steam moving in the opposite direction, and is at once completely vaporized under a pressure of about 10 pounds, and is carried into an adjoining furnace.

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[1] S. F. Peckham. Report on Petroleum.

Air subsequently mingles with the steam and oil vapor previously described, and passes the furnace bridge, and burns within the furnace, and then runs beneath the boilers to the flue and stack.

The old bridge is completely bricked up, excepting a space which extends across the furnace closed only by fire-bricks placed on one end, and it is found that if this "combustion chamber" has a horizontal thickness of more than eighteen inches, the fire-bricks are fused.

Crude oil has been used as a *remedial* agent from the earliest times, it being mentioned by both Pliny and Vitruvius. François Arioste discovered, in 1416, on Mount Libio, in the duchy of Modena, Italy, a rock oil, with which he cured men and animals afflicted with itch. In America the Seneca Indians used crude oil as an external application, and in fact in olden times the therapeutical effect of crude oil was considered almost miraculous.

Throughout the oil regions of Pennsylvania petroleum bears a high reputation as an internal remedy in cases of consumption, and there is no doubt of its efficiency as an external application for muscular rheumatism.

Petroleum products.

Of much greater importance is the utilization of a series of products obtained from crude oil by distillation. From the primitive beginning of the utilization of crude oil as such, an industry has been gradually developed, partially by an increased demand and partially by competition, which insures the use and utilization of all the constituents of the crude oil. Although this industry is at present highly developed, it cannot be said that all products are utilized to the best advantage. Thus the intermediate oils between the actual illuminating and lubricating oils are not profitably disposed of, they having to be used either for heating or mixing purposes, and frequently also for the production of gas. The products of petroleum occurring in commerce are known by various names, according to their specific gravities. A classification of these products has been given on p. 74, but for the sake of convenience may here be repeated.

Volatile oils (light essences).

	Specific gravity.
1. Petroleum ether	0.650 to 0.660
2. Gasoline	0.660 " 0.680
3. C-petroleum naphtha	0.670 " 0.707
4. B-petroleum naphtha	0.707 " 0.722
5. A-petroleum naphtha	0.722 " 0.737

Illuminating oils.

1. Kaiseroel (Imperial oil)	0.780 to 0.800
2. Illuminating oil I (American)	0.800 " 0.810
3. Illuminating oil II (Russian)	0.820 " 0.825
4. Standard white	0.808 " 0.812
5. Prime white	0.800 " 0.806
6. Astralin	0.850 " 0.860

Lubricating oils.

1. Solar oils	0.860 to 0.880
2. Mixed oils	0.880 " 0.890
3. Spindle oil I	0.895 " 0.900
4. Spindle oil II	0.900 " 0.906
5. Machine oil I	0.906 " 0.910
6. Machine oil II	0.910 " 0.915
7. Cylinder oils, pale	0.915 " 0.920
8. Cylinder oils, dark	0.920 " 0.950
9. Vulcan oils	0.910 " 0.960

Besides the above-named products, there are found in commerce a considerable number of light, medium and heavy oils with special names, which will be mentioned further on.

Volatile oils (light essences).

The properties and uses of the volatile constituents of crude oil boiling below 302° F. have already been described on p. 74. They are at present employed to a limited extent only, but with the more general introduction of petroleum engines their use will be largely extended. According to the patented process of A. F. Bang and M. C. Ruffin it is claimed that petroleum-ether may be used for rectifying crude spirits on account of its property of dissolving fusel oil and aldehyde and being itself insoluble in alcohol.

The properties of gasoline have been given on p. 74. It is one of the lightest products of the distillation of petroleum and it has not yet been applied to any important industrial use save the manufacture of illuminating and fuel gas. The quantity produced is increasing yearly, so that the cost of this product is decreasing and it is therefore very extensively used throughout the United States as well as Europe for isolated lighting of small towns, railroad stations, hotels, factories and private residences.

The subject of artificial light has become of great importance to all persons, especially to those out of reach of city gas. It may therefore be of interest to enter into the details of producing light from gasoline and to give a description of the most approved machine for the purpose.

The illuminating apparatuses mostly used are based upon the simple principle of allowing a current of atmospheric air to pass over, or come in contact with, a body of gasolene in so-called carburetters. It is a well known fact that the process of evaporation produces refrigeration, and as the process of making gasoline gas consists simply in the evaporation of gasoline by its coming in contact with the above mentioned current of air, it follows that there is a sensible loss of heat while the gas is burning, and unless this loss is restored, there would be, in the course of a few hours, a marked diminution in the quality of the light.

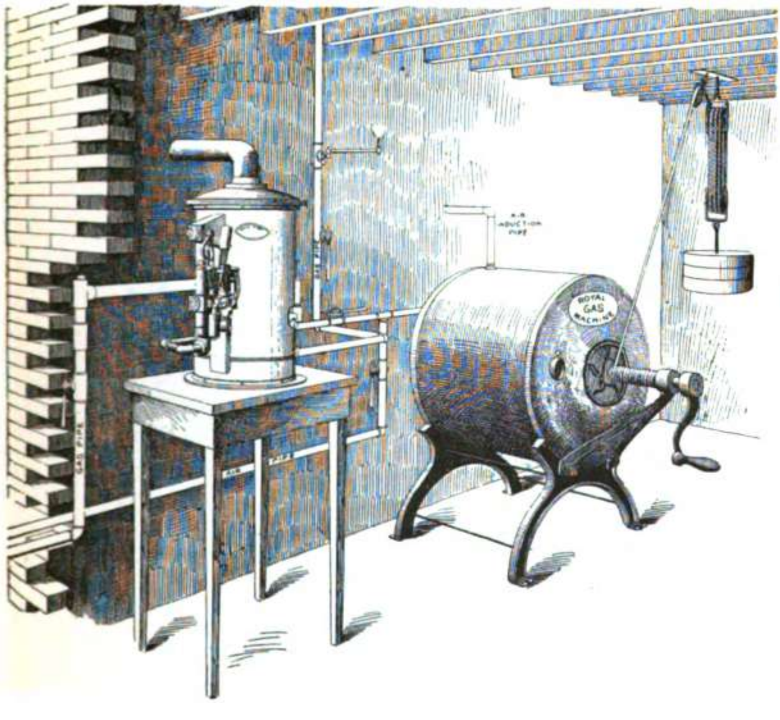
A typical machine for the manufacture of this quality of gas is the Improved Royal Gas Machine, manufactured by the Pennsylvania Globe Gas Light Company, of Philadelphia, who are the owners of the patents. Thousands of this machine are in daily use throughout the United States, and we are credibly informed that not a fire has occurred from one of them, nor a life been lost. The machine has been accepted and approved by the National Board of Underwriters, and in using it there is no increase in insurance rates.

[illegible] working [illegible] Fig. [illegible] power of [illegible] the [illegible] contact

[illegible]

with the body of gasoline in the carburetter, while the gas [illegible] is conveyed to the house through the pipe [illegible] is the pipe for filling the carburetter, and F the vent pipe. The carburetter is buried in the ground about [illegible] feet below the surface, at any convenient distance from the house. By the adoption of this plan any danger connected with this mode of lighting is entirely obviated, it being impossible for fire to communicate in any way with the gasoline. Neither does this arrangement mar the appearance of the ground, as the lawn or garden can be as smooth and level as though it had never been disturbed. The carburetter being in direct contact with the earth, the temperature of which at the above-mentioned depth is about 50° F., it is in obedience to the law of nature that the loss of heat in consequence of vaporization is immediately restored to the carburetter by the warmth surrounding it.

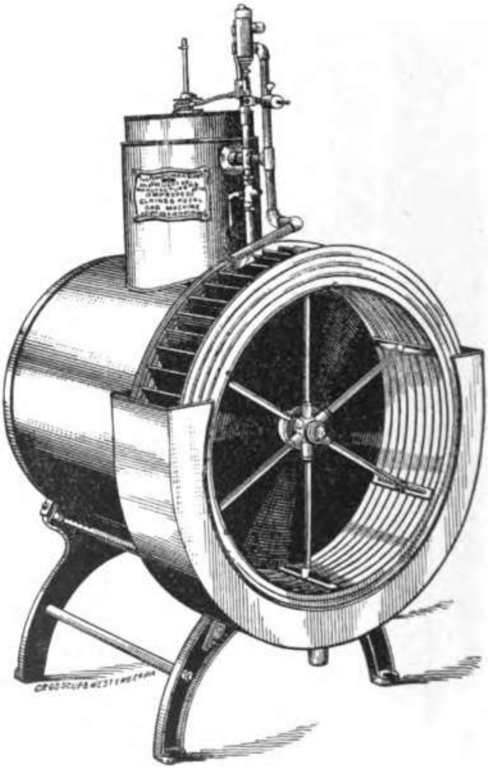
FIG. 192.



The blower or air pump is placed within the building, usually in the basement, and as shown in Fig. 192 is propelled by cord, pulleys and weights. It requires no manipulation excepting to be wound up once or twice a week. Where a flow of water can be obtained, it is recommended to use the blower shown in

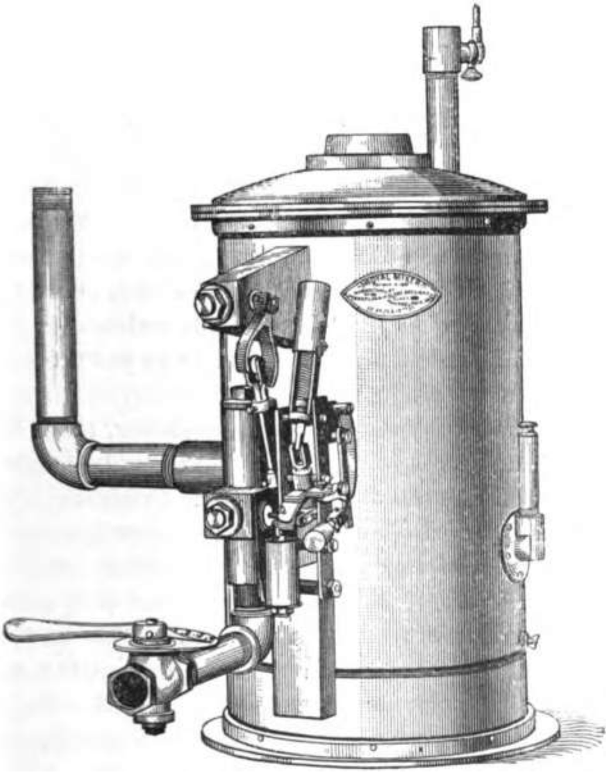
Fig. 193, which is propelled by water power. The holder on top of the blower regulates the flow of water through a valve, in proportion to the number of burners lighted. The blower is automatic in its action, and when the burners are not in use, the water ceases to flow over the wheel. The action of the blower is perfect, producing a uniform and steady volume of air. No attention is required for the winding of weights, oiling of pulleys, etc.

FIG. 193.



A novel and improved appliance has recently been adopted which makes the gas from this machine practically equal in quality in all respects to city gas. This consists of an air *mixer* shown separately in Fig. 194, and connected with the machine in Fig. 192. It is constructed on practical scientific principles. It is automatic in its action and produces a gas, which, when burned through a plain open burner gives a uniform light free from smoke, abolishing the necessity of adjusting burners which required some attention in the old style machines. The apparatus is durable and reliable, and the only attention required is the moving of the handle on the index dial, by which means the gas can be changed to any desirable quality.

FIG. 194.



Taking into consideration the candle power of light, it may safely be said that no artificial light has ever been produced that will compare with this in cheapness, safety and reliability. It has been found from numerous tests that the quantity of gasoline necessary to produce a thousand feet of gas does not exceed six gallons.

The cost of each light equal to an ordinary city gas-burner of about 5 cubic feet is about one-half cent per hour. City gas usually costs from $1.00 to 2.00 per thousand cubic feet, while the gas manufactured by this type of machine will average from 60 to 80 cents per thousand when compared with coal gas, the difference in cost depending entirely on the location of the supply of gasoline. A great deal can be saved in the cost of this material by applying to those who are accustomed to handling it, as there are special methods of transportation which make it more economical and safer for the consumer. As compared with petroleum lamps, the cost is about the same for an equal number of lights, but if the estimate is based on the quality of light furnished, the cost is 50 per cent. cheaper, and 90 per cent. safer.

In districts where coal gas is not accessible, gasoline is also frequently used for lighting streets, and by their system the Pennsylvania Globe Gas Light Company furnishes a light resembling that of coal gas so closely that none but experts can distinguish the difference. Upon the outside of any street lantern is placed a reservoir holding sufficient fluid to burn one night. Connected with this reservoir is a pipe and valve to which is attached a patent burner that is practically a miniature gas machine. By chemical process the fluid flowing into the burner is vaporized, and when mixed with air—entering the side of the burner—becomes a gas which burns with great brilliancy and power.

The properties and uses of *C*, *B*, and *A* naphtha have already been described on p. 75.

The classification of the various products of crude oil boiling below 302° F., as given on p. 554, has been generally accepted. However, it may here be remarked that in no other branch of the petroleum industry exists such confusion as in this, some factories bringing into commerce the same products under all kinds of names, and *vice versa* all kinds of products under the same name.

Use of petroleum and its products for driving motors.

For small powers where steam cannot be used, because of the complication, nor gas, when there are no gas works in the neighborhood, petroleum engines supply a want and have no doubt a great future before them. It is a peculiarity of these motors that the fuel is delivered to them, direct, so to speak, in its original condition. In a steam engine the water must first be evaporated over a furnace; in a gas motor the working agent must either be distilled in a retort, or produced in a generator. The fuel for a petroleum engine may be purchased anywhere. No previous conversion into vapor is needed before it is delivered to the engine, and thus the cost of an additional gasifying or evaporating apparatus is saved. An oil-engine is self-contained, and independent of any external adjunct, but to turn this advantage to account the difficulties of the constructor are somewhat increased. Not only must the engine be designed to utilize the working agent, and obtain mechanical energy from it, but the working agent must itself be produced and the fuel prepared for combustion. This rather complicates the working of the motor, since it must vaporize the oil, keep the quality of the spray produced uniform, and make it a proper medium for the heat imparted to it.

There are two methods by which oil may, in the cylinder of an engine, be turned into a source of energy, viz.: Light petroleum spirit, naphtha, benzine, or carburetted air is exploded, and drives out the piston of an engine by the expansion of the gases, or ordinary illuminating or intermediate oil is used to drive an engine by explosion and expansion, after its evaporation and conversion into petroleum spray. In the first case, atmospheric air at ordinary temperature and pressure is charged with volatile spirit, while in the latter the petroleum is pulverized and broken up into spray by a current of air, with the addition of heat.

It must not be supposed, however, that all oil engines can be rigidly classed under either of these two divisions, because of the complex nature of petroleum, and the different temperatures at which it evaporates.

The earliest attempts to use petroleum to produce mechanical energy were made soon after the introduction of gas engines. At that time, however, it was considered impossible to use ordinary petroleum of about 0.800 specific gravity, because the difficulty of evaporating it was so great. To break it up into spray by a blast of air had not been proposed.

The Brayton engine and the Hock engine appeared almost simultaneously, the former having been patented in the United States and the latter in Austria. Brayton was the first to employ ordinary heavy petroleum and kerosene, boiling at about 302° F. in the cylinder of an engine, instead of light spirit or essence. In the Hock engine benzine or volatile hydrocarbon gas, drawn from a reservoir at the back of the horizontal cylinder, was used.

S. Marcus, of Vienna, uses light hydrocarbons (boiling below 302° F.) in the motor constructed by him. The chief advantage of this motor is its adaptability without difficulty to various industrial requirements. Its principal characteristics are:

1. The use of a peculiar apparatus for the production of a dynamic mixture which is formed from petroleum and air. The inventor calls this apparatus the "vaporizer."

2. The igniting contrivance.

3. The use of a closed cylinder or lid has the double purpose of serving for the reception and expansion of the dynamic mixture, and as a compression-air pump.

However, the engine is also constructed with the use of an open cylinder upon the principle of Beau de Rochaz's four-cycle.

With the first movement of the piston from the rear cylinder-bottom in the direction of the shaft, the dynamic mixture is sucked from the vaporizer; with the second movement—the second cycle—the piston returns to the bottom of the cylinder and compresses the dynamic mixture; at the beginning of the third cycle, as soon as the piston commences its forward motion, an electric spark ignites the gas mixture, by the explosion of which the piston is forced forward and converts the heat developed into work. Finally, the fourth cycle signifies the return of the piston to the bottom of the cylinder and the expulsion of its exhaust gases, which are discharged colorless and odorless.

If the motor is of the two-cycle type, with cylinder closed on both ends, the dynamic mixture is sucked in, ignited and exploded on one side of the piston with the first cycle, the air being simultaneously compressed and forwarded on the other side of the piston. The second cycle discharges, on the one hand, the exhaust gases, and on the other, draws in air. The general construction of the motor will be understood from the following description: The petroleum, crude oil or benzine is vaporized by means of revolving brushes, secured to the periphery of metallic disks. These brushes revolve in a holder partially filled with petroleum, and deposit the fluid taken up upon several polished strips, the petroleum being thereby atomized into infinitesimal particles which are absorbed by a current of air passing by the holder. The mixture of air and petroleum thus formed, is conveyed for the production of energy to the working cylinder of the motor, where it is exploded by an electric spark.

The atomizing apparatus as well as the firing contrivance is kept working with a minimum expense of power by the motor itself.

The vaporizer completely atomizes and vaporizes the fluid, works very economically, and is easily manipulated; it possesses no parts subject to strong wear or frequent repairs. Its use renders possible a uniform and reliable formation of oxyhydrogen gas, and allows of the use of less volatile substances, whereby the expense of running the motor is reduced.

The igniting apparatus is reliable even in damp rooms, and entirely free from danger of fire, the spark being generated in the interior of the exploding space. The Marcus motor may also be used as a gas-motor.

The peculiar mode of atomizing the petroleum in connection with the utilization of the hot exhaust gases, which constitutes a part of the patent, allows not only of the use of very volatile petroleum products, but also of relatively heavier kinds of oil.

Sufficient quantities of working gases are produced by a slight revolution of the fly-wheel; and the automatic igniting apparatus becoming simultaneously active, the motor can be readily and in a very short time set in motion.

Vaporization (production of the dynamic mixture) keeps up with the revolution of the fly-wheel, so that the velocity of the piston can be materially increased. On account of the practical arrangement of the mechanical construction, the limit of the velocity is much greater than with engines of similar construction, and even small motors may make 300 revolutions per minute.

By numerous experiments it has been determined that a horse-power performed by the Marcus motor consumes, on an average, 0.4 kilogramme (0.88 lb.) of oil per hour. The consumption, as a rule, will, of course, be smaller with large, powerful machines, while with very small motors of 1 to 1½ horse-power it may increase to 0.5 or 0.6 kilogramme (1.1 or 1.3 lbs.) per hour and horse-power.

Fig. 195 shows a two-cycle motor with horizontal cylinder *a*, which, in this case, is entirely closed. The front side of the cylinder is screwed to the frame *b*, which, besides the bearings for the fly-wheel shaft *p*, the reversing shaft *s*, and the guide for the cross-head, contains in the interior a holder for compressed air.

Like in a horizontal steam engine, the work of the piston is transferred by means of the piston rod with cross-head and drawing rod *l* to the fly-wheel shaft. The fly-wheel *o* is keyed upon the shaft.

The entire machine rests upon a cast iron base *c*, which contains the electric igniting apparatus *t*, and the petroleum holder with the vaporizer *d*. The cylinder is jacketed so that it can be cooled by water. On the side of the cylinder is the slide *f* with the electrical contact (spark producer) and the cock *g* for the admission of the dynamic mixture and of air. The cylinder is also provided with the exhaust-valve *v* and pot *e*, the governor *h*, the suction-valve *i*, and the compression-valve *k*; finally with the compression-cock *n*, the eccentric *x* with lever-motion for the magneto-electrical igniting apparatus, and a safety-valve, *y*, on the holder for compressed air.

FIG. 195.

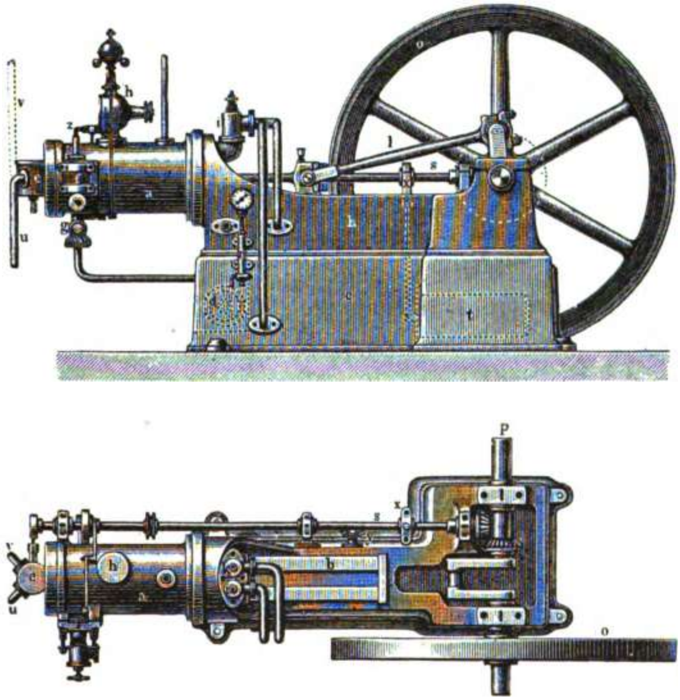


Fig. 196 shows a four-cycle motor with a vertical cylinder, *a*, open on one side and secured to the standards b, b_1. The upper bearings of these standards serve for the fly-wheel shaft *p* and the lower for the beam-shaft *q*. The work of the piston is transmitted to the fly-wheel shaft by the beam *r*, which swings around the shaft *q*, and the two drawing-rods, l_1 and *l*. The other constituents of the motor are the same as in the two-cycle motor.

Fig. 196.

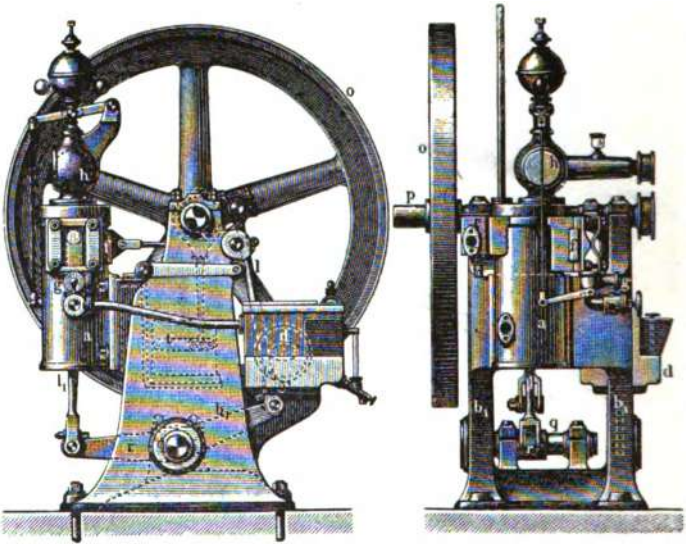
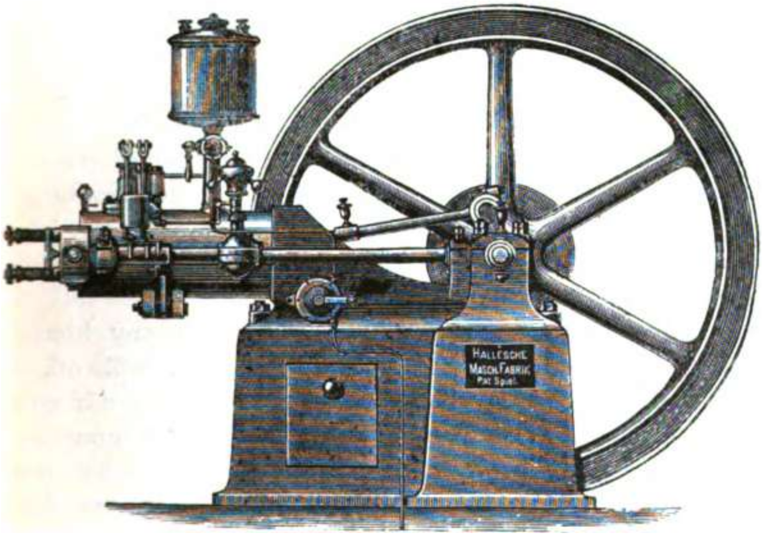


Fig. 197 presents Spiel's petroleum motor. The engine is horizontal and single-acting, standing on a solid base, with the reservoir of oil above. The organs of admission, distribution and exhaust are worked from an auxiliary shaft, geared from the main shaft in the usual way. The exhaust is opened by a cam and levers from this shaft, and ignition is by a flame carried in a slide valve, working at the back of the cylinder; the Spiel being probably the only oil-motor firing the charge in this way. A portion of the compressed charge of oil and air in the cylinder passes through a grooved passage to a chamber in the slide valve which, as the slide is moved by a cam on the auxiliary shaft, is brought opposite a permanent flame in the valve-cover, and fired. A spring effects the return movement of the slide-valve, when released by the cam, and the lighted mixture is brought in line with the cylinder port, when the remainder of the charge is fired. The pressures of the charge in the cylinder, and of the flame in the ignition port, are equalized by means of a small passage connecting them.

FIG. 197.



The oil is drawn from the reservoir and injected into the cylinder by a small pump, the piston of which is worked by a cam, lever and spring from the auxiliary shaft. The air-admission valve is also in connection with a cross-head attached to this pump. At the bottom of the pump is a double-seated horizontal lift valve, usually held open by a spring, in which position it communicates freely with the oil reservoir above. When the plunger pump is driven down, carrying with it the cross-head, the air-valve is first lifted, and air enters a mixing chamber at the back of the cylinder. As the piston continues to descend, the horizontal valve is closed and a passage opened from the pump into the mixing chamber.

The pump sends a jet of petroleum-spirit into the air, and in its passage it is broken into spray by striking against a projection. Thus the out (admission) stroke of the motor piston sucks into the cylinder a stream of air mixed with petroleum spray. The engine has a ball governor which, if the speed be too great, interposes a small projection between the valve-rod of the pump and the levers working it. The two become locked and cannot move, and the valve remains open, admitting air only to the cylinder, until the projection falls back, and the speed is reduced.

The consumption of oil with the motor making 180 revolutions per minute is about 1 lb. per horse-power per hour. With a 14 horse-power Spiel engine, having a cylinder diameter of 9½ inches, with 18 inches stroke, and making 160 revolutions per minute, the consumption of naphtha was 0.81 lb. per horse power per hour. The specific gravity of the oil used was about 0.725.

The *Priestman petroleum motor* uses almost any kind of heavy petroleum, but is not suitable for light, volatile oil. It is described by Mr. Bryan Donkin, Jr.,[1] as follows: "It works best with common petroleum, having a specific gravity of 0.800 and flashing point of 100° F., but it may also be driven with heavy Scotch paraffin of 0.820 specific gravity and flashing point 150° F. Even common creosote of still lower density is available, but there are practical difficulties in the way of using it. Of course, the heavier the oil the thicker the residuum will be, and the more carbon is deposited in the engine, the oftener it must be cleaned. Nor can these very heavy oils be properly treated in an engine cylinder, by raising the temperature. If the oil is too much heated it is converted into oil gas instead of vaporized spray, and tarry deposits accumulate in the working parts. The proper temperature of the charge of oil vapor and air on entering the cylinder has been determined by experiments at from 170° to 300° F., according to the size of the engine. The proportions are 191 cubic feet

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[1] A Text-Book of Gas, Oil. and Air Engines. London, 1894.

of air to 0.015 cubic inch of oil vapor for a 1 horse-power engine.

"The horizontal motor cylinder of Priestman's engine is divided from a compression space, the proportional volumes of the two being—clearance or compression, 88 cubic inches; volume described by the piston, 191 cubic inches for a 1 horse-power nominal engine. The piston works on to a crank shaft through a connecting rod. At the back of the cylinder are two valves—inlet and exhaust. The exhaust is worked by an eccentric on the auxiliary shaft revolving at half the speed of the crank shaft, to which it is geared by wheels in the usual proportion. In the Priestman, as in most other oil-engines, ordinary lift-valves are used of a simple type. Unless almost perfect combustion is obtained, there is much more deposit than in gas engines. The simpler the valves, the less liable they are to become clogged.

"The most important parts of the engine are the vaporizer and spray-maker. The oil tank is under the crank shaft, and, when full, is sufficient to last for two or three days. A glass gauge shows the level of the oil. A small air pump is worked by an eccentric which also drives the exhaust valve. The air to supply this pump is filtered through gauze and cotton wool, and is then compressed into the oil tank at a pressure of 8 to 15 lbs. per square inch above atmosphere. This pressure forces two streams of oil and air into the spray-maker, from whence they are injected into the vaporizer. The oil is drawn from the bottom of the tank, the compressed air from the top, above the level of the oil, and both pass through a six-way cock. When this cock is set upright, the supply of oil and air to the spray-maker is cut off; when the cock is turned to the right they are admitted, and when set to the left they pass to a small lamp below the vaporizer, used to heat it when starting the engine.

"The spray-maker is one of the most ingenious parts of the motor. The oil and air are injected into the vaporizer through two concentric nozzles. The pulverization of the oil and its complete mixture with the air depend on the shape of the nozzles, and their exact form has only been determined by numerous experiments. The oil passes through the central tube in a small stream, and, on being ejected from the mouth of the nozzle, spreads out in a fan shape. The annular air nozzle surrounds the central oil orifice, and the air is turned back with considerable force to meet the issuing of oil at more than a right angle, the result being that both are violently driven out in a spray as fine as required. The oil and air from the spray-maker enter at the pressure of the air-pump. At the same time the in-stroke of the motor piston lifts the non-return valve and draws into the vaporizer a supply of air from the outside through a throttle valve. This auxiliary charge enters through a number of fine holes in the circular air passage of the vaporizer and a filtering layer of cotton wool. The sudden inrush of fresh air sweeps forward the oil and air with it into the cylinder.

"The vaporizer is divided into two parts. In the first the oil and compressed air are mixed with, and broken up by, the air admitted through the above-mentioned throttle valve; in the second the charge is completely vaporized by the heat from the exhaust gases, which, at a temperature of about 600° F., are led through a pipe round the vaporizing chamber before being allowed to escape into the atmosphere. Thus, there are two admissions of air—one to the spray-maker under pressure from the oil tank, the second at atmospheric pressure to the vaporizer through the throttle-valve. In each case the oil is sprayed, and is thus twice pulverized before the actual vaporization by heat begins. Unless the heat from the vaporizer were also applied to the oil spray, it would condense and separate from the air before reaching the cylinder. The vaporizer is contained in the frame of the engine, under the cylinder. The speed of the engine is regulated by means of a spindle above the throttle valve. It contains a small V-shaped opening through which the oil is admitted from the tank to the spray-maker, and the wing of a valve is keyed to the lower part of the same spindle. The size of the sharp end of the V-shaped opening, which is presented to the passage of the oil, can be exactly regulated to admit a given quantity. If the speed is too great the contrifugal governor, which is connected to the spindle by levers, drives it down and partly contracts the opening admitting the oil from the tank. At the same time it acts upon the throttle valve, and reduces the quantity of outer air passing to the vaporizer. Thus the governor acts by diminishing the strength of the explosions, not by cutting them out altogether, and the proportions of oil and air are always the same per stroke. As no explosions are ever missed, the engine works with great regularity.

"The charge after being thus converted into spray and completely volatilized passes through the automatic admission valve to the back of the cylinder. Here the usual series of operations, carried out in the internal combustion engines of the four-cycle type, takes place. The first out stroke draws in the air through the throttle valve; the charge is then mixed in the vaporizer, passes through into the cylinder, and the next stroke compresses it into the compression space. As the inner dead point is reached, the mixture is fired by the electric spark, the explosion drives out the piston, and, during the next back stroke, the exhaust gases are discharged into the jacket round the vaporizer and thence to the atmosphere.

"The electric spark for firing the charge is generated in a battery. Two platinum wires are conducted from this battery to the igniting plug inside the compression space, where they are insulated in porcelain tubes; contact is established at the right moment by a projection on the eccentric rod, and an intermittent spark is produced.

"The shaft driving the eccentric has three functions to perform. It causes the electric ignition of the charge; it works the valve to open the exhaust, and it drives the small air-pump, through which the oil and air are sent from the tank to the spray maker. A small hand-pump is used to pump air into the oil tank before the engine is at work. To start, all that is necessary is to work the handle of the pump, and to turn the six-way cock, that a supply of oil from the tank may reach the lamp below the vaporizer. When the lamp is lit, a few turns by hand are given to the fly-wheel, to draw a charge into the cylinder, the electric current is switched on, and the engine begins to work. The oil tank and vaporizer are easily accessible through the opening in the frame."

The type of the Priestman engine made in this country resembles the straight-line steam engine of Professor Sweet. Professor E. Thompson uses pure silver igniter electrodes in lieu of platinum, as in the English engines. He considers them better, and the wires do not get blackened or coated. His oil engine is started with gas, which is more convenient than oil for the lamp, and it runs at about 260 revolutions per minute.

Lenvic's petroleum motor is also based upon the principle of cold pulverization. Condensing chambers, which are screwed to the cylinder, form a special feature of this motor. The object of these chambers is to act as preparatory heaters to increase the temperature of the gases in order to render complete combustion possible. The motor is furnished with three distributing valves; one connects the cylinder with the valve chest, while the other two convey carburetted as well as atmospheric air into the valve chest. The piston sucks both kinds of air into the cylinder, where they are mixed with pulverized gasoline. When condensation has taken place in the cylinder, the gas mixture is ignited by an electric spark. The motor requires about 400 grammes (14.11 ozs.) of gasoline per horse power per hour and with a velocity of 200 revolutions, does the work of three horse-powers.

The *Daimler Motor Company, Cannstatt*, manufactures stationary petroleum motors for industrial purposes, as well as for driving small boats. The motor is essentially a gas engine, which automatically produces the required gas from the oil, and conveys it for combustion into the working cylinder. Low-boiling petroleum fractions of 0.680 to 0.700 specific gravity are used. A cylindrical brass vessel is filled half full with oil; through this oil atmospheric air is sucked and saturated with hydrocarbons (principle of the carburetter). The production of an explosive mixture with atmospheric air is managed by a regulating cock in front of the combustion-space. If cold air is carburetted it takes up more hydrocarbons, and hence more fresh air has to be introduced. The consumption of oil amounts, on an average, to 0.6 quart per horse-power per hour, and since the motor is automatically provided with gas, all danger from explosion is excluded. The ignition of the gases is effected by a cap kept red hot.

The oil-engine made by Altmann and Küppermann of Berlin is compact and simple. It is vertical, and the piston works upwards on to the crank. Admission, ignition and exhaust are effected from a small auxiliary shaft, worked from the main shaft by two sets of conical wheels. The petroleum is drawn from the reservoir through a suction valve and delivered by a small pump with adjustable stroke into the vaporizer, a shallow vessel heated by a spirit lamp below. The lamp is protected by a cover, and the hot ignition tube projects into the flame. A separate receiver, into which air is compressed by an india-rubber valve, feeds the lamp. The vaporized oil then passes to another valve chamber, where it is diluted with air before entering the cylinder. Here it is exploded and expands in the same way as gas, the usual Beau de Rochas four-cycle of operations being carried out.

In the petroleum-motor of List Bros. (German patent, No. 42,292), the vaporization of the oil is effected by the exhaust gases flowing round and heating the motor. The oil introduced by a pump is thrown against the hot sides, divided, partially vaporized, carried along by the heated air meeting it, and completely pulverized.

G. Ragot's motor (German patent, No. 45,019), is arranged similar to List Bros.' machine.

The gas-producer of F. Wintham (German patent, No. 41,419) which serves for the production of peculiar gas mixtures, consists of a combustion-space surrounded by a condensing chamber, the gasification of the material employed taking place in the latter. The gas produced is conducted to a mixing chamber where it is mixed with air, or air and steam, and then blown under pressure upon a red-hot grate or a filter. With the use of fluid hydrocarbons the effect in this apparatus is attained and maintained by the production of a white heat upon or in the grate or filter. The gases resulting from combustion pass under pressure into an engine, and constitute the driving power. The necessary air may be heated by the exhaust gases radiating heat.

The characteristic feature of Dr. M. V. Schiltz's petroleum motor is the arrangement of the valves by which the preparatory heating of the explosive mixture is rendered possible. The engine uses the four-cycle; the mixture is sucked in, compressed, ignited when compression is complete, and the products of combustion are expelled. The mixture of air and oil is effected in a zigzag channel, with a large vaporizing surface which surrounds the explosion-space, and is to be heated by it. Through this channel the working piston sucks in air, and in it a small pump accurately measures and injects the quantity of oil required for each working period. The oil is pulverized to mist by the strong current of air, and the mist is thrown against the warm walls, where it vaporizes, and is intimately mixed with air. The mixture is thus finished before it passes from the evaporating space through the admission valve into the explosion-space. An ordinary illuminating oil flame serves for igniting the mixture.

F. Wilhelm, of Erfurt, and J. Hargreaves have constructed motors suitable either for illuminating gas or petroleum.

In M. E. Durand's motor only the light volatile constituents of the oil are used, the heavy hydrocarbons being allowed to accumulate on the bottom of the carburetter. The motor consumes about 0.667 quart of benzine of specific gravity 0.710 per horse-power per hour.

Further, may be here mentioned the engines constructed by

J. H. Knight and Harfield (described in The Engineer, 1889, p. 136), by A. E. Tavernier and L. B. Schlesinger, C. V. Korytynsky's engine (German patent, No. 46,128), the motor of the Société des Tissages et Ateliers de construction Diederichs, at Burgoïn, France, and the engine of E. Capitaine, of Berlin.

E. Butler's engine works according to the compound principle. The petroleum engine of G. W. Weatherhogg, of Swenderbury, is a six-cycle engine, with a scavenger charge of air introduced and expelled between each admission of oil-vapor and air. The oil is injected by a pump into a vaporizing coil heated by a blow-pipe flame, and in its onward passage to the cylinder is diluted with the proper proportion of air. Ignition is by hot tube.

Contrivances have also been constructed so that the gas produced may serve not only for driving the engine but also for feeding the heating flame and the igniting flame. Such an apparatus has been constructed by H. Wadzeck, of Berlin (German patent No. 48,637). By a peculiar arrangement of the valves an intimate mixture of the produced gas with atmospheric air is effected by counter-current, and then the gas and air are simultaneously shut off. In this apparatus vaporization of the petroleum products takes place, and at the same time a distribution of the vapors produced for the motive power, as well for the heating and igniting apparatuses.

It has also been proposed to use petroleum vapors as a direct substitute for steam in driving engines. Chevillard describes a motor with petroleum vapors, invented by de Quillfeldt, and constructed by the Societé Anonyme des anciens etablissements Cail, as follows:[1] The peculiarity of this motor is found in the production and use of petroleum vapors which are generated in a manner similar to steam in a boiler, a portion of the vapors being used as motive power and a portion for maintaining combustion. The boiler resembles a serpentine-tubular boiler, and the actual motor a three-

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[1] Revue Indust., Febr. 23, 1889.

cylinder single-acting engine, arranged in compact form below the boiler. The portion of the petroleum serving as motive power is condensed, and again conveyed to the vaporizer. In this manner the engine is made entirely self-acting.

The consumption of oil is claimed to be 4.5 quarts per horse-power per hour. Since oil vaporizes and condenses more readily than water, a very small heating surface suffices for the production of a large quantity of oil-vapor.

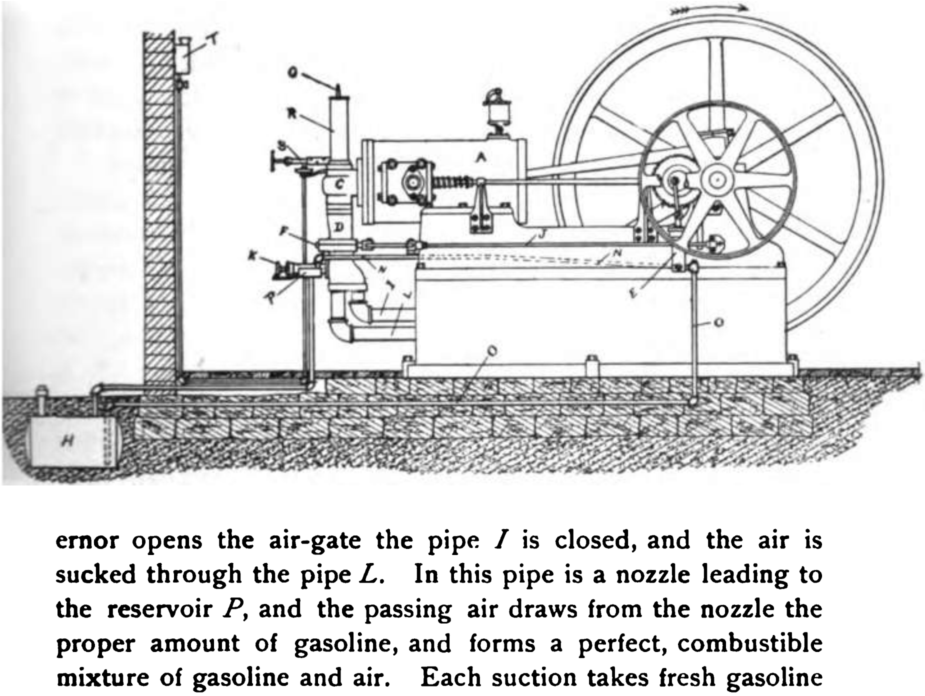
According to a lecture by A. F. Yarrow before the Institution of Naval Architects, experiments in the use of hydrocarbons for feeding steam boilers led to quite favorable results. The hydrocarbons are evaporated in the boiler in the same manner as water, and the vapors evolved brought for expansion into an engine; they are then carefully condensed and reconveyed to the boiler. Benzine of specific gravity 0.725 to 0.730 was used, the consumption amounting to about 5½ quarts per hour. The evaporating temperature being very low, there is said to be no danger of coke-like deposits in the engine and pipe connections.

Instead of benzine a cheaper hydrocarbon (gas oil, paraffine oil) was used as fuel, a considerable saving being thereby effected, so that about 6.5 quarts of this heavy oil were used per 4 horse-powers per hour.

The *Fairbanks-Charter* engine made by Messrs. Fairbanks, Morse & Co., of Chicago, is shown in Fig. 198. *A* is the cylinder, *C* the inlet valve to cylinder, *D* mixing chamber, *E* gasoline pump, *F* air gate, *H* the gasoline supply tank; *I* and *L* are air suction pipes, *J* is a rod coupled to the air-gate and operated by the governor, *K* supply regulating valve, *N N* pipe from pump to reservoir *P*, *O* supply pipe from gasoline tank to pump, *P* is a brass pan or reservoir, *Q* ignition tube, *R* chimney, *S* a Bunsen burner, *T* the burner supply tank.

The fly-wheel runs in the direction of the arrow. The pump *E* works constantly, and keeps gasoline in the small brass reservoir (holding ¼ pint) at a level fixed by the height of the overflow-pipe, which returns the surplus to the supply tank. The pump is very simple, and of such capacity that excessive wear will not prevent its supplying plenty of gasoline. The governor on crank shaft operates the air-gate *F*, whenever a charge of gas is required. The air-gate *F* is a brass-plate having two holes so arranged that in normal position a free passage of air is allowed through the pipe *I*. When the governor opens the air-gate the pipe *I* is closed, and the air is sucked through the pipe *L*. In this pipe is a nozzle leading to the reservoir *P*, and the passing air draws from the nozzle the proper amount of gasoline, and forms a perfect, combustible mixture of gasoline and air. Each suction takes fresh gasoline from the reservoir, always the same quantity as controlled by supply or throttle-valve *K*, and the charges of gas are therefore of equal strength and value.

FIG. 198.



The ignition tube *Q*, is kept at a uniform heat by a simple gasoline burner, furnished with the engine. This tube is surrounded by an asbestos-lined chimney *R*, which retains the heat.

The water tank varies with size of engine and holds sufficient water to keep the cylinder at a proper temperature. The heat of the cylinder causes the water to circulate, the heated water going to the top of the tank, the cold water entering the cylinder from the bottom of the tank. The same water is used continually, there being a very slight loss from evaporation. Running water is often used, dispensing with the water tank and saving the space required for it.

A motor made in several types, stationary and portable, is made by the Vanduzen Gas and Gasoline Engine Company of Cincinnati, Ohio. The admission, ignition and exhaust valves are worked by rods and cams on an auxiliary shaft below the crank shaft and revolving at half the speed. The engine is fitted with a carburetter, though no heat is used to vaporize the oil. An incandescent tube is used for igniting the charge.

The Union Gas Engine Company of San Francisco manufacture several types of engines in which the motive power is derived from either gas or gasoline. One of these engines, the Pacific, which is also manufactured by the Globe Gas Engine Company of Philadelphia, is especially adapted for marine use. It uses the ordinary four-cycle, with electric ignition. It is fitted with reversing gear and has a clutch-lever for starting and stopping the propeller shaft. Water for the cooling jacket is drawn from and returned to the water round the boat. The engine itself is never reversed, but only the direction of motion of the propeller and secondary engine shafts. The same Company also make the Union and Regan gas and gasoline engines.

Use of petroleum for illuminating purposes.

Petroleum possessing the great advantages of an almost inexhaustible supply and consequent cheapness, of burning without smoke or odor and yielding a beautiful light, has caused such a revolution in artificial lighting that the use of vegetable and animal oils for that purpose has been almost entirely abandoned.

American illuminating oils are classed and sold, according to their color, as "Water white," "Prime white," and "Standard white," the latter term being chiefly applied to the products of the Standard Oil Company. The term "Kerosene" was originally used by an American firm as a trade mark for its heavy oils, but it has been gradually applied also to illuminating oils, and those of Russian origin are to-day known under that name.

Under the names "Mineral sperm," "Astralin," "Kaiseröl" (Imperial oil), "Pyronaphtha" and "Möhring oil," illuminating oils of American and Russian origin are distinguished by their great safety as regards fire. They are prepared from the portions of petroleum boiling at a higher temperature and from their specific gravities and boiling points form the transition from the actual petroleum to the intermediate and heavy oils.

On account of its chemical and physical properties petroleum is chiefly employed as illuminating oil in lamps; all other modes of use being of but secondary importance.

Without entering into a description of the historical progress of the evolution of the lamp, it may here be briefly mentioned that its form and arrangement have been changed in correspondence with the illuminating material. From the most primitive form of an open vessel, called *Tschirak* in the Caucasus, in which animal and vegetable oils boiling at a high temperature were burned, it gradually assumed the closed form with a vertical arrangement of the wick for more fluid vegetable oils (rape oil, olive oil). The introduction of petroleum, however, brought about a complete transformation of the lamp.

Each lamp consists of three principal portions, viz.: the oil-holder, the burner and the chimney, the latter serving for the conveyance of air as well as for a protection against exterior air movements. To be sure there are lamps without chimneys, but they burn badly or require complicated contrivances. According to the construction of the burners, the lamps may be divided into two principal groups, viz.: lamps with flat burners and lamps with round burners; the latter may be constructed with or without a flame-disk and the former with two wicks (duplex burner) or with four crosswise wicks. Generally speaking, the round burner is more complicated, while the flat burner is more simple.

To understand the importance of the several constituent parts of the lamp, it will be necessary to consider more closely the activity in burning. Above all it is of importance to consider the behavior of the wick and of the petroleum to each other, and to determine conditions necessary for the attainment of the best illuminating results.

The wick of a lamp consists, as is well known, of a capillary system through which the oil ascends to the flame. The force with which the oil is sucked up through the wick decreases with the lowering of the oil in the holder, the friction becoming constantly greater and the velocity of the current of oil less. The gradual decrease in the supply of oil also affects the intensity of the flame, it becoming weaker, the extent to which this takes place, being chiefly dependent on the properties of the illuminating material used. Besides the construction of the lamp, which has considerable influence upon the intensity of the light, it is frequently supposed that specifically heavier varieties of petroleum ascend in the wick with greater difficulty than specifically lighter. Beilstein, as well as Engler and Lew, have, however, shown that the ascent of the oil in the wick depends solely on its viscosity, and that Russian petroleum is sucked up with greater ease than American, though the latter is specifically lighter. With all lamps the intensity of light decreases already during the first half hour of burning, the reason for this being that during this time the level of the oil is somewhat lowered as well as the temperature, which by heating the air conducted through the burner causes a more rapid vaporization of the oil. The retrogression in the intensity of light during several hours' burning is attributed partially to the lowering of the oil-level, partially to the oil thickening in consequence of the more rapid combustion of the lighter constituents, and finally to the formation by the flame of a ring of carbon on the end of the wick, which checks the access of the ascending oil, and prevents its distribution in the flame.

The researches of Biel, Schmelck and others, prove that the retrogression in the intensity of the flame is partially due to the increased height of ascent in consequence of the lowering of the oil-level, but, according to Engler and Thörner, this constitutes but the smaller portion of all the causes.

As regards the thickening of the oil while burning in the lamp, Albrecht, Junker and Thörner, and more recently Engler and Thörner, have shown that this is not the case, and, hence, has nothing to do with the retrogression of the flame.

The investigations of Engler, Lew, Zaloziecki and Thörner have established the fact that the retrogression of the flame is solely due to the formation of a carbon-ring on the wick, and that the quantity of carbon separated on the wick depends, on the one hand, on the quantity of heavy oils contained in the petroleum, and, on the other, on the suitable arrangement of the respective lamp-system.

As regards the supply of oil the size of the wick is, of course, of material importance. It will be frequently found that in some lamps the width and thickness of the wick are peculiarly disproportionate to the flame. The quality of the cotton and the tissue itself are of great importance as regards the suction-power of the wick. The ascending power of the oil is also reduced by moisture in the wick and, hence, the latter should be dried before use. It is further recommended to frequently change the wick, since after long use its minute canals are obstructed by impurities whereby the ascending power of the oil is decreased.

It has also been endeavored to render carbonization of the wick impossible by substituting for the cotton incombustible mineral substances, such as asbestos, mineral wool, etc. These experiments, however, yielded just as little satisfactory results as the construction of lifting contrivances to prevent the flame from becoming lower during burning. R. Ditmar has proposed an arrangement to convey an abundant and uniform supply of oil to the flame without the use of artificial apparatus. He furnishes the lamp with two wicks, one of which, the "suction-wick," serves only for sucking up the oil and, hence, is considerably thicker than the "burning wick," which is a few centimeters longer.

Chimneys and burners. As is well known, two kinds of burners are used, the older flat burners and the more modern round burners. The form of the chimney has, in the course of time, undergone many changes. With flat burners the chief object of the chimney is the production of a current of air and, hence, it should actually be of a cylindrical shape. However, for practical reasons, to render it more durable, the lower portion, which is exposed to the flame, is made wider. Strictly taken, a rational form of the chimney would be one fitted to that of the flame, consequently of an elliptic cross-section with the longer axis corresponding to the longitudinal direction of the flame. However, such chimneys are seldom used, they being difficult to make and having the further disadvantage of promoting a counter-current. With round burners, the chimney serves not only for the production of a current of air but also for the more intimate mixture of the vapors of combustion with the air sucked in. For this reason it is of a different shape and with a cylindrical cross-section is drawn in at a certain distance from the lower edge. The reason for this provision will be readily understood by raising and lowering the chimney of a burning lamp.

On raising the chimney the flame extends in length, becomes darker and finally commences to soot; on lowering the chimney the flame gradually becomes brighter and at a certain position of the chimney acquires its maximum value. If, however, the chimney is further lowered so that the drawn-in portion presses upon the upper edge of the wick, the flame again decreases, spreads out, is pressed against the sides of the chimney and commences to soot. Hence the intensity of the flame is considerably influenced by the location of the drawn-in portion of the chimney. To explain this influence, Dolinin and Alibegow investigated the manner in which the air is supplied, and arrived at the conclusion that by drawing in the chimney, combustion is more intense, and the illuminating effect more brilliant.

In connection with this the following questions are of importance: What should be the diameter of the drawn-in portion, and how far should it project above the upper edge of the wick? Both these questions are answered by experience that with a distance of 10 to 13 millimeters[1] of the drawn-in portion of the chimney from the upper edge of the wick, the inside diameter of the drawn-in portion should be the same as the outside diameter of the wick, or slightly exceed it (1 or 2 millimeters). The height of the chimney varies, as a rule, between 200 and 260 millimeters.

The effect of the flame-disk—a flat button inserted in the upper portion of the wick-tube—is similar to that of the drawn-in portion of the chimney. The initial direction of the current of air ascending from the wick-tube is changed by striking the disk and is forced obliquely against the flame. By this means the flame is spread out in the form of a corona and presents a greater surface to the external air entering between the wick-tube and the chimney. The metallic disk as well as the drawn-in portion of the chimney is of further importance in that they cause a rise in the temperature which is transferred to the gas-mixture.

In regard to *burners*, it may be said that, to judge from the large number of most varying construction in use, the desired degree of perfection has not yet been attained, and in fact, a great portion of the burners found in commerce answer but incompletely their intended purpose. The increase in the consumption of Russian oil in Europe has led to the construction of special burners, its greater content of carbon excluding the use of burners suitable for Pennsylvania oil. Caucasian oil being very rich in carbon requires a larger supply of air being conveyed to the flame and a very intimate mixture of the air with the hydrocarbon vapors ascending from the wick. Since the most varying qualities and mixtures of illuminating oil occur in commerce, it will be understood that one

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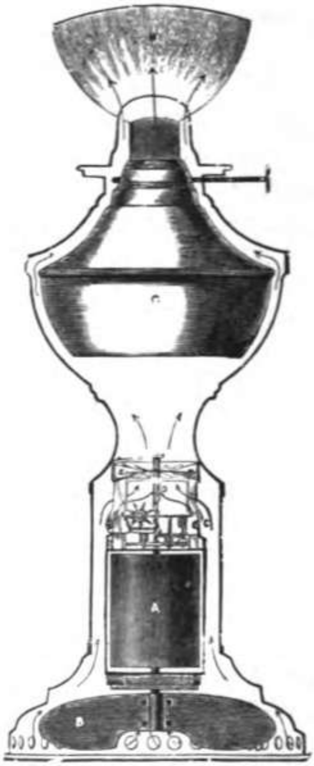
[1] The distance depends on the gravity of the oil, lighter oil requiring a greater, and heavier oils less, distance.

and the same burner is just as little suitable for all kinds of illuminating oil as one and the same grate for all kinds of fuel.

Lamps without chimneys but with special clock work arrangement for furnishing increased aeration of the wick. Lamps so constructed have a revolving fan to force a current of air through and around the wick. The principle involved will be best understood by the illustration, Fig. 199, of the Hitchcock table-lamp. This lamp furnishes a bright, steady light. The diagram shows how sufficient oxygen is delivered at the point of combustion. *A* is a clock-work which, when fully wound up by the key *B*, runs ten hours. This, by a series of wheels,

FIG. 199.



drives the fan *E E*, which delivers a constant current of air in the direction marked by the arrows. This air circulates around the oil receiver *G*, keeping it cool, and in its upward course impinges upon the flame *H* as it passes through the burner. The flame is thereby sufficiently oxygenated to give the fullest volume of light—the force of the mechanism being adjusted for that purpose—and giving to tinted fabrics the proper appearance by night.

Lamps for heavy oils and residuum. A recent method of making use of the more thinly-fluid petroleum residuum and the products of its dry distillation (blue oil, green oil) is their utilization for a peculiar kind of illumination. It was first employed for technical purposes by the chemist Hannay[1] and on account of the peculiar effect and cheapness of the light it has been largely introduced under the various names of *lucigen light*, *Jupiter light*, *Wells light*, *oleo-vapor light*, etc.

In the beginning of the eighties a simple arrangement was used in the large iron works at Staveley in Derbyshire for lighting the yard. A lamp of peculiar construction was connected with an iron tank holding about twenty gallons of coal tar, which is cheap in that locality. This tank stood under pressure from the boiler. The light emitted showed an intensity of about 200 candles, while the consumption of material amounted to about two gallons.

This new mode of lighting was first introduced by the Lucigen Light Company, Limited. Their success brought, of course, a number of new forms and improvements. The Lucigen Light Company itself and George Gerrard of Westminster, have improved their light so as to answer all requirements.

In the meanwhile lucigen illumination was successfully used in 1887, by the French War Department, especially in the mobilizing experiments on a large scale of the 17th army corps. For this purpose lucigen lamps of 2000 candle power each were placed upon eight or nine tall posts at a distance of about

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[1] The inventor of these lamps was Prof. Donny (Soc. d'éncouragement, 1857).

656 feet from each other, and the oil and air-pressure conveyed to them from a common oil-holder and air-reservoir. The lamps burned without interruption for eight to ten hours, and lucigen was found to be one of the most advantageous sources of light as regards brightness as well as the cheapness and simplicity of the entire arrangement. This light was used with special success in 1886, in building the Tay and Firth of Forth bridges. In England and Germany this mode of lighting has been introduced in large machine shops, iron foundries and on wharfs. According to Glaser's Annals, the plant costs less than an electric light plant, while the working expenses are about the same. A lucigen burner of 2000 candle power cost from 48 to 56 pfennige[1] per hour, about the cost of an electric arc light of the same power. It may be remarked that the

FIG. 200.

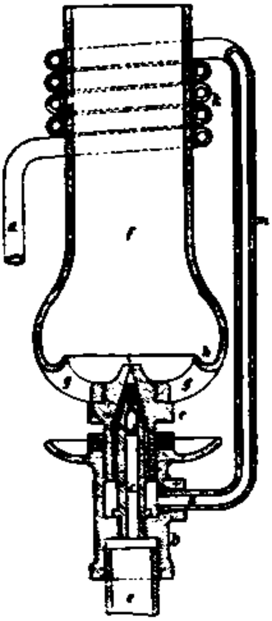
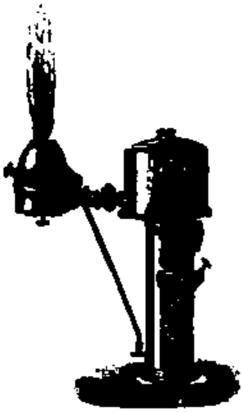


FIG. 201.



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[1] 1 pfennig = 0.2 cent.

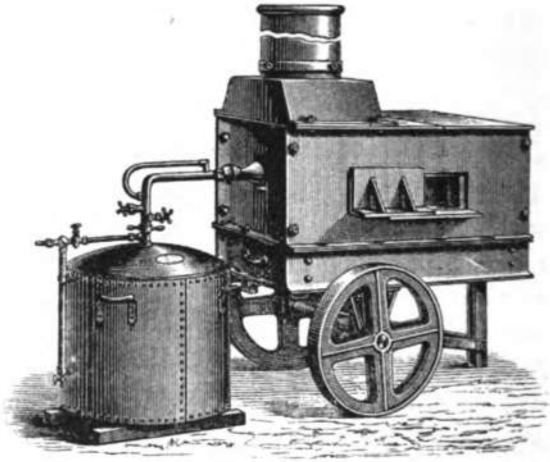
smaller the burner is, the finer and more fluid the oil used must be. Fig. 200 shows the arrangement of a lucigen lamp. The oil is conveyed under pressure through the pipe *o* to the nozzle *d* and the mouth of the burner *e*, the steam or compressed air superheated by the flame reaching at the same time the nozzle *d* and the mouth of the burner *e* through the pipe *a*, coil *k* and pipe *m*. The cylinder of combustion *f* is provided with air holes *g* and the rim *h* to form a gutter for the oil condensing in *f*.

On account of their connections with a principal oil holder and the air forcing pump, the lucigen lamps of older construction have the disadvantage of being transportable to a limited extent only. The Lucigen Lighting Company has adopted a new form, which is shown in Fig. 201. Instead of compressed air steam is used, which is generated in a boiler or in the lamp itself. Further the illuminating material is not pulverized by steam but first gasified and then mixed with steam, a process which will be discussed in speaking of the Jupiter light.

In the lucigen lamp, Fig. 201, the oil is contained in the upper cylinder, while the lower taller cylinder serves for the support of the former and contains the water yielding the steam. The burner itself consists of a shallow iron pan with a large central opening for conveying the substance of combustion into the interior of the burner. The supply of air can be regulated. In setting the lamp to work, the burner is preparatorily heated by a spirit flame; the water-holder is next brought under pressure, and the water through a vaporizing coil then enters the burner, where it is evaporated, passes out as steam in the centre of the burner, and is mixed in the burner with the illuminating agent which has in the meanwhile been gasified. The pressure in the water-holder is constantly maintained by a few strokes of the piston, while the oil from the oil-holder continuously enters the burner through a siphon. This lamp burns as long as the supply of water lasts, the arrangement being such that a fresh charge of oil can be supplied while the lamp burns.

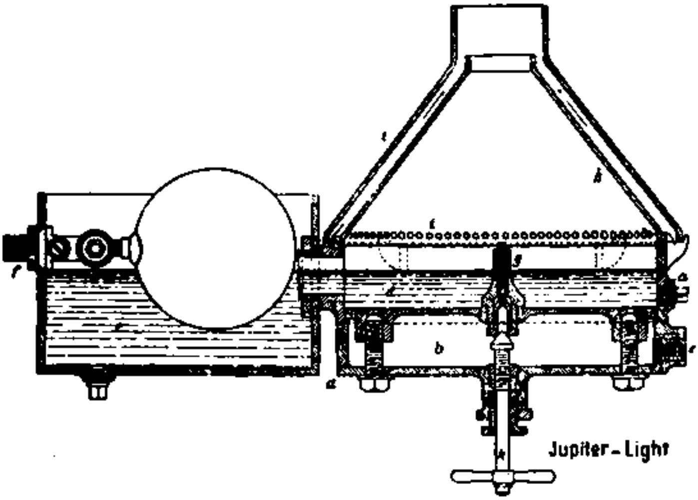
The same Company manufactures a so-called pyrigen furnace, Fig. 202. The lucigen flame is introduced into the furnace and serves for heating rivets for boilers, ship-plates, etc. The furnace may also work in connection with a lucigen lamp, the arrangement of the compressed air being such that it can be simultaneously used for heating, as well as for lighting.

FIG. 202.



Closely related to the lucigen light is the "Jupiter light" of the Harden Star, Lewis and Sinclair Company, Limited, of London. To prevent the loss of oil possible with the lucigen lamp, the liquid combustible body is not pulverized by the introduction of compressed air or steam, but first gasified and then mixed with compressed air for complete combustion. Fig. 203 shows such a lamp. The body of the burner consists of the chamber *a* divided into two compartments by a horizontal partition. In the centre is the tube *g*, which can be regulated by the spindle *h*. At *c* the compressed air enters the chamber *b*, and passes through the pipe *g* into the chamber *d*, which serves as oil-pan. The latter is connected with a lateral oil-vessel *e*; the supply of oil is effected at *f* from the main holder. The oil in the chambers *e* and *d* is kept at the same

FIG. 203.

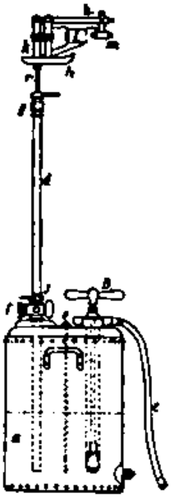


lead by floats. The lamp is covered by a cap, between the walls, *k* and *l*, of which air is conducted to the upper part. For setting the lamp to work, a small quantity of spirits is poured upon the surface of the mineral oil, and after igniting it the cap *k l* is placed in position. When the oil is sufficiently heated for gasification to take place, the compressed air conduit is opened, whereby the mixture of oil vapor with compressed air is effected, and outer air sucked in. The cap *k l* being strongly heated fulfills the twofold object of conducting to the chamber *a* the heat required for the gasification of the oil and the preparatory heating of the compressed air, and of conducting air preparatorily heated to the upper portions of the flame. Thus complete combustion takes place, the result being a brilliant, powerful light, without smoke or odor. Ordinary creosote oils or petroleum residuum are used, and can be obtained at a low price. For several lamps of about 10,000 candle power, 2 horse-powers suffice for the air-compressor. The lamps are made in sizes of from 100 to 2500 candle power. Fig. 204 shows a lamp which consumes about 7 quarts per hour.

While formerly oil-vapor burners were based upon the principle of the formation of a flame by compressed air, a group of lamps has been evolved in more recent times in which only a gasification of the fluid combustible body takes place, and the gas produced is burned together with atmospheric air. To this group belong the *Wells light*, the *oleo-vapor lamp*, which is nearly identical with the first, the *Beacon light*, *Sunlight lamp*, etc. Fig. 205 shows the arrangement of a Wells

FIG. 204.

FIG. 205.



lamp. The cylindrical tank *a* serves as oil-holder. It is filled with oil by means of the hand-pump *B* through the pipe *c*, when by further strokes of the pump an over-pressure of 1 or 1½ atmospheres, indicated by the manometer *j*, is produced. The valve *f*, is then opened and the oil rises through the pipes *d* and *r* to the burner. *K* is the vaporizer where the oil is vaporized to pass through K_1 to the outflow-place where it is ignited, the flame being emitted from the combustion-chamber *l* in the form of a bunch. In setting the apparatus to work a small quantity of wool saturated with petroleum is ignited upon the cup *h* to preparatorily heat the burner. In more recent constructions, the hand-pump *B* is improved so that the piston carries a shiftable sleeve which serves as packing for the piston and as valve-plate. The burner can of course be connected with the oil-holder according to the purposes the lamp is to serve. The pipe *d* can be revolved in a standard of the holder so that the burner can be removed for cleansing, etc. For adjusting the lamp at different heights the pipe *r* is connected with the oil-holder by a number of knee-joint pipes. According to the Revue Industrielle (1889, No. 27, p. 260,) the preparatory heating of the lamp requires about 7 or 8 minutes, and the consumption of oil per hour is for 1000 candle powers 3.5 quarts, for, 2000, 5; for 3000, 6, and for 3500, up to 10.

The *oleo-vapor lamp* brought into commerce by E. Grube possesses, according to Glaser's Annals, 1889, the following characteristics: The apparatus can be readily transported by two men. The preparatory heating of the burner requires from 8 to 10 minutes. The flame, which is about 15¾ inches in height, burns with a beautiful bright light, without evolution of smoke, and is perfectly weather-proof.

FIG. 206.

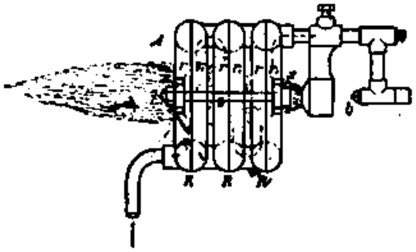
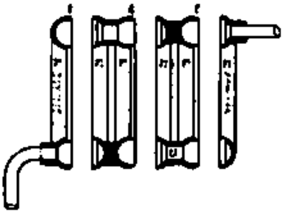


FIG. 207.



The burner is shown in Figs. 206 and 207. The gasifier *A* consists of any desired number of rings *R*. The latter consist of two halves *r* and $r_{,,}$ connected with each other by conical pieces *t*. The separate rings *R* are connected with each other by the channels *n*, as shown in Fig. 207. The oil circulates in the direction of the arrows, and passes out at *x*.

The *Sunlight lamp* differs from the previously-described lamps in that gasification takes place not in the burner itself, but in the oil-holder. The apparatus consists of a boiler with a fire-place underneath. For the purpose of setting the apparatus in operation the boiler is heated, the stop-valve of the pipe leading to the combustion-chamber remaining closed until a pressure of about 7.5 lbs. per 0.061 cubic inch has been attained, when the cock is opened and the gas ignited. A lamp of about 2500 candle power consumes 10 quarts of oil per hour and one to one and a half hundred weights of coke per 10 hours. The light is bright and steady, and printing can everywhere be conveniently read within a radius of about 600 feet.

Utilization of petroleum residuum.

The residuum remaining after the distillation of the crude oil is used for various purposes. According to its derivation it is, as a rule, worked for lubricating oils which are obtained by distillation; where this cannot be done it is utilized in a manner to be described later on. The residuum may be used as such for lubricating purposes, the general rule being that only residuum suitable for the production of lubricating oils is fit to be employed for lubricating purposes. On account of its low price, and, as a rule, great lubricating power, residuum is extensively used by railroads.

Under the name of "Vulcan oil" residuum of American origin was first introduced, towards the end of the seventies, in Europe. Under the name of "West Virginia oil" a very viscous residuum which does not thicken is produced in America. A special disadvantage of lubricating with residuum is its comparatively rapid thickening, or the ointment-like consistency it acquires at low temperatures. Towards the end of the eighties, Russian residuum was introduced in Europe, and on account of its considerable viscosity, high flashing point, and low congealing point, it is now employed by most railroads for lubricating locomotives and cars. Experience has shown that the residuum is also suitable for the cold portions of locomotives, the separate constitutents being sufficiently warm to allow of the residuum being sucked through the wick. However, for cars with periodical and wicking lubrication the case is different, the number of hot boxes being much greater than with the use of distilled mineral oils. The principal reason for this is to be found chiefly in the greater consistency and inferior congealing point of the residuum. Another disadvantage of residuum is that it readily gums, and contains tarry and coke-like impurities which readily clog the capillaries of the wicking. For this reason the managers of many railroads have abandoned wicking-lubrication, and to render the further use of residuum possible have introduced lubrication by pad. This consists of small pads pressed by means of springs to the ends of the axles and kept constantly moist with oil.

Increased competition and many complaints about hot boxes caused the manufacturers of mineral oils to subject the residuum to thorough filtration. As a condition for residuum fit for use the following test has been prescribed: When the residuum is filtered through a paper filter no suspended coke-like particles should be observed with a transmitted light upon the filter. With the so-called winter oils—used in Europe from October to March—the test is made at the ordinary temperature; and with summer oils—employed from April to September—at a higher temperature.

For other branches of industry the use of residuum as a lubricant is of secondary importance, it being only employed for that purpose where large quantities are consumed, for instance, in mines, iron works, etc. One great defect of residuum is that it soils the machinery and forms a crust difficult to remove, and the use of pale transparent oils is to be preferred, if for no other reason than that with their use it can be immediately detected whether the machine to be lubricated is in order. So long as the oil runs off clear the bearing is cold, but when the oil becomes opaque or acquires a dirty color, it is an indication that the respective part of the machine runs irregular, *i. e.*, hot, the oil having become dirty from fine metallic splinters.

When the residuum is not suitable for lubricating purposes or for the manufacture of lubricating oils. [illegible] produced in such large quantities that [illegible] utilization have to be made. [illegible] or other branches of industry, for instance, for the [illegible] gas, etc. An interesting mode of utilization may here be mentioned.

Production of aromatic bodies from residuum.

By the action of high temperatures naphtha residuum undergoes far-reaching changes, and aromatic hydrocarbons, naphthalene and anthracene are formed from it. However, such transformations are always accompanied by the separation of coke and evolution of gas.

As early as the year 1877 Prof. Letny obtained a patent for the production of aromatic hydrocarbons from naphtha. Soon afterwards this matter was more thoroughly investigated by Liebermann and Burg, Wichelhaus and Salzmann, and also by [illegible].

The yield of aromatic hydrocarbons from residuum depends chiefly on the temperature and next on the uniform supply of residuum to the pipes in which decomposition is effected. The superheating of the residuum may be effected so that the tar formed is to contain larger quantities of liquid and solid hydrocarbons.

The residuum is allowed to flow slowly through iron pipes heated to between 1290° and 1480° F., whereby 40 to 50 per cent. tar and 50 to 60 per cent. gases is formed, the loss of coke-separation being slight when the process is correctly executed. When decomposition is effected in the presence of good conductors of heat, the yield of tar, as well as of aromatic hydrocarbons, is much larger. Laboratory experiments have proved copper filings to be most suitable for the purpose. The specific gravity of the tar obtained varies between 0.995 and 1.027, and depends on the temperature, rapidity of supply, etc.

On an average there are obtained from naphtha tar 17 per cent. benzole, 0.4 per cent. anthracene, and 7 per cent. naphthalene. Coal tar yields nearly as much anthracene (0.3 per cent.), but only about half as much (8 per cent.) benzole, and considering that only 10 per cent. of tar is obtained from coal, the yield of benzole from coal is much less than from naphtha. Moreover, as previously mentioned, the yield of hydrocarbons is dependent on the temperature, rapidity of the oil-supply, and the size of the superheated surface of the retorts or pipes in which decomposition is effected. With a temperature below 1290° F., more tar, but of a poorer quality, is obtained, and with a higher temperature less tar, but the quantity of gas is increased and much coke is separated in the pipes. The smaller the supply of oil, within certain limits, the more tar is obtained and the richer it is in benzole and anthracene. With a larger supply considerable oil passes unchanged through the apparatus, and when the temperature is also increased, the separation of coke also becomes greater. The shape of the retort should be such that it presents a large heating surface in comparison with its content. The residuum should not be very thick; the more thinly-fluid it is the better, and heating must be done as uniformly as possible.

According to the investigations of Lermotowa a good quality of tar of specific gravity 0.994 to 1.008 gives the following fractions:

Up to 284° F.	36 per cent.	
" " 392° "	8 "	(congeals on account of its content of naphthaene).
" " 500° "	15.5 "	
" " 572° "	4.7 "	

Lermontowa obtained as much as from 20 to 22 per cent. benzol and about 0.8 per cent. authracene.

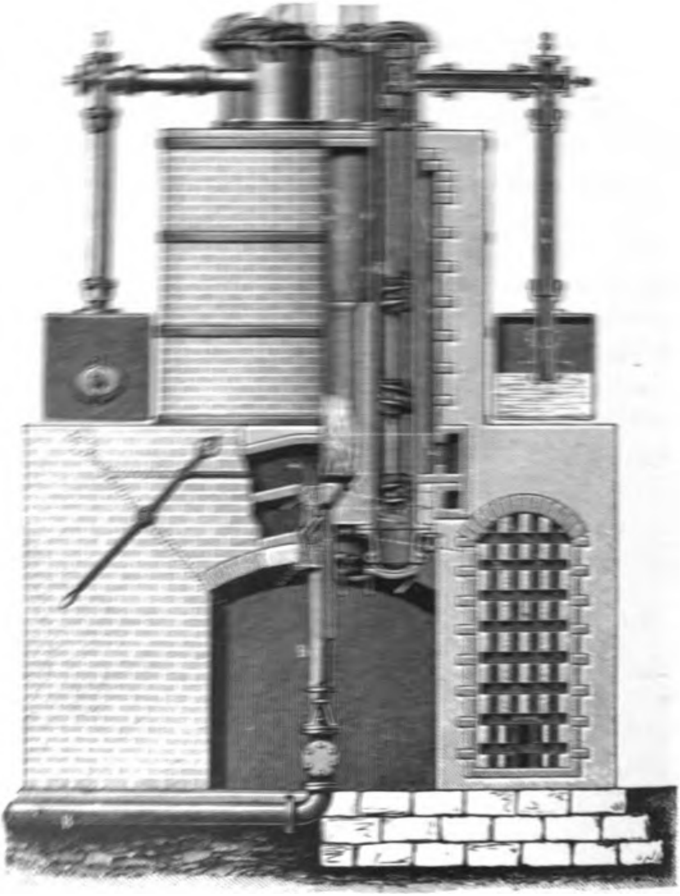
The gas formed by the decomposition is very suitable for illuminating purposes.

The question of the conversion of the residuum into tar-products similar to those contained in coal tar is of great importance, especially for Russia with its immense quantities of petroleum products and entire absence of the color industry.

[illegible] rmantowa and [illegible] large scale by the latter [illegible] solution of this question [illegible]

[illegible] aniline and alizarine manu-

[illegible]



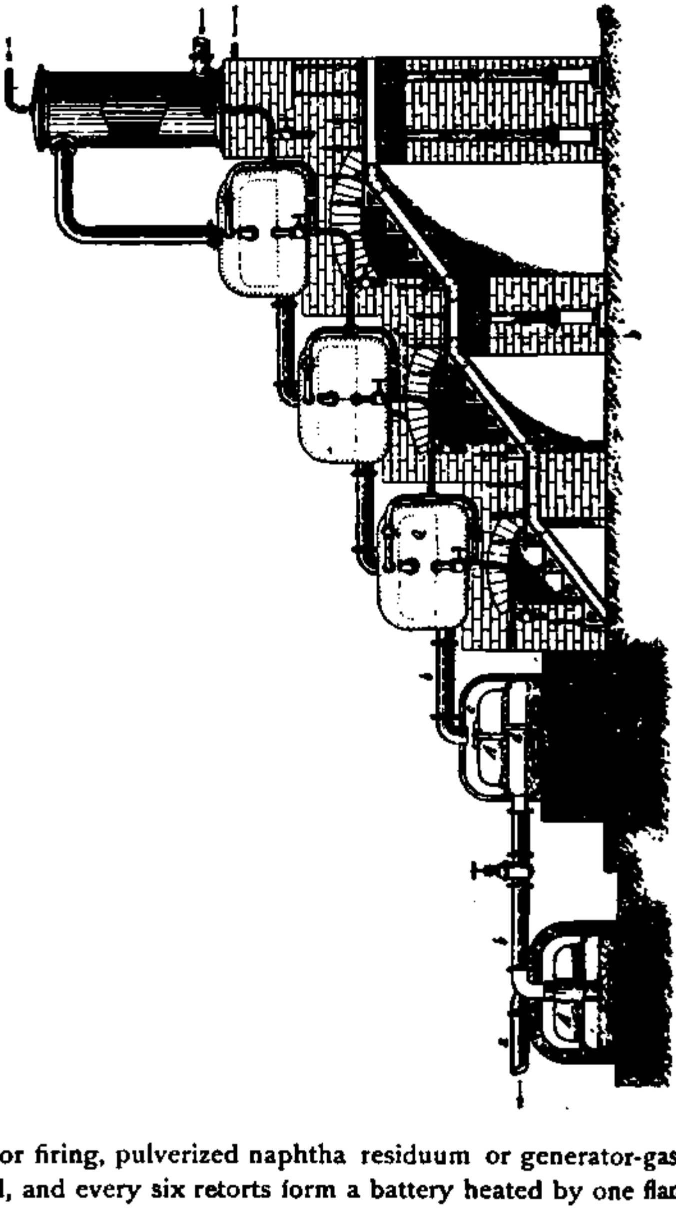
factories in Russia, many attempts have recently been made to obtain aromatic hydrocarbons in paying quantities from residuum; the gas evolved thereby is to be utilized for illuminating and heating purposes, for driving motors, etc.

Fig. 208 shows an apparatus for the production of gas and tar containing aromatic hydrocarbons, which was exhibited, in 1889, by Intschik at the St. Petersburg Exhibition for Illuminating Articles and Gas Industry.

The residuum passes through a pipe into the box *C* located on the upper end of a vertical retort, and flows over the edge of the box upon the distributing cone *A'*. From the teeth of this distributing cone, the fluid in small drops falls, in the form of a hollow cylinder, lower down into the retort. Without touching the sides of the retort, the fluid is first vaporized and later on gasified. To distribute the heat as uniformly as possible in the mixture of gas and steam flowing downward, the retort is divided by partitions into several compartments, which communicate with each other by spiral passages, whereby a revolving motion is imparted to the gases and vapors, so that fresh portions of them come constantly in contact with the hot sides. From the lower part of the retort the gases and vapors pass through the pipe *K* into *B* and then through a system of condensers, Fig. 209, where the vapors are separately condensed. The condensers are arranged in the form of steps, and each of them is kept by superheated steam at a certain temperature, the highest temperature prevailing in the lowest condenser. The mixture of vapor and gas passes through the pipe *a* into the lowest condenser, and yielding there its least volatile constituents, passes through the pipe *b*, into the second condenser, next into the third, and so on. The last volatile portions are condensed by cooling with water.

By an ingenious construction the vapors precipitated in the condensers are at the same time subjected to another fractional distillation. When the fluid in a condenser, for instance, in *Q*. has reached a certain depth it runs through the pipe *b* and the funnel-pipe *C*, which reaches to the bottom into the closed inner chamber *A* of the next condenser, and is again vaporized by the higher temperature prevailing therein. The vapors are condensed in coolers, while the non-vaporized residuum after reaching a certain depth, runs off through the pipe *d* into the outer chamber of the condenser.

FIG. 209.



For firing, pulverized naphtha residuum or generator-gas is used, and every six retorts form a battery heated by one flame.

By this mode of construction it is claimed the residuum can be converted without a great consumption of fuel into tar-products rich in aromatic hydrocarbons.

Utilization of petroleum and petroleum products as fuel.

The use of petroleum in one or other of its varied forms as fuel is traceable to the remotest antiquity. Its combustible nature, with its heat-producing and light-bearing properties, very early attracted the notice of even the most barbaric and uncivilized nations. Its scientific adaptation to numerous practical uses, in accordance with its chemical composition, belongs to modern times. During the last thirty years a great deal of attention has been paid to the subject, resulting in many valuable inventions which have been reduced to practice.

Although it has been claimed that liquid fuel was used in the commencement of this century, the first attempts of any importance in this direction were made in the United States, where, in 1862, Bidle, and Shaw and Linton, obtained a patent on an apparatus for the use of liquid fuel on steam-vessels. The Bridge-Adam apparatus for locomotives appeared in 1863. However, notwithstanding the many patented inventions for the use of liquid fuel, this mode of firing did not become of any technical importance, in a wider sense, until the question of oil firing was again taken up in consequence of the prolific wells of the Caucasus yielding such an abundance of petroleum that other provisions, besides working it into illuminating and lubricating oils, had to be made for its utilization.

In most countries exhaustive experiments in the use of liquid fuel have been made.

In England experiments, promoted and conducted by Selwyn, were commenced in 1864, and are still carried on. The apparatuses constructed by Aydon, Selwyn, Tarbuth, and others, were tried in propelling vessels of various tonnages, and their non-success was simply due to the high price of oil.

At the same time, in France, Audouin made experiments to utilize the heavy oils of coal tar for the generation of steam.

Assisted by the Emperor Napoleon III., M. Sainte Claire Deville made an exhaustive examination of the subject. The results of this investigation were published in the Journal of the French Academy of Sciences for the years 1868 and 1869. These papers contain full particulars of his analyses of the different oils employed, together with drawings of the furnaces by means of which the oil was burned. Experiments were made both upon locomotive and marine boilers. He was obliged to report that at the then prevailing price of petroleum, it could not advantageously compete with coal.

The question of the employment of petroleum as fuel in this country in competition with our abundant coal supply is yet engaging the minds of some of our acutest inventors. So far, however, the general verdict seems to be that where the *economy of fuel* alone is to be considered, petroleum must take a second place. It is true that when economy of space for storage of fuel and convenience of handling are to be considered, no fuel can be placed in competition with it. These two considerations are essential factors in determining its use.

In Russia M. Spakowski has assiduously labored for the introduction of liquid fuel for the generation of steam. A furnace constructed by him in 1866 and improved later on, is considered to-day one of the best in use on steamers on the Caspian Sea. His furnace was succeeded by those of Kamenski, Lenz, Brandt, Urquhardt and others. At present nearly all steamers on the Caspian Sea and the Wolga are fired with liquid fuel, and all the locomotives on the Batoum-Baku railroad are fitted with apparatus for burning petroleum refuse, instead of coal, under their boilers. Coal in that part of Russia being dear and scarce, the economy thus realized is considerable. The evaporative power of residuum from the distillation of petroleum, which alone has to be considered in this connection, is nearly twice that of coal. This is shown by the theoretical evaporative values of different liquid fuels as compared with solid fuels exhibited in the appended tables, as well as by experiments made in practice.

a. Various Kinds of Petroleum.

Names of Oils.	Specific gravity at 0° C.	Chemical composition.			Expansion-coefficient.	Quantity of evaporated water referred to the unit of oil consumed.	Calorific effect in units of heat.
		Carbon.	Hydrogen.	Oxygen.			
Heavy naphtha from West Virginia	0.873	83.5	13.3	3.2	0.00072	14.58	10.180
Light naphtha from West Virginia	0.8412	84.3	14.1	1.6	0.000839	14.55	10.223
Light naphtha from Pennsylvania	0.816	82.0	14.8	3.2	0.00084	14.05	9.963
Heavy naphtha from Pennsylvania	0.886	84.9	13.7	1.04	0.000721	15.30	10.672
American Petroleum	0.820	83.4	14.7	1.9	0.0000868	14.14	9.771
Naphtha from Parma	0.786	84.0	13.4	1.8	0.000706	13.96	10.121
" " Pechelbronn	0.912	86.9	11.8	1.3	0.000767	14.30	9.708
" " "	0.892	85.7	12.0	2.3	0.000793	14.48	10.020
" " Schwabweiler	0.861	86.2	13.3	0.5	0.000858	15.36	10.458
" " "	0.829	79.5	13.6	6.9	0.000843		
" " Hanover	0.892	80.4	12.7	6.9	0.000772		
" " "	0.955	86.2	11.4	2.4	0.000641		
" " East Galicia	0.870	82.2	12.1	5.7	0.000813	14.23	10.085
" " West Galicia	0.885	85.3	12.6	2.1	0.000775	14.79	10.231
Schist oil from Wauas (Ardèche)	0.911	80.3	11.5	(NO) 8.2 OSN	0.000896	12.24	9.046
Coal tar from the Paris gas house	1.044	82.0	7.6	10.4	0.000743	12.77	8.916
Naphtha from Balachany	0.882	87.4	12.5	0.1	0.000817	....	11.700
Light naphtha from Baku	0.884	86.3	13.6	0.1	0.000724	16.40	11.460
Heavy naphtha from Baku	0.938	86.6	12.3	1.1	0.000681	15.55	10.800
Naphtha residuum from Baku refineries	0.928	87.1	11.7	1.2	0.00091	....	10.700
Naphtha from Java	0.923	87.1	12.0	0.9	0.000769	15.02	10.831
Heavy petroleum from Ogaio	0.985	87.1	10.4	2.5	0.000685	14.75	10.081

b. Solid Fuels.

		Calorific effects in units of heat.
Coal	on an average	7500
Coke	"	6500
Brown coal	"	4500
Peat, air-dry	"	3000
Wood	"	2800

These tables show:

1. That the chemical composition of the oils gives some idea of their value as fuel; the quantity of heat evolved by their combustion generally increases with their content of hydrogen and decreases with their content of oxygen.

2. The magnitude of the heating power of a fuel is dependent on the prevalence of carbon, because the product of combustion of the latter—carbonic acid—carries off but one-fourth of the heat of the product of combustion of hydrogen—steam.

3. The specific gravity of an oil exerts no influence upon its calorific effect; hence the heating value of an oil cannot be determined from its specific gravity.

Practical experiments with Russian petroleum refuse burnt in a series of shallow troughs under ordinary boilers have shown that it evaporates 14½ pounds of water per pound of refuse; coal burnt under the same boiler gave an evaporation of seven to eight pounds of water per pound of coal. Prof. Unwin tested the evaporative value of petroleum under a steam boiler, and found it to be 12.16 pounds water (from and at 212° F.) per pound of oil burned. The rate of evaporation was 0.75 pound of water per square foot of heating surface. He estimates the calorific value of the petroleum he used at about 25 per cent. higher than an equal weight of Welsh coal.

In using oil-firing for metallurgical purposes, pulverization has to be effected by means of air, it being impossible to attain with pulverization by means of steam as high a temperature as is required for melting iron or other metals. Pulverization by means of steam is also absolutely useless in welding some metals. Various experiments with steam-pulverization in smelting furnaces have shown that a complete fusion of the iron could not be attained, no matter how long the pulverizer was kept in operation. For this reason steam-pulverization has not been introduced for forges and other metallurgical processes, air being exclusively employed. With the use of air forced through a compressor into the apparatus the fire becomes brighter and the iron soon acquires the temperature required for welding; cast-iron also is readily fused. This effect is produced not only by the high temperature, but according to Goulischambaroff, may be explained as follows:

Since with steam-pulverization there remains more disposable oxygen originating from the decomposition of the steam than with air-pulverization, a portion of the oxygen exerts an oxidizing influence upon the iron and prevents welding. The oxygen in a nascent state acts very energetically upon the red-hot iron, even if there is an excess of hydrogen in the furnace.

The advantages of oil-firing for metallurgical purposes are: 1. Saving in time; the work being accomplished 3½ times more rapidly. 2. Saving in fuel and consequently in money, the expense with the use of petroleum refuse as compared with coal being in the Caucasus as 2 : 3.

From the above mentioned results of experiments it will be seen that the evaporative power of liquid fuels is greater than that of solid, but in estimating the one or other material, not only the absolute evaporative power has to be considered, but also the quantity of heat which can be utilized. With solid fuels only about 60 per cent. of the evaporative power is utilized, the other 40 per cent. being lost. This is due to the fact that in heating with solid materials, the loss of heat is four times greater than with liquid fuel. In heating with the former the emission of a black smoke from the chimney will, as a rule, be observed, which is due to incomplete combustion. Attempts to attain complete combustion with solid materials have thus far been successful only at the expense of the heat evolved, an excess of air which is required for complete combustion having a cooling effect. On the other hand, with liquid fuel burnt in a pulverizing apparatus of correct construction and working properly, an excess of air is not required and only gases of combustion escape from the chimney.

The useful effect of the boiler is also much greater with the use of liquid fuel. Scheurer-Kestner and Menier found that with coal the useful effect varied between 0.5 and 0.62, while Besson in his experiments with petroleum found it to be 0.8. The latter worked with a boiler under a pressure of 45 lbs., corresponding to a temperature of the steam of 135° C. One kilogramme of dry steam at this temperature contains a heat of $606.5 + 0.305 \times 135 = 648$ units of heat. By supposing that petroleum evolves in round numbers 11000 units of heat, it follows that this quantity of heat equals $\frac{11000}{648}$, corresponding to the heating capacity of 17 kilogrammes of dry steam. By taking the average evaporative power of 1 kilogramme of petroleum at 13.75, the useful effect of heating with petroleum is:

$$\frac{13.75}{17} = 0.8.$$

The apparatuses used for the combustion of liquid fuel are known as *forfunkas* or *sprinklers*, and may be considered small injection-pumps in which the oil flowing in slowly is carried away and pulverized, to finally reach the fire-box in the form of a fine spray.

Regarding the useful effect of forfunkas valuable guides are furnished by Professor Thieme's experiments.[1]

He supposes that the consumption of steam amounts to 10 per cent.[2] of that generated in the boiler, and that the evapor-

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[1] Practischer Cursus der Dampfmaschinen. Supplementband I (Russian).

[2] According to "Engineer," 1886, No, 1795, forfunkas use 8 to 10 per cent steam; according to Wossnessensky, Lenz's forfunka uses ⅓ per cent. According to Wasiljew the consumption of steam by a forfunka of Schirokow corresponded to 0.66 horse power, the respective boiler being of 14 horse powers and feeding 21 forfunkas. See also Lew: "Die Feuerungen mit flüssigen Brennmaterialien." Stuttgart, 1890.

ative power of petroleum is twice that of coal, so that 1 kilogramme of petroleum generates 15 to 16 kilogrammes of steam; further, that the consumption by weight of petroleum compared with that of steam in a forfunka is in the proportion of

$$1 : 1.5 = 0.7.$$

With injectors the proportion of water to steam is:

$$12 : 1 = 12.$$

Hence the condensation of steam in the forfunka is very small, the steam being utilized only for the pulverization of the petroleum. If p designates the tension of steam in the boiler, p' the atmospheric pressure (p and p' in kilogrammes per 1 square meter), $g=9.81$ meters the acceleration of the gravity, d the density *i. e.*, the weight of 1 cubic meter of steam of the tension p, and w' the cross section of the steam-outlet, the consumption of steam in kilogrammes per second is

$$P = K.\, w'\, d \sqrt{2g\,\frac{p-p'}{d}} \quad \ldots\ldots\ldots\ldots (1)$$

in which K is the coefficient which for conical mouth-pieces K is to be taken $=0.90$ and for straight $K=0.64$,

The outflow-velocity of the steam in millimeters is

$$v' = 0.975 \sqrt{2g\,\frac{p-p'}{d}} \quad \ldots\ldots\ldots\ldots (2)$$

in which 0.975 means a coefficient.

The total outflow velocity of steam and petroleum:

$$V\,(1.5+1) = 1.5\, v'$$
$$V = 0.6\, v' \quad \ldots\ldots\ldots\ldots (3)$$

The quantity of oil which passes through the outlet w per second is:

$$\frac{P''}{d''} = K.\, w.\, v \quad \ldots\ldots\ldots\ldots (4)$$

when d'' is the density, *i. e.* the weight of 1 cubic meter of oil equal on an average to 780 kilogrammes, and v the velocity in millimeters per second, which, like in injectors, varies from 2 to 5 meters.

Example: The size of a forfunka with flat outlet and fed from a 25 horse-power boiler with a tension of four atmospheres is to be determined. Suppose that with good insulation 20 kilogrammes of steam are generated per horse power per hour, then the consumption of steam by the forfunka per second is:

$$P = 0.1 \frac{25.20}{3600} = \infty\ 0.014 \text{ kilogramme}$$

$p = 10334.4 = 41336$ Kilos per 1 sq. meter.
$p' = 10334$ Kilos per 1 sq. meter
$2g = 19.62$ meter.

Density of the steam at four atmospheres:

$$d = 2.23 \text{ Kilogrammes.}$$

These values put into formula (1) give:

$$P = 0.014 = 0.64.\ w'.\ 2.23 \sqrt{19.62 \frac{31.002}{2.23}}$$

$$0.014 = 745.6.\ w'.$$

$$w' = 0.000019 \text{ sq. m.} = 19 \text{ sq. mm.}$$

If the width of the slit be taken at ¾ mm., the length of the slit will be:

$$19.\ \frac{4}{3} = 26 \text{ mm.}$$

To a consumption of steam of 0.014 kilogramme per second corresponds a consumption of petroleum of $0.7.\ 0.014 = \infty\ 0.01$ kilogramme $= \frac{0.01}{870} = 0.0000115$ cubic meter.

With $v = 5$ m. velocity, the outlet opening for the petroleum is:

$$w = \frac{0.0000115}{0.64.5} = 0.000047 \text{ sq. m.} = 47 \text{ sq. mm.}$$

With the assistance of the formulæ given above, it is easy to determine the size of a forfunka, for instance, for a fire-box formerly fired with coal and whose consumption of coal per shift is known.

If A is the consumption of coal in kilogrammes per twenty-four hours, $\frac{A}{2}$ would be the consumption of petroleum in the same time, if the calorific effect of petroleum be taken as twice that of coal, and $\frac{A}{2\;24\;3600}$ the consumption of petroleum in kilogrammes per hour. Now $0.7.\,P = \frac{A}{2\;24\;3600}$ and $P = \frac{A}{2\;24\;3600.0.7}$ is the consumption of steam per second of the forfunka. w' as well as all the other values can be determined, since the values d, p, must be known.

The cross sections found from the formulæ will have to be taken somewhat larger in order to be on the safe side in all cases; the supply can be regulated by the insertion of valves if the forfunka itself cannot be shifted.

Apparatuses for Stationary Boilers.

Although one of the apparatuses first proposed for oil-firing was described, in 1843, by Peclet,[1] the year 1862 must be considered as the year of the birth of oil-firing.

The apparatuses constructed for the combustion of liquid hydrocarbons vary according to whether the fuel is to be used in a liquid, gaseous or vaporous state. Hence a distinction is made between apparatuses for hearth-fire, gas-fire and spray-fire.

The original aim was to burn the liquid fuel directly under the boiler, analogous to firing with solid material. However, combustion being incomplete, and the quantity of soot produced very large, it was sought to modify the primitive mode of hearth-firing by exposing the oil in a state of greater division to the access of air. The most perfect mode of hearth-firing, however, proved inadequate, the openings for the supply of oil becoming clogged by deposits of coke, soot and residuum.

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[1] Traite de la Chaleur, 1843.

The practical introduction of firing with gasified fuel was also unsuccessful, the oil-pipes becoming in this case choked up with non-vaporized residuum. Independent of the great expense, there is the further disadvantage of the danger arising from the high temperature of the oil vapors, which is three times as high as steam at the same tension.

The most recent method of combustion by pulverizing the liquid fuel by steam, or more seldom by air, has, however, been generally applied to practical purposes. In this method of firing, the oil on entering the fire-box is pulverized by a jet of steam or air, and is thus completely burned almost without smoke. The air required for combustion is supplied by the draught produced by the out-flowing jet.

The advantage of the employment of the steam-jet consists in the mechanical effect of the intimate mixture of the gaseous fuel with the oxygen necessary for combustion, and, moreover, the steam probably exerts a chemical effect. At a higher temperature all hydrocarbons are inclined to deposit carbon if the latter is not immediately consumed. Now it is probable that the oxygen of the steam combines with the carbon of the hydrocarbon, while the hydrogen of both is liberated. The mixture of carbon monoxide and hydrogen is completely burned immediately after the introduction of sufficient air. It is, of course, not meant that heat is gained by the decomposition of the steam and subsequent re-combination of the constituents, but simply that the oxygen fixed by the decomposition forms, so to say, an insulating material for the carbon which facilitates combustion.

Apparatuses for Petroleum and Residuum Firing.

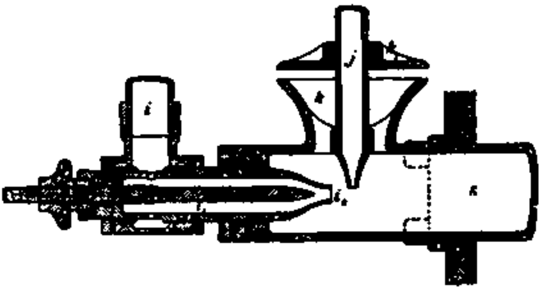
The most simple, but at the same time, most incomplete mode of firing, as still practiced in some small refineries at Baku and in Galicia, consists in introducing the liquid fuel in shallow troughs into the fire box, or allowing it to drip upon stones, or in some cases directly upon the bottom of the hearth. This mode of combustion is very incomplete, it being accompanied by a voluminous formation of soot, and a thick black smoke constantly escapes from the chimneys of such plants.

Audouin's method of firing with liquid fuel was first tried in 1865, then abandoned, and again introduced in 1867. Audouin being a gas expert, was especially interested in the utilization of the heavy tar oil. He placed in the fire-box a tube of refractory material about 3 feet long, the object of which was to maintain the high temperature required for the volatilization and complete combustion of the oil, and to protect the iron plate from being burned. The door of the fire-place and its casing were replaced by a plate of refractory material, to which were attached at the top and in the centre rows of small iron pipes. By means of a small tap each of these pipes could be cut off from the supply pipe, leading from the oil tank placed above the boiler. To the mouth of each pipe on the inner side of the plate of refractory material was fitted a vertical groove. The oil coming from the supply-pipe, on entering the grooves, was ignited and trickled down in them. For stationary boilers Audouin allowed the oil to flow from a supply pipe into a channel cut into the upper narrow surface of the plate of refractory material that takes the place of the fire-box door, from which it overflowed into the vertical grooves. The plate was provided, between the grooves, with openings, about 0.19 inch wide, through which the air required for combustion entered the fire-box. The supply of air could be regulated by a valve movable in sections, and fitted in front of the openings.

Aydon, Wise and Field's nozzle sprinkler is one of the oldest methods of burning liquid fuels. The apparatus is of very simple construction. The petroleum or other liquid fuel is injected by means of super-heated steam into the furnace, so that it spreads over the entire surface of the fire, and is completely burned.

The apparatus is shown in Fig. 210. It consists of an injector, into which the super-heated steam passes through the pipe i. The admission of steam is regulated at i_2 by means of the plug i_1. The petroleum reaches the injector through the shiftable pipe *j*. A corresponding quantity of air entering through the opening *R*, is mixed during the passage through the pipe R_2 with the steam and petroleum. The supply of air is regulated by raising or lowering the pipe *j*. The jet thus consists of superheated steam, air and petroleum, and is injected into the furnace through a pipe entering above the door of the fire-box. This jet strikes a fire-clay bridge placed at a distance of a few feet from the door of the fire-box. A small quantity of coal is kept burning upon an iron plate for the ignition of the petroleum jet. The air required for the combustion of the petroleum is introduced through openings in the fire-box door.

FIG. 210.



In fitting a Cornwall boiler with this apparatus no changes were required except boring a few holes in the fire-box door. In half an hour the apparatus can be removed and the former arrangement for coal firing restored. Practical experiments on a large scale with this apparatus gave the following results:

Combustion was very complete. An intense violet flame filled the space on the other side of the bridge, which proved the thorough decomposition of the fuel, while the absence of smoke furnished further evidence of the correctness of the principle upon which this invention is based. During two hours 19½ kilogrammes (42.9 lbs.) of water were evaporated for every kilogramme (2.2 lbs.) of oil injected. During the experiment the boiler furnished steam of 2½ kilogrammes (5.5 lbs.) pressure per square centimeter (0.155 square inch) to an engine which kept all the machinery of the works moving. The apparatus requires but little attention. By regulating the supply of oil and steam the flame can be immediately augmented or decreased.

H. de Bay and Ch. de Rosette's sprinkler. De Bay and de Rosette of Paris propose (German patent No. 31,962) to introduce the oil by compressed air or steam into a retort which is heated by the fire itself. For this purpose the oil runs from the holder *A*, Fig. 211, together with compressed air admitted through the nozzle *a*, into the retort *C*. The gases produced pass through *D* into a holder *E*. A stronger current of compressed air enters the holder *E* through the pipe *F* and carries the gases through the filtering pipes *m* and *n* to be burned for heating the boiler as well as the retort *C*. This effect is claimed to become still more perfect by placing pipes *G*, Fig. 212, which contain barium, potassium permanganate or other substances readily yielding oxygen, in the firebox. A current of compressed air enters these pipes, becomes heated during its passage through them, absorbs the oxygen evolved, and passes into the fire-box through the pipe *x*. By the entrance of this current of air rich in oxygen, combustion is claimed to be

FIG. 211.

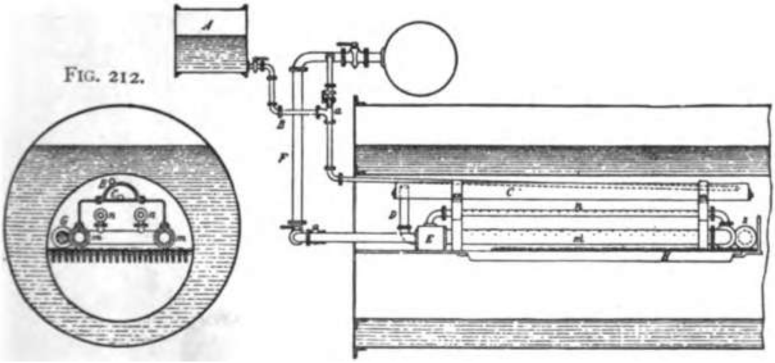


FIG. 212.

made more complete and the flame forced more towards the front portions of the grate, so that no combustible substance can reach the chimney. The grate is covered with one or more plates *H*, upon which is placed a layer of sulphate of lime or barium to prevent cold air from penetrating through the bars of the grate.

F. Mörth's Sprinkler. A mixture of hydrocarbons and superheated steam is introduced into the fire-box of a boiler by means of a net-work of pipes *B*, provided with holes *m*, Fig. 213, and a pipe *C* also provided with holes *n*, placed in the front part of the fire-box. For the purpose of regulating the supply of gas-mixture, a nozzle *q*, provided with screw threads, is placed on the end of the injector *A*, Fig. 214, at the mouth of the chamber *h* and a nozzle *q'* of similar shape at the mouth of the chamber *h'*.

FIG. 214.

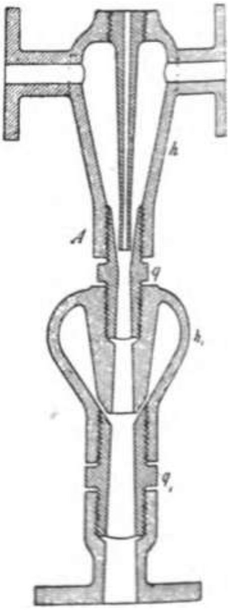
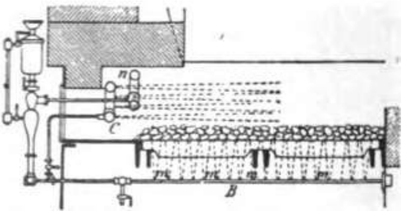
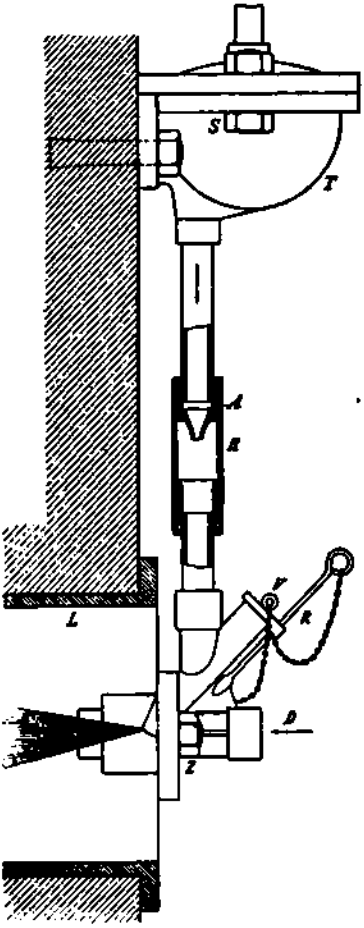


FIG. 213.



Körting's Tar Sprinkler. This sprinkler is constructed of iron, and essentially consists of a pipe from the front end of which the tar issues in a thin layer to be atomized by a jet of steam striking it at an adequate angle. It is then mixed with atmospheric air and conducted to the combustion chamber.

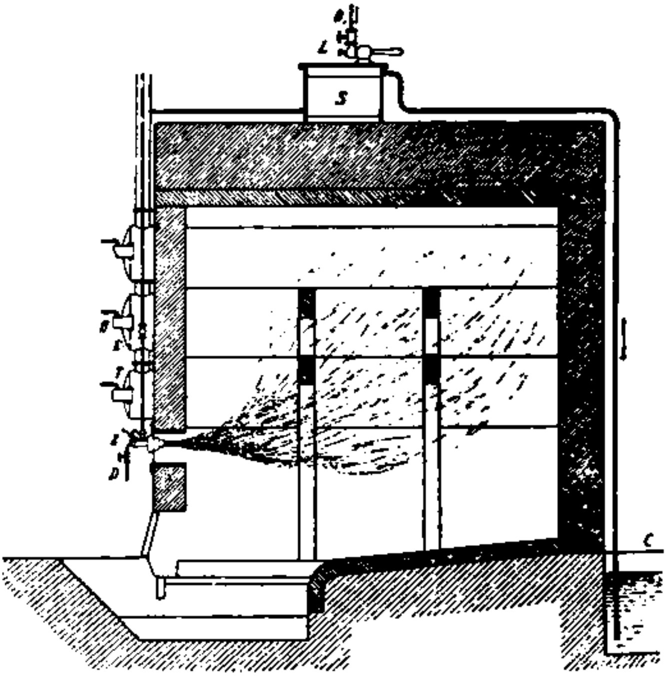
FIG. 215.



The steam issues in a very peculiar manner, the effect being that not a trace of tar can fall down. The supply of tar is regulated by the nozzle *A*, Fig. 215, the bore of which may be larger or smaller according to requirement. By the pot *T* and the sieve *S* in it all impurities are retained, so that the nozzle *A* can clog up only under peculiar conditions. To be able to clean it in such case without taking the apparatus apart, it is only necessary to push back the case *H* and clean the nozzle *A* with a needle. In case the actual pulverizer *F* should become choked up, it can be immediately cleaned, while working, by means of the needle *R*, after removing the lid *V*.

The pulverizer *Z* is placed by means of a short nozzle in an opening in the furnace wall. The jet of steam, as mentioned above, sucks with great energy the air for combustion through this air nozzle, thus essentially assisting the attainment of perfect combustion. Combustion is regulated by the steam-pipe *D*, and slides on the side of the pulverizer, which can be so

FIG. 216.



arranged that only sufficient air to effect combustion without smoke is admitted.

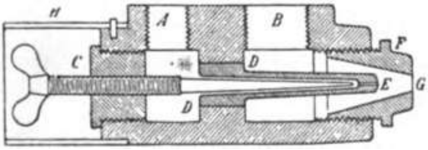
In gas-houses the tar holder is placed upon the retort furnace, Fig. 216, to keep the tar warm and thinly fluid.

Of great importance in tar-firing is a continuous supply of tar, so that combustion is not interrupted. It is therefore recommended to place a second holder *S* upon the furnace, and connect it also with the pulverizer. From each holder a separate conduit, about 1 inch in diameter, leads close up to the pulverizer, and each nozzle for regulating the supply is provided with a stop-cock, so that the tar may be taken from either of the conduits as desired. With the use of furnaces, in which the lowest retort lies in the centre of the furnace, the pulverizer should be placed as low down as possible, so that the very hot flame cannot act directly upon the lowest retort. With furnaces in which the retorts lie on both sides, and in two rows, and above them in the centre, a fifth or seventh retort, the pulverizer may be placed at the ordinary height of the fire-box.

At the present time Körting's sprinkler is also used for oil firing.

Drory's Tar and Oil Sprinkler.—The object of H. J. Drory's apparatus for tar and oil is to effect as complete combustion as possible, without smoke, of the liquid fuel supplied at fixed intervals. The nozzle *D*, Fig. 217, sits in a circular iron frame with a straight upper surface, which is provided with two apparatuses *A* and *B*. The liquid fuel is brought into *A*, while *B* serves for supplying previously heated compressed air, or dry steam. The tar or oil is then

FIG. 217.



sucked into the nozzle, and on leaving it at *E* is forced against the opening *G* of the mouth-piece *F*, and pulverized.

Inside of the nozzle *D* is a shiftable needle *C* protected from injury by the case *H*. The object of this needle is, on the one hand, to regulate, according to requirement, the flow of oil to the opening *E*, and, on the other hand, to clean *E* when necessary. To attain complete combustion the distance between the opening *E* of the nozzle and the opening *G* of the mouth-piece may be changed as required, the mouth-piece *F* being for this purpose provided with screw-threads, so that it can be shifted.

A form of sprinkler much used is shown in Fig. 218. It consists of a 1-inch iron pipe *D*, the front end of which is flattened so that a slit about 0.019 to 0.039 inch wide remains open through which the steam conducted through the pipe may pass out. The tar or oil supplied by the pipe *N* is distributed in the cup-like shoulder *A*, and runs from the front end of the latter over the slit, where it is pulverized by the steam, and finally burned.

FIG. 218.

FIG. 219.

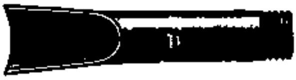


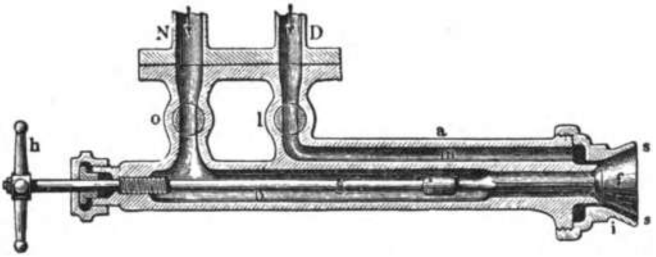
FIG. 220.

FIG. 221.

By giving the pipe *D* the form of Fig. 219, 220 or 221, the flame formed will be more pointed, broad or medium. The admission of air and oil or tar is regulated by cocks on the prolongations of the pipes *N* and *D*.

Brandt's forfunka or slit-sprinkler. This apparatus is shown in Fig. 222. The pipes *b* and *m* pass through the cast-brass piece *a*, *b* serving for the residuum which enters at *N*, and *m* for steam, which is admitted at *D*. The residuum passes out through an annular slit which can be regulated by means of the cone *f*, the handle *h* and the spindle *g*, while the steam escapes through a slit arranged around this annular slit. Between the cone *f* and the headpiece *i*, the residuum and steam are mixed, and appear at *s* in the form of a fine spray which is ignited. When the apparatus is used, the cocks *o* and *l* are open, the admission of steam and residuum not being regulated by them, but by shifting the cone *f*.

FIG. 222.



Figs. 223 and 224 show the arrangement of the apparatus as fitted to an ordinary Cornwall boiler. The residuum runs from the holder *R* through the pipe *N* into the burner, while the steam is supplied from the dome of the boiler through *D*. At *r* the entire burner can be revolved, and by turning it 90° it projects from the door *t*. To render explosions impossible ignition is effected while the burner is in this position, hence, before its introduction into the fire-box. The necessary air enters through holes in the door *t* as well as through a larger aperture, the size of which can be regulated by means of a slide.

FIG. 223.

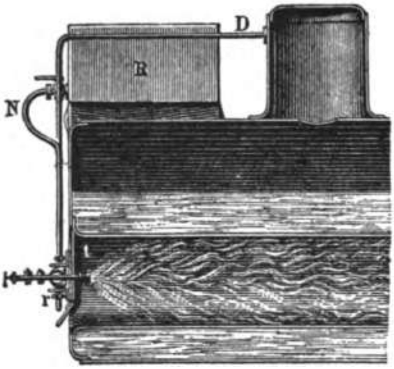
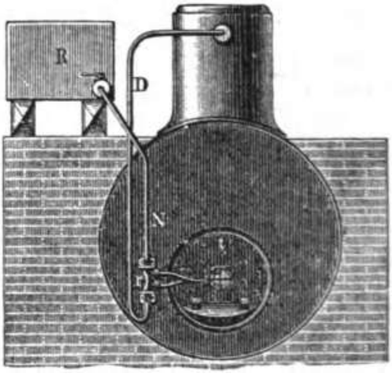


FIG. 224.



Lenz's slit-sprinkler. This apparatus is shown in Figs. 225, 226, and 227. It consists of the double brass-pipe *a a'*, with which is connected the cylindrical mixing chamber *h*, which can be closed, below and above, by means of the screw-lid *g*. The rods *o*, which can be shifted by means of a key at *p* and *p'*, run at *t* and *n* in solid bearings and terminate in eccentric arbors. The latter gear together with semi-cylindrical sliding pieces *e*, and, according to the turn given at *p* and *p'* and the position of the eccentric arbors, these sliding pieces can be shifted up or down so that they approach more or less the tongue *b*, whereby the supply of steam and residuum is accurately regulated. The residuum in the form of fine spray passes out

FIG. 225.

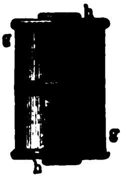
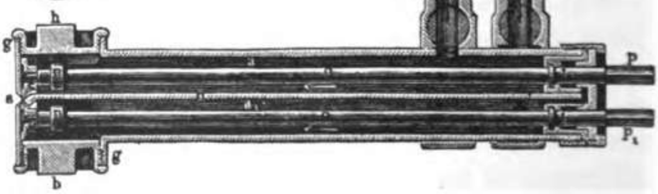


FIG. 226.

FIG. 227.



through the horizontal slit-like mouth *s*, which runs half or somewhat less around the cylindrical chamber *g*. The supply-pipes *D* and *N* for steam and residuum are provided with cocks. This forfunka consumes about 6.6 to 7.7 lbs. residuum of specific gravity 0.910 with ignition point 284° F. per hour per horse-power.

Joganson's sprinkler. This apparatus is shown in Figs. 228 and 229. A cast-iron pipe with screw-threads on the ends is divided into two compartments by the partition *C*. The upper compartment for the petroleum communicates at the right with the oil supply-pipe *P*, screwed into the coupling box *B*, and the lower compartment with the steam-pipe *Q*. Two semi-circular disks *M* and *N* are placed in the coupling-box *D*, one above the other, so that a small slit *p p* (Fig. 230) remains open, through which the oil and steam can pass. This forfunka is placed in the fire-box so that it projects into it not more than a quarter of the length of the pipe *A* (Fig. 228). By this mode of construction a long flame is obtained, the regulation of which is rendered possible by valves inserted in the pipes *P* and *Q*. The consumption of steam by this forfunka is comparatively large.

FIG. 228.

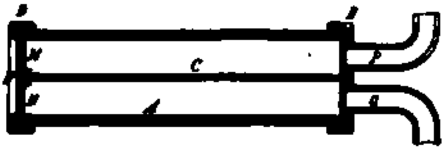


FIG. 229.

FIG. 230.

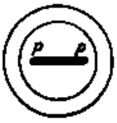


FIG. 231.

Schuchoff's forfunka is shown in Figs. 232, 233 and 234. It is much more complete than the preceding, and is extensively used. It is made of copper and consists of three principal parts *A*, *B* and *C* (Fig. 232). *A* is a pipe provided with tubes and terminates in a cone. *B* represents a coupling box with the tube *b*, *C* a hollow spindle with the opening *a* and the guide *g*. The oil enters the spindle *C* through *b* and the opening *a*, and passes out at *f*. At *m* the steam enters the annular space *p p*, washes around the spindle *C*, and escapes through the conical end of the pipe *A*. It strikes the jet of oil from the periphery to the centre, pulverizes it and produces a flame, the shape of which is seen in Fig. 233.

FIG. 232.

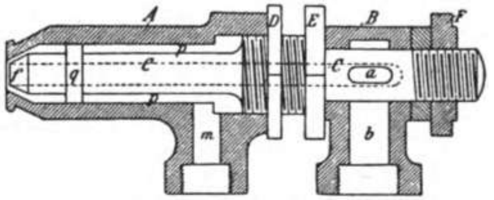
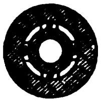


FIG. 233.

FIG. 234.



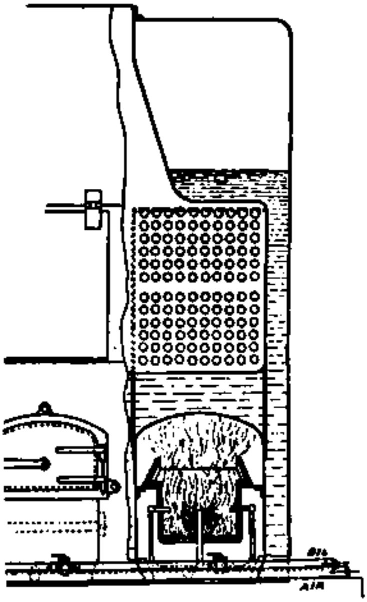
By turning the spindle *C* the supply of steam is regulated. When the spindle is properly set, the nut *D* is screwed against *A*. The coupling box *B* is secured by the nuts *E F* and the disk *H*. The chief defect of this apparatus is that the steam, at the moment it issues from the pipe *A*, strikes the periphery of the oil-jet, in consequence of which the latter is drawn in and combines to a jet of larger diameter only at a distance of 1 ½ feet from the mouth-piece, so that the front portions of the boiler are but slightly heated, which is of great disadvantage. The consumption of steam is quite large; generally speaking, the apparatus gives satisfactory results.

Apparatuses for Steamers.

For marine purposes oil-firing possesses many advantages. Marine boilers have often been fired by petroleum. About 1867 experiments were made by Mr. Isherwood, of the United States Navy, on board the gunboat "Pallas," on liquid petroleum as fuel. He was convinced of its superiority to coal in heating value, convenience of storage, weight, bulk, absence of stoking, and consequent saving of manual labor. He found also that the lighter oils, which explode very easily, burn completely and leave no deposit. Against these advantages must be set the great drawback of using petroleum to any great extent as marine fuel, namely, the danger of carrying an inflammable oil, giving off volatile gases at a low temperature in bulk at sea.

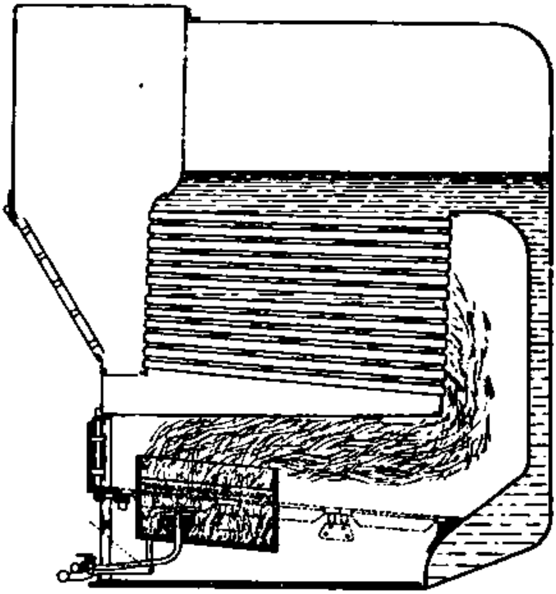
The use of petroleum for steam fuel is determined by its cost relative to other kinds of fuel. With the low price of petroleum at Baku and the absence of wood and coal on the steppes of Russia and the shores of the Caspian sea, there can be no question that petroleum is the cheapest and best fuel to be had in that region. In fact, the Baku oil fields have created the Caspian fleet. But in the United States the question lies between petroleum and anthracite coal for ocean steamers, and bituminous coal on the western rivers, and while there may be circumstances under which the increased cost of firing with petroleum would not be a valid objection to its employment, a considerable increase in the use of petroleum for marine purposes in the United States cannot be looked for in the near future.

FIG. 235.



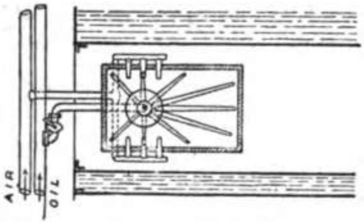
Bidle's pan furnaces, figs. 235, 236 and 237 were constructed, in 1862, in North America, and designed especially for marine boilers. They consist of an iron box cast in one piece, and at the bottom. The latter slants slightly backwards and is provided with grooves radiating from the centre, see ground plan (Fig. 237), which ensures an equal distribution of the oil. A pump sucks the oil from storage-tanks in the bilge, and forces it into a box over the boilers. From this box it is conveyed through a pipe along the outside of the front wall of the boiler, and it then runs through branch-pipes into the separate furnaces. These branch-pipes enter in the centre of the fire-box, and immediately below their mouths are surrounded by an iron basket filled with red hot coal or coke, which serves the purpose of igniting the oil. The oil that escapes ignition runs into the grooves, where it is burned. Small apertures (Fig. 236) in the bottom of the fire-box, in the immediate vicinity of the entrance of the oil, were provided for the purpose of admit-

FIG. 236.



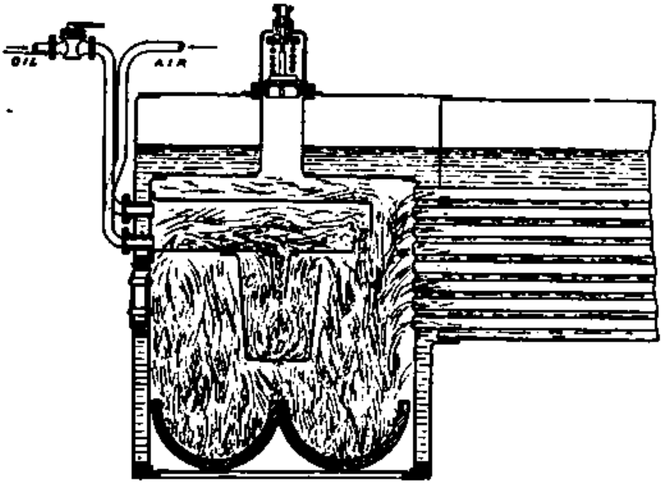
ting sufficient air for perfect combustion, but were found to be insufficient and large volumes of smoke were the result.

Fig. 237.



Bidle blew in more air by introducing fans and increasing the number of apertures. Combustion was thereby improved, but the entire arrangement became too complicated by the fans which required special steam engines.

Fig. 238.

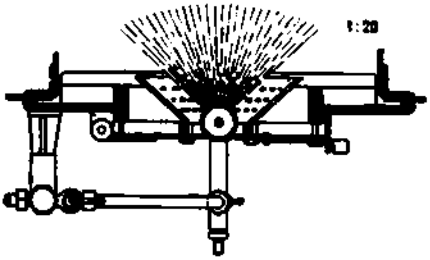


Shaw and Linton's furnace, patented in 1862, in the United States, is designed for locomotive and machine boilers, and forms the transition from hearth furnaces to gas furnaces. As shown in Fig. 238, the crude oil passes from a holder placed at a higher level into a tank in the furnace, and flows on to the fire-plate *A*, previously heated by a wood or coal fire. The lighter oils vaporize and pass at *B* from the tank into the fire-box, where they are consumed. The non-vaporized oil runs into the vessel *C* secured below *A*, which is heated to a greater temperature, and here the heavier oils are vaporized. The residue remaining non-vaporized passes through the opening *D* to the floor of the furnace, the grate of the latter having been removed and replaced by a cast-iron plate provided with depressions. The residue is burned upon this plate. Alongside the oil supply-pipe enters a pipe for the introduction of air.

This mode of firing was defective in that the quantity of oil vapors evolved could not always be brought into accord with the amount which could be consumed, and to avoid explosions a safety-valve for the escape of the excess of hydrocarbons had to be placed upon the furnace. During the trials made by Shaw and Linton with a marine engine, the oil was forced by a pump from tanks in the bilge into a holder placed over the boiler. Draught was promoted by a jet of steam blown into the furnaces. To produce this jet of steam a subsidiary boiler was heated with anthracite coal before the generation of steam commenced in the main boiler, twenty-eight minutes being required for the latter purpose with crude oil or residuum, and sixty minutes with coal. 2.2 pounds of crude oil or residuum evaporated 22.79 pounds of water, while the anthracite, it is claimed, did not evaporate more than 11.2 pounds of water. The temperature of combustion was so great that the chimney became red-hot about twelve inches from its base, which proved that the heating surface was too small for the perfect utilization of the heat. The introduction of this apparatus had to be given up on account of the large working expenses it entailed.

Lenz's new slit sprinkler. To make this apparatus more suitable for locomotive and marine boilers, the straight slit-like mouth has been replaced by a circular aperture running round the cylindrical chamber, which insures a circular flow of the oil-spray. In order to obtain a flame spreading more upward and downward, as shown in Fig. 239, the tongue also had to be somewhat modified.

FIG. 239.



In all other respects the sprinkler is arranged like that described on p. 618. By these improvements the usefulness of Lenz's sprinkler has been considerably extended; it is, however, also more expensive and less simple.

Spakowski's nozzle-sprinkler. This apparatus, Figs. 240 and 241, was first used in 1870, for marine boilers. It has since been much improved, and its present simple form has been applied to four steamers built in 1879 and 1880, for the Caspian Sea trade. The liquid fuel, in this case illuminating oil residuum, flows out of the inner nozzle, which protrudes about one millimeter into the mixing pipe (Fig. 241), while the steam issues from the annular aperture surrounding this nozzle.

FIG. 240.

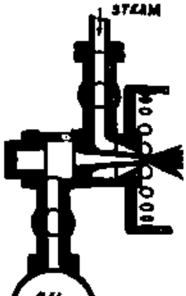
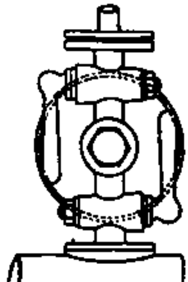


FIG. 241.



Through holes bored in the periphery of the mixing pipe the jet of steam and oil sucks in the necessary quantity of air. The mixing pipe at the same time prevents excessive air expansion of the steam-jet, and thus slightly assists in pulverizing the oil. The pulverization of the oil in this apparatus is, however, not done as efficiently as in Urquhart's latest improvement. The jet of steam surrounding the oil acts vigorously only from underneath the upper portion, expanding without materially assisting pulverization, so that by looking through a piece of blackened glass into the flame, drops of oil can be observed falling down into the furnace, where they are burned in their liquid state. The flame has a broom-like shape and is very long, so that it acts most vigorously upon the fire bridge and heats the other portions of the fire-box only by radiation, and even that unequally. For very large fire-boxes one sprinkler is not sufficient, two or three being required, which causes complication. The supply of oil and steam for each sprinkler is regulated by means of separate cocks.

The first sprinkler constructed by Spakowski was used in 1870, on the Caspian Sea steamer "Ivan," which is fitted with a Penn low-pressure engine. The boiler had two furnaces and worked with a pressure of 1.25 kilogrammes (2.75 lbs.) per square centimeter (0.155 square inch), and had been previously used for fourteen years with coal-firing. Each furnace was furnished with three sprinklers, which, with 92 revolutions of the engine per minute and 45 indicated horse-power, consumed 4.25 kilogrammes (9.35 lbs.) of residuum per horse-power per hour. In 1873, the steamer "Helma," which also had a low-pressure engine, was fitted up with Spakowski's sprinklers for oil-firing. The boiler worked 1.5 kilogrammes (3.3 lbs.) of pressure per square centimeter (0.155 square inch) and had two furnaces, each one provided with a sprinkler. With 85 revolutions per minute and 21 indicated horse-power, 3.11 kilogrammes (6.84 lbs.) of residuum were required per indicated horse-power per hour. In regard to this considerable consumption of oil, it has to be remarked that the oil did not flow into the sprinkler from a tank at a higher level, but had to be sucked up from tanks in the hold by an injector, which caused a great waste of steam. Finally, the engines were furnished with injection-condensers only.

Apparatuses for locomotives.

The use of petroleum for firing locomotives required a modification of the apparatuses previously described; constructions had to be found which produce a broader flame and in which the fire-box is not attacked by the point of the flame.

The first experiments were made, in 1868, by M. St. Claire Deville. He first tried vertical grates the openings of which were so calculated that back of them a fixed quantity of mineral oil could be burned without the formation of smoke and without the use of a perceptible excess of air. The latter condittion St. Claire Deville considered of the utmost importance, because, as shown by him, one of the greatest advantages, in an economical respect, of the use of mineral oils for firing, is that the oxygen has to be withdrawn from all the air conveyed to the fuel in order to attain perfect combustion. The further such grate was placed inside the hearth, the more it was withdrawn from the cooling influence of the air, and the more strongly it was heated during the combustion of the mineral oils.

St. Claire Deville considered the grate a series of lamps, and the grate-bars the wicks, the oil being vaporized by them in internal grooves. The air which entered the hearth through the open spaces between the bars produced a very bright and a very short flame, about 9.84 inches in length. Outside the flame no products of combustion were perceptible, but a stout platinum wire introduced into the dark portion became immediately red hot. The flame was therefore deprived of its carbon like the outer (oxidizing) flame of the blow-pipe, with which the apparatus may be compared. To augment the vaporizing surface of the oil without increasing the external dimensions of the grate, the rear wall of the grate was inclined at a certain [illegible] grate was furnished with a [illegible] oil; the latter ran over [illegible] upon a cast-iron sup[illegible] prevent the oil from [illegible] engine, or from falling [illegible]

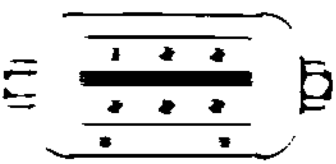
[illegible] grate was effected by [illegible]

[illegible] a locomotive con[illegible] in an oblong position [illegible] surface as possible.

[illegible] fitted, in 1870, with [illegible] kilogrammes (7.7 to [illegible] feet) traversed, or say 8 [illegible] The oil was completely [illegible] in the atmosphere of the [illegible] simple cock, according [illegible] which, as soon as no excess [illegible] In case of acci[illegible] the oil could be auto[illegible] was immediately extin[illegible]

[illegible] [illegible] apparatus, shown in Figs. 242

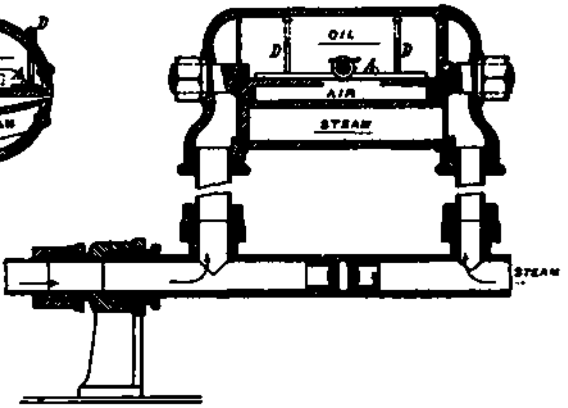
Fig. 242.



and 243, was, at the commencement of the eighties, considered the most effective, and was preferably used for locomotives. It is attached to the boiler by movable pipes, and has the advantage of directing the flame on to a fire-proof brick hearth (Fig. 243), which very soon acquires a very high temperature and ignites any non-consumed drops of oil reaching it, thus making combustion almost complete. The apparatus itself consists of a central body with three channels; the upper channel supplying residuum, the middle, air, and the lower, steam. The ends of the sprinkler are fitted with the distributing pipes for oil and steam, and as seen in Fig. 243 are secured by screws to the central body. The jet of steam issuing from the slit of the sprinkler sucks the air throngh the central channel and brings it into direct contact with the particles of oil to be burned, thus

FIG. 243.

FIG. 244.



promoting their complete and smokeless combustion. The supply of oil is regulated by a slide *A* with sprinkler *B* and hand-wheel, while the steam is regulated by a cock or valve. Two setting screws *D* prevent the slide *A* from slipping back when the apparatus is working. For inspection and cleaning the sprinkler is brought into the position indicated by dot in Fig. 245. This apparatus consumes such a large quantity of oil per horse-power per hour that it can be used only where oil is to be had for next to nothing.

Korting's pipe-sprinkler. This apparatus is represented by Figs. 247 to 250. Its distinguishing feature is that instead of the oil the steam passes through the inner pipe while the oil is supplied to the outer pipe, this arrangement facilitating the cleansing of the discharge aperture in case of stoppages. The

FIG. 245.

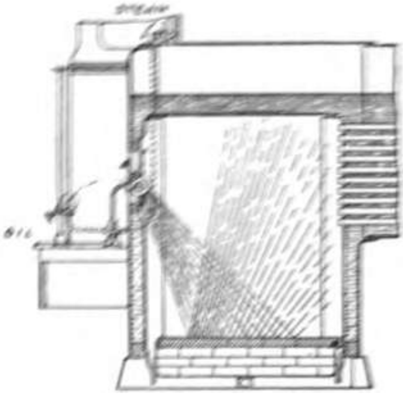
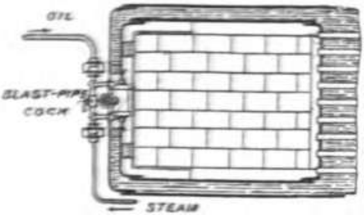


FIG. 246.



steam reaches the outlet through a pipe which becomes somewhat narrower a short distance from its mouth. This pipe is secured by a socket, to the back of which is fastened an elastic chuck with two pivots, worked by two small levers. Upon the axis of these levers sits another lever which can be moved by

FIG. 247.

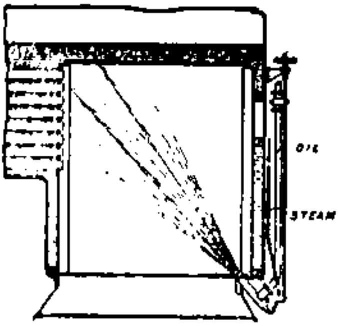
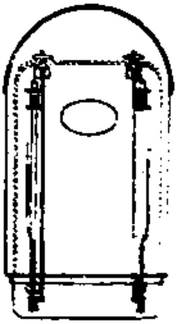


FIG. 248.



means of a drawing-rod and hand-wheel from any desired place on the front of the boiler. When this lever is moved the socket is pushed over the inner pipe and regulates the discharge of oil, while the jet of steam may be shut off by a valve or cock. To improve combustion on the surface of the oil-jet [illegible] and steam passing out sucks in air through holes in the sides of the out-flow cone. The air otherwise required for combustion enters through the ash-pit. With locomotive boilers the jet of flame is projected, as shown in the illustration, against the upper corner of the fire-box, but with marine boilers it is thrown back on the fire-bricks behind. Korting's pipe-sprinkler is especially intended for locomotive and marine boilers.

FIG. 249.

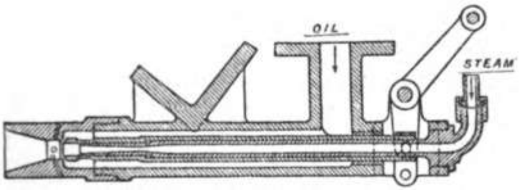
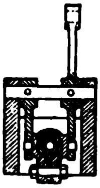


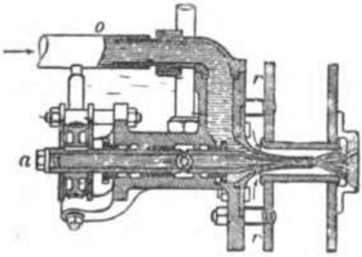
FIG. 250.



It has the advantage of being very simple in construction and it can be rapidly and thoroughly cleansed after unscrewing the mouth-piece.

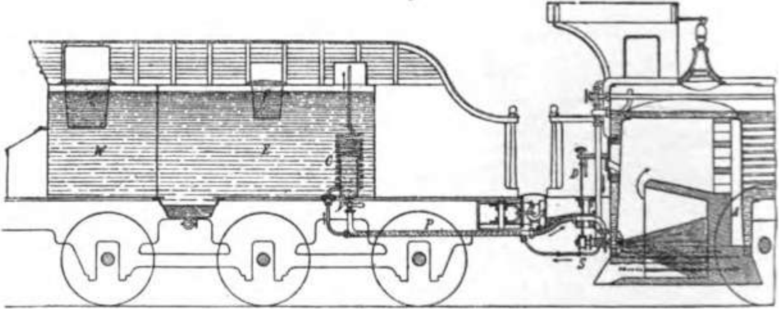
Urquhart's sprinkler, Figs. 251 to 254, is a very simple apparatus for locomotive firing. The residuum is injected into the furnace by a simple blast. The principal advantage of this sprinkler is that it allows of the fire being immediately interrupted as well as most accurately regulated while running and stopping at stations. The pipe *a* (Fig. 251) containing steam from the boiler passes down the center of the oil supply pipe *o*; the steam and oil mingle at the mouth of the nozzle,

FIG. 251.



and are injected in the form of fine spray into the fire-box. At the junction *r* of the pipe and the fire-box, air is drawn by suction to the nozzle and enters with the steam and oil. The tank *E* containing the oil takes the place of the former coal-space in the tender between the water tanks *W*, so that in winter on heating the water by the steam-pipe *S*, the oil is also heated. With the discharge-cock *V* there is further connected a steam coil *C*, so that the oil enters, in a warm state, the pipe *P* leading to the furnace, through which the pipe *S* is also conducted for further heating. Any water separated from the oil collects in a depression in *W*. To retain impurities the filling aperture and discharge at *C* are fitted with filters. An arrangement of the brick-work (regenerative firing) Figs. 253 and 254, by which the air entering through the front door of the ash-pit is thoroughly heated, has also proved quite successful. The two tubes *B* allow of the flame heating also a portion of the tube-plate under the fire-tubes. The supply of oil is regulated by means of the spindle *D*, which is fitted with double screw thread, brass nut and indicator. The latter moves upon a brass scale graduated from 0° to 20° and allows the fireman to regulate the supply of oil during the night, since in the dark vapor cannot be accurately distinguished from the smoke of the chimney. What used to be the fire-door is bricked up, leaving only a peep-hole through which it may be observed at night whether the fire is bright or dark. To determine the quantity

FIG. 252.



of oil consumed, the oil tanks in the tender are fitted with a gauge, about 1 inch in diameter. This gauge is more than 5 feet long and is secured to a wooden frame furnished with an inch-scale. Each mark on the scale is equivalent to a number of pounds of petroleum in the rectangular tank; and the engineer is thus enabled to read off on the scale the quantity of petroleum consumed. The tank of a six-wheel locomotive holds 3½ tons of petroleum, and this quantity suffices for running a train of 480 tons gross weight, exclusive of locomotive and tender, a distance of 250 miles. Urquhart's system was first used, in 1882 on the Grazi-Tsaritzin line, and the best proof of its economy is that, from that time to 1888, it has gradually and entirely superseded coal. The saving in money is stated by Mr. Urquhart to be 43 per cent. In 1882, the consumption of coal per engine mile, including wood for lighting up was 55.65 lbs., costing 7.64 *d.* In 1887, 30.72 lbs. of petroleum refuse were used per engine mile, costing 4.43 *d.* The expense of repairs was also much less, owing to the absence of sulphur in the oil. There are 423 miles of railway on the Grazi-Tsaritzin line, and 143 engines are now fired with petroleum.

FIG. 253.

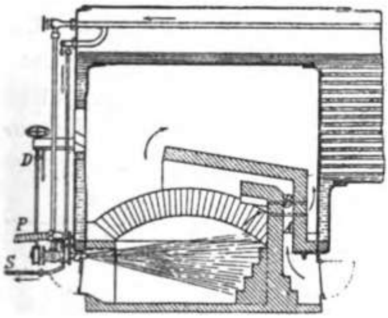
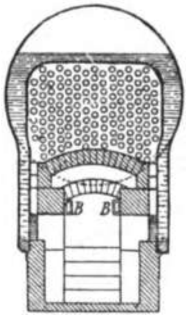


FIG. 254.



For initial firing and generation of steam, steam is conveyed to the petroleum locomotive by an engine kept for that purpose, whereby the sprinkler is set to work and a draught at the same time created in the chimney. For initial firing steam may also be taken from a stationary boiler. If direct steam cannot be had, it has to be generated. In the practice steam of a pressure of 3 atmospheres can be generated from cold water inside of twenty minutes; by using this steam a pressure of eight atmospheres can be obtained in about 40 or 50 minutes from the time the sprinkler is first set to work. If warm or hot water can be had for feeding, a pressure of seven or eight atmospheres may be attained in about 20 to 25 minutes.

By observing the vapor issuing from the chimney, the admission of oil may be accurately regulated, the rule being that the vapor should be transparent and light, since if such be the case, the air is introduced in proper proportion to the petroleum burned. Moreover, combustion is entirely under the control of the engineer, and can be conducted without the generation of smoke.

Apparatuses for hearths.

Of the various constructions for this purpose only a few may here be mentioned.

Nobel and Wittenstrom's step-furnace has been used for a number of years, it being also employed by Ostberg in the manufacture of his wrought iron (mitis) castings. The system consists of a series of iron troughs arranged in the shape of steps. The oil enters the topmost trough, and then overflows into the others, until it is all burned. The difficulties of attaining by this arrangement perfect, smokeless combustion have been overcome by Messrs. Nobel and Wittenstein by the introduction of an artificially increased draught. By bringing the cross section of the chimney into a certain proportion to the surface of the oil exposed to the fire and by carefully regulating the admission of compressed air, Ostberg claims to have attained a temperature sufficiently high to fuse wrought iron in crucibles at a distance of 11.81 inches from the grate-surface.

Westphal's sprinkler. From a tank placed 3 to 6 feet above the burner, the petroleum runs through the pipe *L*, Figs. 255 and 256 and the valve *T* into the conduit *K*, and through small apertures *o* into annular grooves *E*, lying one in the other, from which it passes out upward through annular slits. On leaving these slits the oil is struck and pulverized by a current of air, and when ignited burns with a very vigorous flame which enters the hearth at *H* through the nozzle *S*, which is lined with refractory material. The current of air produced by a blowing engine passes through the pipe *W* and is divided by the interspaces *r* between the slits *t*. The mouth of the pipe *W* can be set by a valve *A*. The ignition of the petroleum above the burner *B* is effected by means of a torch through an opening in the nozzle *S*, which can be closed by the lid *d*. The cock *U* on the conduit *L* serves to empty the latter through the tube

FIG. 255.

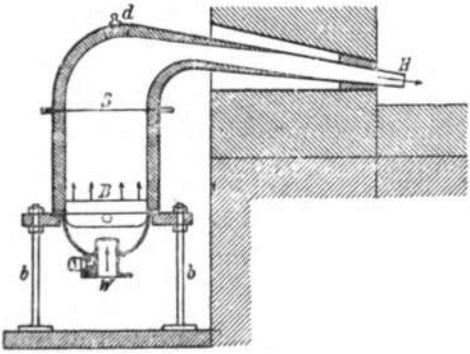
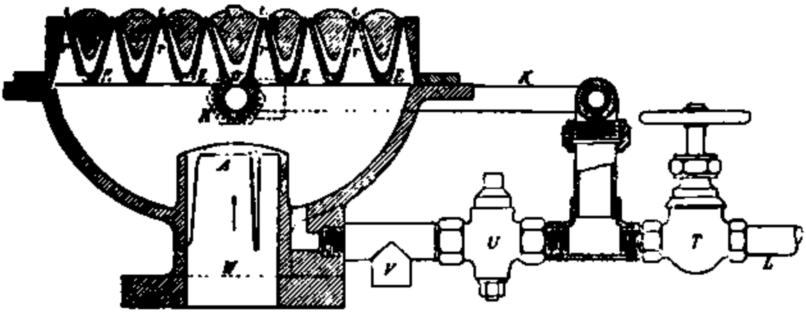


FIG. 256.



V, when required. As seen in Fig. 251 the entire apparatus rests upon four supports *b* and can readily be placed anywhere. For the purpose of cleaning, the actual burner *B* can be easily removed and inspected.

The following advantages are claimed for this burner: The attainment and maintenance of a very high temperature; a pure flame without soot and without injurious gases; ready regulation of the intensity of the flame, and a clean and cheap process of working. The apparatus is much used in Baku and on the Volga. Three sizes, of 5.9, 7.87 and 9.84 inches external diameter, are now manufactured. The price of a 7.87 burner in Baku is about $63.00. It consumes about 33 lbs. of petroleum per hour.

Petroleum stoves and furnaces for domestic purposes.

For domestic purposes a great variety of stoves, some of them quite pretentious in size and ornamental in appearance, are already extensively employed. In these, generally, a high-test oil is used. They are mostly employed by small families, and in the summer season, when the heat of a large coal-burning cooking stove would be almost insupportable. The advantages consist chiefly in the fact that as soon as the necessity for the stove ceases, the fire is extinguished without loss of fuel, and as soon as the necessity reappears, the fire is made and in full blast without loss of time. These are two very important desiderata. Besides, there is a positive economy in fuel, to say nothing of superior convenience and cleanliness. In these stoves either round or flat wicks are used, the size of which is proportional to the amount of heat required. The heat generated is quite sufficient for the ordinary purposes of a small family.

Uses of lubricating oils.

The advantges, both pecuniary and beneficial, accruing to modern civilization, from the introduction of the heavy products of petroleum for the lubrication of machinery are hardly second to those resulting from the introduction of the cheap and beautiful light furnished by its illuminating portion. It would be difficult to exaggerate its importance and value to the textile manufacturer, to the iron industry, and to the railroad interests. The hydro-carbon oils, for the purpose of lubrication, were at first received with but little favor; indeed, the opposition was all but universal. The disagreeable odor always associated with the imperfectly prepared oils first offered, disinclined superintendents of mills and factories to give them a trial, even at prices much lower than those which they were accustomed to pay. Insurance companies, on account of the explosible inflammable vapors, said to be inseparably connected with them, refused to take risks, except at greatly increased rates, upon factories where they were employed. The objections urged against their introduction were not wholly without foundation, and incited the manufacturers to increased diligence in removing them. Improved methods of treating these oils soon resulted in greatly improved products; the prolific yield of the crude material from the wells further reduced their market price. Accurate methods of testing their real economic value were discovered and introduced into use, and thus through their real merit in the face of often ignorant opposition, these oils have made their way into general use and favor. It is not to be inferred from what has been said, that animal and vegetable lubricating oils are driven from the market, or are likely to be. They have distinctly important uses, and whether alone or combined with hydrocarbon oils, will still be employed for the purpose of lubrication. Nothing has contributed more rapidly and more effectually to disarm the ignorant opposition before alluded to, than the accurate tests of their working value to which all kinds of machinery oils are now subjected. These have resulted not only in discovering desirable qualities in the hydrocarbon oils hitherto unsuspected, but have pointed out methods by which objectionable features have been either wholly removed or greatly modified.

Prof. R. H. Thurston, in his "Treatise on Friction and Lost

Work in Machinery and Mill Work," furnishes the following characteristics of a good lubricating material:

1. Enough "body" or combined capillarity and viscosity to keep the surfaces between which it is interposed from coming in contact under maximum pressure.
2. The greatest fluidity consistent with the preceding requirements, *i. e.*, the least fluid-friction allowable.
3. The lowest possible coefficient of friction under the conditions of actual use, *i. e.*, the sum of the two components, solid and fluid-friction, should be a minimum.
4. A maximum capacity for receiving, transmitting, storing, and carrying away heat.
5. Freedom from tendency to decompose or to change in composition by gumming or otherwise on exposure to the air or while in use.
6. Entire absence of acid or other properties liable to produce injury of materials or metals with which they may be brought in contact.
7. A high temperature of vaporization and of decomposition, and a low temperature of solidification.
8. Special adaptation to the conditions, as to speed and pressure, of rubbing surfaces, under which the unguent is to be used.
9. It must be free from grit and from all foreign matter.

The consumer will readily recognize in the above all the desirable qualities that he requires, and the manufacturer those points of excellence he aims to secure in his products. As to what lubricant to use under certain specified conditions of temperature, speed, and pressure, a practical trial under these conditions will be the best teacher.

The managers of numerous railroads hold, even at the present time, to the principle which, however, has not been practically proven, that for lubricating passenger, mail and baggage cars, vegetable oil or a mixture of vegetable and mineral oils should be used. Among some the opinion prevails that for lubricating cars running at greater velocity, a better quality of oil has to be used, it being supposed that with an increase in the velocity there is greater danger of hot-running. Opinions differ also in regard to the choice of lubricants for locomotives; the position of the management of many railroads being such that experimenting never ceases. Exact experiments on a large scale with entire trains have not been made, so that theoretical speculations are frequently the only guide. Joseph Grossman, in his work "Die Schmiermittel," arrives at some novel conclusions. His deductions, based upon Coulomb's experiments and the more recent examinations of R. H. Thurston, show that from a theoretical standpoint it would seem rational to lubricate freight cars with a better, though more expensive quality of oil, and passenger cars with the ordinary cheap oil. This, however, cannot be carried out in every case, since with the greater number of freight cars used it would be scarcely possible to lubricate them with expensive oil and the smaller number of passenger cars with cheap oil. For railroads with a level track or slight grades, the use of a better quality of oil may therefore be recommended, while railroads with steeper grades, which can derive no advantage from the use of expensive oils, may secure an economical advantage by the choice of as cheap an oil as possible; in the first case a very thinly-fluid, but as viscous an oil as possible, should be selected, and in the latter very thickly-fluid oils.

For locomotives it is advisable for economical reasons to use two kinds of oil. For cylinders and slide valves, oils distinguished by a very high flashing point should only be used, vegetable and animal oils being best for the purpose, since they do not evolve inflammable vapors at the high temperature (356° F.) which prevails in the cylinder. On the other hand, mineral oils have stood the test only in very rare cases, tolerably favorable results having been attained only with special fractions, or still better with thoroughly refined residuum. This furnishes one of the best illustrations of the principal difference between vegetable and mineral oils. With the use of the former the slide valves and locomotive always feel greasy, while, after the same working time, mineral oil leaves the sides of the cylinders dry, they frequently appearing corrugated, and coke-like separations are observed on the slide-valves and pistons. This is largely due to the fact that at these high temperatures, mineral oils, as compared with vegetable oils, lose so much of their viscosity that they adhere in a scarcely perceptible manner to the sides and suffer partial decomposition in consequence of the prevailing high temperatures and the pressure to which they are exposed, this phenomenon being also frequently observed in large stationary engines. Hence the annoying buzzing of the cylinder can be traced either to an insufficient consumption of lubricating oil or to readily decomposable oils, the natural consequence being a considerably larger consumption with the use of mineral oils. For the cold parts of locomotives pale mineral oils and thoroughly refined residuum are very suitable, experience having shown that the best mineral oils for the purpose are such which at 122° F. show the same viscosity as rape oil at the ordinary temperature.

For lubricating marine engines, mineral oils are suitable only in very rare cases. The high temperatures prevailing in the engine-rooms require lubrication, especially of high-pressure cylinders, with very viscous mineral oil of especially good quality and high flashing point, or still better, with animal oil or a mixture of both.

For the lubrication of the cold parts of stationary engines, the well-known mineral machine oils are very suitable and, with the exception of the slide-valves and cylinders, may be used on every part of the engine, all principal transmissions and shafts, while the cylinder and piston should be lubricated with vegetable oils, or still better with pure mineral fats free from acid, the so-called crude vaselines. As previously mentioned, pale oils are to be preferred to dark oils, if for no other reason than that dangerous friction of parts of the engine is indicated by the change in the color of the oil caused by small metallic splinters.

Mineral oils of poorer quality are well adapted for lighter transmissions and rapidly running turbines.

For the working parts of fine machines, for instance the spindles of spinning machines, which make 8,000 to 10,000 revolutions per minute, and for looms, the selection of a good mineral oil is of the utmost importance. For the lubrication of spindles thickly-fluid and very viscous oils cannot be used; thinly-fluid and at the same time sufficiently viscous oils with a high flashing point being only suitable for the purpose.

The following summary of the properties of mineral oils is given in Spon's "Encyclopaedia of Arts:"

1. A mineral oil flashing below 300° F. is unsafe.

2. A mineral oil losing more than 5 per cent. in 10 hours at 60° or 70° F. is inadmissible, as the evaporation creates a gum, or leaves the bearing dry.

3. The most fluid oil that will remain in its place, fulfilling other conditions, is the best for all light bearings at high speeds.

4. The best oil is that which has the greatest adhesion to metallic surfaces and the least cohesion in its own particles; in this, fine mineral oil stands first, sperm oil second, neat's-foot oil third, and lard oil fourth; consequently the finest mineral oils are best for light bearings and high velocities. The best animal oil to give body to fine mineral oils is sperm oil. Lard oil and neat's-foot oil may replace sperm oil when greater tenacity is required.

5. The best mineral oil for steam cylinders is one having a density of 0.900 and a flashing point of 540° F., with burning point of about 600° F.

6. The best mineral oil for heavy machinery has a density of 0.890 and a flashing point of 360° F.

As previously mentioned, the distillates obtained from the residuum may be grouped according to their specific gravities and viscosities, the so-called solar or mixing oils being the lightest products obtained. The specific gravity of these oils varies between 0.860 and 0.890, according to their derivation. In consequence of their slight viscosity and low flashing point they are not suitable for lubricating purposes, being employed only for small machinery, such as clocks, sewing machines, etc. Since these fractions form quantitatively the greater portion of the products obtained, provision must be made for their utilization. If their specific gravity is low enough, they are, in some cases, used as an addition to illuminating oils, and if pale enough and only slightly fluorescent, they are under the name of mixing oils added to vegetable oils to make the latter cheaper. They are also used as wool oils for preparing wool, as saturating oils in sugar houses, for the production of vaselines and pale wagon grease, and finally, in an unrefined state, for the production of oil-gas.

Of greater value, of course, are the heavy products of distillation, discussed above, which are used for lubricating purposes. Besides the general rules which govern the selection of a lubricating oil, it is also of interest to know the difference in the quality of mineral oils according to their derivation, in order to draw a conclusion as to their availability.

The cylinder oils embrace all the distillates boiling at a high temperature, while the machine oils include all other distillates, from the solar and mixed oils up to the cylinder oil.

The cylinder oils form a strictly defined group for one and the same purpose, while, on the other hand, the machine oils may be divided into various groups, they finding numerous applications.

As will be seen from the tables pp. 644 and 645 the specific gravities of Russian cylinder oils, which were examined by Künkler, rise from 0.911 to 0.923, and their flashing point from 188° to 238° C. (370.4° to 460.4° F.), and the specific gravities of machine oils of the same derivation from 0.893 to 0.920 and their flashing points from 138° to 197° C. (280.2° to 386.6° F.) The specific gravity of the American machine oils examined varies between 0.884 and 0.920, and their flashing point between 187° and 206° C. (368.6° and 402.8° F.), and the specific gravity of American cylinder oils between 0.886 and 0.899, and their flashing point between 280° and 283° C. (536° and 541.4° F.).

If we now consider the conherence of the oils with regard to the purposes for which they are to be used, it will be seen that all oils serving the same purpose also possess approximately the same viscosities, and consequently that the viscosity is closely connected with the lubricating power. Thus the Russian spindle oils of 0.893 to 0.895 specific gravity show at 50° C. (122° F.) a viscosity of 3.15 to 3.44, and Russian machine oils of 0.903 to 0.909 specific gravity, at 100° C. (212° F.) a viscosity of 2.07 to 2.88. American spindle oils of 0.908 to 0.911 specific gravity possess a viscosity of 3.15 to 3.35, while the American cylinder oils of 0.966 to 0.889 specific gravity examined show at 100° C. (212° F.) a viscosity of 4.17 to 4.82.

These investigations show that, as regards flashing point and viscosity, American cylinder oils are far superior to the Russian, and on the other hand, that Russian machine and spindle oils surpass those of American origin.

It will further be seen from the tables, which also agree with the practice, that flashing point and viscosity are independent of each other, and that even very viscous oils may possess a low flashing point. The American oils congeal near 0° C. (32° F.) with the separation of paraffine, while the Russian oils acquire an ointment-like consistency at —10° C. (+14° F.). American as well as Russian cylinder oils thicken sooner than machine oils.

The lighter Russian oils possess a bluish, and the American oils a greenish, fluorescence. American oils, almost without exception, are distinguished, as compared with Russian oils, by a better odor and taste, and greater purity of color. They also show less inclination to volatilization, and consequently are of greater constancy.

Regarding the properties of German oils, Engler finds that the Oelheim and older Alsace pit oils resemble Russian oils in so far that rising specific gravities correspond to rising viscosity and flashing point. The more recent Alsace oils, however, are distinguished from Russian oils by less viscosity if used for the same purpose, and by congealing at a higher temperature.

As regards viscosity the Oelheim pale oils are inferior to Russian, and about equal to American oils.

Origin.	Specific gravity at 17.5° C.	Commencement of the evolution of vapor, °C.	Flashing point, °C.	Burning point, °C.	Congeals ointment-like at °C.	Portions passing over up to 310° C., in per cent. by volume.			Viscosity—degree. Water = 1.						
									20° C.	30° C.	50° C.	60° C.	70° C.	100° C.	150° C.
							RUSSIA.								
For spindles and similar machinery	0.895	105	163	190	—10° liquid...	1.	pale yellow..............	greenish and blue.....	11.80	......	3.40	......	......	1.53	......
" " " " "	0.895	110	165	194	—10° " ..	1.5	" "	" " "	10.96	......	3.15	......	......	1.40	......
" " " " "	0.893	105	167	193	—10° " ..	10.0	" "	" " "	11.80	......	3.44	......	......	1.55	......
" " " " "	0.895	110	164	193	—10° " ..	8.0	" "	" " "	11.05	......	3.30	......	......	1.33	......
For steam engines as substitute for rape oil, olive oil, etc.....	0.909	128	197	234	—10° liquid...	5.0	yellow..................	greenish and blue.....	......	......	6.08	......	......	1.76	......
" " " "	0.905	120	195	234	—10° " ..	5.5	"	" " "	......	......	6.05	......	......	1.77	......
" " " "	0.906	120	180	220	—10° " ..	4.0	"	" " "	......	......	5.86	......	......	1.71	......
" " " "	0.903	125	195	235	—10° " ..	6.0	"	" " "	......	......	6.34	......	......	1.86	......
" " " "	0.905	123	185	230	—10° " ..	5.0	"	" " "	......	......	6.05	......	......	1.80	......
For steam cylinders............	0.916	130	215	265	—10° " ..	36.0	red-yellow, transparent....	" " "	......	......	11.65	8.55	5.09	2.21	1.40
" " "	0.923	118	208	235	— 8° congeals	16.0	black-brown..............	greenish without blue.	......	......	......	10.01	8.06	2.88	1.53
" " "	0.916	130	227	283	— 7° "	38.0	dark red..................	greenish, slightly blue.	......	......	16.19	9.34	6.73	2.50	1.48
" " "	0.911	110	218	267	—10° "	27.0	red-yellow	" " "	......	......	10.44	7.13	5.67	2.15	1.44
" " "	0.916	130	238	280	— 7° "	27.5	dark red, transparent......	" " "	......	......	......	10.98	6.76	2.65	1.36
" " "	0.912	110	188	225	—10° "	4.0	black-brown..............	greenish..............	......	......	18.40	8.51	5.78	2.30	......
" " "	0.916	142	218	264	—10° liquid...	10.5	reddish..................	green, slightly blue....	......	......	10.23	7.00	4.44	2.07	......
For axles, transmissions, ordinary purposes....................	0.916	100	170	200	—10° liquid....	5.0	black-brown..............	greenish..............	......	......	8.73	......	......	2.03	......
For engines, locomotives, etc.....	0.920	120	185	212	— 8° congeals	2.0	"	"	......	......	13.84	......	......	2.42	......
For heaviest load................	0.909	127	187	233	—10° liquid...	14.0	pale red..................	greenish and blue.....	......	......	7.94	......	......	1.88	......
For axles, transmissions..........	0.913	97	170	196	—10° " ..	5.0	black-brown..............	greenish..............	......	......	10.38	......	......	2.01	......
For ordinary lubricating purposes	0.908	80	138	170	—10° " ..	21.0	"	"	......	......	8.84	......	......	2.03	......
For machines, transmissions.....	0.906	120	191	231	—10° " ..	4.5	"	green and blue........	......	......	6.40	......	......	1.78	......
For axles......................	0.909	82	142	180	—10° " ..	13.0	"	greenish..............	......	......	7.30	......	......	2.09	......
For gas motors and light machinery......................	0.900	115	175	207	—10° liquid...	5.0	yellow..................	greenish and blue.....	......	......	4.50	......	......	1.63	......
							AMERICA.								
For spindles, etc., and for mixing with fat oils..................	0.911	110	187	234	— 2° liquid...	0.0	pale yellow..............	greenish and blue.....	9.23	4.80	3.13	......	......	1.46	......
For spindles....................	0.908	180	200	240	— 2° " ..	0.5	"	" " "	10.96	6.46	3.39	......	......	1.61	......
For engines....................	0.920	185	206	245	± 0° " .	3.0	reddish-yellow............	" " "	......	8.90	4.03	......	......	1.65	......
For steam cylinders............	0.886	184	283	[illegible]	+ 5° " ..	25.0	transparent reddish-yellow.	greenish..............	......	......	......	......	11.73	4.17	1.78
" "	[illegible]	185	[illegible]	344	+ 4° " ..	[illegible]	black-brown..............	"	......	......	......	......	10.61	4.80	1.98
For axles, transmissions........	[illegible]	[illegible]	[illegible]	[illegible]	+ 4° " .	1.0	"	"	......	14.73	......	......	6.09	......	2.10

Origin.	Specific gravity at 17.5° C.	Commencement of the evolution of vapor, °C.	Flashing point, °C.	Burning point, °C.	Congeals ointment-like at °C.	Portions passing over up to 310° C., in per cent. by volume.			Viscosity—degree. Water = 1.						
									20° C.	30° C.	50° C.	60° C.	70° C.	100°C.	150°C.
GERMANY.															
a. Hanover.															
For machines, transmissions, etc.	0.928	95	155	193	— 9° liquid..	5.0	black-brown	greenish	......	......	15.48	......	......	2.69	......
For transmissions, axles.........	0.916	100	164	193	—10° " ..	3.0	"	"	......	......	8.65	......	......	1.73	......
For ordinary lubricating purposes.	0.910	95	162	193	—10° " ..	3.0	"	"	......	......	3.84	......	......	1.63	......
b. Alsace.															
For ordinary lubricating purposes.	0.921	105	152	195	— 2° liquid..	9.0	bluish-green	greenish............	......	......	4.55	......	......	1.60	......
For mixing purposes	0.885	80	115	142	—10° " ..	60.0	pale yellow............	greenish and blue.....	......	......	1.92	......	......	1.25	......
c. Saxony.															
For ordinary lubricating purposes.	0.994	80	135	168	— 6° liquid..	20.0	black-brown	almost without green..	......	......	3.17	......	......	1.40	......
For mixing purposes	0.897	80	126	150	— 0° " ..	50.0	pale yellow............	strongly greenish	......	......	1.86	......	......	1.25	......
" " "	0.904	80	126	150	— 0° " ..	17.0	black-brown	" "	......	......	2.36	......	......	1.28	......
VEGETABLE AND ANIMAL OILS.															
Rape oil, crude..................	0.920	170	260	....	—10° liquid..	......	....	....	9.03	......	4.0	......	......	1.78	1.34
" refined	0.911	185	305	....	—10° " ..	......	....	....	11.83	......	4.96	......	......	2.05	1.40
Peanut oil....................	0.907	195	300	....	— 6° congeals	......	....	....	10.17	......	4.03	......	......	1.82	......
Sesame oil....................	0.920	180	280	....	—10° liquid..	......	....	....	9.80	......	4.03	......	......	1.82	......
Olive oil.....................	0.914	145	205	....	—10° " ..	......	....	....	10.30	......	3.78	......	......	1.80	......
Castor oil....................	0.963	195	275	....	—10° " ..	......	....	....	......	......	16.46	......	......	3.01	......
Linseed oil..................	0.930	185	285	....	—10° " ..	......	....	....	6.30	......	3.21	......	......	1.76	......
Neat's-foot oil...............	0.916	215	305	....	—10° " ..	......	....	....	11.63	......	4.44	......	......	1.92	......
Tallow	0.951	180	265	....	+42° " ..	......	....	....	......	......	5.19	......	......	2.50	1.73

From what has been said it will be seen that in selecting a lubricating oil, its viscosity has first to be considered. The next consideration is its flashing point, this being of special importance if the oil is to be used for lubricating heated parts of the engine (cylinder, slide valves, etc.) or for lubricating parts exposed to great friction. The third is its congealing point, this being of importance if the oil is exposed to great differences in temperature. All other properties are of varying importance according to requirement.

Mineral oils possess the valuable property of least attacking metals. Redwood's investigations of the influence of lubricating oils on metals at the ordinary temperature show that mineral oil has no effect upon copper and zinc and attacks brass least and lead most. Rape oil has no effect on brass and tin; attacks iron least and copper most. Olive oil attacks copper most and tin least.

Redwood's experiments also show that metals are least attacked by mineral oils and most by tallow. Similar experiments gave, according to "Le Moniteur des Produits chimiques," nearly the same results, iron being least attacked by castor oil and most by lard oil. Bronze is most attacked by olive oil and tin as well as lead least. Copper is most attacked by lard, but not by mineral oils, which also have but little effect on bronze. Copper is also strongly attacked by olive oil and castor oil. The experiments proved tallow to be unsuitable for lubricating parts of machines composed of iron and copper.

Engler and E. Kneiss trace the solubility of metals in liquid hydrocarbons to the fact that the metals, in the presence of air, are converted into metallic oxides, which are dissolved by the acids formed from the hydrocarbons by oxidation with air. In their investigations various metals in shallow dishes under layers of oil of turpentine, rosin oil and petroleum, were for some time exposed at a certain temperature to the action of the air, and the quantities of metal dissolved determined. American petroleum, with the access of air, dissolves nothing of tin, zinc, magnesium and sodium, even after acting upon them for months, and traces of lead and copper only after a long time. At higher temperatures it was shown that the solubility does not constantly increase with the temperature; and that the quantity of metal dissolved is the greater, the more of it is used in proportion to the oil. It was also shown that the oxidizing effect of the oil increases (with an arsenic solution) with the quantity of the oil, and decreases with the thickness of the layer of oil, but augments again with the concentration of the arsenic solution.

Use of Petroleum for Medicinal Purposez.

Petroleum ether. Like methane, ethane and propane, the butane contained in petroleum ether is perfectly harmless when mixed with sufficient oxygen and inhaled. However, if not mixed with oxygen it rapidly produces stupor. On the other hand pentane produces stupor only when mixed with sufficient oxygen. Applied to the skin petroleum ether acts as a local anaesthetic, partially in consequence of the cold produced by rapid vaporization and partially by reducing irritation of the sensory nerves. Petroleum ether may also contain hydrocarbons with a higher boiling point (heptane, œnanthilic hydrogen C_7H_{11}, and octane, caprylic hydrogen C_8H_8). Its stupefying action is then less rapid, the octane producing first strong and lasting excitement and later on stupor, the latter being as deep as that produced by chloroform.

Petroleum ether is also used for ointments or is applied in the form of drops or spray to the afflicted parts. It has also been quite successfully used for rheumatic pains and as an anaesthetic in minor operations.

The action of benzine is essentially the same as that of petroleum ether. It is fatal to low organisms, for instance, caterpillars, itch-insects, lice, fleas, etc., and is used for the destruction of such parasites. It is also employed in place of turpentine for washing domestic animals, because it does not cause the hair to fall out, but just the reverse promotes its growth.

Prof. Trousseau has successfully used petroleum, in place of nitrate of silver and blue-stone, in the treatment of conjunctivitis. Prof. Miller obtained with it the same results, and recommends it especially for children and nervous persons. Dr. Dubief designates petroleum a medium antiseptic (IX. Congress of the French Opthalmological Society, May 5, 1891).

In cases of poisoning by petroleum, emetics are given, the stomach is emptied by means of the stomach-pump and ice is applied to the head.

L. Lewin has investigated the action of petroleum. According to his opinion the question whether petroleum is a poison can be answered neither in the affirmative nor in the negative, the answer depending always on the special case. In "poisoning" by taking petroleum internally appear partially diseases of the stomach and intestines, partially diseases of the kidney and disturbances of the central nerves. The behavior of the secretions and excretions deserves special mention. In the urine albumen and morphotic elements are frequently found; the quantity of urine first decreases, later on increases to a considerable extent, and petroleum, it is claimed, floats upon the surface. The excrements always contain petroleum. The treatment consists of washing out the stomach, emetics, and in case of collapse, stimulants. According to Lewin's experiments on animals an injurious effect upon the organism is produced only by residuum and heavy oils. The urine of rabbits poisoned with petroleum showed a petroleum odor, but did not contain unchanged petroleum; when boiled with nitric acid a peculiar pine odor appeared. After repeatedly introducing petroleum into the organism albumen appeared in the urine, and when treated with nitric acid a resinous body separated which can be extracted with ether and is very probably a changed petroleum product. The dissection of "poisoned" animals showed irritation and inflammation of the stomach, lacerations of the bottom of the stomach and vessels, and prominent black points filled with blood on the mucous membrane of the stomach. By reason of these investigations Lewin considers petroleum a poison. According to his opinion petroleum vapors when inhaled are not poisonous, injurious effects being produced only under extraordinarily bad external and individual conditions.

Skin diseases are, however, of frequent occurrence among workmen handling petroleum, especially the heavy oils, and hence the utmost cleanliness and frequent warm baths are recommended.

The skin diseases appear as acne in various forms, in most cases, on the thighs, knees, arms, trunk, neck, face, ears, and scrotum. They are as a rule caused only by heavy oils.

Officinal petroleum reddens the skin and causes the epidermis to scale off and the hair to fall out, though its action is weaker than that of oil of turpentine; the hair, however, grows again rapidly. Taken internally in excessive doses, it has caused oppression, giddiness, palpitation, faintness and headache. Absorbed by the blood it acts similarly to oil of turpentine. It kills tape-worms, lice, etc., but does not destroy bacteria. It is preferably used in veterinary practice.

Perhaps no more important contribution has for a number of years been made to the Pharmcopœia than the dense product known variously as cosmoline, vaseline, petroline, etc. It is a pale yellow, translucent, slightly fluorescent, semi-solid substance. It melts at about 100° F. and has a specific gravity of 0.850. It is insoluble in water, slightly soluble in alcohol, freely so in ether, and miscible in all proportions with fixed and volatile oils. It is not acted upon by hydrochloric acid or solution of potash, and has all the other characteristics of a mixture of paraffines. An ultimate organic analysis made by Mr. J. Mass gave 97.54 per cent. of hydrocarbons. Under the microscope, cosmoline, in common with most other fats, is found to contain numerous small acicular crystals, doubtless consisting of a paraffine of a higher melting point than the mass: but these do not in any way interfere with its usefulness because of their extreme minuteness and easy fusibility. Cosmoline may be kept indefinitely without becoming rancid, and this, together with its indifference to chemicals and its readiness to take up any perfume, is sufficient to recommend it for pharmaceutical and toilet purposes in place of the fats generally used.

In the preparation of ointments, cerates, etc., it is in many respects far superior to the animal and vegetable fats hitherto employed. Having no chemical affinity or action on any of the medical ingredients used, ointments compounded with cosmoline as a base remain unchanged for years.

Cosmoline is prepared from the residuum of the distillation of petroleum conducted on the vacuum process. This residuum is brought into settling tanks, heated by steam to keep their contents in a liquid state. After the complete separation of the fine coke it is withdrawn from these tanks and passed through the bone-black cylinders, during which process the color is nearly all removed, as well as the empyreumatic odor.

The manufacturers of petroleum ointment in Germany, who use the term vaseline almost exclusively to designate the product, employ as raw material mineral tar, a kind of soft native bitumen from Alsace and Galicia, and residues of American petroleum which are of a semi-liquid or unctuous condition and yield a correspondingly softer or denser vaseline.

The raw material is purified and decolorized, either by treatment with sulphuric acid and bichromate of potassium and subsequent digestion with animal charcoal, or by treatment with the latter substance alone. Below are given two processes furnished by two German factories. The first one accompanies a petition for the granting of the privilege of establishing the works; the second was communicated by the manufacturer.

First process. 1. The oil is heated by steam to about 86° F., mixed at this temperature with 10 per cent. of its weight of sulphuric acid of 60° B., stirred for half an hour and allowed to rest, so that the carbonized portions may separate.

2. When clear the oil is washed with an aqueous solution of potassium bichromate, whereby any remaining excess of sulphuric acid is, at the same time, removed.

3. The residue from the acid treatment is mixed with lime, neutralized, and disposed of to manure factories.

4. The clear oil from the second stage of the process, after being washed, is heated by steam to 176° F., mixed with 10 per cent. of its weight of granular animal charcoal, and then allowed to rest to permit the animal charcoal to subside.

5. After the latter is separated, the liquid portion is filtered through filters heated by steam.

6. The residue is subjected to hydraulic pressure, the expressed oil filtered, and the solid portion again used in the next operation, a sufficient quantity of fresh animal charcoal being added to make up for any loss or waste.

Second process. The raw materials, residuum or mineral tar, are rendered fluid, and the liquid, after the separation of all extraneous matters, is passed through a series of charcoal filters such as are used in sugar refineries.

After passing through twelve to fifteen of these cylindrical filters, the original brownish-black color of the liquid has become wine-yellow. To render it colorless and limpid as water, double the number of filters are required. The liquid acquires a lower specific gravity the more discolored it becomes, but when it has become colorless the specific gravity remains stationary, no matter how long filtration may be continued. After it has thus been freed from all bituminous matter, it is transferred to the "duplicator" where it is brought in direct contact with superheated steam, and the temperature is allowed to rise to 480° F. Samples taken occasionally from the boiler should show no changes in the product after this temperature has been kept up for a few hours. The finished vaseline, amounting to about 25 or 30 per cent. of the raw material, is finally filtered and filled into cans for shipment.

A great drawback in this method is the rapid exhaustion of the animal charcoal, which is able to decolorize only a small percentage of its own weight of crude vaseline. It is, therefore, necessary to provide extensive facilities for extracting the portion of vaseline retained by the charcoal and to regenerate the latter, which may be done by superheated steam at a temperature of 752° to 932° F. It is for this reason that most factories use sulphuric acid for purifying, by means of which the raw material may be brought to the color of beer, so that only about one-third as much charcoal is required for final decoloration. It is, however, almost impossible to get rid of the last traces of the chemicals employed, and for this reason the quality of the vaseline obtained by the other process is much superior. It is pure white, like the best tallow, and entirely tasteless. It is also odorless, not only when rubbed upon the hand, but also when melted in water; the latter property distinguishing it from all other varieties, which, on melting in water, evolve a faint odor of petroleum. When melted, it yields a clear colorless liquid which, on cooling, returns to its former homogeneous condition. Cold 98 per cent. alcohol dissolves, on shaking, 2.2 per cent. of vaseline. The residue left after the evaporation of the alcohol is liquid at ordinary temperatures. Hot alcohol dissolves it completely to a clear solution. On cooling, the vaseline separates in flakes. It behaves in the same manner towards benzol and ether, but is not completely soluble in the latter even on warming. It does not impart an acid reaction to water, and is not affected by solution of potassa. Boiling sulphuric acid of 1.600 specific gravity and boiling nitric acid of 1.185 specific gravity have no effect on it. Fuming nitric acid colors it yellowish-red and sulphuric acid of 1.820 grayish-black. The acid itself acquires a yellowish-brown color. The specific gravity of the vaseline is 0.848.

Saponification of Petroleum Products.

The fact that petroleum absorbs oxygen has already been discussed in the chapter on "Manufacture" and only the industrial application of this property needs here to be mentioned. E. Schaal * has endeavored to convert petroleum into acids by treating it in the presence of alkaline reagents with a current of air. Hydrocarbons boiling between 302° and 752° F., together with a few per cent. of a finely pulverized mixture

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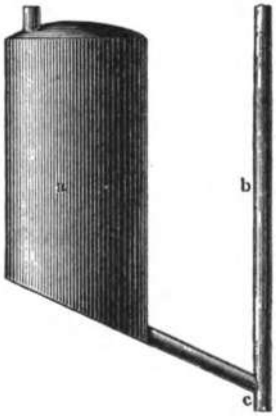
* German patent No. 32705.

of lime and caustic soda, are heated to the boiling point in a boiler *a*, Fig. 257, provided with a back-flow condenser. A current of air or oxygen is then blown in, more alkali is gradually added, and the soap formed drawn off at *C*. The same object is said to be attained by bringing the hydrocarbons with about 20 per cent. of caustic alkalies, or alkaline carbonates, or other alkaline mixtures, in connection with oxygen-conveying substances (copper salts, etc.) in a fine state of division, into intimate contact with the air. Many hydrocarbons readily oxidize with chloride of lime, and others not at all. When the action of the chloride of lime is complete, the lime is removed by hydrochloric acid, the acids formed are extracted with alkali, and the oil-mixture remaining behind is treated for a few hours longer with soda lye at 392° to 572° F. The fatty acids formed may be separated by distillation in vacuum. The most volatile acids yield, especially wlth methyl, ethyl, propyl, butyl, amyl and other alcohols, sweet-scented ethers for perfuming purposes. The acids boiling at higher temperatures form with glycerin combinations resembling natural oils, while the acids boiling at the highest temperature yield soaps and fats. It is also claimed that the sulpho-combinations of these acids, which

FIG. 257.



are obtained by slightly heating with one-half or equal portions of sulphuric acid, may be used for Turkey-red dyeing. By treating petroleum distillates with soda lye, oxygenated hydrocarbons are withdrawn, which in the presence of soaps and alcohol may also be converted into water-soluble combinations. Engler and Bock also found that petroleum contains saponifiable naphthalene-carbonic acids, while Zaloziecky supposes them to be the hydrocarbons of the methane series, which can readily be converted into acids.

A distinction has to be made between this oxidizing property of the hydrocarbons and their saponification with fats, the latter consisting simply in an intimate mixture of the hydrocarbons with sebates. This process is well known, the production of wagon grease and consistent lubricants for which mineral oil is used being based upon it.

A novelty in this process is the use of sebates, which, when melted, are capable of absorbing large quantities of mineral oil. Prof. Dittmar of Glasgow succeeded in preparing such a mixture which contained but a few per cent. of such sebates as cementing material. The fact that mineral oil could be made consistent in so simple a manner led to the most extravagant expectations, such as solid petroleum which could be readily transported, etc. Such expectations, however, have not been fulfilled.

The so-called naphtha candles have also proved useless. The mode of preparing them in the factory of K. L. Miller, in St. Petersburg, has not progressed beyond the experimental stage. Petroleum with fats or fatty acids which are boiled with water of ammonia or ammoniacal salts is used, or ammonia gas is introduced into a solution of fatty acids in petroleum. Candles prepared from this mass have the defect of the petroleum vaporizing from them, thus imparting to them a disagreeable odor and bad appearance. Coating with varnish (amber or copal varnish) produced only a temporary effect, the varnish being gradually dissolved in the oil. It has also been endeavored to give the surface a better appearance by the addition of resin and wax. According to statements emanating from the factory the candles are prepared from 65 per cent. stearic acid, 30 per cent. petroleum, 5 per cent. water, and about 0.8 per cent. ammonia. An analysis by the Technological Institute of St. Petersburg, however, gave only a content of 10 to 12 per cent. petroleum, and 82 to 85 per cent. stearic acid, 4½ to 5 per cent. water and 0.6 to 0.75 per cent. ammonia, the candles having thus lost in the course of a month the greater portion of their petroleum. By being further exposed to the air for 45 days they lost 10 per cent. in weight. Photometric examinations were rendered difficult by the fact that the candles burn with a very flickering flame and the separation of much carbon on the wick. The illuminating power of a candle (four to the pound) was found to be equal to 1.05 standard candles with a consumption of 10.5 grammes (162 grains) per hour.

The use of fats for lubricating purposes, if not rendered necessary by special conditions, must under all circumstances be designated as unsuitable. The advantage of a slight consumption of material is nullified by greater friction and consequent greater consumption of fuel, as well as increased expense in repairing bearings, etc. The loss by friction alone counterbalances the greater consumption of liquid oils. A consistent fat answers the intended purpose only when it becomes fluid, *i. e.* when the lubricated portions of the engine become heated to or above the melting point of the fat. This increase in the temperature can be attained only by friction of the metallic surfaces, and greater expense of power, consequently greater consumption of fuel is required to overcome these resistances. Hence for lubricating machines, transmissions, etc., all fats should be rejected. It is different in the lubrication of cylinders and slide valves, for which purpose neutral fats may be used. Lubrication with tallow is absolutely to be excluded.

Consistent fats, especially the so-called rosin-soaps, which consist of lime soaps of rosin-oil in connection with petroleum distillates of less value or residuum, are used as wagon grease, etc. Their preparation does not come with in the scope of this work, and the reader is referred to books on that subject.

[illegible] [illegible] [illegible] [illegible] [illegible] two consistent products of [illegible] mineral [illegible] but not identical with vaseline, that may be mentioned. One is a product much used in [illegible] under the name [illegible]. As indicated by the name [illegible] mineral [illegible] is viscous. It probably consists of a mixture of metallic oleates. The "bakusin" of [illegible] is a mineral lubricant. It is made by thoroughly mixing 100 parts petroleum and [illegible] parts [illegible] oil with about 10 to 30 parts concentrated sulphuric acid and [illegible] three times the quantity of water. After allowing the whole to stand for some time, the lower aqueous layer is drawn off and the mass neutralized with soda or [illegible] lye.

The requirements of the market and especially the numerous applications for which petroleum products are used, have brought about the production of lustreless and perfumed oils. Mineral oils, even those which are but slightly colored, always show a more or less strong fluorescence which, according to their derivation, is greenish or bluish. By this fluorescence they can be readily recognized, and it is therefore difficult to use them as an addition to olive or rape oil, and for the production of artificial fish-oil. They are also readily recognized by their characteristic petroleum odor. For the removal of the lustre and odor various means are used. In many cases the oil is rendered lustreless by treatment with small quantities of *nitric acid*, whereby it acquires a brown color, almost loses its fluorescence, and in this form is especially suitable for the production of artificial fish-oil. Recently light-colored mineral oils have been rendered almost lustreless, without essentially injuring them, by a slight addition of nitro-bodies, the nitro-naphthalenes being especially suitable for the purpose; the quantity varies between ½ and 1½ per cent. of the oil. However, the fluorescence cannot be entirely removed, it being always perceptible especially in thicker layers. Oils rendered lustreless have the defect of gradually becoming darker. An aniline color, "*jaune anglais*," very probably a chinoline coloring matter, has also been recently used with success.

The oils are chiefly perfumed by the addition of oil of turpentine, nitro-benzole and volatile oils, which simply cover the petroleum odor. Rosemary oil is also used, especially for oil which is to serve as an addition to degenerated olive oil.

Heavy petroleum products are also used to prevent boiler incrustations, for impregnating wood, gypsum, etc. According to M. Carden's experiments, petroleum not only prevents the formation of incrustations in boilers but also dissolves old incrustations. Care should be taken not to use large quantities at one time, otherwise emulsions boiling with difficulty are formed. According to L. Lyne the lighter oils are to be preferred to heavy oils.

CHAPTER XIII.

NATURAL GAS AND OIL GAS.

Natural Gas.

THE term "natural gas," "rock gas," "inflammable gas" or "earth gas" is applied to a mixture of several gases. It always occurs associated with petroleum or where the geological conditions indicate the presence of the latter.

The principal use made of natural gas is for lighting and heating purposes. As an illuminant it is much inferior to coal gas. On account of its low specific gravity and small content of carbon it gives a flickering flame, strongly affected by draught. For this reason care should be taken to give the burner as narrow a slit as possible, and in lighting streets to see that the lamps are tightly closed.

The candle power of the natural gas of the Pittsburgh district is usually given as 8 candle power, of the Findlay, Ohio, from 12 to 14, and of the Mendota, Illinois, as about 12.

Many experiments have been made to increase the illuminating power of natural gas by carbonization with liquid hydrocarbons; the results, however, have not been satisfactory. It has also been endeavored to produce a brighter flame by altering and improving the burner.

The most careful and interesting experiments that have been made in the use of natural gas as an illuminant have been made at Findlay, Ohio, under the direction of Mr. E. B. Philipp.* The results of these experiments, briefly stated, are that the best form of burner for natural gas is the argand. With a 36 hole lava tip argand burner, an accurate corrected candle

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* Natural Gas, by Jos. D. Weeks. Washington, 1886.

power of 12.57 was obtained. Where a flat flame was desired, various flat flame Bray burners were used, with a corrected candle power of 10.85. A special bat's-wing burner made by the American Meter Company gave a corrected candle power of 11.57. These tests were made with the crude gas, but by partially purifying it by passing it through lime boxes, removing the carbonic acid and sulphuretted hydrogen, the candle power was increased to 13.17. Mr. Philipp says in regard to the results obtained: "The best general results are obtained by using burners consuming from 8 to 9 cubic feet per hour. When burned thus, the gas gives a good, satisfactory light, excelling in a number of instances some qualities of coal gas."

FIG. 258.

In addition to the argand burners, various forms of regenerative burners have been used, chief among which are the Siemens and the Haupt. The Haupt seems in some respects better adapted to burning natural gas than even the Siemens. These are too well known to need description. Besides these, what is known as the Todd burner, Fig. 258, has given most excellent results. This burner is constructed on the principle that there is not enough carbon in the gas to give sufficient illumination under ordinary methods of burning; hence, the air before it comes in contact with the gas, is heated to a very high degree, and striking the gas, burns the hydrogen at once and makes the carbon incandescent. The air is heated by passing through three saucer-shaped perforated steel plates, placed concentrically, attached at the rims, but separate elsewhere through their outer and inner surface, and so arranged that the perforations in two consecutive plates are not opposite each other. This is attached to the gas service pipe immediately under the burner, which is simply a cap placed on top of the service pipe, the pipe having holes drilled immediately under this cap. The flame plays around the cap like the flame of an argand burner, and heats the steel plates through which the air passes immediately beneath it. Of course, the air passing through the small perforations of the steel regenerator is split up and highly heated.

Various devices have been invented for the use of natural gas in stoves and grates, and where the plumbing is properly done accidents can only occur on account of the gross carelessness of those who start the fires. Automatic regulators have been applied, by which the temperature of a room may be continued at the same degree, with scarcely any variation for an indefinite period of time. The cheapness of natural gas, together with its convenience, makes it a very desirable fuel. It requires no store house, nor handlers, produces no ashes or other waste matter, and if proper care is exercised may be used for domestic or manufacturing purposes with as much safety as any other fuel.

The greatest value of natural gas is, however, for industrial purposes. The demand for it in the Pennsylvania areas is enormous, hundreds of millions of cubic feet being consumed daily. The first gas piped any considerable distance was, according to Jos. D. Weeks, from what is known as the Harvey well, near Larden's mills, in Butler county, Pennsylvania. This, at the time it was bored, in the fall of 1874, was the most powerful gas well in the section. In 1875 it was purchased by the National Gas Company, limited, and piped 17 miles through a 6-inch pipe made of iron ¼ inch thick, to the mill of Messrs. Spang, Chalfant & Co., at Era, near Pittsburgh. The gas was turned into the pipe in October, 1875, and traversed the 17 miles in 20 minutes, the pressure at the wells observed being 119 pounds. The first use of gas in glass making appears to have been at the Rochester tumbler works, at Rochester, Pennsylvania.

In 1883, Mr. J. B. Ford, at the Pittsburgh plate-glass works, at Creighton, Pennsylvania, succeeded in securing a supply of gas for his glass works, since which time these works have been run entirely by natural gas. The quality of the glass it is said has been considerably improved.

It was not until 1883, with the piping of the gas of the Murraysville district to Pittsburgh and the striking of gas in the Westinghouse well, at Homewood, Pittsburgh, that natural gas began to be used extensively as fuel. Prior to this time its use had been exceptional and at isolated works, but with the piping of this gas, and the striking of the Westinghouse well, the extension of its use became instant and well-nigh universal for manufacturing purposes in the neighborhood of Pittsburgh. Its introduction into the rolling mills of Wilson, Walker & Co., and Shoenberger & Co., and the flint-glass furnace of the Fort Pitt glass works, was rapidly followed by its adoption in other establishments, until now few of the important manufactories of Pittsburgh, that are so situated as to obtain a supply of gas cheaply, use any other fuel.

From the Pennsylvania fields the search for gas extended to portions of New York, Ohio and West Virpinia resulting in the discovery of large areas of gas-producing territory in each of these States. A very productive gas-territory has been opened some 6 miles south of East Liverpool, in West Virginia, the gas from which has been piped to this town and is being used in the potteries for fuel and light.

In the Caucasus oil territory, especially in the Apscheron oil-field, enormous quantities of gas issue from fissures and crevices. In the Surachani district this gas has for some time been used by the Tartars for burning lime, and recently it has been utilized on a large scale for this purpose, all the lime employed in building in Baku and its vicinity being burned with it in the neighborhood of Surachani. Engler, on his visit to the Apscheron district, saw along the railroad from Surachani to Balachani, at least 70 piles of limestone placed free upon the ground, the flames entering these piles from small holes in the ground. When the lime is sufficiently burned the holes are stopped up. Fresh pieces of limestone are then piled up, the holes again opened, and the gas is ignited. The gas is also used in some refineries at Surachani, the most productive wells of this district being enclosed in the immense yard of the Kokoreff refinery. Pipes of quite large diameter driven in the ground supply the gas for lighting the yard. The gas is also used in the houses within the limits of the refinery and for heating the stills. Forty large sheet-iron boxes connected by pipes have been placed in a large square pit for the collection of gas. From this reservoir pipes lead to the still of the illuminating oil refinery. Mirzoeff also uses the gas for lighting and for heating iron in the machine shop. The gas issues from a slit-like vertical shaft and the flame about 3 feet wide passes into a horizontal reverberatory furnace into which the iron to be heated is brought.

In the fifties Admiral Wassiljeff made the attempt to conduct the gas issuing from the ground in the island of Swatoi into a chimney and use the latter as a light-house. However, the flame was constantly extinguished by explosions, which were very probably caused by the diameter of the chimney-flue being too large or not sufficiently air-tight.

According to analyses by Bunsen and Schmidt the Caucasus natural gas consists of:

Methane	92.49	93.09	92.24	97.57	95.56
Olefines	4.11	3.26	4.26	——	——
Carbon monoxide	0.93	2.18	3.50	2.49	4.4
Hydrogen	0.94	0.98	——	——	——
Nitrogen	2.13	0.49	——	——	——

According to Sadtler the gas contains only from 60 to 90 per cent methane, and only traces of carbon monoxide, but from 5 to 22.5 per cent. hydrogen. From the odor he also presumes the presence of sulphurous gases as an admixture.

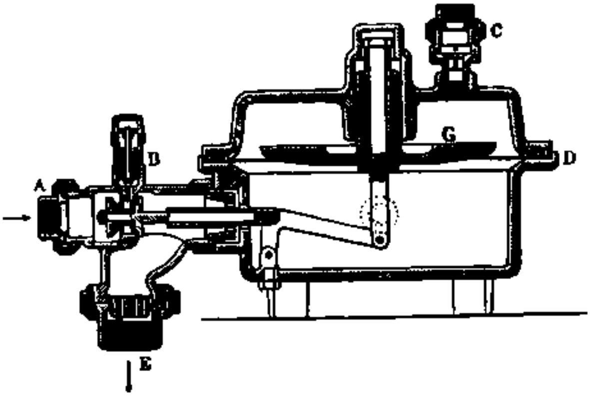
It remains to say a few words regarding the utilization of natural gas, especially for industrial purposes.

The considerable pressure which prevails at the well and in the principal conduits renders the use of the gas difficult, and hence it has to be endeavored to reduce this pressure to a minimum to make economical consumption possible. The older method of regulating the pressure consisted in an ordinary reservoir-system in which the high pressure of the principal conduits was reduced by a large hydraulically closed reservoir to the minimum of one pound for the so-called low-pressure conduits for streets and houses. This system, however, did not prove satisfactory, its action varying under varying conditions of consumption, as well as with the pressure of the atmosphere. Greater security was offered by the method introduced in 1883 and 1884, by George Westinghouse, Jr., which consisted in an independent and automatic reduction of the gas pressure for private and factory use. The Westinghouse regulator for house use is so arranged that not only the pressure in the conduits is reduced to a safe and economical limit, but in case of disturbances in the principal conduit, an automatic safety valve is closed and cuts off the connection between the principal and house conduits, which is of great importance.

By reducing the gas-pressure these combined regulators and safety-valves also regulate automatically the consumption of gas.

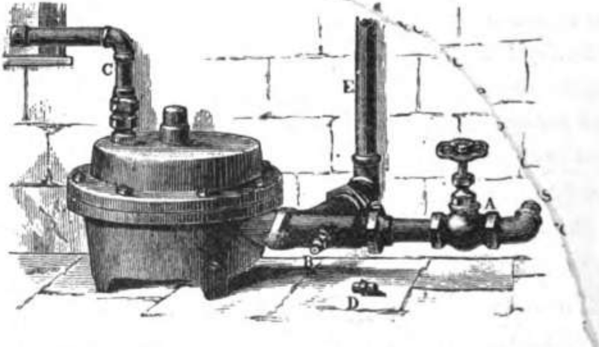
Fig. 259 shows a Westinghouse regulator in cross-section. It consists of a capsule *C*, diaphragm *D*, safety-valve *B*, the latter with inlet-opening *A*, and outlet-opening *E*. The gas enters at *A*, and when the pressure becomes too strong, the diaphragm *D* is raised and the supply of gas regulated by leverage upon the valve *B*. With insufficient pressure the weight *G*, and consequently the diaphragm *D* goes down,

Fig. 259.



whereby the valve is entirely closed and connection between *A* and *E* is cut off. Fig. 260 is an exterior view of the apparatus.

Fig. 260.



For factory purposes the regulator is arranged as follows: *A*, Fig. 261, is the actual regulator, *B* and *C* the loaded lever with weight. At *D* the gas enters the regulator, which can be regulated by the valve *G*, and at *A* it leaves the regulator through the pipe *F*. *J* indicates the prevailing pressure. The excess of gas passes out through *E*. These regulators have been generally introduced in Pittsburgh.

Figs. 262 to 276 represent a series of furnaces fitted for natural gas, the direction in which the gas and air enter the combustion-space being chiefly shown. One of the greatest difficulties in the use of natural gas is the deposit of carbon in the flues, a badly constructed furnace becoming choked up in a few hours. Such deposit is always caused by an insufficient or incorrect supply of air.

FIG. 261.

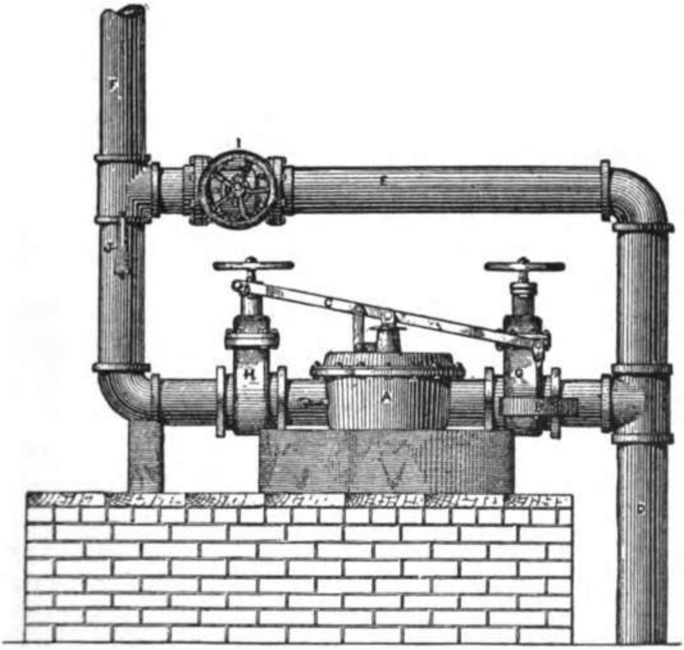


Fig. 262 is an ordinary puddling furnace originally arranged for coal, but now fitted for gas. The gas enters through four 8½ inch pipes, is ignited, and after playing around the walls *A* and *B* passes into the hearth. The air enters at *b* through a 29½ inch pipe and is mixed with the burning gas. The furnace works 8 to 9 tons of iron in 10 hours with a gas pressure of 10.58 ozs.

Fig. 263 is a directly-acting puddling furnace with an inclined wall *A*, in which a better mixture of the gas and air is effected.

Fig. 264 is a continuously working regenerative furnace. The gas enters through four 8½ inch pipes above the fire-bridge, while the air enters beneath the furnace (the former ash-pit) through a heating space, where it is preparatorily heated and then mixed at the fire-bridge with the burning gas.

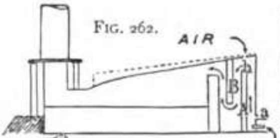


FIG. 262.

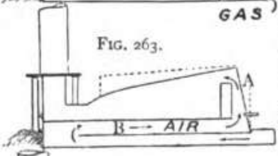


FIG. 263.

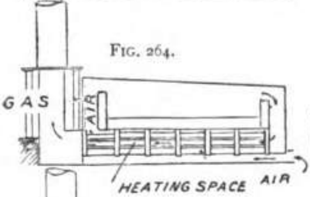


FIG. 264.

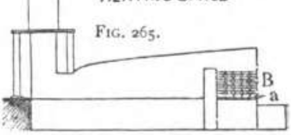


FIG. 265.

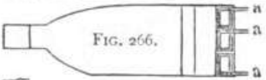


FIG. 266.

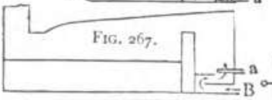


FIG. 267.

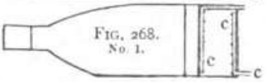


FIG. 268. No. 1.

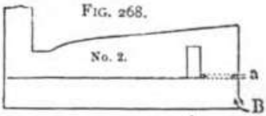


FIG. 268.

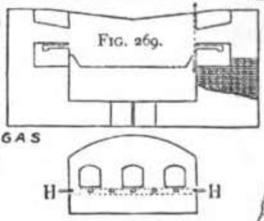


FIG. 269.

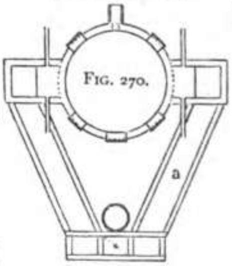


FIG. 270.

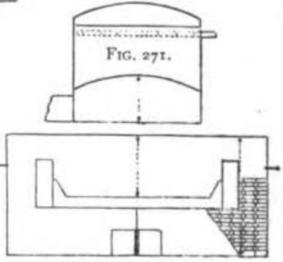


FIG. 271.

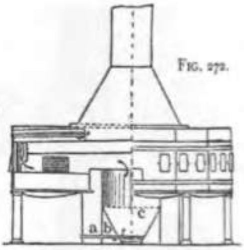


FIG. 272.

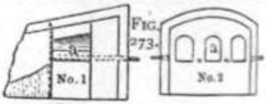


FIG. 273.

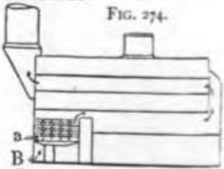


FIG. 274.

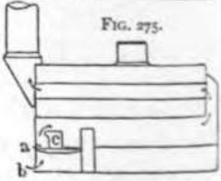


FIG. 275.

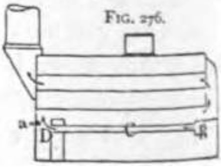


FIG. 276.

Fig. 265 is an ordinary puddling furnace. The gas enters at *a*, and the air at *B*.

Figs. 266 and 267 show the arrangement of a furnace based upon the principle of an argand burner, the air entering the centre of the flame. The air passes in at *B*, plays around a brick arch, and ascends between the burners *a a a*.

The furnace Figs. 268, Nos. 1 and 2, is arranged similar to the preceding. The air enters in the centre and on the sides of the flame. The furnace is said to yield excellent results and be free from deposits, etc. The gas enters the furnace at *a* and *b* through two 29½ inch pipes, and the air through *B*.

Figs. 269, 270 and 271 are also regenerative furnaces with open hearths. Fig. 272 is a plate furnace. The gas enters below at *a* in the centre, passes out through small apertures; the burning gas mixture ascends and spreads over the entire surface.

Figs. 273, Nos. 1 and 2, are smelting furnaces, and Figs. 274, 275 and 276, boilers with gas-firing. The gas enters at *a*, and the air at *b*.

Oil-gas.

From the residuum of the distillation of petroleum and certain products of distillation—the blue and green oils—gas is also produced by decomposition. The blue and green oils are products of distillation obtained from the less valuable petroleum residues and derive their names from the strong fluorescence inclining in the first case to blue and in the latter to green. The specific gravity of these products varies between 0.870 and 0.905. On account of their slight lubricating value and strong smell they are used only for the production of wagon grease, and in more recent times, for the manufacture of oil-gas.

Practical experience has shown that the heavy hydrocarbons, especially the fractions of 0.870 to 0.890 specific gravity, give the best results as regards yield and illuminating power of the gas. Lighter oils give a larger volume of gas and decompose more rapidly, but the illuminating power of the gas produced is far less; while heavier oils yield less gas and leave a large quantity of residue in the retort, which causes a rapid destruction of the latter by burning. Crude petroleum containing much benzine and illuminating oil is less suitable for the production of oil-gas than crude oils which contain little benzine and illuminating oil, but a large quantity of heavy oils. This is explained by the fact that since the temperature of the retorts has to be maintained at between 1652° and 1832° F., the benzine and illuminating oil are decomposed under regular carbonization, while the heavy oils are just properly distilled at that temperature. Hence if crude oil is to be used for the production of oil-gas, it is best to take such as is not suitable for the manufacture of illuminating oil. Another disadvantage of the use of crude oil is that it leaves a heavy residue of graphite in the retorts, which is not the case with distilled heavy oil.

The manufacture of gas from these residues is cheaper and more simple than the process of distilling gas from coal; besides, the cost of a plant of the same capacity is about one-half.

Oil-gas possesses greater illuminating power than coal-gas. It burns with a white flame, and when properly purified, is entirely odorless. It contains four or five times as many ethyls and homologous hydrocarbons as coal-gas. According to an analysis by A. Hilger the composition of oil-gas is as follows:

Specific gravity of the gas	0.724	
Heavy hydrocarbons	28.91	per cent.
Light hydrocarbons	54.92	"
Hydrogen	5.65	"
Carbon monoxide	8.94	"
Carbonic acid	0.82	"
	99.24	per cent.

S. Lamansky, chairman of a commission of the Russian Technical Society of St. Petersburg for "the examination and availability of naphtha or oil-gas," gives the results of these investigations as follows:

"Oil-gas, according to Rudnew, shows no combinations of sulphur, ammonia, or carbonic acid. It is therefore less injurious to living beings than coal-gas. It does not freeze up even in the most severe cold, and its illuminating power decreases only to an inconsiderable extent. Its quality is not affected by long storage. The specific gravity of the gases tested by the Commission was determined at the ordinary temperature of a room with a Bunsen apparatus. It varied between 0.67 and 0.88. The intensity of light was also determined with a Bunsen photometer. The appended table shows the mean results of various determinations, each of them having been made at the same time by several observers. A spermaceti candle with a flame 1.77 inches long served as the unit of light."

Naphtha gas from the factory.	Specific gravity of the naphtha gas.	Consumption of gas in one hour for one candle power in cubic meters.	
		In argand burners.	In flat burners.
Of Kusnezow, St. Petersburg	0.75	0.0031	0,0027
Of Petrow and Tokarew	0.88	0.00254	0.0028
Of the mechanic factory of Nobel	0.82	0,030	0,0028
Of Siemens and Halske's factory of regenerative burners at St. Petersburg	0.85	0.0041	0.00424
Of Kalnikni's brewery	0,67	0.00389	0.00398

The average hourly consumption of naphtha gas for one candle power amounts to 0.00299 cubic meter with an argand burner and 0.00302 cubic meter with a flat burner. The cost of the gas could not be accurately determined, it varying with that of the raw material, etc. It was, however, shown that a burner of 15 to 17 candle powers consumes per hour 45 liters naphtha gas and 150 liters coal gas, and the cost per hour with oil-gas is about 2.3 pfennige and with coal gas 4.47 pfennige.

As regards the manufacture of oil-gas on a large scale, the various systems in use are based upon the same principle. It is obtained by dry distillation, the oil being decomposed in horizontal or vertical cast-iron retorts heated to a cherry red (1652° to 1852° F.) Such gas plant consists of a furnace containing the retorts, one or more condensers for the precipitation of the tar-vapors escaping from the retorts, a washing apparatus and one or several purifiers, in the first of which the gas is purified mechanically, and in the latter chemically. Further, of a gas-meter for measuring the product, a gas holder, a pressure-regulator for the uniform distribution of the gas and avoidance of loss, and a manometer box for watching the process of distillation.

The manufacture of the gas is so simple that it can be done by one workman, and since each retort, according to its size, can furnish 15 to 25 cubic meters of gas per hour, but a few hours are required for filling the holder, and the operation may be interrupted at any time.

It is an error to suppose that oil-gas does not require thorough chemical purification, and for this reason the so-called "cheap" gas apparatuses are insufficient for the practice, and especially for working on a larger scale.

Oil-gas to be perfectly free from tar, ammonia and sulphur, should have at least 40 to 45 square meters (430.57 to 484.39 square feet) purifying surface per 50 cubic meters (1765.7 cubic feet) of hourly consumption, and 8½ square meters (94.49 square feet) condensing surface per 50 cubic meters of hourly transmission.

Most of the cheap oil gas apparatuses have only condensing and mechanical purifying contrivances, but no washer and no purifier filled with bog iron ore, and hence furnish a reddish light diffusing a strong odor. In an unburnt state thoroughly purified oil-gas may evolve some odor; however, during combustion carbonic acid and a small quantity of aqueous vapor should be generated, but no sulphurous acid. The retort forms the most important portion of the plant, and in the course of time it has assumed various shapes, and forms the basis of numerous systems.

According to Grotowsky gas apparatuses with horizontal retorts are arranged as shown in Figs. 277 to 280.

The cast-iron retorts *B* rest in the brick furnace *C*. When

FIG. 277.

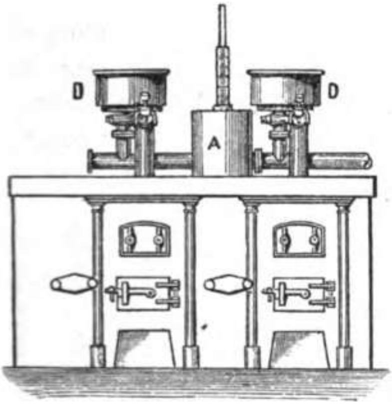


FIG. 278.

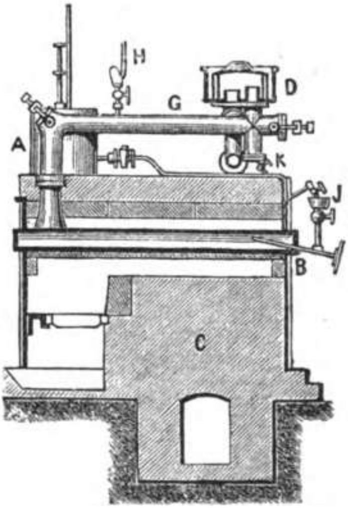
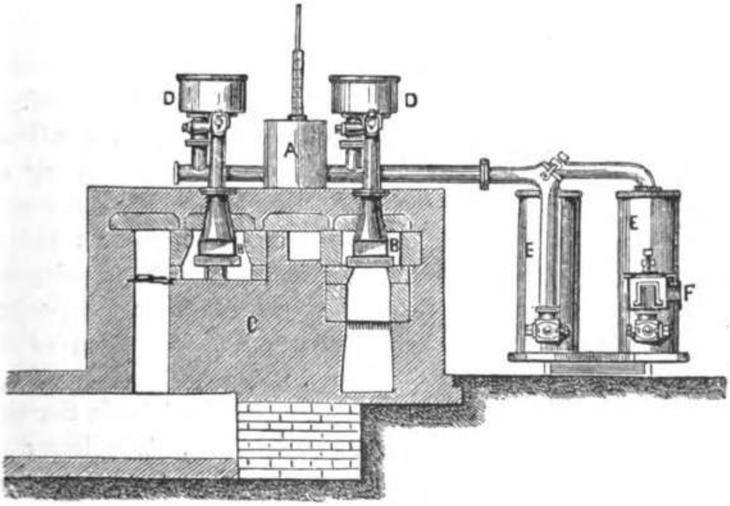
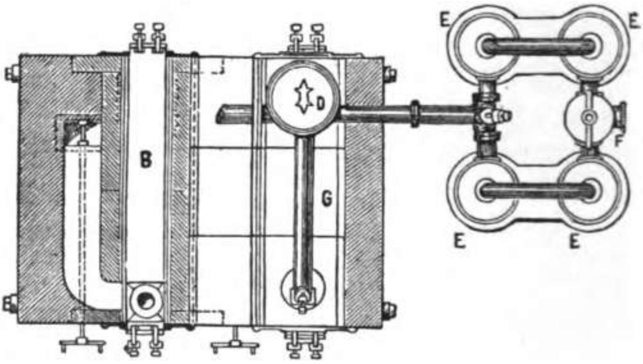


FIG. 279.



the retorts have been heated to a red heat, the oil is introduced from the holder *A* through the inlet *J*. The gases and tar vapors ascend in corresponding pipes to the vessel *D*, which contains a layer of tar to prevent the gas from passing back into the retorts. From here the gas enters the condensers *E*, in which it is freed by coke from the condensable portions of tar. The gas then passes through *F* and from there into the gasometer. The manometer *H* serves for measuring the pressure when the gas leaves the retort. The test cocks *K* serve for judging of uniform production, to control the color of the gas and to discharge the tar precipitated in the pipe *G*.

FIG. 280.



The principal point in the operation is to attain a uniform brick-red heat, which is readily effected by manipulating the draughts, etc. Irregular heating may cause the retorts to crack, which would occasion loss of gas, etc. When the retort is but slightly heated, much tar is formed in the condensers, the oil not having yielded all substances suitable for production. Superheating the retort causes the separation of too large a quantity of coke.

The yield with the same material depends solely on the temperature at which the operation is carried on. The lower the temperature, the smaller the yield of gas, which possesses, however, greater illuminating power; and the higher the temperature the more gas, but of less illuminating power, is obtained.

The following points serve as indications of the correct and uniform production of gas:—

1. A uniform cherry red heat of the retorts.
2. A pale brown color of the gas coming from the test-cocks.
3. Proportional production of tar; which may vary from 26 to 30 per cent., but should not exceed 33 per cent.
4. Slight heating of the tar-condenser.

Hübner, in 1870, constructed a vertical gas retort, which has been improved by Schumann. It is, as a rule, lined partially or entirely with chamotte. The process of manufacturing the gas is the same as with horizontal retorts.

The advantages claimed for vertical retorts are as follows:

With the same wall surface the vertical retort permits within a certain period of time a much larger charge of oil than the horizontal retort, because the oil can be very well conveyed to various portions of the red-hot walls and the oil vapors formed be readily brought into more intimate contact with the latter. For this reason the vertical retort possesses greater capacity than the horizontal form.

The yield from a vertical retort is more uniform and larger, because gasification is more complete, and tarry and asphalt-like residues cannot collect in it.

A smaller quantity of fuel is required for the production of a certain quantity of gas.

Of the more modern gas producers, Hirzel's apparatus with spherical retort and gas augmenter may be mentioned. It is shown in Figs. 281 and 282.

A is the furnace for the retort *B*. The retort is fed from the oil-holder *L* by means of the siphon-like contrivance *a* in such a manner that only as much oil as can at one time be decomposed to gas reaches the heated retort, so that the latter is always empty and the manufacture of gas may be interrupted at any time by closing the cock on the pipe leading from the oil-holder *L*. *R R* are manometers which indicate the pressure in the retort and in the condenser.

The gas generated in the retort passes through the pipe *D* into the tar cylinder, the so-called hydraulic box *E* placed upon the furnace, in which it has to pass first through a layer of tar. This layer of tar closes the mouth of the pipe *D* so that it is impossible for any of the gas to flow back from the gas-holder into the retort. It never decreases, but to prevent, on the other hand, its increase, a pipe *F* is provided on the side of the hydraulic box *E*, through which an excess of tar passes together with the gas into the condenser *G* filled with coke. From the condenser the gas passes into the special purifiying apparatus *I*, filled with a suitable purifying mass, in which it is freed from all

FIG. 281.

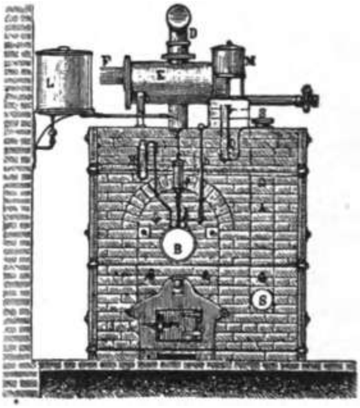
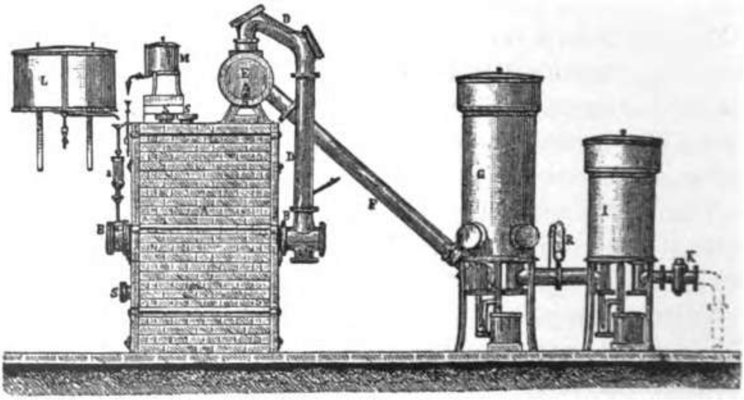


FIG. 282.



impurities. From this purifying apparatus it passes through *K* into the gasometer.

To increase the yield of gas Hirzel's apparatus is provided with a so-called gas-augmenter. It consists of a vertical *U*-shaped retort *S*, which is filled with small pieces of coke and heated by waste gases of the principal retort. From a vessel *M* water drips through the siphon pipe *Q* into one of the legs of the retort *S*. Water-gas is formed which by mixing with the oil vapors increases the yield.

The furnace of R. Schwarz is furnished with a retort which can be revolved by an endless chain. The oil entering the hot revolving retort describes in it a spiral course, so that it constantly meets fresh gasifying surfaces.

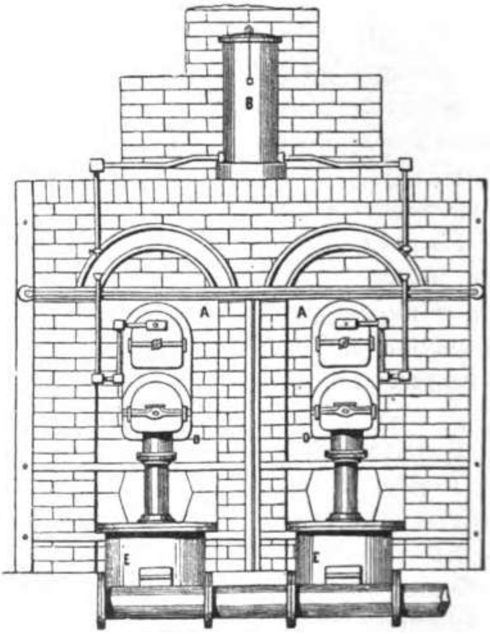
D. H. Knapp uses two retorts, one inside the other; the oil is vaporized in the inner retort and gasified in the space between the two retorts.

Pintsch's gas producer consists of two retorts, one above the other; the oil is gasified in the upper retort, and the gas produced again heated in the lower, whereby condensation is reduced to a minimum and the yield of gas consequently increased to a maximum. Pintsch's retort is especially suitable for the manufacture of permanent gas for lighting railroad carriages.

All other systems with simple retorts 2¾ to 5 feet long, vaporize, as a rule, the higher oils only, while the heavier oils pass over into the hydraulic box and condenser, and run off from the latter together with the tar. Pintsch was led to the construction of the double retort by the desire to produce an oil-gas for lighting railroad carriages, which could be compressed without again liquefying and losing any of its illuminating power.

Pintsch's apparatus is shown in Figs. 283 and 284. From the oil-holder *B* placed on top of the furnace, the oil intended for gasification passes through an inverted siphon, over sheet-iron trays *C*, into the upper retort *A*, and descends through pipes to the lower retort *D*. It has now become a thick yellow vapor, in which shape it enters a hydraulic box *E*, where it is partially washed, and thence passes to the condenser, the tar being carried off by overflow pipes to a separate tank, The gas is finally purified by forcing it through a vessel, the lower part of which is filled with water, and the upper with lime and sawdust. When cooled it can be stored in the condenser at a pressure of about 10 atmospheres. The illuminating power of the gas produced is about 40 or 50 candles, but the pressure causes it to lose 20 per cent. of its lighting power.

FIG. 283.

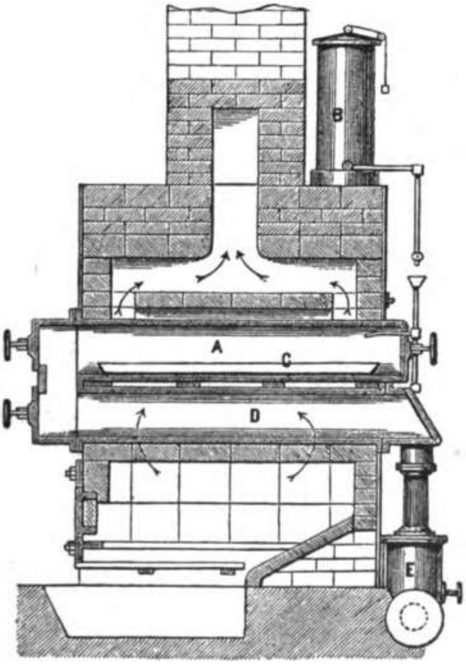


Oil-gas may be used not only for illuminating and heating purposes, but also for motors.

Burners for oil-gas should be furnished with very narrow openings, otherwise the flame readily soots, on account of the high content of carbon. The price of oil-gas, of course, varies according to the cost of the raw material, fuel, mode of operating, etc.

Finally it may be of interest to mention the experiments of S. Lamansky and L. Jawein, which show the decrease in the illuminating power of oil-gas by the admixture of air, as well as the explosive property of such mixture.

FIG. 284.



Gas-mixture.	Specific gravity.	Hourly consumption in cubic feet.	Intensity of light.	Hourly consumption for one candle.
Oil-gas	0.685	3.3	31	0.107
Mixed with 5 per cent. of air....	0.719	3.3	25	0.132
" 10 per cent. of air...	0.732	3.3	21	0.157
" 20 per cent. of air....	0.755	3.4	15	0.226
" 50 per cent. of air....	0.796	3.3	5	0.600

From the above table it will be seen that by an admixture of air the specific gravity of oil-gas is increased, while the illuminating power is considerably reduced.

The results of the experiments regarding the explosive property of a mixture of oil-gas and air were as follows:

Oil gas. volumes.	Air. volumes.	Explosion.
1	[illegible]	None.
1	[illegible]	Slight.
1	[illegible]	Heavy.
1	7 to 9	Very heavy.
1	[illegible]	Heavy.
1	[illegible]	Slight.
1	17 to 17.7	Very slight.
1	[illegible]	None.

Hence a mixture of oil-gas and air is explosive in the proportion of 1 volume gas to 5.6 to 17.7 volumes air, *i. e.*, when the mixture contains not less than 85 per cent. and not more than 94.6 per cent. air. The most violent explosive mixture is 1 volume oil-gas with 7 to 9 volumes air.

APPENDIX.

USEFUL TABLES.

TABLE I.*

SPECIFIC GRAVITY AND CONTENT OF DILUTE SULPHURIC ACID ACCORDING TO J. KOLB.

Specific Gravity at 15° C. (59° F.) Referred to Water of 0° C. (32° F.) = 1.

Degrees Baumé.	Specific Gravity $d\,\frac{15}{0}$.	100 Parts by Weight Contain H_2SO_4.	1 Liter Contains H_2SO_4 in Kilogrammes.	Degrees Baumé.	Specific Gravity $d\,\frac{15}{0}$.	100 Parts by Weight Contain H_2SO_4.	1 Liter Contains H_2SO_4 in Kilogrammes.	Degrees Baumé.	Specific Gravity $d\,\frac{15}{0}$.	100 Parts by Weight Contain H_2SO_4.	1 Liter Contains H_2SO_4 in Kilogrammes.
1	1.007	1.9	0.019	23	1.190	25.8	0.307	45	1.453	55.4	0.805
2	1.014	2.8	0.028	24	1.200	27.1	0.325	46	1.468	56.9	0.835
3	1.022	3.8	0.039	25	1.210	28.4	0.344	47	1.483	58.3	0.864
4	1.029	4.8	0.039	26	1.220	29.6	0.361	48	1.498	59.6	0.893
5	1.037	5.8	0.060	27	1.231	30.9	0.381	49	1.514	61.0	0.923
6	1.045	6.8	0.071	28	1.241	32.2	0.400	50	1.530	62.5	0.956
7	1.052	7.8	0.082	29	1.252	33.4	0.418	51	1.540	64.0	0.990
8	1.060	8.8	0.093	30	1.263	34.7	0.438	52	1.563	65.5	1.024
9	1.067	9.8	0.105	31	1.274	36.0	0.459	53	1.580	67.0	1.059
10	1.075	10.8	0.116	32	1.285	37.4	0.481	54	1.597	68.0	1.095
11	1.083	11.9	0.129	33	1.297	38.8	0.503	55	1.615	70.0	1.131
12	1.091	13.0	0.142	34	1.308	40.2	0.526	56	1.634	71.6	1.170
13	1.100	14.1	0.155	35	1.320	41.6	0.549	57	1.652	73.2	1.210
14	1.108	15.2	0.168	36	1.332	43.0	0.573	58	1.671	74.7	1.248
15	1.116	16.2	0.181	37	1.345	44.4	0.597	59	1.691	76.4	1.292
16	1.125	17.3	0.195	38	1.357	45.6	0.619	60	1.711	78.1	1.336
17	1.134	18.5	0.210	39	1.370	46.9	0.642	61	1.732	79.9	1.384
18	1.142	19.6	0.224	40	1.383	48.3	0.668	62	1.753	81.7	1.432
19	1.152	20.8	0.239	41	1.397	49.8	0.696	63	1.774	84.1	1.492
20	1.162	22.1	0.258	42	1.410	51.2	0.722	64	1.796	86.5	1.554
21	1.171	23.3	0.273	43	1.424	52.6	0.749	65	1.819	89.7	1.632
22	1.180	24.5	0.289	44	1.438	54.0	0.777	66	1.842	100.0	1.842

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* Landolt and Boernstein, Physik-chem. Tabellen, S. 140.

TABLE II.*

OF SPECIFIC GRAVITY AND CONTENT OF CONCENTRATED SULPHURIC ACID.

1. According to F. Kohlrausch.
Specific Gravity at 18° C. (64.4° F.)
Water of 4° C. (39.2° F.) = 1.

Per Cent. H_2SO_4.	Specific Gravity $d\,\frac{18}{4}$.	Per Cent. H_2SO_4.	Specific Gravity $d\,\frac{18}{4}$.
90	1.8147	96	1.8372
91	1.8200	97	1.8383
92	1.8249	98	[1] 1.8386
93	1.8290	99	1.8376
94	1.8325	100	1.8342
95	1.8352	—	—
—	—	—	—

[1] Maximum density.
Expansion co-efficient = 0.00055.

2. According to Lunge and Naef.
Specific Gravity at 15° C. (59° F.)
Water of 40° C. (39.2° F.) = 1.

Per Cent. H_2SO_4.	Specific Gravity $d\,\frac{15}{4}$.	Per Cent. H_2SO_4.	Specific Gravity $d\,\frac{15}{4}$.	Per Cent. H_2SO_4.	Specific Gravity $d\,\frac{15}{4}$.
90.	1.8185	94.	1.8372	98.	1.8412
*90.20	1.8195	*94.84	1.8387	*98.39	1.8406
91.	1.8241	95.	1.8390	*98.66	1.8409
*91.48	1.8271	*95.97	1.8406	99.	1.8403
92.	1.8294	96.	1.8406	*99.47	1.8395
*92.83	1.8334	97.	1.8410	*[2]100.00	1.8384
93.	1.8339	*[1]97.70	1.8413	*100.35	1.8411

* Directly observed.
[1] Maximum density.
[2] Minimum density.
Expansion co-efficient = 0.0010.

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* Landolt and Boernstein: Physik-chem. Tabellen, S. 140.

TABLE III.

SHOWING THE CONTENT OF CRYSTALLIZED AND ANHYDROUS SALTS IN SOLUTIONS OF CARBONATE OF SODA.

According to H. Schiff.

Specific Gravities.	Per cent. of Crystallized Soda.	Per cent. of Anhydrous Salts.	Specific Gravities.	Per cent. of Crystallized Soda.	Per cent. of Anhydrous Salts.
1.0038	1	0.730	1.1035	26	9.635
1.0076	2	0.747	1.1076	27	10.005
1.0114	3	0.112	1.1117	28	10.376
1.0153	4	1.482	1.1158	29	10.746
1.0192	5	1.853	1.1200	30	11.118
1.0231	6	2.223	1.1242	31	11.488
1.0270	7	2.594	1.1284	32	11.859
1.0309	8	2.965	1.1326	33	12.230
1.0348	9	3.335	1.1368	34	12.600
1.0388	10	3.706	1.1410	35	12.971
1.0428	11	4.076	1.1452	36	13.341
1.0468	12	4.447	1.1494	37	13.712
1.0508	13	4.817	1.1536	38	14.082
1.0548	14	5.188	1.1578	39	14.453
1.0588	15	5.558	1.1620	40	14.824
1.0628	16	5.929	1.1662	41	15.195
1.0668	17	6.299	1.1704	42	15.566
1.0708	18	6.670	1.1746	43	15.936
1.0748	19	7.041	1.1788	44	16.307
1.0789	20	7.412	1.1830	45	16.677
1.0830	21	7.782	1.1873	46	17.048
1.0871	22	8.153	1.1916	47	17.418
1.0912	23	8.523	1.1959	48	17.789
1.0953	24	8.894	1.2002	49	18.159
1.0994	25	9.264	1.2045	50	18.530

TABLE IV.

SPECIFIC GRAVITY AND PER CENT. BY WEIGHT OF POTASH AND SODA LYES.*

POTASH-LYE.						SODA-LYE.					
Specific gravity at 15° C. (59° F.)	Per cent. by weight. KHO.	Specific gravity at 15° C. (59° F.)	Per cent by weight. KHO.	Specific gravity at 15° C. (59° F.)	Per cent. by weight. KHO.	Specific gravity at 15° C. (59° F.)	Per cent. by weight. NaOH.	Specific gravity at 15° C. (59° F.)	Per cent by weight. NaOH.	Specific gravity at 15° C. (59° F.)	Per cent. by weight. NaOH.
1.009	1	1.230	25	1.525	49	1.012	1	1.279	25	1.529	49
1.017	2	1.241	26	1.539	50	1.023	2	1.290	26	1.540	50
1.025	3	1.252	27	1.552	51	1.035	3	1.300	27	1.550	51
1.033	4	1.264	28	1.565	52	1.046	4	1.310	28	1.560	52
1.041	5	1.276	29	1.578	53	1.058	5	1.321	29	1.570	53
1.049	6	1.288	30	1.590	54	1.070	6	1.332	30	1.580	54
1.058	7	1.300	31	1.604	55	1.081	7	1.343	31	1.591	55
1.065	8	1.311	32	1.618	56	1.092	8	1.353	32	1.601	56
1.074	9	1.324	33	1.630	57	1.103	9	1.363	33	1.611	57
1.083	10	1.336	34	1.642	58	1.115	10	1.374	34	1.622	58
1.092	11	1.349	35	1.655	59	1.126	11	1.384	35	1.633	59
1.101	12	1.361	36	1.667	60	1.137	12	1.395	36	1.643	60
1.110	13	1.374	37	1.681	61	1.148	13	1.405	37	1.654	61
1.119	14	1.387	38	1.695	62	1.159	14	1.415	38	1.664	62
1.128	15	1.400	39	1.705	63	1.170	15	1.426	39	1.674	63
1.137	16	1.412	40	1.718	64	1.181	16	1.437	40	1.684	64
1.146	17	1.425	41	1.729	65	1.192	17	1.447	41	1.695	65
1.155	18	1.438	42	1.740	66	1.202	18	1.457	42	1.705	66
1.166	19	1.450	43	1.754	67	1.213	19	1.468	43	1.715	67
1.177	20	1.462	44	1.768	68	1.225	20	1.478	44	1.726	68
1.188	21	1.475	45	1.780	69	1.236	21	1.488	45	1.737	69
1.198	22	1.488	46	1.790	70	1.247	22	1.499	46	1.748	70
1.209	23	1.499	47			1.258	23	1.509	47		
1.220	24	1.511	48			1.269	24	1.519	48		

* According to Th. Gerlach from Landolt und Boernstein: Physik-Chem. Tabellen, S. 144.

*The World's Production of Petroleum.**

In the following table is given for the first time an estimate of the world's production of petroleum. It is not claimed that this is complete, but simply an approximation to the actual facts. It will probably be found to be an underestimate rather

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* Mineral Resources of the United States, 1893. Petroleum, by Jos. D. Weeks, p. 532, Washington, 1894.

than an overestimate. The production is given in barrels. Often the reports of production are in tons. In such cases, we have assumed, in the absence of definite information, that a ton produced 7 barrels of crude petroleum.

WORLD'S PRODUCTION OF PETROLEUM.

Countries.	Production.
	Barrels.
United States (1893)	48,412,666
Russia, Baku (1893)	33,104,126
Russia, elsewhere (1890)	251,543
Austria-Hungary (1890)	816,000
Canada (1893)	798,406
Peru (1890)	350,000
India (1891)	146,107
Germany (1892)	103,323
France (1891)	70,000
Japan (1890)	48,027
Argentina (1891)	21,000
Italy (1891)	8,085
Great Britain (1892)	1,526
Other countries (estimated)	200,000
Total	84,330,809

From the above table it appears that the total production of petroleum in the world can be estimated at about 84,330,809 barrels. Of this the United States produced 48,412,666, or 57 per cent.; Russia produced 33,355,669 barrels, or nearly 40 per cent.; Austria-Hungary is third in point of production, its output in 1890 being 816,000 barrels, or less than 1 per cent,; while the production of Canada in 1893 was 798,406 barrels, or a little less than nine-tenths of one per cent.

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