PETROLEUM:

ITS

PRODUCTION AND USE.

BY

BOVERTON REDWOOD, F.I.C., F.C.S.

Abridged from the Cantor Lectures before the Society of Arts, London.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STREETS.
1887.

PREFACE.

The following pages have been reprinted from the *Journal of the Society of Arts*, London, with the omissions of such portions as would seem to be of little or no interest to American readers. The petroleum industry occupies a wide field in this country, and the amount of capital invested in it is very great, and while, therefore, all that was stated by Mr. Redwood in his lectures was admirable, and doubtless of much interest to his English hearers, very much, on the other hand, would prove to be of no material value to the American reader. We feel on the whole, however, that the subject matter of these lectures, with the exceptions stated, are worth preservation, and believe that all that is here given will be found to be of interest to readers here. It has been deemed better to change the matter from the lecture form in which it appeared in the columns of the *Journal of the Society of Arts*.

W. H. F.

PETROLEUM AND ITS PRODUCTS.

CHAPTER I.

In the United States petroleum exists, saturating strata of sand-rock. When first wells were drilled in America nothing was known about these strata; but ultimately, in the valley of Oil Creek, the existence of three well-defined oil sands was ascertained. These oil sands in the Oil Creek district are of considerable regularity as regards their thickness and the intervening distance between them, the first sand being 40 feet thick, with an interval of 105 feet between it and the second sand, which is 25 feet thick; an interval of 110 feet occurring between the second sand and the third, the thickness of the latter being 35 feet. In some localities, however, the second sand is split into two well-defined sands, with from 15 feet to 30 feet of slates or shales intervening, and this has given rise to the definition of a fourth sand. In drilling on high ground in the Oil Creek district, several upper sand rocks were also perforated; these were termed "mountain sands." In addition to the three regular sands, there was often found, about 15 feet to 20 feet above the regular third, a fine-grained muddy gray sand, from 12 feet to 25 feet thick; this was termed the "stray third."

The Venango oil sand group is described by Mr. Carll* as a group in the strictest sense of the term, having a well-defined top and bottom, and consisting of a mass of sandstone deposits from 300 to 380 feet thick, with layers of pebbles and many local partings of slate and shale. These figures may, he states, be varied somewhat, but it will be found, as a general rule, that a thickness of 350 feet will, in nearly every case, embrace all the sands belonging to the Venango group, even the fourth, fifth, and sixth sands, as the lower members of the group in some localities have been called. The

* See Penna. Geological Report—Second Report.

oil is principally obtained in the third sand.

As the area of the oil-producing territory was extended, it was found that the underlying geological formation varied considerably, the sand-rock disappearing, and its place being taken by shales at the same geological horizon.

The several groups of oil-producing rocks are, as Mr. Carll remarks, locally well-defined under certain areas; but they have their geographical as well as their geological limits, and as far as is at present known, the geographical limit of one group never overlaps that of another. Hence, it must not be presumed that each particular sandstone or its oil will be found in every locality where its horizon can be pierced with the drill, or that a measured section of the rocks in one place can be precisely duplicated in detail in another. Therefore the most skillful oil-producer, the most expert geologist, cannot tell how many other oil horizons may exist at intermediate depths beneath the surface (*i. e.*, in the scale of the formation), but which have, as yet, escaped the oil-miner's drill.

In Western Pennsylvania the sand-rock varies in character from a coarse-grained, uncemented sandstone, to a pebble conglomerate, composed of coarse pebbles, of white, or slightly colored opaque quartz, overlaid by marls and slates, often highly silicated, forming very hard and impervious crusts. This pebble conglomerate consists of two varieties, occupying separate horizons, in one of which the pebbles are nearly spherical, and in the other flattened. Between these beds of sandstone or conglomerate that contain the oil are beds of shale, with which are thin beds of sand and "shells." These shells are described by Professor Leslie as hard crusts of white flint.

Mr. Peckham* remarks that petroleum is found in the principal producing territories in the United States and Canada, saturating porous strata, and overlying superficial gravels; it occurs in Canada

*Tenth Census U. S.

and West Virginia beneath the crowns of anticlinals; while in Pennsylvania it occurs saturating the porous portions of formations that lie far beneath the influence of the superficial erosion, like sandbars in a flowing stream or detritus on a beach. These formations or deposits, taken as whole members of the geological series, lie conformably with the inclosing rocks, and slope gently toward the southwest. The Bradford field in particular, says Mr. Peckham, resembles a sheet of coarse-grained sandstone, 100 square miles in extent, by from 20 to 80 feet deep, lying with its southwestern edge deepest, and submerged in salt water, and its northeastern edge highest, and filled with gas under an extremely high pressure.

In relation to the geology of natural gas, Mr. Ashburner points out that the oil and gas regions of Pennsylvania are shown by the strata drilled by the gas wells in the neighborhood of Pittsburg to be one in a geological sense. The general conditions upon which the occurrence of natural gas seems to depend, from a consideration of the facts at present at our command, are (*a*) the porosity and homogeneousness of the sandstone which serves as a reservoir to hold the gas; (*b*) the extent to which the strata above or below the gas-sand are cracked; (*c*) the dip of the gas-sand, and the position of the anticlines and synclines; (*d*) the relative proportions of water, oil, and gas contained in the gas-sand; and (*e*) the pressure under which the gas exists before being tapped. Other conditions may, however, as Mr. Ashburner remarks, be still discovered, which will have as important a bearing upon the problem as those which have been stated.

Vasilieff, who published an article on the "Oil Wells of Baku," in the *Russian Mining Journal*, for September last, an abstract of which, by William Anderson, has recently appeared in the Minutes of the Proceedings of the Institution of Civil Engineers, states that the petroleum bearing strata of the Caucasus belong to the lower miocene series of the tertiary epoch, the deposits extending in a N.E. to S.W. direction, and the dip ranging apparently between 20° and 40°. The petroleum-bearing beds are composed of sand, calcareous clays, marls, and in places, compact sandstone, often of great thickness, penetrated by bands of pyrites. The number of oil-bearing strata is unknown, but three oil-sands have, up to the present time, been defined.

Petroleum is generally considered to have resulted from the slow decomposition of vegetable or animal matter, either in the rocks in which it is found, or in underlying strata. Berthelot, however, in 1866, propounded the theory that petroleum was formed by the action of carbonic acid and steam on the alkali metals; and in the following year Mendelejeff, in a celebrated essay, read before the Chemical Society of St. Petersburg, and subsequently published in the *Revue Scientifique*, gave in detail his reasons for believing petroleum to be the product of the action of water upon iron or other metal, and carbon, at a high temperature and under great pressure.

The view that petroleum is indigenous to the rocks in which it is found has been strongly supported by Dr. Hunt and Professor Leslie. Mr. Peckham, after a prefatory remark that his studies, extending over twenty years, have led him to the conclusion that, as yet, very little is known regarding the chemical geology of petroleum, expresses the opinion that all bitumens, from the solid to the gaseous, have, in their present condition, originally been derived from animal or vegetable remains, but that the manner of their derivation has not been uniform. Referring to the hypothesis that petroleum is indigenous in the rocks in which it is found, and to that which regards all bitumens as distillates, he remarks that there remains the modifying fact that there are four kinds of bitumen:—

1. Those bitumens that form asphaltum and do not contain paraffine.

2. Those bitumens that do not form asphaltum and contain paraffine.

3. Those bitumens that form asphaltum and contain paraffine.

4. Solid bitumens that were originally solid when cold or at ordinary temperatures.

The first class includes the bitumens of California and Texas, doubtless indigenous in the States in which they are found; and probably also some of the bitumens of Asia.

Too little is known, Mr. Peckham adds, about petroleum at the present time to enable any one to explain all the phenomena on any hypothesis, but it seems to him that the varieties of petroleum found in New York, Pennsylvania, Ohio, and West Virginia are distinctly of vegetable origin, and are the product of fractional distillation, as shown by the large amount of paraffine in the Bradford oil, under the enormous pressure to which it is subjected; while the Kentucky and Californian oils are evidently of animal origin, and have not been subjected to distillation. It is not, he considers, the effects of heat as represented by volcanic action that have produced the petroleum, but rather the effects of slow and gentle changes at low temperatures, due to metamorphic action upon strata buried at immense depth. Regarding the nature of the metamorphic action, he states that it is sufficient for our purpose to know that from the upper silurian to the close of the carboniferous periods, the currents of the primeval ocean were transporting sediment from northeast to southwest, sorting them into gravel, sand, and clay, forming gravel bars and great sand beds beneath the riffles and clay banks, in still water, burying vast accumulations of seaweeds and sea animals far beneath the surface. The alteration due to the combined action of heat, steam, and pressure, that resulted in the formation of the Appalachian system, from Point Gaspé, in Canada, to Lookout Mountain in Tennessee, involving the carboniferous and earlier strata, distorting and folding them, and converting the coal into anthracite, and the clays into crystalline schists along their eastern border, could not have ceased to act westward along an arbitrary line, but must have gradually died farther and farther from the surface. The great beds of slate and limestone containing fucoids, animal remains, and even indigenous petroleum, must have been invaded by this heat action to a greater or less degree, and thus, in accordance with the theory of Professor Leslie, a chronic evaporation or distillation of the whole mass of oil in the crust of the earth (within reasonable reach of the surface) has been going on, converting the animal and plant remains into oils, the light oils into heavy oils, the heavy oils into asphalte and albertite; the process being accompanied with the liberation of gas. Dealing, in connection with this theory, with the objection of those who, supporting Berthelot's and Mendelejeff's views, point out that there is no evidence of the action of heat upon the rocks holding the oil, and no residues of fixed carbon, Mr. Peckham replies that we must seek the evidences of heat action at a depth far below the unaltered rocks in which the petroleum is now stored. If petroleum, he adds, is the product of a "purely chemical process," we should not expect to find paleozoic petroleums of a character corresponding with the simple animal and vegetable organisms that flourished at that period, and tertiary petroleums containing nitrogen, unstable and corresponding with the decomposition products of more highly organized beings, but we should expect to find a general uniformity in the character of the substance, wherever found, all over the earth.

The subject, while one of speculation, is one that obviously is of practical importance, as affecting the sources and duration of supplies of petroleum, its profitable development, and commercial permanence.

Petroleum occurs, as we have seen, in all forms, from the gaseous to the solid. In its liquid form it varies greatly in physical properties, as well as in chemical composition, and in regard to the proportion of the different commercial products yielded on distillation.

Dr. Krämer gives ·780 and ·970 as the extreme limits of variation in the specific gravity of liquid petroleum; and in illustration of the well-known fact that contiguous wells often yield oils of very different quality, instances the case of two wells in the Oelheim district, of the same depth, and within two meters of each other, one of which yields an oil of sp. gr. ·880, and the other an oil of sp. gr. ·905.

The material known as "ozokerit," large quantities of which are exported from Galicia, may be described as native paraffine wax. Immense deposits of a similar material are, as I have said, stated to exist in the island of Tcheleken, on the Trans-Caspian coast. In Boryslaw and Stanislaw (Galicia) the ozokerit occurs partly in beds and partly in pockets in the miocene formation, and is obtained in small pieces or in masses of several hundred pounds weight.

Crude petroleum, in the liquid form, consists almost entirely of carbon and hydrogen, usually in the proportion of about 85 per cent. of the former to 15 per cent. of the latter, but there are also sometimes present in small quantity oxygen, nitrogen and sulphur.

Reichenbach examined paraffine in 1824, and rock oil ten years later. Early attempts to determine the composition of petroleum were also made by Laurent. In 1857, De La Rue and Müller described the products they had obtained from Rangoon petroleum. In 1863, Schorlemmer isolated some of the constituents of American petroleum, and about the same time Pelouze and Cahours succeeded in separating from this oil twelve distinct hydrocarbons, which were found to be homologues of marsh gas (CH_4), and of which the general formula is $C_n H_{2n+2}$.

Of the more volatile hydrocarbons, viz., those boiling between 0° C. and 130° C. there have been shown to be two series present, those of the first series which have the higher boiling points being normal, while those of the second agree for the most part in boiling point with the corresponding synthetically prepared iso-paraffines. There are grounds for belief in the occurrence of a third series of paraffines in the fraction referred to. From the crude oil, as it issues from the earth, methane, ethane, and propane are given off in gaseous form, so that from American petroleum the paraffines referred to have been separated.

Methane is a colorless inodorous gas, burning with a yellow flame of little luminosity. Ethane is also a colorless, odorless gas. Propane liqeufies at —20° C. Normal butane condenses at 0° C. to a liquid, boiling at 1° C., which constitutes the greater part of the petroleum product known as "cymogene." Normal pentane occurs with iso-pentane in the most volatile portion of petroleum spirit. Hexane, heptane, octane, and certain of their isomers constitute the greater part of the liquid known as "benzoline."

The less volatile portions of American crude petroleum, boiling above 260° C., contain paraffines of still higher order, those containing 20 per cent. of carbon atoms, or more, being crystalline solids. There are also present hydrocarbons of the C_nH_{2n} series, which, however, according to Markownikow, who terms them naphthenes, differ from the olefines. Dr. Krämer, who has exhaustively examined three varieties of German petroleum, inclines to the belief that the so-called naphthenes are mixtures of paraffinöid and benzenöid hydrocarbons.

From the least volatile portion of American crude petroleum a peculiar solid crystalline hydrocarbon was separated by Morton in 1873. To this hydrocarbon, which in its reactions resembled impure anthracene, the name of "thallene" was given. Morton subsequently found that the spectrum of "thallene" differed from that of impure anthracene. This product was subsequently examined by Prunier; and more recently by Dr. Divers and Mr. Nakamura, who have isolated a body of the formula $C_4H_3)_n$ boiling between 280° and 285° C.

In 1875, Hell and Meidinger obtained

from Wallachian petroleum an acid, forming alkali salts resembling soft soap. The analysis of the acid, the ether, and the silver salt, agreed best with the formula $C_{11}H_{20}O_2$. These chemists expressed the opinion that heavy Wallachian petroleum contains a series of probably homologous acids. Markownikow has found in a fraction of Russian petroleum, boiling between 220° and 230° C. as much as 5.25 per cent. of oxygen. This chemist, continuing the research of Hell and Meidinger, ascertained the occurrence also of bodies of a phenolöid character. Dr. Krämer has recently examined the oxygenated bodies present in German petroleum.

Caucasian petroleum has, during the past few years, been the subject of much research at the hands of several chemists, among whom may be mentioned Markownikow and Oglobine, and it has been shown that this material is altogether different in composition from American petroleum, and that it consists for the most part of hydrocarbons of the C_nH_{2n}

series, isomeric both with the olefines, or true homologues of ethylene, and with the hexhydrides of the benzines. The hydrocarbons in question exhibit the closest resemblance to the paraffines, but are of higher density than their isologues. They are attacked by chlorine yielding chlorinated derivatives; but on oxidation are completely destroyed, without furnishing characteristic products. The following is a list of the hydrocarbons of this group, which have been separated from Caucasian petroleum:

	Boiling point.
C_8H_{16}	119° C.
C_9H_{18}	136° "
$C_{10}H_{20}$	161° "
$C_{11}H_{22}$	180° "
$C_{12}H_{24}$	196° "
$C_{14}H_{28}$	240° "
$C_{15}H_{30}$	247° "

Ethylene (C_2H_4), which appears to be the lowest member of the series of olefines capable of existing in the separate state, is at ordinary temperatures and pressures a colorless gas, burning with a luminous white flame.

Hydrocarbons of the aromatic ($C_nH_{2n}-6$) series are also found in petroleum.

Pawlewski reports that a volatile product of the distillation of Galician petroleum, examined by him, contained as much as 4.9 per cent. of hydrocarbons of this group.

The burning oil obtained from American petroleum contains a considerable proportion of olefines produced from the paraffines.

The following tabular statement is based upon the analyses of natural gas made by Mr. Carnegie at his works near Pittsburgh, and quoted by Professor Dewar:

COMPOSITION OF SIX SAMPLES OF NATURAL GAS.

	1.	2.	3.	4.	5.	6.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Marsh Gas	72 18	65.25	60.70	49.58	57.85	75.16
Hydrogen	20.12	26.16	29.03	35.92	9.64	14.45
Ethylic hydride	3.6	5.5	7.92	12.30	5.20	4.8
Olefiant Gas	.7	.8	.98	.6	.8	.6
Oxygen	1.1	.8	.78	.8	2.1	1.2
Nitrogen	nil.	nil.	nil.	nil	23.41	2.89
Carbonic Acid	.8	.6	nil.	.4	nil.	.3
Carbonic Oxide	1.0	.8	.58	.4	1.0	.6

The co-efficient of expansion of crude petroleum varies according to the proportion of the more volatile hydrocarbons present, as is shown in the following table:

Sp. Gr. at 15° *C.*	*Expansive Coefficient for* 1° *C.*
Under .700	.00090
.700 to .750	.00085
.750 to .800	.00080
.800 to .815	.00070
Over .815	.00065

The rate of expansion has also been found to vary according to the temperature.

In practice it is customary to add to or subtract from the observed specific gravity .004 for every 10° F. above or below 60° F., and this is found to afford a sufficiently close approximation to the truth for all commercial purposes in the case of all the ordinary petroleum products.

Tables for calculating the alterations in volume of crude petroleum with accuracy, are in use in America. These tables were constructed on Gay Lussac's formula:

$$\frac{1+k\,t}{1+a\,t}=\frac{P-p}{P}$$

where P = weight of fluid before heating it;

p = weight of the fluid after heating, and after the apparent expansion has been removed;

t = change of temperature;

k = co-efficient of expansion of the glass;

a = co-efficient of expansion of the fluid.

Chapter II.

Every oil well is naturally divisible into three sections, viz., (1) surface clays and gravels, (2) stratified rocks containing more or less water, (3) stratified rocks, seldom water-bearing, including the oil sands. The first division requires a conductor; and the second division requires casing to shut off the water from the third section. The earlier method of excluding the water, by placing a seed-bag round the tubing was found unsatisfactory, as the tubing could not be removed for repairs without disturbing the seed bag, and letting water into the well. In 1868 cast-iron drive pipe was adopted as a substitute for the wooden conductor used in the earlier wells. The most important alteration made in 1868 was, however, the introduction of 3¼-inch casing as a permanent fixture. This casing extended to the bottom of the water-bearing rocks, and was furnished either with the seed bag or with a leather cup, which was forced open against the sides of the well by a pressure of the water. The tubing of 2¾-inch external diameter and extending nearly to the bottom of the well was then placed inside and suspended from the casing. To obtain a supply of water for the boiler a small pipe was often inserted between the tubing and the casing into the water chamber above the seed-bag. Although the 1868 well was a great improvement on the earlier wells, it possessed defects. Thus the casing being

$3\frac{1}{4}$-inches internal diameter, while the uncased part below it was $5\frac{1}{2}$ inches, fishing tools could not be easily introduced, and if it became necessary to deepen the well only $3\frac{1}{8}$-inch bits could be used. The improvements which followed are best exemplified by describing one of the wells of 1878. This well has an 8-inch wrought iron drive pipe, armed at the bottom with a steel shoe. The pipe is driven down to the bed rock, and an 8-inch, or strictly speaking, $7\frac{7}{8}$-inch hole is drilled to the base of the water-bearing strata. At this point, the bore is gradually reduced to $5\frac{1}{2}$ inches and there a bevel shoulder is made; $5\frac{1}{2}$-inch casing, provided at the lower end with a collar to fit the beveled shoulder, is then inserted and a sufficiently water-tight joint is thus made. Drilling with $5\frac{1}{2}$-inch bits is then continued until the required depth has been reached. When gas is obtained in sufficient quantity to furnish fuel for the boiler it is conveyed through a 2-inch pipe connected with the casing beneath the derrick floor, and passing into the door of the furnace. A $\frac{1}{4}$-inch steam pipe, fitted with an elbow, and $\frac{1}{8}$-inch jet is inserted in the gas pipe close to the fire box, and a blast of steam is thus caused to issue with the gas. The apparatus acts as an exhauster, drawing the gas from the well, and preventing the flame from running back. The cost of a well in the Bradford field in 1871 was about $3,000.

The "water-packer," introduced in 1875, is a device to prevent water that may pass into a well below the casing from gaining access to the oil-sand, and to stop the ascent of gas on the outside of the tubing. It is applied round the tubing at any desired point, and its effect is to shut off all communication between the annular space outside the tubing above it and the oil chamber below. The oil and gas are thus confined in the well chamber, and many wells are thus caused to flow that would otherwise require pumping. Under these circumstances the flow is intermittent, taking place when sufficient gas-pressure has accumulated. There are many forms of water-packer, but one of the simplest consists of a band of india-rubber, which, on compression, is forced against the walls of the well. If the well does not flow, the oil requires to be raised to the surface by a pump. The working barrel of the pump is placed at the bottom of the well on the end of the tubing, a perforated piece of casing of proper length, termed the "anchor," being attached to the lower end of the working barrel. To the sucker of the pump the required number of wooden sucker rods, screwed together, are attached, the upper end of the string of rods being connected with the walking beam. There is, of course, a valve at the bottom of the working barrel, and in the sucker. The sucker is provided with a series of three or four leather cups, which are pressed against the working barrel by the weight of the column of oil. The sucker rods are of ash, 1½ inches in diameter by 24 feet to 28 feet in length. When a number of contiguous wells are to be pumped, an arrangement termed a "grasshopper" apparatus is employed.

By this means several wells can be pumped by the action of a single walking beam.

Most petroleum wells in the United States are "torpedoed" on the completion of the drilling, in order to increase the flow of oil. The torpedo is a charge of nitro-glycerine in a suitable shell, which is lowered to the oil-bearing rock, and there exploded, with the effect of opening fissures into the surrounding rock. The shells, which are of tin plate, are of two kinds. One form is lowered to the bottom of the well by a string that can be easily detached and rests on what is termed an "anchor," which is simply a cylindrical tin tube of such length as will bring the torpedo to the required position. To the upper end of the shell is fitted a "firing head" consisting of a circular plate of iron, only slightly smaller than the bore of the well, having projecting vertically downwards from its lower surface a rod on which a percussion cap is placed. Beneath the cap is an anvil. The lowering cord having been detached and drawn up, a cast-iron weight, termed a "go-devil," is dropped into the well, and this weight striking the disc explodes the percussion cap and fires the torpedo. The other form of shell is suspended by a cord, which serves as a guide for a perforated weight running on it. The usual size of the former description of shell is 3½ inches diameter by 10 feet in length, a shell of these dimensions holding twenty quarts of nitro-glycerine. Frequently as large a charge as eighty quarts is used, and it is then usual to employ four shells of the dimensions given, the lower end of one fitting into the upper end of another, and only the top shell of the series having the firing head. Shells of the other description are commonly termed squibs. They are of much smaller dimensions, holding only about a quart of the explosive liquid, and are now generally used to bring about the explosion of the large torpedo. I extract the following from the *Petroleum Age* for last August:—

"There are nine glycerine firms at

work in the Bradford field, and all their men are kept busy from morning till night. The size of the shot used is rarely less than eighty quarts. The constant enlargement of the cavity in the oil-bearing rocks necessitates the use of dynamite squibs for exploding the shells, and the old method of dropping a 'go-devil' on the firing-head of the torpedo has been almost entirely superseded. The cans in which the nitro-glycerine is transported about the field have been enlarged from six to eight quarts capacity, and each shooter's wagon carries ten cans, or eighty quarts of the powerful explosive. It is estimated that over eight tons of glycerine were used in the Bradford field during the month of July."

The torpedo is usually exploded under about 50 feet of water. Little or no sound is heard, but a slight quiver of the ground is often perceptible. A few moments after the explosion, however, the fluid in the well is shot into the air with great violence, forming a magnificent fountain, and small pieces of rock are also thrown out. The torpedo and exploding weight are blown into small fragments. A few minutes later the well begins to flow, but there is usually a sufficient interval to admit of the casing being connected with a tank in which the oil is collected. The torpedo was invented by Colonel Roberts, and patented by him in 1864.

Some authorities are of opinion that the use of the torpedo is of little value, its effect being simply to clear the pores of the rock of obstructions, and the apparent increase in the yield of oil being simply due to reaction from the immense gas pressure produced by the explosion. Many wells, however, that produced no oil on the completion of the drilling (technically termed "dry-holes") have, through the use of the torpedo, been caused to yield abundantly. In Russia the torpedo is never used.

A modification of the rope system of drilling, known as the rod system, is adopted in Russia and in Galicia. The rod system consists in the substitution of rods of 40 to 60 feet in length, screwed together, for the portion of the drilling cable which passes from the end of the walking beam to the string of tools. Iron rods are used in Russia, and wooden rods in Galicia. In the latter country, where the character of the strata is such that the drilling is difficult, and the hole very liable to depart from the vertical line, in which case the well is rendered useless, the rods, in some cases, work in guides. The rod system is stated by some authorities to be preferable to the rope system for use in Russia, and also in Canada, but it is a less expeditious method of drilling, the time occupied in disconnecting the rods, when the tools are drawn up for the removal of the pulverized rock, and the sharpening of the bit, being considerable, especially when the well has become deep. In Russia it is usual to commence drilling with a bit as much as 15 inches or 16 inches, or even more, in diameter, but it is generally found necessary to gradually diminish the size of the bit as the drilling proceeds.

The depth of the petroleum wells in the United States increased from 436 feet in 1861. to 1,606 feet or more in 1878. There has been a further increase in depth since the latter year, especially in certain localities. Thus the comparatively recently drilled Gordon well in Washington county has a depth of 2,400 feet. The cost of this well is stated to have been $7,500 to $8,000.

The average depth of the petroleum wells in the Caucasus has also been progressive, having increased from 154 feet in 1873, to 450 feet in 1884. Certain of the wells are, however much deeper, one having a depth of 721 feet. It has been estimated that the average level of the oil in the Baku (Balakhani-Saboontchi) oil field is lowered to the extent of 56 feet for every 500,000,000 gallons extracted.

The irregular character of the strata renders the operation of well-drilling, as a rule, more costly in Southern Russia than in the United States, the expense of a well in the Baku district being stated at from £1,000 to £3,000, according to circumstances. The depth of the wells in Galicia range from 250 to 350 meters.

The yield of petroleum wells varies greatly. Of the producing wells in the United States, numbering 20,000, or more, the great majority furnish only a few barrels of oil per day, but some are stated to have yielded, for a short time, as much as 260,000 gallons per 24 hours. This splendid yield is, however, completely eclipsed by that of some of the wells in the Baku district. In well-drilling in the latter locality, it is usual to affix to the top of the casing a strong iron cap, provided with a sliding valve, as soon as the oil is "struck." The petroleum is thus bottled up, and is only drawn off as required. In Baku, in the autumn of 1884, one of these capped wells was opened. On drawing the slide a mighty column of crude petroleum, more than a foot in diameter, immediately shot up to a height of over 100 feet, with a roar, and this magnificent fountain continued to play as long as the valve remained open, forming a lake of oil in the neighborhood of the derrick. This well yields at the rate of 1,125,000 gallons per 24 hours whenever opened. The celebrated Droojba well, and one of Nobel's wells, both yielded, however, for some time, about double that quantity. In the case of the Droojba well, the flow commenced before the cap could be fixed, and the well was for four months quite uncontrollable, sending up a fountain to a height of 200 to 300 feet, and deluging the surrounding land with the oil. The sand thrown up with the oil did considerable damage to neighboring property, engine-houses and workshops being partially buried in it. The use of the caps is not free from difficulty, for the oil contains so much sand, that in its rapid flow under the great pressure prevailing, a considerable thickness of iron is quickly cut through. The principle of capping wells is not adopted in the United States, the object there being to drill the territory acquired as quickly as possible, and take out the oil. It has been demonstrated in the United States that there is a lateral flow of oil through the oil-sand (in one instance red paint put into a well was pumped out of another about half-a-mile distant), and it is therefore impossible for an owner or lessee of oil territory to preserve the oil beneath the surface. The oil must be raised, or it would be drained away by wells on neighboring property.

The average length of time during which an oil well in the United States will yield oil in remunerative quantity has been estimated at five years, but, from what has been stated, it will be apparent that the period must necessarily vary within very wide limits.

The pressure of the oil in the Baku capped wells is frequently as much as 200 lbs., or even in some cases probably 300 lbs. per square inch, and although the upper part of the casing is anchored to the ground, there is some danger of the fittings being blown off when the valve is closed after drawing off a supply of oil. There are about 400 wells in the Baku district, only some 100 of which are productive,* and of the latter not more than 20 were flowing wells. These 20 wells would, however, for a time, yield more than enough crude oil for the manufacture of the 1,800,000, to 2,000,000 gallons of burning oil which the world daily consumes. Wells in the Baku district which do not flow cannot be pumped in the ordinary way, in consequence of the large quantity of sand present (sometimes as much as 30 to 40 per cent.), and the oil is raised to the surface in cylinders resembling the sand-pump.

The cylinder used commonly holds 45 gallons, and it is stated that from 18,000 to 20,000 gallons can thus be raised from each well in a working day of 10 hours.

The gas-wells in the United States are similar to the oil-wells, the casing heads

* Vasilieff gives the average yield of these 100 wells as 32 tons per well per day.

of some in the neighborhood of Clarksville being firmly secured to the ground by chains.

According to Mr. Carnegie, the largest gas-well known yields about 30,000,000 cubic feet of gas in 24 hours, but half this quantity may be considered as the product of a good gas-well. The pressure of the gas at the mouth of one of these wells was shown by the gauge to be 187 lbs. on the square inch, and at the works where the gas was used, nine miles form the well, the pressure was 75 lbs. per inch.

When wells have ceased to yield oil in remunerative quantity in the United States, it is usual to draw out the iron casing for use in other wells; but as this operation allows surface water to gain access to the oil-sand, and as it has been found that the yield of adjacent wells is prejudicially affected by this "flooding," as it is termed, the Pennsylvania Legislature enacted that abandoned wells should be "plugged" by filling them with sand. The prejudicial effect of the flooding of the oil-bearing strata has, it appears, recently been experienced in the Caucasus, the percentage of water in the oil raised in that locality being, according to Vasilieff, steadily on the increase.

When the oil has reached the surface, either by flowing or being pumped, it is conducted into a tank, usually of wood, holding about 250 barrels. In America, quantities of crude petroleum are always stated in "barrels" of 42 American gallons (5 American gallons = 4 Imperial gallons). In the early days of the industry in the United States, the only method of transporting the oil from the well was to place it in oak barrels holding 40 or 50 gallons, and to convey these brarels by road to Oil Creek, where their contents were emptied into bulk barges holding about 2,000 barrels. As Oil Creek was not navigable, arrangements were made with mill owners for the use of the surplus water stored in the dams, and at intervals the barges were floated down from dam to dam until they reached the mouth of the

Creek, at its junction with the Alleghany River, from which point there was good flat-boat navigation to Pittsburgh. This method of transportation was not only very costly, but was also attended with frequent loss of oil through the barges coming into collision while being floated down. On one occasion from 20,000 to 30,000 barrels of oil were thus lost. Added to this, the roads over which the barrels had to be drawn to the water were little better than paths through the woods. Nevertheless, the system, for want of a better, was for some time largely adopted, over 1.000 boats, 40 steamers, and 4,000 men being engaged in the traffic.

In the latter part of 1862, a branch of the Atlantic and Great Western Railway was carried into the oil regions, and at a later date the Alleghany Valley Railway was opened up from Oil City, at the mouth of Oil Creek, to Pittsburgh, and a number of narrow-gauge railways were constructed as feeders.

Crude oil was at first conveyed by rail, in barrels coated internally with glue, but the small quantity of water present in the oil was found to dissolve the glue, and cause the barrels to leak. To remove this difficulty, and to reduce the cost of handling the oil, tank wagons were adopted in 1865 or 1866. These wagons at first consisted of an ordinary truck, on which were placed two circular wooden tanks, or tubs, holding from 2,000 to 4,000 gallons. In 1871 the tank car now employed was introduced. This consists of a cylinder of boiler-plate, lying upon a four-wheeled truck, and provided with a dome similar to that which a horizontal steam boiler has. The tank is furnished with means of filling at the top, and with a valve beneath by which it can be emptied. The tank is now usually about 24 feet 6 inches in length by 66 inches in diameter, and holds from 4,500 to 5,000 gallons.

Tank barges, 130 feet by 22 feet by 16 feet, divided into eight compartments with water-tight bulkheads, and holding 2,200 barrels, are also at present used for the conveyance of crude oil on the Alleghany River.

In 1862 a bill was introduced into the Pennsylvania Legislature for a pipe-line from Oil Creek to Kittanning, but this and a subsequent scheme for laying a pipe-line down the Alleghany River to Pittsburgh, were strongly opposed and came to nothing. According to Mr. C. L. Wheeler, the credit of having first suggested the laying of a pipe-line belongs to General Karns, while a Mr. Hutchinson was the first to carry out the idea. Hutchinson's pipe, which was only about three miles in length, was, however, defectively constructed, and leaked so much that little if any of the oil run in at one end reached the other. Mr. Peckham states that the first successful pipe was laid by Van Syckle, of Titusville, in 1865. This line, which was four miles in length, and another, were afterwards worked by the Alleghany Transportation Company, though not at first without considerable opposition from the teamsters, who more than once maliciously severed the pipes. However, by the employment of armed patrols, the lines were preserved from destruction, and after a time the opposition ceased. Gradually a system of pipe-lines, running from the wells to central stations and thence to loading stages on the railway lines, was constructed, and in 1876 there were eight or nine companies owning pipe-lines in the oil regions, and issuing negotiable certificates for the oil which they collected.

At the present time there is in the oil regions of the United States a complete network of 2-inch piping connecting the various wells with storage tanks and trunk lines. These pipes run across country and through streets; it is impossible to get any accurate statistics of their collective length, but it is safe to say that there are thousands of miles of this 2-inch piping thus employed in the collection of the crude oil.

In 1875, the first trunk line was laid. This extended from the lower oil country to Pittsburgh, a distance of sixty miles, and was 4 inches in diameter. Like the first pipe-lines from the wells, it had for a time to be protected by armed men.

As the refining trade developed it became concentrated on the seaboard and on the shore of Lake Erie, and the transportation of the crude material to the refineries became a business of very great importance. From 1878 to 1881–2, the construction of great trunk lines was continuous. Consolidation of the transporting companies also took place, and at the present time the pipe-lines, with one exception, are under the control of a very wealthy corporation, known as the National Transit Company, which is said to have $15,000,000 invested in oil transporting plant. This company owns the following lines:—

		Miles.
From Olean, N. Y., to New York, Bayonne and Brooklyn............	(length)	300
From Colegrove, Pa., to Phila .	"	280
From Millway, Pa., to Baltimore..	"	70
From Hilliards, Pa., to Cleveland.	"	100
From Four Mile, Cattaraugus Co., N. Y., to Buffalo..........	(length)	70
From Carbon Centre, Butler Co., Pa., to Pittsburgh....................	(length)	60

A total, including the duplicate lines, of about 1,330 miles. The New York line consists of two 6-inch tubes for the entire distance, with a third 6-inch tube for a portion of the way, and is provided with eleven pumping stations about 28 miles apart. The transporting capacity of this line is about 28,000 barrels per day. The greatest elevation of the pipe between stations above tide-water is 2,490 feet. The Philadelphia pipe has a diameter of 6 inches with six stations; the Baltimore pipe is 5 inches in diameter without a break; the Cleveland pipe 5 inches with four stations; and the Buffalo and Pittsburgh pipes 4 inches with two stations.

The pipe is made specially, and is of wrought iron, lap-welded. It is tested to a pressure of 1,500 lbs. per square inch, the working pressure being 900 to 1,200 or even sometimes 1,500 lbs. The pipe is in lengths of 18 feet, provided at each end with coarse and sharp taper threads, nine to the inch, and the lengths are connected with long sleeve couplings, also screwed taper. The line is usually laid two or three feet below the surface of the ground, though in some places it is exposed, and at intervals bends are provided to allow for contraction and expansion. At the different pumping stations there are storage tanks of light boiler plate, usually 90 feet in diameter by 30 feet in height, the oil being pumped from the tanks at one station to those at the next, though sometimes loops are laid round the stations, and oil has thus been pumped a distance of 110 miles with one engine. The pumping engines chiefly employed are the Worthington engines, constructed at the Worthington Works in New York, and at each station there is usually a duplicate set. The characteristics of these pumps are, according to the *Engineering News*, independent plungers with exterior packing, valve boxes subdivided into small chambers, and leather-lined metallic valves with low lift and large surfaces. The engines vary in size from 200 to 800 horse-power. The pumps are so constructed that before one plunger has completed its stroke another has taken up the work. The column of oil is thus kept continuously in motion, and the violent concussions which occur when the oil column is allowed to come to rest between the strokes are avoided.

The tanks usually hold about 30,000 barrels. They are of boiler plate, roofed with wood, covered with sheet iron, the roof being usually slightly conical.

The system of issuing certificates for the crude oil stored, adopted by the National Transit Company, is as follows: When a producer has filled the tank at his well, he summons an officer of the company, who, in association with the well owner, gauges the quantity of oil, issues a voucher for the amount, less 3 per cent. to cover loss in transit, and runs the oil into the company's pipes. The oil thus received by the company is treated like a deposit in a bank, and is transferable by written order. Such order, when accepted by the company, is known as a certificate, but as dealings on the Oil Exchange are usually on the basis of 1,000 barrels, certificates are, as far as possible, made out only for this quantity. The oil is held rent free for 30 days, and at the expiration of this time a charge is made for storage. Only a limited amount of classification of the crude oil in the pipe line system is possible, and obviously the oil from a particular well loses its identity as soon as it passes into the company's pipes. The heavy oil from the Franklin and other districts, and also some of the lighter crude oils, are, therefore, transported in barrels.

The trunk line is owned by the Tidewater Pipe Company. This line, which consists of one pipe 6 inches in diameter, extends from Rixford, in the Bradford field (about eight miles, as the crow flies, southeast of the town of Bradford), in a general southeasterly direction, to Tamanend, in Schuylkill county; there the oil is transferred to tank cars, and conveyed by the Reading Railroad to Chester, a town fifteen miles from Philadelphia, or to Bayonne, New Jersey. From

Rixford to Tamanend is a distance of about 170 miles, and in this distance there are five pumping stations. Instead of the stations being placed, as they are on the National Transit Company's lines, at pretty regular distances of 25 or 30 miles apart, they are separated by intervals corresponding in some measure with the incline, the greatest distance being 55 miles, and the shortest 24 miles. By the use of loop lines round the stations, the oil is, however, frequently pumped, in hot weather, when it is most fluid, a distance of eighty miles. The working pressure is 1,000 lbs. per square inch, and the capacity of the line 10,000 barrels per twenty-four hours. At this high pressure leaks occasionally occur, and workmen have had their hands cut to the bone by the fine stream of oil issuing from some minute orifice when engaged in stopping the leaks.

A very interesting feature of the pipe-line system of transportation is the arrangement adopted for cleaning the pipes, and removing obstructions caused by sediment. The apparatus used is termed a "go devil," a name which, as we have seen, is also applied to the iron weight which serves to explode the torpedo. The pipe-cleaning "go-devil" consists in many cases of a brush of steel wire of conical form, fitted, at the base or rear end of the cone, with a leather valve in four sections, strengthened with brass plates and also furnished with long steel wire guides. This instrument is impelled by the stream of oil, and travels at the rate of about three miles an hour. Its progress can be traced by the scraping sound which it makes, and it is followed from one pumping station to another by relays of men on foot. It must never be allowed to get out of hearing, otherwise, in the event of its progress being arrested by an obstruction, it may be necessary to take up a considerable length of piping to ascertain its position.

We have now to consider the method of transportation of crude petroleum in the Caucasus. Up to the year 1876, the transport of oil in this locality took place in large barrels, which were conveyed from the wells to the refineries in primitive two-wheeled Persian carts, termed "arbas," one barrel being placed in the body of the vehicle, and another slung between the lofty wheels. Thousands of these carts were at one time in use, and it is stated that as much as £100,000 per annum has been paid to the carters for this method of transportation. Messrs. Nobel Brothers were the first to substitute a pipe line for the "arba" system of conveyance, and their example being soon followed, there are now seven or more pipes connecting the Balakhani-Saboontchi oil field with the Baku refineries some eight or nine miles distant. Of these lines, Messrs. Nobel own the two largest, of the respective diameters of 6 inches and 5 inches. Messrs. Nobel's first line is stated to have cost £10,000, and the average cost of a 6 inch line is stated by Mr. Marvin to be about 8,000 roubles per verst. Messrs. Nobel's experiment was attended by the same difficulties that were experienced in laying the first pipe lines in the United States, the native carters strenuously opposing the interference with their business, and the greater lawlessness prevailing in the Caucasus, and the ferocity of the opponents, rendering the task of protecting the line one of no small difficulty and danger. It was, in fact, found necessary to erect a series of watch-houses along the route, in which armed men were stationed. The capacity of the seven pipe lines is estimated at more than 700,000,000 gallons per annum. A considerable quantity of crude oil is also transported in tank wagons by rail.

The ozokerite of Galicia is obtained by sinking shafts from 130 feet to 260 feet in depth, to the beds or pockets in which the material occurs, and then driving tunnels. The shafts generally pass through about 25 feet to 30 feet of gravel or boulders, and then through blue loam and plastic clay. In this clay, usually at a depth of 140 feet to 150 feet from the surface of the ground, the ozokerite, or earth wax, is found in layers of from 1 foot to 3 feet in thickness, the purest being of a honey-yellow color, and of the hardness of beeswax. Much of the ozokerite is, however, in small pieces, and is obtained in admixture with earthy matter, from which it is separated by fusion.

Chapter III.

The third division of our subject relates to the processes adopted for the manufacture and distribution of the various commercial products, as well as to the methods employed for ascertaining the quality of these products and their suitability for the purposes to which they are to be applied.

Petroleum, as we have seen, consists of a mixture of hydrocarbons of varying volatility, and the first operation performed upon the crude oil consists in the partial separation of these hydrocarbons by a process of fractional distillation. Before proceeding to describe the apparatus and process, however, it may be well to mention that some of the heavier crude oils are used for lubricating purposes, either in the state in which they are obtained from the wells, or after their density has been increased by the evaporation, at a comparatively low temperature, of a portion of the more easily volatilized hydrocarbons present. Such oils, called "natural oils" or "reduced oils," are found to be of greater lubricating value than distilled oils of similar density. They are often purified by filtration through animal charcoal.

In the manufacture by this process of the best oils for the lubrication of steam engine cylinders, a product of less density is obtained, which, after being filtered through animal charcoal, and subsequently deprived of fluorescence (or "debloomed," as it is technically termed) by exposure to the sun, is known as "neutral oil." The product is employed for oiling wool, and sometimes as a spindle oil in silk mills, where a specially fine oil is required. The term "amber oil" is commonly applied to an oil made similarly to cylinder oil, but of less density. This oil, which is red rather than amber in color, is purified simply by filtration through animal charcoal, and therefore without the use of acid. It is to some extent used as an engine oil in the United States, and as a lubricant for printing presses.

The first attempts to refine petroleum commercially in the United States were probably made in the year 1854, when a still having a capacity of five barrels was erected in Pittsburgh, for refining the small quantity of crude oil obtained in the neighborhood ; but the scarcity of the raw material prevented for some time any important development of the industry. Up to the year 1862, the stills commonly employed had a cylindrical cast-iron body with boiler-plate bottom and cast-iron dome with goose neck bolted on. The capacity of these stills was usually about twenty-five barrels, and the charge was distilled to dryness. At the present time the process of distillation is divided into two distinct parts. In the first part of the process stills of two forms are usually employed. These forms are respectively the plain cylindrical still, and what is known as the "cheese-box" still. The former consists of a cylinder of boiler plate,* 30 feet in length by 12 feet 6 inches in diameter, furnished with a dome 3 feet in diameter from which passes a vapor pipe 15 inches in diameter. This still is set horizontally in a furnace of brick-work, usually so constructed that the upper part of the still is exposed to the air. The "cheese-box" still has a body and dome-shaped top of boiler-plate, and a double curved bottom of steel plate. It is 30 feet in diameter and 9 feet in height, and is set on a series of brick arches. The vapor is passed from the still through three pipes into a vapor chest, and thence through forty 3-inch pipes. Wet steam is usually introduced into the exit pipes of these stills so that it may mingle with the vapor.

The working charge of the cylindrical stills is about 600 barrels and of the cheese

* The lower half of the cylinder is generally of steel.

box stills about double that quantity. Connected with the stills are the condensers. These were formerly copper worms, but now consist of iron pipes, usually straight, passing through tanks of cold water. A modern condensing arrangement may be described as consisting of a series of forty separate 3-inch pipes, the vapor passing in at one end, and the condensed oil flowing out at the other end of each pipe. In some cases, methods of fractional condensation, more or less complicated, designed to effect the more complete separation of the commercial products, are adopted.

In the second part of the process of distillation, cylindrical stills, which are commonly of steel, and hold about 260 barrels, are employed.

The crude petroleum on reaching the works is placed in storage tanks, and is thence pumped into the stills. A fire having been lighted in the furnace beneath the still the temperature of the oil is gradually raised, and the more volatile constituents distilled off. The crude naphtha thus obtained is sometimes collected in two fractions. Sufficient of the lighter hydrocarbons having been separated to give the next commercial product (which is the burning oil of commerce) the required flashing point or fire test, the distillation is continued until a point is reached at which the operation must be arrested, otherwise the burning oil would have too high a specific gravity. The product of burning oil is frequently divided into two or more fractions. In practice, the termination of the collection of the naphtha and the burning oil respectively takes place when the distillate issuing from the condensers reaches a specified density. The percentage of these two commercial products varies according to the character of the crude oil, and the method of distillation; the average yield may, however, be stated to be about 12 per cent. of naphtha, and 75 per cent of burning oil (110° fire test). Of the higher class of burning oil known as "water-white oil," only from 12 to 20 per cent is obtained. The fluid residue in the still, known as residuum, and amounting to about 6 per cent., having been run off, there remains a quantity of coke, which represents from 1 per cent. to 1½ per cent. of the original charge. The time occupied in working a charge is from three to four days. This separation of the naphtha and burning oil constitutes the first part of the process of distilling the crude petroleum. The second part of the process, which is usually conducted at other works, consists in distilling the residuum to dryness, and obtaining lubricating oils and solid paraffine. The residuum, which has an average specific gravity of about 19° B. (equal to .942) is, when practicable, conveyed from one refinery to the other in bulk barges. The time occupied in the working of the charge is about thirty hours. The distilled products are collected in several fluid fractions, holding the solid hydrocarbons in solution. The coke which remains in the still at the end of the process amounts to about 12 per cent.

Superheated steam is often passed into

the stills during the distillation. In the production of some of the special grades of "reduced oils," vacuum stills are employed. The crude naphtha is redistilled by steam heat in cylindrical stills holding 500 barrels, and is sometimes separated into the following commercial products, the more volatile of which are colorless:

No.	Density.	Name.	Use.
1.	90°B ..	Rhigolene or cymogene.	For surgical purposes.
2.	88°/86°B ..	Gasoline.	For air-gas machines.
3.	76°B ..	Boulevard gas fluid.	For street naphtha lamps.
4.	73°/68°B ..	Prime city naphtha (benzoline.)	For "Sponge Lamps," &c.
5	62°B ..	Benzine.	For oil-cloth and varnish making.

The time occupied in working the charge is about 48 hours. The percentage of these products varies, but as a rule amounts to about 25 per cent. of the first three collectively, rather more than 25 per cent. of the 4th and about 40 per cent. of the 5th.

Such is an outline of the method of distilling crude petroleum in the United

States. There are, however, many detail variations, the precise conditions under which the operation is conducted being by no means uniform. In all cases, however, the principal object in view is to obtain the largest yield of burning oil, lubricating oil and paraffine, consistent with these products being of satisfactory quality.

The next step in the process of refining consists in a treatment of the distillate with sulphuric acid. This operation is conducted in tall cylindrical wrought iron tanks, 40 feet or more in height by 20 feet or more in diameter, sometimes lead-lined, holding from 1,200 to 1,800 barrels, and termed agitators. The oil having been pumped into the tank, a blast of air under a pressure of 5 to 7 pounds per square inch is introduced through a pipe at the base of the tank, and the oil thus brought into a condition of active agitation. Oil of vitriol is then forced to the top of the tank by air pressure, and is gradually " showered " into the petroleum through a perforated leaden pipe, in the proportion of about six pounds of acid to one barrel of oil. After the agitation has been continued for a sufficient length of time to bring the acid thoroughly into contact with the oil, the air blast is shut off, and the tarry acid (termed acid tar or sludge acid) having been allowed to settle to the bottom of the tank, is drawn off. The acid is occasionally recovered and concentrated for further use. The oil is then agitated with water, next with a solution of caustic soda, to complete the removal of the acid, and finally with water again, to which sometimes a little ammonia is added. The oil is then run into a shallow rectangular iron tank, usually provided with a steam coil for raising the temperature in cold weather, where the water which it contains settles out, and the oil becomes bright. In connection with this tank there is an arrangement for "spraying" the oil. This operation consists in running the oil in fine streams through small orifices in pipes placed about the tank, and its effect is to remove some of the more volatile hydrocarbons present, and thus bring the "test" of the oil up to the required point. From the settling tanks the oil passes to the barreling or canning tanks.

The treatment of the less volatile of the naphtha distillates with acid is similar to that which is applied to the oil, but mechanical agitation, by means of a vertical revolving shaft fitted with arms, is usually substituted for the air blast, as the latter would cause the evaporation of the more volatile constituents. A similar method of agitation was formerly adopted in treating the burning oil. The acid treatment is applied to the naphtha with the object of deodorizing, but in the case of the oil an improvement of color as well as of odor results.

The lubricating oil distillates are also treated with acid, but before being subjected to this process they are cooled in order to separate the solid hydrocarbons. The cooling was formerly effected somewhat rapidly, but it has now become the practice to operate upon a considerable bulk of oil, and to reduce the temperature slowly, as it is found that the paraffine is thus obtained in a more crystalline form. The cooling or chilling tanks, employed at some of the most modern works, have a capacity of 3,000 gallons, and the period occupied in the cooling is as much as twenty-six hours. The reduction of temperature is effected through the medium of a solution of magnesium chloride, brought to the required temperature by means of an ammonia refrigerating apparatus. This liquid circulates through a number of cells alternating with similar cells containing the oil. At the expiration of the period named, the semi-solid mass is removed from the cooling tank, placed in bags, and subjected to hydraulic pressure at a temperature of 40°F. To effect a further separation of the oil, the press cakes are then broken up, or melted and recrystallized, and subjected to a second pressure of about 200 pounds per square inch at a temperature of 70°. The residuum yields about 9 per cent. of paraffine by this treatment. For the production of hard and colorless paraffine wax, or of wax suitable for candle making, the paraffine scale obtained as described is purified by crystallization from petroleum spirit, or by exposing it to a temperature just sufficient to cause the fusion and draining out of the hydrocarbons of lowest melting point, and by subsequent filtration through animal charcoal. The expressed oil, which varies in specific gravity, according to the manner in which the various fractions have been separated in the process of distillation, is then subjected to an acid treatment similar to that which the burning oil undergoes, and is thus converted into finished lubricating oil.

Some lubricating oils are finished by evaporation and by filtration through animal charcoal, the best oils for the lubrication of engine cylinders passing through the latter process. Petroleum lubricating oils consist chiefly of olefines (C_nH_{2n}). The most volatile of the fractions obtained in the distillation of the petroleum residuum, having a specific gravity of .820 (42°B.) and low flashing point, contains but little paraffine, and is sold for gas-making in the condition in which it issues from the condensers.

The semi-solid mixture of uncrystalline hydrocarbons known as vaseline, is obtained by the Chesebrough Manufacturing Company, under their patent, by evaporating off the more volatile portion of a suitable kind of crude petroleum and purifying the residue by filtration through animal charcoal. The product thus obtained is a colorless or pale yellow translucent semi-solid, possessing slight fluorescence. It is freely soluble in petroleum or shale spirit, benzol, ether, chloroform, carbon disulphide and turpentine. Vaseline is a mixture of hydrocarbons of which the chemical composition chiefly ranges from $C_{16}H_{34}$ to $C_{20}H_{42}$. There is reason to believe that olefines are present, but the substance consists mainly of paraffines.

The yield of burning oil from a crude petroleum of given quality has been largely increased during recent years. This has been acccomplished by the adoption of the process known as "cracking." We have seen that the crude petroleum produced in the States of Pennsylvania and New York consists principally of the hydrocarbons known to chemists as paraffines. The researches of Thorpe and Young have demonstrated that the paraffines (C_nH_{2n+2}) when heated to temperatures above their boiling points, are converted into olefines (C_nH_{2n}), carbon being deposited, and gaseous products evolved. It is this operation of dissociation which is termed "cracking," and its employment enables the refiner to break up the hydrocarbons which are too heavy to be burned in ordinary lamps, and too fluid for use as lubricants, and convert them into hydrocarbons which may be allowed to pass into the burning oil distillate without unduly increasing its density. The process of cracking is carried out by conducting the operation of distilling the burning oil so slowly that the less volatile hydrocarbons become condensed in the upper part of the still, and fall back into the heated oil, where they are heated to temperatures above their boiling points, and become "cracked." A far larger yield of burning oil is thus obtained. The gaseous products are conducted into the still furnace, and serve as fuel. This process has been subjected to a good deal of adverse criticism, based upon the view that the chemical composition of the olefines renders them inferior to the paraffine for illuminating purposes, and that their capacity of forming substitution compounds with the acid used in refining leads to the contamination of the burning oil with sulphur products. There is no doubt good theoretical ground for this contention, and it is frequently found that the American petroleum oil of commerce, though showing no trace of the presence of acid when shaken with barium chloride solution, is blackened on heating, and during distillation gives off sulphur dioxide. It is not, however, certain that in the practical use of the oil any distinct disadvantage can clearly be traced to the action of the operation of cracking, and it is obviously to the interest of the poorer classes, who so largely use petroleum oil as a source of light and heat, that a system of manufacture which considerably increases the yield, and therefore diminishes the cost of the product, should not be hastily condemned. Moreover, it should be borne in mind that the proportion of cracked oil in the product is not usually very large, and therefore, that objections which would attach to the use of the cracked oil alone may not apply to the product as a whole. By some it is claimed that distillation of the burning oil over caustic alkali has the effect of removing the substitution products formed in the acid treatment. The burning oils chiefly manufactured in the United States are of the following grades: 110° fire test, 70° Abel test; 120° fire test, 73° Abel test; 150° fire test.

The color of the first four grades usually ranges from "Prime White" to

"Standard White" (straw color to pale yellow), while the fifth grade is "Water White" (colorless). The rules of the New York Produce Exchange provide that refined petroleum for contract purposes shall be standard white or better, with a burning test of 110° Fahrenheit, or upwards, and a specific gravity not below 44° Beaumé, United States Dispensatory Standard (not above .811 specific gravity). Formerly the bulk of the oil intended for export was refined to 110° fire test, the United Kingdom, however, taking 120° fire test oil. Since the introduction of the Abel system of testing, however, a large proportion of the oil has been refined to a test of 70° Abel for shipment to the Continent of Europe, and of 73° Abel for shipment to England. The oil of 150° fire test is considerably lower in specific gravity than the other grades (say .786 to .793). Oils are also specially refined, that is, made to stand special tests, where so required. In addition to the products enumerated, an oil of high specific gravity, and high flashing point, intermediate in character, in fact, between the ordinary burning oils and the lubricating oils, is made. This oil was originally produced by the Downer Kerosene Oil Company under the name of mineral sperm oil, for use in lighthouses, and its use is now compulsory on some of the American railroads. It is also largely used on board ship. Of this oil, as now manufactured, the crude petroleum yields about 10 per cent., the product having a specific gravity of about .829, and a fire test of about 300° F. (Flashing point, open vessel, about 270° F.; closed vessel, about 240°F.). This product is frequently termed mineral colza oil, or mineral seal oil.

The number of grades of lubricating oil manufactured are so great, and their qualities so various, that it is difficult to give any satisfactory enumeration of them. The oil varies in color from yellow to very dark red, and is strongly fluorescent.

The solid paraffine (using the term in its commercial sense) is, like the oil, a mixture of various hydrocarbons of different specific gravities, boiling points, and melting points. The paraffine scale separated from the oil of .905 specific gravity has an average melting point of about 125°F. (American test), and that from the oil of .885 specific gravity a melting point of about 117° F.

"Paraffine wax" is a white or bluish-white translucent waxy solid of lamino-crystalline structure, devoid of taste and smell. The hydrocarbons of which it is composed are characterized by chemical indifference; hence the name (*parum affinis.*) The specific gravity, melting point, and boiling point of the material vary with its composition. At a temperature below its melting point paraffine wax becomes plastic, a characteristic which is of such practical inconvenience when the substance is used as candles, that it is the practice in candle making to add a small quantity of stearic acid, which to some extent diminishes the tendency of the candle to bend in a warm room.

When two pieces of paraffine wax are struck together, a sharp metallic sound is emitted, especially if the melting point of the specimen be high. Exposed for some time under a slight pressure to a temperature below its melting point, paraffine wax undergoes a molecular change and becomes transparent; but upon a change of temperature, or upon being struck, the original translucent appearance returns.

Paraffine wax is freely soluble in petroleum or shale oil and spirit, in ether, in benzol, and in essential oils. It is sparingly soluble in hot absolute alcohol, but separates on cooling. It is insoluble in rectified spirit and in water.

When boiled with concentrated nitric acid, paraffine is oxidized with the formation of succinic acid, and a small quantity of butyric acid. Paraffine is also oxidized when heated with potassium permanganate and sulphuric acid. At a high temperature it is slowly attacked by concentrated sulphuric acid, and chlorine passed into melted paraffine attacks it slowly. When heated with sulphur, paraffine is decomposed, sulphuretted hydrogen being evolved and carbon deposited.

A considerable quantity of crude petroleum is exported from the United States to France, to be refined there, the French duty on the refined oil encouraging the home industry. The rules of the New York Produce Exchange provide that crude petroleum shall be understood to be pure natural oil, neither steamed nor treated, free from water, sediment or any adulteration, and of the gravity of 43° to 48° Beaumé (.816 to .794 sp. gr.).

Crude naphtha and residuum are also exported in comparatively small quantities. The naphtha is required to be water-white and sweet, and of gravity from 68° to 73° Beaumé, while the residuum is to be understood to be the refuse from the distillation of crude petroleum, free from coke and water, and from any foreign impurities, and of gravity from 16° to 21° Beaumé (.96 to .93 sp. gr.).

Natural and reduced lubricating oils

(West Virginia, &c.) are sold under contract rules, fixing the limit of setting point, the latter oils being divided into two grades termed respectively summer reduced oil and winter reduced oil.

Some of the refineries in the United States are of great size. Thus the works at Bayonne, New Jersey, owned by the Standard Oil Company, in whose hands the greater part of the refining trade is concentrated, covers about 67 acres, and is capable of turning out from 10,000 to 12,000 barrels of refined oil per day. At some of the most modern works the plant is for the most part uncovered by roofing. Precautions are, however, taken against the spread of fire, water sprinklers and steam jets being fitted to the storage tanks, and hydrants being provided. At all large refineries there is a well-drilled fire staff. At the Bayonne works the fire brigade is drilled twice a month, and four fire hoses can be brought into action upon a tank in 30 seconds, 1 minute 10 seconds, 1 minute twenty seconds and 1 minute 30 seconds respectively from the blowing of the alarm whistle, three of the hoses being brought some distance. At the works of the Pratt Manufacturing Company there is a fire wall which prevented the spread of fire from a burning tank some time ago, although, according to the evidence, the fire burned with great fierceness until all of the oil in the tank had been consumed, and the wind was blowing towards the wall. It is considered that a properly protective fire wall should be five feet higher than the tank and about ten feet distant from it.

The export of the oil has, with the exception of one shipment, hitherto taken place exclusively in barrels of the size mentioned, or in tin cans of rectangular form, holding five American (or four Imperial) gallons, which are packed in twos in wooden cases. The manufacture of the barrels, cans and cases is, as may be supposed, a very important business. The barrel works of the Standard Oil Company at Bayonne are capable of turning out 10,000 to 12,-

000 barrels per day, and the operation of barrel making at these works is an interesting one to witness. The oak staves are purchased ready jointed and seasoned, in Michigan, and the barrel heads are brought to the Bayonne works ready glued up. The first operation in barrel making at these works consists in fitting the necessary number of staves together in a thick wrought-iron ring encircling 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 toward the bulge of the barrel by means of an ingenious 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 12 pounds, and the total length of iron required for a set is 443½ inches, so that putting the out-turn of finished barrels from this 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 3 barrels being required. The glue solution is poured into the barrels ot, the barrel 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 this 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. Old 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 2,000 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.

The barrels are filled from a rack provided with a series of pipes connected with a barreling tank. Each pipe has at its exit end a float connected with a valve, which shuts off the oil when the barrel has been filled to within one gallon of its contents. The shives with which the barrels are closed are of wood and are put in with glue. A package which remains perfectly tight and free from leakage as long as it is handled carefully, and the continuous skin of glue remains intact, is thus produced.

The can of petroleum is a package standing a good deal of rough usage. The empty can is so strong, notwithstanding that the tin plate from which it is made is thin, that a full-sized man may stand upon it without crushing it. Cans are used exclusively in the shipment of oil to warm climates, as the barrel, though less expensive per gallon of oil, is liable to become leaky when subjected to a high temperature.

Within the past few months two vessels, the Crusader and the Andromeda, have been fitted with tanks for the conveyance of the refined burning oil in bulk. The former vessel is provided with an arrangement of tanks patented by Mr. L. V. Sone, of New York. The patent specification contains twelve claims, but the most important feature of the system appears to be the provision of auxiliary tanks above the level of the storage tanks and in communication with them. The storage tanks can thus always be kept quite full of oil, the auxiliary tanks serving to hold the surplus when the contents of the storage tanks become expanded by heat, and supplying the deficiency when contraction takes place. The tanks with which the Crusader is fitted are of boiler plate, cylindrical in form, of various sizes, but of the average capacity of 125 barrels. There are 45 tanks, and the total carrying capacity of the vessel is, therefore, about 5,500 barrels. All the tanks are connected with a steam pump on deck, by means of which they can be charged or discharged in about ten hours.

About a month after the Crusader arrived in London, the Andromeda reached Bremen with a cargo of 684,641 American gallons of petroleum oil in bulk. This vessel contains 72 tanks, which, instead of being cylindrical, are principally rectangular. Expansion tanks similar to the auxiliary tanks of the Crusader are provided.

The only special feature in the process of refining petroleum in Canada is the treatment of the burning oil distillate with a solution of litharge and caustic soda for the purpose of removing sulphur. Notwithstanding the adoption of this process, the refined petroleum, or burning oil, has not, however, always been free from this impurity. In 1876 a sample of Canadian petroleum oil produced a deposit of a bluish-black color on the chimney of the lamp in which it was burned. On examining the deposit small beads of liquid were found to be deposited where the glass was very hot, and a piece of litmus paper applied to these beads was reddened and then charred. On washing out the chimney with water, and adding to the liquid a solution of barium chloride, a copious precipitate was produced. It was evident that the liquid condensed on the glass was sulphuric acid, and on burning a weighed quantity of the oil, and collecting the products of combustion, sulphur was found to be present in the oil to the extent of 116 grains per gallon. Another sample of Canadian oil, used in a greenhouse to the detriment of the plants, contained 119 grains of sulphur to the gallon.

We now pass to the consideration of the method of refining and transporting petroleum oil adopted in Russia. Most of the Caucasian refineries are situated in the Tchorni Gorod or Black Town of Baku, on the shores of the Caspian. There may be seen refineries of all sizes, the smallest being constructed and managed in a primitive fashion. The largest works are those of the Nobel Company, an organization occupying in relation to the refining of Russian petroleum, a position analogous to that which the Standard Oil company holds in regard to the American refining trade. The works of the Nobel Company cover from 78 to 80 acres, and the dwellings of the employes another 40 acres. In regard to the substantial character of the buildings and completeness of the arrangements, the refinery is equal to any in the United States. The only essential respect in which the plant differs from that described, in treating of the American refineries, is in the adoption of a process of continuous distillation, the stills, each of the capacity of 4,400 gallons, being arranged in groups or series of not more than twenty-five, and a stream of oil continuously flowing through the entire number. The crude oil entering the first still parts with its most volatile constituents, passing into the next still, has rather less volatile hydrocarbons distilled from it, and finally flows from the last still in the condition of residuum, which in Russia is termed *astatki* or *masut*. The several stills are maintained at temperatures corresponding with the boiling points of the products to be volatilized. Attempts have been made to carry on a system of continuous distillation of petroleum in America, and an apparatus for the purpose was patented in the United States by Stombs and Brace, of Newport, Kentucky, April 10, 1860 (Patent No. 27,842), but the process has never been practically employed in that country. Mr. Ludwig Nobel has said that the method of continuous distillation adopted in his works was specially suited to Baku petroleum, the quantity of burning oil separated being comparatively small, and the residuum, therefore, not very much less fluid than the crude oil. The fuel used under all the stills in Baku is petroleum residuum or *astatki*. At many of the smaller works, the liquid fuel is simply allowed to flow on the hearth of the furnace, and in thus using it a very large amount of dense black smoke is evolved;

but in the larger and better conducted refineries, arrangements are adopted for burning the fuel with a proper admixture of air, and smokeless combustion is thus obtained. At the Nobel refinery the two most volatile distilled products are of specific gravity .754 and .787 respectively, while the kerosene (burning oil) has a specific gravity of .820 to .822. The more volatile products are largely burned as fuel, as there is little demand for them, and in fact a considerable quantity is burned to waste in order to get rid of it.

At the Nobel works the kerosene distillate is pumped into lead lined agitators of the capacity of 57,000 gallons, where, in the manner already described, it is treated with about $1\frac{1}{2}$ per cent. of sulphuric acid, washed with sea water (fresh water being very scarce in Baku), treated with caustic soda solution, and washed again. The oil then passes to the settling tanks, and is afterward stored in large tanks, one of which holds 1,500,000 gallons. The whole process of treatment occupies 15 to 16 hours. The sulphuric acid is made in a neighboring factory from sulphur imported from Daghestan. The oil is almost superfine white in color, and has an average flashing point of about 32°C. (Abel test.) Of such product the crude oil yields, on an average, only about 27 per cent., and of oil quite free from color, or water-white, and having a flashing point of 50° C., only about 22 per cent. can be obtained. At Baku, the Caspian Company make three grades of burning oil of the respective specific gravities and flashing points of (1) ·815—30° C.; (2) ·820—25° C., (3) ·821/·822—22° C. Of the first quality, the crude oil yielded 20 per cent., of the second 33 per cent., and of the third 38 per cent. The yield of burning oil from Baku petroleum is therefore comparatively very small, and to this the fact that the oil, although of so high a specific gravity, burns well is no doubt partly due, since the product is necessarily very homogeneous, the most volatile hydrocarbons present not differing very greatly in boiling point from the least volatile present. Besides this, however, the hydrocarbons of which the Baku oil is composed possess apparently greater power of ascending the wick of the lamp by capillary attraction than is found in ordinary American oils. Taking ordinary petroleum lamp wicks of two different qualities, and using them as siphons, in a given time the following quantities of the oils enumerated were removed by capillary attraction from a vessel into which the wicks dipped, the conditions of the test being the same in each case ;

	Best Wick. grs.		Inferior Wick. grs.
American oil (" water-white ").	205.0	..	104.2
Russian oil	202.6	..	94.2
American (ordinary)..........	146.0	..	69.7

Russian oil does not burn equally well in all the forms of lamps which have been constructed for use with the American product, but as the result of a large amount of comparative photometrical testing of the two classes of oils burning in lamps of various construction during the past two or three years, taking the lamps now in common use as a whole, the Russian oil, though giving less light than good ordinary American oil at the commencement of the burning, when the lamp is full of oil and freshly trimmed, affords a flame of somewhat greater permanence, the light emitted in the burning of the American oil diminishing to a greater extent as the level of the oil in the reservoir becomes depressed, the difference being, doubtless, due to the greater power which the Russian oil has of ascending the wick. In the use of Russian oil, however, it is essential that the air passages in the burner should be quite free from obstruction by dirt, otherwise the flame will receive an insufficient supply of oxygen, will be of comparatively feeble luminosity, and will be liable to smoke. As a rule the Russian oil burns better in a flat-wick burner than in a round-wick burner, but burners of the latter class are now being constructed in which it yields a good flame.

The astatki, or residuum, as it flows from the kerosene still, has a specific gravity of about .903, and is chiefly used as fuel. A portion of it is, however, converted into lubricating oil, and a smaller portion into an oil or oils similar to the "mineral sperm oil" obtained from American petroleum. Of the lubricating oil the residuum yields about 30 per cent., and of a product similar to the American "Mineral Colza" oil, about 12 per cent. Messrs. Ragosine were the first to introduce an oil of this character made from Russian petroleum. This oil, which is frequently termed "pyronaphtha," as now imported into England has a specific gravity of about .865, a fire test of 265° F., and a flashing point of about 230° F. open test, or 205° F. closed test. This oil, like the similar American product, has not hitherto been much used for domestic purposes, as the lamps intended to burn it did not give a satisfactory light. Lamps are now, however, being introduced which burn it well.

The lubricating oil distillates obtained from Baku petroleum differ from the American products in containing little or no solid hydrocarbons, the greatest quantity obtainable amounting only to a quarter of one per cent. of the crude oil. In the island of Tcheleken there is, however, petroleum to be obtained which yields as much as 6 per cent. of paraffine.

This absence of solid hydrocarbons deprives the Baku refiner of a source of profit possessed by the American refiner, but on the other hand enables him to make cheaply a lubricating oil which bears exposure to a very low temperature without becoming solidified or even depositing any paraffine. Professor Dewar has suggested that the products of Baku petroleum may be distinguished from those of American petroleum by exposing them to a temperature sufficiently low to cause the separation of the solid hydrocarbons which are held in solution at common temperatures.

The lubricating oils manufactured by Messrs. Ragosine include the following:

Extra heavy cylinder oil, sp. gr. .920.
Cylinder and valve oil, sp. gr. .912/.915.
Engine machinery oil, sp. gr. .905/.907.

Dark cylinder oil, sp. gr. .918/.920.

Russian lubricating oils are characterized by the possession of great viscosity in relation to specific gravity, but the viscosity of the Russian oils is more affected by a rise in temperature, a feature which is undoubtedly a disadvantage, but in the case of both classes of oils the greater the viscosity the greater the diminution in viscosity as the temperature is raised.

When paraffines are heated to temperatures above their boiling points dissociation occurs and olefines are produced:

$$C_{20}H_{42} = C_5H_{12} + C_{15}H_{30} = C_7H_{16} + C_{13}H_{26}, \text{ \&c.}$$

At a very high temperature hydrocarbons containing still less hydrogen are produced. This well known fact has been taken advantage of by Mr. Nobel to manufacture from Russian petroleum residuum, or astatki, benzine, naphthalene and anthracene. The process employed consists in breaking up the astatki on the highly heated floor of a cupola regenerative furnace. The first destructive dis-

VISCOSITIES OF RUSSIAN AND AMERICAN OILS.

Temperature. Fahr.	1	2	3	4	5	6	7
50°	712½	145	425	1030	2040	2520	—
60	540	105	295½	680	1235	1980	—
70	405	90	225	485	820	1320	—
80	326	73	171	375	580	900	—
90	260	63½	136	262	426	640	—
100	213½	54	111	200	315	440	1015
110	169	50	89½	153	226	335	739½
120	147	47	78	126	174	245	531
130	123½	44¾	63½	101	135½	185	398½
140	105½	41	58	82	116	145	317½
150	95½	37½	52	70½	95	115	250
160	85	—	46	63½	83½	93½	200
170	76	—	—	58	70½	77½	161
180	69	—	—	52½	61½	67½	134½
190	64½	—	—	47	56½	61	115½
200	58½	—	—	42	48½	54	99¼
210	54	—	—	40	—	—	85
220	50	—	—	38	—	—	77
230	47¼	—	—	—	—	—	70½
240	45½	—	—	—	—	—	64½
250	43¼	—	—	—	—	—	59¼
260	—	—	—	—	—	—	54
270	—	—	—	—	—	—	48½
280	—	—	—	—	—	—	46½
290	—	—	—	—	—	—	44¼
300	—	—	—	—	—	—	42⅗

1. Refined rape oil.
2. American mineral oil, sp. gr. .855
3. " " " .913
4. " " " .923
5. Russian " " .909
6. " " " .915
7. " " " .884*

* Semi-solid at common temperatures.

tillation thus effected is stated to yield from 30 to 40 per cent. of tar containing from 15 to 17 per cent. of 50 per cent. benzol. By a second destructive distillation of the heavy oils remaining after the separation of the benzol, 70 per cent. of tar is obtained, containing from 7 to 10 per cent. of 5 per cent. benzol, 16 per cent. of naphthalene, 2 to 3 per cent. of "dry green grease" (or 30 per cent. anthracene), and 24 per cent of pitch. There is also obtained in the process 75 to 100 cubic feet, per c. f. of astatki, of gas having an illuminating power described as five times that of coal-gas.

We have already seen that American petroleum oil is principally transported in barrels and cases. As, however, suitable timber for barrel making is scarce in Russia, Mr. Nobel found it necessary to devise some other method of distributing the oil, and great credit attaches to him for the admirable system of bulk transportation he has organized. The oil is pumped from the refineries at Baku into tank steamers on the Caspian sea.

These steamers, which were constructed at Motala, in Sweden, are about 250 feet in length by 28 feet beam, and have a draft of water when loaded of 10 to 12 feet. The whole of the forward portion of the vessel forms one great tank, the engines and boilers are amidships, and two cylindrical tanks are placed aft. The oscillation of the oil in the forward tank is prevented by bulkheads. The tanks hold collectively 225,000 gallons (5,500 barrels), and can be filled in 4½ hours. The fuel used for steam generation is petroleum residuum, 29 tons being consumed on the voyage from Baku to the mouth of the Volga, a distance of about 460 miles. The engines are of 120 horse-power nominal, and the mean speed of the vessels 10 knots per hour. Several tank steamers have recently been constructed for the shipment of petroleum oil in bulk from Batoum to ports on the Black sea, the Baltic and elsewhere.

These vessels are built on the principle of the boilers and engines being placed in the stern, and the oil storage tanks forward. Two bulkheads with water between prevent the possibility of any oil finding its way into the boiler space. The steamers are constructed throughout of Bessemer steel, and have been favorably classed at Lloyds.

In the tank steamers described, the oil is conveyed to mouth of the Volga, where, in consequence of the water being shallow, it is transferred to tank barges, in which it is carried to Tsaritsin, an important storage center on the Volga, 364 miles from the point at which the steamers discharge. At Tsaritsin the oil is pumped into tank wagons (similar to those used in America) on the Tsaritsin-Griazi railway, and thus finds its way to a large number of storage centers throughout Russia. From these centers the oil is distributed in barrels which can easily be returned to be refilled.

A considerable quantity of the oil is also conveyed from Baku to Batoum, on the Black Sea, over the Trans-Caucasian railway, in tank wagons, a distance of 560 miles, but the carrying capacity of this line is only about one million and a half of barrels per annum, in consequence of its being carried over a pass (the Suram Pass) 3,000 feet above sea level, where the gradient is in places as much as 1 in 22. It is contemplated to largely increase the carrying capacity of the line by tunneling the pass, and it has also been proposed to lay a pipe line from Baku to Batoum. In the meantime, however, arrangements are being completed to fully utilize the existing facilities by shipping the oil from Batoum in tank steamers, and, as the Volga navigation is closed in winter, there is no doubt that the Trans Caucasian route will be largely made use of.

In the following table the varied yield of commercial products is shown :

	Naphtha.	Burning Oil.	Lubricat'g Oil.
	%	%	%
Persia..................(sp. gr. .777)	1.4	87.5	——
East India................(" .821)	3.6	62.5 (sp. gr. .800)	32.0
Kyouk Phyou, Burmah....(" .818)	none	55.7 (" .800)	31.3
Minbyin, Burmah..........(" .866)	none	15.1 (" .810)	65.9
Western Barangah, Burmah(" .888)	none	7.2 (" .815)	89.3
" " (" .835)	2.5	66.1 (" .810)	27.3
Assam......................(" .933)	none	none	94.2
India.......................(" .935)	none	20.0 (sp. gr. .805)	60.0
Russia.....................(" .836)	20.0	40.0	37.5
" ....(" .942)	none	none	90.0
Hanover....................(" .843)	10.0	60.0 (sp. gr. .812)	27.5
South America............(" .852)	none	50.0 (" .808)	45.0
" ....(" .900)	none	none	91.5
New Zealand..............(" .828)	none	60.0 (sp. gr. .808)	38.0
Italy........................(" .787)	45.0	45.0 (" .806)	5.0
United States, Wyoming...(" .911)	2.5	27.5	57.5
" " ...(" .945)	none	10.0	72.5

We now enter upon the consideration of the process of manufacturing the various commercial products from shale. True shales, when heated to redness in a closed vessel, do not cake, so that the soft and black residue, after all the volatile matter has been driven off, retains the original form of the fragments. The proportion of mineral matter in the shale is usually 73 per cent., but is occasionally as much as 80 per cent.

In the earlier days of the industry two methods of distillation, one intermittent and the other continuous, were employed. In the former system, which was that first adopted, the shale, previously broken into fragments of suitable size, was heated in cast-iron retorts, similar to those employed in coal-gas manufacture, the retorts being discharged and recharged when the whole of the volatilizable matters had been driven off. The latter system was conducted in a cylindrical or oval retort of cast iron, about 2 feet in diameter by 8 feet or 10 feet in length, set vertically in a furnace.

In this vessel the shale, previously broken by machinery, was exposed to a dull red heat for twelve to twenty hours; a jet of steam being introduced at the bottom of the retort, and the products conducted from the top. The steam was employed to sweep away the products as formed, and prevent their dissociation by over-heating. The furnace was so constructed that the lower part of the retort received the greatest heat, and from time to time a portion of the exhausted shale was removed from the bottom of the retort, which was sealed with water, and a corresponding quantity of fresh shale was introduced at the top; the process being thus continuous. By this process about 33 gallons of crude oil and 80 gallons of ammoniacal liquor per ton of shale were obtained, the latter being large in volume and of low strength, in consequence of the condensation of the steam employed.

The method of distillation devised by Mr. Henderson differs principally from the intermittent system already described, in the retorts being vertical, and in the provision of an arrangement for employing as fuel the spent shale, which sometimes contains as much as 12 to 14 per cent. of carbon. The retorts are, in this system, placed in an oven above the furnace. They are about 15 feet in length, and hold about 18 cwt. of shale. The bottom of the retort consists of a door, which can be opened so as to allow the spent shale to drop into a combustion chamber beneath the oven. The material, as it is discharged from the retort, is black, but it soon becomes incandescent, and aided by the incondensable gaseous products of distillation (occasionally also by the addition of a small quantity of coal), it constitutes a valuable fuel. In this system of distillation the upper part of the retort is the most highly heated, and the products are re moved from the bottom, a stream of superheated steam being passed in at the top. There are four retorts in each oven, and each retort is charged once in sixteen hours; but the charging takes place in rotation at intervals of four or five hours, so that a regular supply of fuel is furnished to the combustion chamber below.

Although, in the meantime, the older method of intermittent distillation had been improved, it is generally admitted that the introduction of the Henderson retort resulted in an increased yield of paraffine.

The retort invented by Messrs. William Young and George Beilby, the Pentland pattern of which is now also largely in use, is composite, the upper part being of iron, and the lower of fire brick. In this apparatus the shale is exposed to a comparatively low temperature while in the iron portion—the oil products being thus driven off without risk of their being overheated—and then passing downwards into the more highly heated fire brick portion, in consequence of the withdrawal of a portion of the spent material, is subjected to a heat suitable for the formation of the ammonia. Steam is passed into the retort at the base. The retorts are set in groups of four, and usually are heated through the medium of a gas producer instead of by an ordinary open furnace. By this method of distillation the yield of paraffine is increased, while the gain of sulphate of ammonia is stated to be no less than 14 lbs. per ton of shale.

The oil vapors are condensed by being passed through a series of 70 to 100 vertical 4 inch pipes.

Crude shale oil is of a dark green color, and has a specific gravity of .865 and upwards. The first step in the process of refining consists in the distillation of the oil to dryness in cast-iron pot-shaped stills, into which steam, often superheated, is passed, the product being condensed in the manner already described when treating of the distillation of petroleum. The oil having been treated with sulphuric acid and caustic soda, these processes being termed "washing," is next subjected to fractional distillation in cylindrical boiler-plate stills of a capacity of 4,000 to 5,000 gallons. Steam is introduced into the stills after the more volatile products have passed off. The first product obtained is crude naphtha, and at a higher temperature the burning oil distillate issues from the condensers and is collected separately. The heavy oil which remains is distilled in cast-iron vessels. The burning oil distillate thus produced is subjected to acid and alkali treatment, and undergoes a second fractional distillation, an additional quantity of naphtha being separated, and some heavy oil remaining in the still. The burning oil distillate then passes through a third chemical treatment and distillation, and is, in some cases, finally agitated with acid and alkali, and thoroughly washed. The crude naphtha receives the usual chemical treatment, and is separated by fractional distillation into commercial products. From the heavy oil, lubricating oils are manufactured, and paraffine separated and purified substantially as in the case of the similar petroleum products. It was formerly the practice to crystallize the paraffine rapidly, by bringing the heavy oil into contact with the surface of a revolving drum through which cooled calcium chloride solution was made to circulate, the paraffine adhering to the cool surface being scraped off and removed. Mr. Henderson, and subsequently Mr. Beilby, however, patented systems of slow cooling in considerable bulk, as adopted in petroleum refineries in the United States. Various other systems have been adopted at Addiewell and Bathgate for the slow cooling of the oil containing paraffine, it being now generally recognized that the production of large crystals of paraffine resulting from this method of working facilitates the expression of the oil, and effects a saving in press cloths. From the gaseous products passing away through the condensers crude gasoline is obtained, by a process of scrubbing with heavy oil in a coke tower, or by subjecting the gas to pressure. The crude gasoline passes through a similar process of purification to that which the crude naphtha undergoes.

From the intermediate oils, burning oils of high specific gravity and flashing points are obtained.

Without going minutely into details of manufacture, which are by no means the same at all works, an intelligible outline description of the comparatively lengthy and complicated process by which the various shale products are obtained is here given. In practice the various similar distillates obtained in the intermediate operations are mixed together, the process, as a whole, having for its object to classify the various hydrocarbons by successive fractional distillations. It should be stated that the crude shale oil yield, in addition to the products enumerated, acid and basic bodies.

At the works of Young's Paraffine Light and Mineral Oil Company, the following is the average yield of the various commercial products from the crude shale oil:—

	Per cent.
Gasoline	0.25
Naphtha—sp. gr. .700 to .760	5.75
Burning oils :—	
No. 1, sp. gr. .802 to .804, F.P. 110° (Abel test)	
No. 2, sp. gr. .810 to .812, F.P. 100° (Abel test)	37.00
Crystal (No. 1, chem. treated)	
Lighthouse oil, sp. gr. .810 to .820 F.P. 140° (Abel test)	
Lubricating oils of various specific gravities	14.50
Paraffine (solid)	11.00
Loss	30.50
	100.00

The percentages given are only approximate, and are often purposely varied by alterations of the processes to suit the requirements of the markets. The loss is no doubt frequently considerably smaller than the proportion stated.

At the Broxburn works the average yield is as follows:—

		Per cent.
Naphtha—sp. gr. .730...............		5 00
Burning oils:—		
Petroline—sp. gr. .800/.802......	}	37.28
No. 1, oil—sp. gr. .808/.810......		
Lighthouse oil—sp. gr. .810.....		
Lubricating oils.....................		17.40
Solid paraffine........................		12.52
Loss		27.80
		100.00

Mr. Alfred H. Allen, in his "Commercial Organic Analysis," asserts that shale-burning oil contains about 36 per cent., by measure, of paraffines, and 64 per cent. of olefines and other hydrocarbons acted on by fuming nitric acid; while in American refined petroleum (burning oil) these proportions are reversed; and he gives the following comparative statement, based upon the relative percentages, by measure, of hydrocarbons present in the various commercial products which withstand a consecutive treatment with nitric acid, 1.45 specific gravity, concentrated sulphuric acid, fuming sulphuric acic, and caustic soda; remarking, however, that the quantitative composition is liable to considerable variation, and hence must not be interpreted too literally:*—

NAPHTHA.

From Shale.—At least 60 to 70 per cent. of heptylene, C_7H_{14}, and other hydrocarbons of the olefine series, C_nH_{2n}. The remainder paraffines, C_nH_{2n+2}. No trace of benzine or its homologues.

From Petroleum.—At least 70 per cent of heptane, C_7H_{16}, and other hydrocarbons of the paraffine series, C_nH_{2n+2}. The remainder apparently olefines, with distinct traces of benzine, C_6H_6, and its homologues.

BURNING OIL.

From Shale.—50 to 80 per cent. or more, of the higher members of the olefine series, C_nH_{2n}. The remainder paraffines, C_nH_{2n+2}.

* In regard to the burning oil made from American petroleum, the proportion of olefines present depends upon the extent to which the process of "cracking" has been adopted, as already explained.

From Petroleum.—50 to 80 per cent. of the higher members of the paraffine series, C_nH_{2n+2}. The remainder chiefly olefines, C_nH_{2n}.

LUBRICATING OIL.

From Shale.—Chiefly olefines, C_nH_{2n}, with some polymerized members of acetylene series, C_nH_{2n-2}.

From Petroleum.—A large proportion of higher olefines, C_nH_{2n}; but less than in corresponding shale product.

VASELINE.

From Shale.—No such product.

From Petroleum.—Chiefly higher paraffines of low melting point.

PARAFFINE WAX.

From Shale.—Solid paraffines, C_nH_{2n+2}.

From Petroleum.—Solid paraffines, C_nH_{2n+2}.

Instead of acting on the olefines by nitric and sulphuric acids as described, bromine may be used to effect their separation from the paraffines, and a process of analysis based upon this fact has been devised by Mr. Allen.

Mr. J. J. Coleman found that the liquid obtained on subjecting the gaseous products of shale distillation to cold and pressure, consisted chiefly of olefines:—Butylene, C_4H_8; amylene, C_5H_{10}; and hexylene, C_6H_{12}.

The following results, obtained by Mr. Galletly with paraffine from Boghead coal, show that the specific gravity of this product increases with its melting point:—

Specific gravity.	Melting point.
.8236	89.6° F.
.8480	102 2° "
.8520	104.9° "
.9090	128.0° "
.9110	128.0° "
.9243	136·4° "
.9248	138.2° "
.9400	176.0° "

The ozokerite, separated by melting from the earthy matter with which it is associated, and purified by treatment with

Nordhausen oil of vitriol, has a deep yellow color, and in that condition is stated to be used as an adulterant of beeswax. To obtain a material suitable for candle making, it has, however, hitherto been necessary to subject the ozokerite to distillation in a current of super-heated steam, the products being about 5 per cent. of gaseous hydrocarbons, 3 per cent. of naphtha, 6 per cent. of semi-solid "ozokerine," 12 per cent. of soft paraffine (melting point 44½ to 46° C.), distilled ozokerite (melting point 61° C.), and a black waxy residue. The grayish colored distilled ozokerite thus obtained is refined by a process similar to that which paraffine from petroleum or shale undergoes. The refining of ozokerite is carried out on a large scale by Messrs. J. C. and J. Field.

About the time when Mr. James Young laid the foundation of the present shale oil industry, Mr. Reece Reece and Sir Robert Kane were working upon Irish peat, and Sir Frederick Abel has stated that in 1851 or 1852 he saw some small candles made from peat paraffine. According to Dr. Edmund J. Mills, peat furnishes from 3 to 6 per cent. of tar, the specific gravity of which is about .954, and Vohl states that peat tar yields, on the average, about 20 per cent. of burning oil (specific gravity .82), and about 22 per cent. of lubricating oil. The percentage of paraffine appears to vary considerably, as it is placed by different writers at from 0.1 per cent. to 3.4 per cent.

It will be interesting at this point to consider, briefly, the extent of the world's consumption of mineral illuminating oils. We find that the estimated total out-turn by all the refineries in the United States, for the year ended December 31, 1885, was 732,650,628 American gallons, or 14,365,698 barrels of 51 American gallons (equal to about 40 imperial gallons). The approximate home consumption in the United States amounted to about 253,-665,075 American gallons, or 4,973,825 barrels; and the quantity exported was 5,381,099 barrels, and 17,254,611 cases, collectively equal to 446,982,159 American gallons. The detailed shipping statistics give the respective quantities for the year 1885 as 6,985,637 barrels, and 16,528,844 cases, a discrepancy which may be due to differences in dates. On the latter basis, the total gross weight of the barrels would be 1,222,486 tons. If piled six high, as they commonly are when stored, the barrels would cover a space of about half a square mile, and if placed end to end would extend for a distance of 3,638 miles. The tin-plate used in the manufacture of the cases amounts to nearly 38,502 tons, and would cover more than five square miles and 431 acres.

The burning oil manufactured in Baku during the year 1885, amounted to 27,000,000 poods, equal to 118,800,000 imperial gallons. Of this, about 17,000,000 poods were consumed in Russia, and about 5,000,000 poods, equal to 22,000,000 gallons, were exported, leaving a balance of 5,000,000 poods in stock at the end of the year. We have thus a total of over 700,000,000 gallons of burning oil manufactured per annum in the United States and Russia; to this the similar products manufactured at the refineries on the continent of Europe and in Scotland have to be added.

We have seen that petroleum consists of a mixture of hydrocarbons, varying in volatility, and that the line of demarkation between petroleum spirit and petroleum oil is a purely arbitrary one, there being but little difference between the inflammability of the least volatile hydrocarbon present in the spirit and the most volatile in the oil on the one hand, and between the most volatile hydrocarbon present in the still heavier product and the least volatile in the oil on the other hand. The presence of too large a proportion of the denser products prevents the oil from burning freely; while the presence of an undue proportion of the hydrocarbons of lower boiling point renders the oil unsafe for use in ordinary mineral oil lamps. At an early period in the development of the mineral oil industry, attention was accordingly directed to the necessity of drawing such lines of demarkation as would insure the supply to the consumer of an oil of satisfactory character. The specific gravity of the product was found to afford a sufficient indication of the amount of the denser hydrocarbons present, but not of the inflammability of the product, since a percentage of the more volatile hydrocarbons, too small to materially alter the specific gravity of the oil, was found to be sufficient to produce an inflammable atmosphere in the oil reservoir of the lamp. It was, therefore, obviously necessary to apply a special test to determine the inflammability of the liquid. The earliest attempts in this direction took the form of pouring the oil on to water heated to a given temperature, passing a light over the surface, and noting whether the oil evolved inflammable vapor or itself ignited, the temperature at which the oil first gave off enough vapor to ignite being termed its "flashing point," and that at which it caught fire its "fire test."

After some years of experience, it was found that the testing of the oil in an open cup was attended with certain disadvantages, and various forms of closed cup were introduced.

The greater number of the petroleum testing instruments employed at the present time, and all those whose use is prescribed by law may be divided into the two classes referred to, viz., those which have an open cup and those in which the oil cup is provided with a cover, and the use of instruments of the latter class is largely on the increase. It has also been proposed, however, to determine the inflammability of the oil by noting the tension of its vapor at a given temperature, and various forms of apparatus have been devised with this object, but since there is no definite, or at any rate no simple relation between vapor tension and inflammability, this method of testing has not found favor.

Of the forms of open cup tester, that which is known as Tagliabue's has been very largely used for many years. The apparatus consists of a glass cup containing the oil, placed in a water bath heated by means of a small spirit lamp. A thermometer is suspended in the oil, and the temperature noted at which on passing a burning splinter of wood across the surface of the oil either a flash of ignited vapor is obtained, or the oil itself takes fire. The ignition of the oil is always preceded by a flash, but the number of degrees of temperature through which the oil must be raised between its flashing and igniting varies according to the character of the oil.

The English Petroleum Act, passed on the 29th July, 1862, provided that "Petroleum for the purposes of this Act shall include any product thereof that gives off an inflammable vapor at a temperature of less than 100° of Fahrenheit's thermometer," but as the method of testing was not described, the Act was practically inoperative. On the 13th July, 1868, an amending Act was passed, defining "petroleum" for the purposes of the Acts as including "all such rock oil, Rangoon oil, Burmah oil, any product of them, and any oil made from petroleum, coal, schist, shale, peat, or other bituminous substance, and any product of them, as gives off an inflammable vapor at a temperature of less than 100° of Fahrenheit's thermometer." Appended to the Act was a schedule prescribing the form of apparatus and method of testing to be adopted. This apparatus consists of a slightly conical oil cup of thin sheet iron, provided with a flat rim, and a raised edge, ¼-inch high. Across the cup, and fixed to the edge, is a wire, which is thus ¼-inch above the flat rim. The oil cup is supported by the rim in a tin water bath. The water bath having been filled "with cold, or nearly cold," water, the oil cup, supported as described, was filled with the oil to be tested, care being taken that the liquid did not cover the flat rim. A thermometer with a round bulb, and so graduated that every 10°F. occupied not less than ½ inch on the scale, was then placed in the oil so that the bulb was immersed about 1½ inches beneath the surface. A screen of pasteboard or wood of specified dimensions was then placed round the apparatus, and a "small flame" applied to the bottom of the water bath. When the temperature reached 90° F., a "very small flame" was passed across the surface of the oil on a level with the wire, this application of the test flame being repeated for every rise of "two or three degrees" in temperature until a "pale blue flicker or flash" was produced. The temperature was then noted, and the experiment repeated with a fresh sample of the oil, withdrawing the source of heat when the temperature approached that noted in the first experiment, and applying the test flame at every rise of two degrees. Various modifications of the open vessel tester have been devised, especially in the United States.

Arnaboldi's apparatus is similar to Tagliabue's, but is of larger size, and in one form has an adjustable mechanical arrangement for applying the test flame at a prescribed distance from the surface. Messrs. Lockwood Brothers and Holly's apparatus is provided with an independent oil lamp, by means of which a test flame can be moved across the testing cup at any required height above the oil surface. In Mr. George M. Saybolt's testing apparatus, which was a few years ago adopted by the New York Produce Exchange, the ignition of the vapor is effected by means of an electric spark.

The greater part of the earlier petroleum legislation in the United States was based upon fire test and not upon flashing point; and the present rules of the New York Produce Exchange recognize no other test as the basis of commercial transactions in petroleum oil, but in many of the States the petroleum laws now prescribe a test of flashing point.

One of the earliest forms of closed vessel testers is that of Tagliabue. This is provided with a brass oil cup with a cover, attached to which is a spring valve and dwarf chimney. The opening of this valve and the simultaneous passing of a small flame into the chimney through a lateral orifice determines a current of air through the upper part of the oil cup, which sweeps out the inflammable vapor and brings it into contact with the flame. In Michigan and Wisconsin the tester has a copper oil cup with a copper cover, provided with a small orifice to which the test flame is applied. The present New York State tester is precisely similar to that last described, except that the oil cup is of large size and has a glass instead of a copper cover to the oil cup. The closed vessel tester employed in Austria is similar in principle to Tagliabue's. Parrish's naphthometer used in Holland is provided with a stationary flame, fed by the oil in the testing cup. The Foster tester is similar in principle. In Millspaugh's tester the oil cup is of glass, and is immersed only to the extent of one-tenth of its depth in the water bath, the object, apparently, being to prevent the overheating of the surface of the oil. Mann's tester represents an attempt to reproduce in the testing apparatus the conditions which prevail in an ordinary petroleum lamp, the burner of the lamp being replaced by a tube, the stopper of which is blown out, when, upon the introduction of a flame through a lateral opening, ignition of the vapor occurs. In Pease's closed tester the vapor is ignited by an electric spark.

Professor Arthur H. Elliott, of New York, has recently made a large number of comparative experiments with the various instruments described, and has embodied the results in a report to the New York State Board of Health.

About the year 1870, a closed tester with electric spark arrangement was in use by the late Dr. Letheby in his laboratory at the London Hospital. The oil cup was of glass, and was provided with a hinged metal cover, which was blown open when the vapor was ignited by the spark.

Dr. Attfield has recommended that the flashing point should be taken by warming the oil in a test-tube, and inserting a flame into the mouth of the tube.

A Petroleum Bill, which sought to amend the law in several very desirable respects, was introduced into Parliament in 1871, but in consequence mainly of the test standard being fixed at a point (85° F.) which was higher than the equivalent of the existing test standard, the bill was opposed by the petroleum trade, and the proposal to change the method of testing withdrawn. The bill passed on the 11th of August in that year, repealing the two previous acts but prescribing the open test. In the following year the subject of testing was investigated by a select committee of the House of Lords, and a great deal of evidence was taken, but no satisfactory conclusion was arrived at.

At this period the position of the petroleum-testing question in England was by no means promising. It had been found that the existing legal directions for testing were not sufficiently precise; the results obtained differing greatly, according to the interpretation of the expression "small flame," as applied to the source of heat; and "very small flame," as applied to the test flame; the officials employed by the local authorities frequently condemned oil that had been passed by independent and unbiased experts acting on behalf of the traders; and retailers had thus no means of protecting themselves from the risk of being fined for selling oil flashing below the legal standard. Accordingly, with the concurrence and approval of the Metropolitan Board of Works, and of the Petroleum Association, Sir Frederick Abel was requested by the Government to undertake the investigation of the subject of petroleum testing, with the object of devising a satisfactory test. The outcome of Sir Frederick Abel's long and painstaking experimental inquiry, in which Dr. Kellner rendered valuable assistance, was the adoption by Parliament, on the 11th of August, 1879, of what is now so well known as the Abel test. The instrument and its use are thus described in the Schedule of the 1879 Petroleum Act:

Specification of the Test Apparatus.

The following is a description of the details of the apparatus:—The oil cup consists of a cylindrical vessel 2 inches in diameter, $2\frac{2}{10}$ inches high (internal), with outward projecting rim $\frac{5}{10}$ inch wide, $\frac{3}{8}$ inch from the top, and $1\frac{7}{8}$ inches from the bottom of the cup. It is made of gun metal or brass (17 B. W. G.) tinned inside. A bracket, consisting of a short, stout piece of wire bent upwards, and terminating in a point, is fixed to the inside of the cup to serve as a gauge. The distance of the point from the bottom of the cup is $1\frac{1}{2}$ inches. The cup is provided with a close-fitting overlapping cover made of brass (22 B. W. G.), which carries the thermometer and test lamp. The latter is suspended from two supports from the side, by means of trunnions upon which it may be made to oscillate; it is provided with a spout, the mouth of which is one-sixteenth of an inch in diameter. The socket which is to hold the thermometer is fixed at such an angle, and its length is so adjusted that the bulb of the thermometer when inserted to full depth shall be $1\frac{1}{2}$ inches below the center of the lid.

The cover is provided with three square holes, one in the center $\frac{5}{10}$ inch by $\frac{4}{10}$ inch, and two smaller ones, $\frac{3}{10}$ inch by $\frac{2}{10}$ inch, close to the sides, and opposite each other. These three holes may be closed and uncovered by means of a slide moving in grooves, and having perforations corresponding to those on the lid.

In moving the slide so as to uncover the holes, the oscillating lamp is caught by a pin fixed in the slide, and tilted in such a way as to bring the end of the spout just below the surface of the lid. Upon the slide being pushed back so as to cover the holes, the lamp returns to its original position.

Upon the cover, in front of and in line with the mouth of the lamp, is fixed a white bead, the dimensions of which represent the size of the test flame to be used.

The bath or heated vessel consists of two flat-bottomed copper cylinders (24 B. W. G.), an inner one of 3 inches diameter and $2\frac{1}{2}$ inches high, and an outer one of $5\frac{1}{2}$ inches diameter and $5\frac{3}{4}$ inches high; they are soldered to a circular copper plate (20 B. W. G.) perforated in the center, which forms the top of the bath, in such a manner as to enclose the space between the two cylinders, but leaving access to the inner cylinder. The top of the bath projects both outwards and inwards about $\frac{3}{8}$ of an inch, that is, its diameter is about $\frac{6}{8}$ inch greater than that of the body of the bath, while the diameter of the circular opening in the center is about the same amount less than that of the inner copper cylinder. To the inner projection of the top is fastened, by six small screws, a flat ring of ebonite, the screws being sunk below the surface of the ebonite, to avoid metallic contact between the bath and the oil cup. The exact distance between the sides and bottom of the bath and of the oil cup is one half an inch. A split socket similar to that on the cover of the oil cup, but set at a right angle, allows a thermometer to be inserted into the space between the two cylinders. The bath is further provided with a funnel, an overflow pipe and two loop handles.

The bath rests upon a cast-iron tripod stand, to the ring of which is attached a copper cylinder or jacket (24 B. W. G.) flanged at the top and of such dimensions that the bath, while firmly resting on the iron ring, just touches with its projecting top the inward turned flange. The diameter of this outer jacket is 6½ inches. One of the three legs of the stand serves as a support for the spirit lamp attached to it by means of a small swing bracket. The distance of the wick holder from the bottom of the bath is 1 inch.

Two thermometers are provided with the apparatus, the one for ascertaining the temperature of the bath, the other for determining the flashing point. The thermometer for ascertaining the temperature of the water has a long bulb and a space at the top. Its range is from about 90° to 190° Fahrenheit. The scale (in degrees of Fahrenheit) is marked on an ivory back fastened to the tube in the usual way. It is fitted with a metal collar fitting the socket, and the part of the tube below the scale should have a length of about 3½ inches measured from the lower end of the scale to the bulb. The thermometer for ascertaining the temperature of the oil is fitted with collar and ivory scale in a similar manner to the one described. It has a round bulb, a space at the top, and ranges from about 55° Fahr. to 150° Fahr.; it measures from end of ivory back to bulb 2¼ inches.

DIRECTIONS FOR APPLYING THE FLASHING TEST.

1. The test apparatus is to be placed for use in a position where it is not exposed to currents of air or draughts.

2. The heating vessel or water bath is filled by pouring water into the funnel

until it begins to flow out at the spout of the vessel. The temperature of the water at the commencement of the test is to be 130° Fahrenheit, and this is attained in the first instance either by mixing hot and cold water in the bath, or in a vessel from which the bath is filled, until the thermometer which is provided for testing the temperature of the water gives the proper indication; or by heating the water with the spirit lamp (which is attached to the stand of the apparatus) until the required temperature is indicated.

If the water has been heated too highly, it is easily reduced to 130° by pouring in cold water little by little (to replace a portion of the warm water) until the thermometer gives the proper reading.

When a test has been completed, this water bath is again raised to 130° by placing the lamp underneath, and the result is readily obtained while the petroleum cup is being emptied, cooled, and refilled with a fresh sample to be tested. The lamp is then turned on its swivel from under the apparatus, and the next test is proceeded with.

3. The test lamp is prepared for use by fitting it with a piece of flat plaited candle wick, and filling it with colza or rape oil up to the lower edge of the opening of the spout or wick tube. The lamp is trimmed, so that when lighted it gives a flame of about 0.15 of an inch diameter, and this size of flame, which is represented by the projecting white bead on the cover of the oil cup, is readily maintained by simple manipulation from time to time with a small wire trimmer.

When gas is available, it may be conveniently used in place of the little oil lamp, and for this purpose a test-flame arrangement for use with gas may be substituted for the lamp.

4. The bath having been raised to the proper temperature, the oil to be tested is introduced into the petroleum cup, being poured in slowly until the level of the liquid just reaches the point of the gauge which is fixed in the cup. In warm weather the temperature of the

room in which the samples to be tested have been kept should be observed in the first instance, and if it exceeds 65°, the samples to be tested should be cooled down (to about 60°) by immersing the bottles containing them in cold water, or by any other convenient method. The lid of the cup, with the slide closed, is then put on, and the cup is placed into the bath or heating vessel. The thermometer in the lid of the cup has been adjusted so as to have its bulb just immersed in the liquid, and its position is not under any circumstances to be altered. When the cup has been placed in the proper position, the scale of the thermometer faces the operator.

5. The test lamp is then placed in position upon the lid of the cup, the lead line or pendulum,* which has been fixed in a convenient position in front of the operator, is set in motion, and the rise of the thermometer in the petroleum cup is

* The pendulum should be 24 inches in length from the point of suspension to the center of gravity of the weight.

watched. When the temperature has reached about 66°, the operation of testing is to be commenced, the test flame being applied once for every rise of one degree, in the following manner:—

The slide is slowly drawn open while the pendulum performs three oscillations, and is closed during the fourth oscillation.

NOTE.—If it is desired to employ the test apparatus to determine the flashing points of oils of very low volatibility, the mode of proceeding is to be modified as follows:—The air-chamber which surrounds the cup is filled with cold water to a depth of 1½ inches, and the heating vessel or water bath is filled as usual, but also with cold water. The lamp is then placed under the apparatus and kept there during the entire operation. If a very heavy oil is being dealt with, the operation may be commenced with water previously heated to 120°, instead of with cold water.

By no means the easiest part of Sir Frederick Abel's task was the determination of the equivalent test standard, since the Abel instrument furnishes no exception to the rule that the flashing point of a given sample of mineral oil is far lower in a closed than in an open vessel, and it was therefore necessary to deal with the conflicting views already referred to, as to the proper mode of conducting the test with the open cup instrument, in order to determine the equivalent standard. Eventually, as the outcome of joint experiments, it was ascertained that the difference between the results afforded by the open-cup instrument and the Abel tester ranged from 25° to to 29° Fahr. Taking the mean difference of 27°, the new standard was accordingly fixed at 73° Fahr.

There are yet some other systems of testing to be described. In 1882, Braun, of Berlin, patented a magnetic pendulum arrangement for applying the test flame in the Abel apparatus. In 1881, Engler and Haas made a number of experiments with the Abel apparatus and other testing instruments, and expressed the opinion that the addition of an arrangement for agitating the oil was desirable.* They based their opinion apparently upon the facts that in all the closed testers there is during the operation a layer of vapor of gradually increasing thickness formed upon the surface of the oil; that consequently no two apparatus will give concordant results unless the size and shape of the oil cup, the height to which the cup is filled, the rate of heating, the distance from the surface of the oil at which the test-flame is applied, the size of the test-flame, the dimensions of the orifices in the cover, and other conditions are the same; and, further, that since the temperature of the oil is not uniform throughout, the position of the thermometer bulb must be precisely defined. There is no doubt that with the use of a mechanical arrangement for agitating the oil and the air in the cup, results less dependent upon the conditions enumerated are obtained, but since all the standard measure-

---

* **Victor Meyer is stated to have been the first to propose the addition of a stirrer.**

ments are most carefully adhered to, and the position of the thermometer bulb is prescribed, the objections to the apparatus are not valid, and it is quite possible that the use of a stirrer might in practice be found to introduce some element of error. Liebermann has recommended the blowing of air through the oil during the process of testing, and Beilstein devised an apparatus, based upon this principle, which consisted of a glass cylinder to hold the oil, with a tube passing to the bottom, and furnished with a rose jet. At intervals, air was forced through the jet at a rate sufficient to raise a foam of a prescribed depth upon the surface of the oil, and the test-flame was at the same time applied. Stoddard subsequently suggested a modification of Beilstein's apparatus, in which the rose jet was replaced by a glass tube drawn out to a small orifice.

Bernstein's tester is constructed on the principle of gradually heating the oil until a temperature is reached at which, on raising the level of the oil, vapor is forced out of the testing chamber, and ignited at a stationary flame. Ehrenberg has proposed to use a syringe to expel the vapor from the closed testing cup, and thus bring it into contact with a flame.

Of apparatus in which the flashing point of the oil is only determined inferentially by noting the vapor tension, the best known is the Salleron-Urban instrument, which is used to some extent in France.

In a table published in 1866, Salleron and Urban give the following figures of specific gravity and vapor tension of petroleum products at 15° C.:—

Density at 15° C.	Tension in mm. of water.
.812	0
.797	5
.788	15
.772	40
.762	85
.756	125
.735	410
.695	930
.680	1,185
.650	2,110

In the United States there is found considerable diversity of opinion among authorities as to the method of testing and the standard to be selected, and almost all the States have adopted different legislation in these principles. When petroleum was first introduced in that country as an illuminant, it was often used carelessly and improperly, and many accidents occurred. An exaggerated estimate of the risk involved in the use of the oil was thus formed, and laws were then passed, which, in some instances, were so stringent that they could not be enforced. Moreover, recent experiments by Sir F. Abel and others, in England, and by the officials of the Normal Eichungs Kommission in Berlin, have shown that an oil of high flashing point may, in some cases, be actually less safe than one of lower flashing point. The experience of several years has demonstrated that the proper use of an oil of comparatively low flashing point (say 70° Abel test) is free from danger, and there is reason to believe that authorities in the United States are beginning to realize that their petroleum laws would be rendered far more effective for the protection of the public by the substitution of more moderate test requirements.

Petroleum legislation in this country has hitherto been confined to those products which give off an inflammable vapor below the legal limit. Exception has, however, been taken to this by the Metropolitan Board of Works, who contend that between oil which flashes at 72°, and oil which flashes at 73°, there can be no practical difference in regard to inflammability. In advancing this view, however, it appears to have been forgotten that since the liquids which flash below the standard can only be stored and sold in comparatively small quantities, and under troublesome restrictions, the practical effect of such legislation is that elaborate precautions are adopted to insure that all the burning oil imported has a flashing point not below the limit; the only liquid dealt with in accordance with the provisions of the Acts being petroleum spirit (benzoline and gasoline). Placing of the sale of burning oil (flashing not below 73° F.) under legislative restrictions would be to obliterate, to some extent, the distinction which the present laws have created. Moreover, there are probably no grounds for supposing that petroleum oil constitutes a dangerous article in the ordinary stock of an oilman. On the contrary, there is a good deal of evidence in support of the opposite view. Thus, to take one instance only, in the case of one of the most recent fires at an oilman's shop almost the only portion of the contents of the shop which had escaped destruction were three barrels of petroleum oil, constituting, according to the evidence given, the whole stock of this material on the premises at the time of the fire. These barrels were a good deal charred, but still held a considerable quantity of oil. Petroleum is, in fact, a far less dangerous liquid than is commonly supposed, as was pointed out some years ago, and again last year, by Sir Frederick Abel in lectures at the Royal Institution. Statistics show that the destruction of petroleum-laden ships by fire is very rare, and at least one case is on record where a vessel carrying petroleum having been set on fire by lightning, the fire was extinguished and the cargo brought safely into port. Many barrels discharged from the vessel in question bore evidence of the heat to which they had been subjected, being in some cases so much charred that a penknife blade could be driven through the staves, and yet these barrels still held the oil intact.

In consequence, partly, of the expressed views of the Metropolitan Board of Works, a Petroleum Bill was introduced by the Government in 1883 to place the storage and sale of petroleum oil under legal restrictions; but the measure was practically condemned by a Select Committee of the House of Lords, and was withdrawn. Subsequently Colonel Majendie, her Majesty's Chief Inspector of

Explosives, made a visit to Germany, Austria, France, Belgium, and Holland, for the collection of information in regard to petroleum legislation in those countries. In a memorandum issued in 1884, Colonel Majendie set forth the result of his observations and inquiries, the information he collected being supplemented by particulars obtained from consular reports and other sources. The result of the inquiry showed that in all the principal countries of Europe the traffic in mineral oil was to a greater or less extent under the control of State or municipal authorities, but in many respects the restrictions were far less stringent than those proposed by the Bill of 1883. There is no doubt much to be said in favor of the contention that the storage of mineral oils in large quantities should take place only under specified conditions, so that in the event of a fire occurring, outflow of burning oil from the premises could not occur, but it is difficult to see how legislation to give effect to this view could fairly and justifiably be advocated unless it took the shape of a comprehensive measure embracing other inflammable liquids.

We have now dealt with that which is the most important of all the tests applied to petroleum products, since, as we have seen, legislative enactments framed in the interest of public safety are based upon it. There are, however, many commercial tests worthy of attention.

The color of petroleum oil is determined in this country (as regards oil for export), in England, in Germany, and in Russia (in the case of oil for export), by the use of a chromometer patented by Mr. R. P. Wilson, a member of the committee of the Petroleum Association of London, in 1870. This instrument is fitted with two parallel tubes furnished with glass caps, and at the lower end of the tubes is a small mirror, by means of which light can be reflected upwards through the tubes into an eye-piece. One of the tubes is completely filled with the oil to be tested, and beneath the other tube, which remains empty, is placed a disk of stained glass of standard color. On adjusting the mirror and looking into the eye-piece, the circular field is seen to be divided down the center, each half being colored to an extent corresponding with the tint of the oil and of the glass standard respectively. An accurate comparison of the two colors can thus be made. The glass disks, which for the English trade are of five shades of color, termed—good merchantable, standard white, prime white, superfine white, and water white, are issued by the Petroleum Association of London, and the instruments are all precisely similar in construction; thus the testing of color, wherever these chromometers are used, is placed upon a uniform basis.

A German modification of the instrument (devised by Stammer), is provided with an arrangement for shortening the column of oil, and thus obtaining an exact match with the standard. The extent of shortening being indicated on the scale, the color of the oil can be recorded in terms of the standard with considerable precision.

Both fire test and flashing point of lubricating oils are determined by testing the oil in an open cup. There is no generally, or at any rate universally, accepted method of applying these tests, and important discrepancies between the results of different operators frequently occur. These discrepancies chiefly arise from variations in the rate of heating the oil. Pensky, of Berlin, constructs a closed cup apparatus for testing lubricating oils, which in principle resembles the Abel instrument. As, however, the trade are accustomed to judge of the volatility of lubricating oils by their open vessel flashing points or their fire tests, the closed cup cannot usually be employed. The method of heating the oil adopted by Pensky, which consists in placing the oil cup in an air chamber in a cast-iron vessel which can be strongly heated, is a convenient one, and on using the Pensky apparatus without the oil-cup cover, and adjusting the Bunsen burner flame, which is used as a source of heat, so that the temperature of the oil is raised at the rate of about 10° per minute, there are obtained concordant flashing points and fire tests, which agree with those furnished by the method of testing usually adopted in America. A gas flame not more than a quarter of an inch in diameter, produced by the use of a small jet, is a good test flame to use.

The so-called "cold test" of lubricating oils is the temperature at which the oils either become cloudy or cease to flow through crystallization of paraffine. The test is usually applied by slowly cooling a sample of the oil in a tube about 1⅜ inches in diameter, and noting the temperature at which on inclining the tube the oil no longer flows, or that at which separation of paraffine commences.

The viscosity of mineral lubricating oils is a feature which is intimately associated with their lubricating properties. The subject has been dealt with somewhat fully in a paper read at a meeting of the

Society of Chemical Industry by the author,* and the apparatus commonly employed in testing consists of an arrangement for noting the length of time occupied by a given quantity of the oil in flowing through a small orifice of given dimensions and form at a given temperature.

Paraffine scale, or partially refined paraffine wax, usually contains oil, and sometimes water. The percentage of oil is determined by subjecting a weighed quantity of the material to a given pressure at a given temperature for a specified time, and noting the loss in weight. The author published in the *Journal of the Society of Chemical Industry*, in August, 1884, the particulars of the method of testing which he employs, and gave comparative results obtained under various pressures, with various lengths of exposure to the pressure at various temperatures, and with various quantities of material. The experi-

---

* Published in the *Journal of the Society of Chemical Industry*, on the 29th of March, 1886.

ments showed that differences of temperature affect the results far more than differences in pressure and in the quantity of material do. This is not surprising when we consider that there is no actual line of demarkation between the solid and liquid hydrocarbons obtained from petroleum. It is, however, important that the same pressure should always be employed, and accordingly, some years ago a press was constructed which indicates the amount of pressure by the extent of deflection (magnified by levers) of the steel cross head. The test is made at 60° F., the temperature of the press plates being indicated by thermometers placed in mercury cups; the quantity of material employed is 500 grains, the pressure is 9 tons over the whole surface of the circular press cake, 5⅝ inches in diameter, and this pressure is maintained for five minutes, the oil expressed being absorbed by blotting paper. The author recently had a press constructed in the United States for use in testing, which is furnished with a long, heavily-weighted lever in place of the spring cross-head. With this press similarly concordant results were obtained, and the objection to a spring, that it may become weaker through use, does not, of course, attach to the weighted lever method of indicating pressure. Mr. McCutchon, of Young's Paraffine Oil Company, constructed a testing press in which coiled steel springs were substituted for the elastic cross-head, and this press has been adopted by the Scottish Mineral Oil Association. Mr. William Walls, of Glasgow, recommends the use of a hydraulic press, and Messrs. Clarkson & Beckitt, of Glasgow, a few months ago, constructed a well-made press of this nature. A hydraulic press is portable, occupies less space than a screw press, and admits of a specific pressure being applied with ease and certainty. This press acted promptly even after being out of use many days. Under a great pressure the scale is liable in some cases to be squeezed out of the cloth, and the quantity of oil expressed is not materially increased. Thus, in some comparative experiments conducted at various pressures, all the other conditions being alike, the author obtained the following results :—

PRESSURE ON WHOLE CAKE.

Sample.	9 tons oil.	13.3 tons oil.	20 tons oil.
A...	2.9 per cent..	3 1 per cent..	not taken.
B...	14.8 "	..14.4* "	..not taken.
C...	2.5 "	..not taken.	..2.9 per cent.
D...	5.5 "	..not taken.	..6.1 "

Water in paraffine scale is usually determined by heating a weighed sample to a temperature somewhat above the boiling point of water, and maintaining it at that temperature until it ceases to lose weight.

The so-called "melting point" of paraffine is, in the case of the recognized American and English methods of making the test, the temperature at which the sample, after having been melted, and while in the process of cooling,

* Temperature slightly lower.

begins to solidify. The American test is conducted by melting sufficient of the samples to three parts to fill a hemispherical dish $3\frac{3}{4}$ in. in diameter. A thermometer with a round bulb is suspended in the fluid so that the bulb is only three-fourths immersed, and the material being allowed to cool slowly, the temperature is noted at which the first indication of filming extending from the sides of the vessel to the thermometer bulb occurs. The English test is made by melting the sample in a test tube, about three-quarters of an inch in diameter, and stirring it with a thermometer as it cools, until a temperature is reached at which the crystallization of the material produces enough heat to arrest the cooling, and the mercury remains stationary for a short time. The results afforded by this test are usually from $2\frac{1}{2}°$ to 3° F. lower than those furnished by the American test. The melting point is also sometimes determined by observing the temperature at which a minute quantity of the sample, previously fused into a capillary tube and allowed to set, becomes transparent when the tube is slowly warmed in a beaker of water.

Chapter IV.

By far the most important of the uses to which the products of petroleum are as yet applied is that of illumination, and it is to this use that we should accordingly direct our attention. In regard to the employment of the solid products of petroleum in the form of paraffine candles not much need be said. Liebig in 1851 expressed the opinion that "it would certainly be esteemed one of the greatest discoveries of the age if any one could succeed in condensing coal-gas into a white, dry, solid, odorless substance, portable, and capable of being placed upon a candlestick or burned in a lamp," and it may fairly be said that in the paraffine candle we have a source of light possessing all the characteristics which

Liebig considered so desirable. Price's Patent Candle Company and Messrs. J. C. and J. Field are well known to have been conspicuously successful in their efforts to improve the manufacture of paraffine candles, the introduction of the "self-fitting" end, and the adoption of various devices to render the candle more ornamental.

The principal defect possessed by paraffine candles is a liability to bend when exposed to the air of a warm room. This tendency is to some extent overcome by mixing the paraffine with a small percentage of palmitic or stearic acid, and it is found that candles made of this mixture are also less liable to smoke than those made from pure paraffine. Ozokerite candles have a higher melting point than those which are made of petroleum or shale paraffine, and are in this respect better suited for use in warm climates.

Young's Paraffine Light and Mineral Oil Company have made an ingenious use of soft paraffine in the handy little miners' lamp.

There probably is no exhaustive account of the various improvements which, from time to time, have been effected in appliances for burning mineral oils with a view to the production of light; and in the attempt to compile a reccord having any pretensions to completeness, great difficulties may be anticipated.

We know, from the accounts given by historians who wrote prior to the commencement of the Christian era, that petroleum was used as an illuminant in remote ages. The appliances for burning the oil, were, without doubt, of a very primitive description, consisting simply of an oil vessel furnished with a wick of some fibrous material. Lamps of this character are still used for burning crude petroleum in various localities. The earthen-ware petroleum lamp of somewhat artistic form, but very primitive construction, is found in use in provincial Russia, and little glass and tin lamps are met with in the bazaars in India.

For the lighting of the derrick during the operation of well-drilling in the

United States, the large iron two-spouted kettle-shaped lamp, fed with crude petroleum, is still commonly employed. With none of these lamps is a chimney used, and the flame produced is dull and smoky.

Much interesting and valuable information in reference to the subject of mineral oil lamps was given by Sir Frederick Abel in a lecture delivered at the Royal Institution last year. The lecturer expressed the belief that mineral oil lamps were first constructed in Germany, about the years 1852-3, and somewhat extensive inquiries made since quite confirm this view. Many years previously, however, viz., in 1820, coal-naphtha, produced under Lord Dundonald's patent of 1781, was introduced as an illuminant by Mr. Astley, for use in the so-called founder's blast lamp, in which the combustion was aided by a current of air artificially produced. Read Holliday was also among the first to suggest the employment of coal naphtha for illuminating purposes, and the vapor lamp which he patented is still largely employed.

Other inventors designed lamps for vaporizing coal-naphtha, and burning the vapor at a jet. Various ingenious arrangements for maintaining a uniform oil level were also devised during the latter part of the 18th century. These arrangements, many of which were described by Mr. Leopold Field in his Cantor lectures on "Solid and Liquid Illuminating Agents," delivered in 1883, were applied to lamps burning fixed oils ; but some are of special interest to us as being applicable to mineral oil lamps. Thus the "bird-fountain" system of maintaining the oil level, which is stated to have been first adopted by Miles in 1781, is applied in one class of petroleum lamps now in use. This arrangement consists of an oil reservoir closed at the top, and communicating by a tube with the wick case of the burner, which is at a lower level than the top of the reservoir. As the oil in the wick case is drawn up to the flame and consumed, a few bubbles of air pass into the reservoir, and a corresponding quantity of oil flows out. The principle of pumping the oil up to the flame, which was devised by Carcel in 1798, is also at present in use in burning mineral oils, chiefly for lighthouse illumination, but also, to a small extent, for domestic lighting.

The first lamps in which mineral oils were burned in this country with any degree of success were those which had been designed some years previously for use with rectified oil of turpentine, known as "camphine." These lamps were constructed upon the principles described by Ami Argand in the specification of the patent granted to him in 1784, and, in view of its great value, it will be interesting to consider the nature of Argand's invention. The specification states that the patent is for "a lamp that is so constructed as to produce neither smoak nor smell, and to give considerably more light than any lamp hitherto known;" and the method by which these results are obtained is thus described:—

" My method of giving light by lamps or any other illuminating instruments or things, consists in wholly converting into flame and light any inflammable and combustible matter whatever that may be used as the pabulum, fuel, or subject of such light, which in the common mode of producing light is only in part burnt, consumed, and converted into flame, the rest going off in smoak or soot. This is effected in its various modes of application, first, by causing a current of air to pass through the inside of the flame; secondly, by increasing that current of air and producing another current of air on the outside of the flame by means of a chimney, dome, funnel, tube, pipe, or other contrivance, covering, surrounding or enclosing the flame, or the vehicle, or the receptacle or vessel containing it, so that the fresh air which continually rushes into the said chimney, dome, funnel, tube, or pipe, or passes through it to supply the place of that which is decomposed and rarefied by fire or flame, and which, growing lighter, escapes continually through the top of the said chimney, dome, funnel, tube or pipe, shall have free access and circulation; or thirdly, by applying such chimney, dome, funnel, tube, or pipe to common wicks, where the full effects of the principle are not required.* ' This effect of increasing the light, by converting the smoak into flame, is obtained by the means above mentioned, which may be used either separately, or, where a greater advantage is required, the methods above described may be combined. The vehicles which contain the light are made of various forms and various materials."

The Argand lamp, to quote a description of it published many years ago, "embraces so many improvements upon the common lamp, and has become so general throughout Europe, that it may be justly ranked amongst the greatest discoveries of the age. As a substitute for the candle, it has the advantage of great economy and convenience, with much

* It is stated that the use of a chimney had been previously suggested by Quinquet.

greater brilliancy; and for the purpose of producing heat it is an important instrument in the hands of a chemist. We may, with some propriety, compare the common lamp and the candle to fire made in the open air, without any forced method of supplying it with oxygen; while the Argand lamp may be compared to a fire in a furnace, in which a rapid supply of oxygen is furnished by the velocity of the ascending current. This, however, is not the only advantage of this valuable invention. It is obvious that if the combustible vapor occupies a considerable area, the oxygen of the atmosphere cannot combine with the vapor in the middle part of the ascending column. The outside, therefore, is the only part which enters into combustion; the middle constituting smoke. This evil is obviated in the Argand lamp, by directing a current of atmospheric air through the flame, which, instead of being raised from a solid wick, is produced by a circular one, which surrounds the tube through which the air ascends." Argand's original lamp had an iron chimney, but a cylinder of glass was soon substituted. Smethurst, or Lange, afterwards proposed the employment of a chimney with a shoulder or constriction in place of the simple cylinder.

In 1818 Sir Thomas Cochrane obtained a patent "for lamps in streets, which effectuate and regulate the combustion of a certain purified essential oil or spirit obtained from different ligneous, carbonaceous, or bituminous substances usually called spirit of tar, or oil of tar." The principal feature of the invention seems to have been the construction of the "burner or wick-holder of a length proportioned to the volatility of the said essential oil or spirit compared to that of the viscous oil of whales, or of other gross and sluggish oils now in use." In 1822 A. and D. Gordon patented the construction of lamps with wicks made of platinum, gold, silver, or copper drawn into fine threads, or of glass drawn into capillary tubes, bound into a compact bundle; also the use with such wicks of a burning fluid composed of spirit of wine or wood spirit mixed with essential oils. In 1839 Goldsworthy Gurney and Frederick Rixon obtained a patent for the "oleo-oxygen or Bude light, produced by administering to the flame of oil or gas lamps or burners a jet or stream of pure oxygen." In 1840 George Halpin, Jr., patented the application of a mechanically produced air blast to an Argand burner, and described the use of "an additional tube placed within that usually forming the inner casing of an Argand lamp." The drawings accompanying the specification also show the construction of a burner with three concentric wicks. In the same year Thomas Young, of Queen Street, London, obtained protection for improved methods of supplying the oil to the burner, and for the use of a perforated plate "at a position above the point of combustion of the wick of lamps, and thereby obtaining a more favorable application of air to the flame of lamps." A year later a patent was granted to William Newton for "lamps, burners, and apparatus for the production of light and heat for domestic and other useful and ornamental purposes, partly from certain substances which have not yet been brought into general use for such purposes and by such means, some of the said substances being the hydrocarbons usually called coal-tar, oils or liquids, naphtha, vegetable tar, oils or liquids, and the liquids obtained by distillation and rectification of the resins, schistus, petroleum, maltha or mineral pitch, mineral naphtha, asphaltum, bitumen, caoutchouc, animal oil and the various hydrocarbonaceous substances that may be extracted from vegetables, grain, plants, and trees, and most of the inflammable oleaginous or resinous substances that are both to be vaporized at certain temperatures, according as they may vary in nature and specific gravity." The burners in respect of which the use of this remarkably comprehensive list of burning fluids was claimed, were provided with various complicated arrangements for supplying the fluid to the wick, and in some cases for causing the vaporization of the fluid before its ignition. In the same year (1841) William Young filed a lengthy specification of improvements in lamps, part of which related to arrangements for burning "naphtha or turpentine spirit." William Young's lamp, which was of the Argand type, was at first used with rectified oil of turpentine, known as camphine, but on the introduction of coal oil as an illuminating agent, Young's "Vesta" lamps were used to burn it. In one form of this lamp two, three, or more flat wicks were so held in curved wick holders as to produce a tubular flame, and air was admitted to the inner surface of the flame between the wick tubes. A collar of wood was inserted between the burner and the oil reservoir, to prevent the conduction of heat to the latter.

In 1842 George Roberts, a miner, was granted a patent, part of which related to improvements in lamps for burning "naphtha, turpentine, or such spirits as are usually burned in lamps." The lamp described in the specification as suitable for use with naphtha or other spirits was of the Argand form, the essential feature of the invention being the use of as many as four perforated disk air deflectors, so arranged as to "deflect air on to the wick, and also on to and all around the flame after it is formed, such deflection of the air being at intervals apart, consequently the air will be deflected on to the flame at different heights, the air being prevented passing into the upper part of the chimney except with the flame." The patentee states that "by combining the use of the four disks, as above described, a lamp, such as above described, may be made suitable for burning naphtha and other spirits, without smoke, producing a very powerful light." This early recognition of the important principle of distributing the air supply is of considerable interest. Three years later, viz., in 1845, the same inventor obtained protection for, among other improvements in the construction of lamps, the use, in the center of an Argand wick tube, of "a flat disk of metal, to the outer edge of which a curved piece of perforated metal is attached, thus forming a cap through which the air will pass in small streams to the flame;" also for the similar use of a trumpet-mouthed deflector receiving air through a hollow rod, the top of the deflector being closed with a flat disk, and the sides perforated. Air diffusers of similar construction form important features of mineral oil lamps patented later. Mr. Roberts also specified the use of wicks of cane or porous wood, or of asbestos. Samuel King's patent of 1856 relates chiefly to arrangements for providing in a suitable manner a supply of air to the flame of an Argand burner. An additional patent for further improvements in the arrangements for the distribution of the air was taken out by King in 1859. A patent for a chimneyless burner (flat wick) was granted to George Young in 1867.

N. J. Fenner is authority for the statement that a distiller of the name of Baker, carrying on business on Bow Common, was probably the first to introduce rectified oil of turpentine as an illuminating agent under the name of camphine. This was somewhere about the year 1835. The manufacture of camphine was subsequently, according to Mr. Fenner, carried on by Messrs. Jupp, C. Price and Co., P. Murphy, Flockton, Garton, and Fenner, all of whom were turpentine and resin distillers, the wet steam process of rectification being generally employed. In consequence of the high price of colza and fish oils, camphine had at this time a large sale as an illuminant, notwithstanding its liability to fill the room with "blacks" and its many other defects. In 1856 Mr. Chappel, a solicitor, consulted Messrs. Fenner as to commercially utilizing an asphaltum imported from Cuba, and experiments having shown that the material yielded 75 per cent. of crude oil from which good burning and lubricating oils could be made, a company was formed and the process carried on successfully for some time, the oil selling at 3s. 7d. to 3s. 8d. per gallon. Before long, however, the introduction of the cheaper American petroleum rendered the industry unprofitable.

The products at first manufactured by James Young were not well adapted for illuminating purposes, attention having been concentrated upon the manufacture of lubricating oils; but in 1853 the increasing consumption of the burning oil, which, for three or four years previously had been manufactured in Hamburg, by Noblée, led Mr. Young to make inquiries which resulted in his finding that suitable burners were being constructed by Mr. C. H. Stobwasser, of Berlin. Mr. Young then obtained some of the burners in question, and entrusted to Messrs. R. Laidlaw and Son, of Edinburgh, the manufacture of similar appliances. The earliest of these is on the Argand principle, with an annular wick case, and is called a "solar-oil lamp," while those made subsequently for burning petroleum have flat wick tubes.

Stobwasser & Co. first made the solar-oil (Argand) burners, and the flat wick burners about 1852 or 1853. The solar-oil burner was constructed for use with the liquid termed "photogene," made by Noblée from coal, while the flat wick burner was used with the oil distilled from lignite. The solar-oil at first manufactured would not burn in the flat wick burners, as originally constructed, but a slight alteration of the burner, and an improvement in the quality of the oil, overcame the difficulty.

Gesner states that the first lamps suitable for burning kerosene that were employed in America, were imported from Vienna by Mr. J. H. Austen, who, about the year 1854, was engaged in the coal oil industry. According to Dr. Schweitzer, Professor of Chemistry in the University of Missouri, the coal oil manufactured about this time was of such comparatively high density that it could be burned in ordinary lamps. The subsequent development of the petroleum industry, however, rendered it very necessary to devise special lamps. The first patent taken out for a petroleum lamp, so-called, in the United States, was dated 1859, and in that year forty applications for patents for petroleum lamps, burners and appliances in general were granted. In the succeeding year the number of similar grants was 71, in the next year 53, and in the one after 101. From that time to 1878 the number ranged from 63 to 186; and judging by the number of new kinds of lamps which are offered for sale every year in America, the energy of the American inventor shows no signs of diminution.

Meanwhile, in England, the improvement of appliances for burning mineral oils was steadily progressing. Messrs. Joseph Hinks & Son, of Birmingham, who had commenced business as lamp manufacturers about the year 1860, patented October 28, 1865, the well-known duplex burner,* the introduction of which has done so much to popularize the use of mineral oils for illuminating purposes. The patent which was granted

* Dr. Angus Smith had previously constructed a two wick burner.

to James and Joseph Hinks was described as being for "the improvements hereinafter described in the burners of lamps for burning paraffine oil and other volatile liquid hydrocarbons, whereby two or more flat flames, or one circular, or nearly circular flame, may be produced by the use of two or more single flat wicks." The general construction of the burner was thus described:—"Our invention consists in the employment in the same burner of two or more flat or curved wick cases or holders, in which said cases or holders single flat wicks are placed. Each of the said wick cases is provided with an axis and pinions for raising and lowering the wick therein contained. The wick cases or holders are either straight or slightly curved, or of the figure of semi-ellipses, or semi-circular, so as to produce, when arranged in the burner, flat, or elliptical, or circular flames. The cone or deflector has two or more straight or curved openings in it, through which the wicks may pass. That portion of the top of the cone between the curved openings (when curved openings and curved wick holders are employed) serves as a substitute for the ordinary button used with circular wicks; or a circular hole may be used in the cone, and the ordinary button employed. When flat wick cases are employed, straight openings are made in the cone." In the original form of the flat-wick burner the two wicks were brought together into one wick tube in the lower part of the burner. Subsequent improvements effected by this firm have resulted in the production of a burner, the good features of which are too well known to need enumeration; and their conspicuous merit, from an artistic as well as mechanical point of view, is apparent. In 1871, Holver Holverstone, of Cambridge, Mass., patented a dual burner, having two flat wicks in a cone furnished with a single slot. Litigation between this inventor and Messrs. Hinks resulted in an amicable arrangement.

On January 22d, 1886, Messrs. Thomas Rowatt & Sons patented the "anucapnic" burner, which differs from those already referred to in being provided with a double cone. The use of this appliance admits of the ordinary chimney being replaced by a globe, without any diminution in the brilliancy of the light. The provisional specification, filed by Thomas Rowatt, the younger, states that his "improvements in lamps for burning paraffine, petroleum, belmontine, and other hydrocarbon oils without the use of a chimney," consists in obtaining "the necessary current of air by carrying down a tube of metal or any other suitable material from the dome to within a short distance of the bottom of the burner, extending its lower rim laterally, so that the opening remaining between the edge of this rim and the lower body of the burner becomes an air channel with a much greater superficial area than the area of the bottom neck of the tube, consequently the tube becomes an air-sluice when the lamp is lighted." The specification further states that in order that complete combustion might be effected, it was found that a second current of air must be projected on to the flame above the dome referred to. The arrangement is therefore described in the complete specification as consisting of "two round-topped hollow cones or domes, one exterior and the other interior, both being so arranged as to produce two separate and distinct currents of air." Messrs. Thomas Rowatt & Sons patented an improved anucapnic burner in 1878, and in 1882 obtained protection for a duplex chimneyless burner with single-slotted double dome, which they term the "Lorne" burner. In the latter burner the wick tubes are inclined towards each other at the top and bottom, so that the flames coalesce, and the wicks beneath the burner are in contact. Increased luminosity and increased capillary attraction result. This firm was the first to construct burners with a screw to attach them to the collar of the lamp, the burners previously made in this country being provided simply with a conical tube fitting into the collar.

Young's Paraffine Light and Mineral Oil Company, some years ago, commenced the manufacture of lamps on a large scale, and have introduced several burners of novel and valuable character. Among these are the "Champion" burner, with circular wick, the "Regulator" burner, and the "Triplex" burner, which is furnished with three flat wicks arranged triangularly. The "Champion" burner was patented by A. E. Ragg, in 1878 and 1880. The claims in the specification of the former patent are for the use of a central perforated cone or tubular chamber within the wick-tube circle, for supplying the upper portion of the flame with a series of small separate injected currents; for the use of a series of rays or divisions projecting from or approaching close to the wick-tube or tubes, "so as to separate the impinging current of air into a series of currents separated by quiescent intervals, thus causing serrations in the flame;" for the mode of "preventing smoke in lamps by adjusting the cap to that height above the surface of the wick, that on the cap being placed in position the flame changes from yellow to white;" and for the use of two flat wicks in an Argand burner, in such a manner that they are brought to a cylindrical contour at the top. In the specification of the subsequent patent the claims are for the use of a disk or button (either alone or in conjunction with a perforated tube), of such size as to extend over the entire area embraced by the inner wick tube, and the greater portion or whole of the wick, "so as to deflect the flame outwards to a much greater extent than heretofore, and at the same time to cause the central current of air to be deflected into the flame above the wick with a correspondingly greater force." Under this patent, improvements in the construction and fitting of the air chamber and gallery, and an arrangement for regulating the level of the oil, are also claimed as novelties. The patent for Ragg's "regulator" burner, dated 24th October, 1878, is based upon his other patent of the same year (dated 3d June) already referred to. A considerable portion of the specification relates to improvements in the method of constructing the wick tubes so as to admit of the use of two flat wicks as described. One claim is, however, for the "regulator," which consists of a cap attached to the cone, and so formed that it covers up a portion of the wick, and excludes it from the action of the flame. "It is preferred that the portion of the wick covered up shall be the extreme ends." The inventor states that this addition to the burner regulates the height to which the wick may be turned up, and thus prevents it from being turned up high enough to cause the throwing off of smoke or unconsumed carbon, and insures a uniform and perfect trimming of the wick. The unconsumed portion of the wick protected by the "regulator" is also said to act as a feeder to the flame, so that in the use of the lighter oils the flame is maintained of full size for a greater length of time, while oils too heavy for use in lamps of the usual construction are caused to burn satisfactorily. An additional claim is for a chimneyless flat-wick burner, provided with a shallow trough placed above the wick-tube, and with the bottom cut away over the wick. This trough becomes heated, and is stated to deflect the air currents so as to produce a broad flame. The "Triplex" burner was patented by Doty, in 1876, the claims being for the arrangement of three flat wicks triangularly; for the "flaring" or outward inclination of the wick-tubes; and for the construction of the cap with three intersecting hemispheres.

Mr. A. M. Silber is well known to have devoted a large amount of time and attention to the improvement of mineral oil burners, and has published the results of his efforts in an instructive paper read before the Society of Arts in 1870. The excellent results obtained with the Silber burner, which is of the round, or Argand form, are due largely to the use of an inner tube so constructed and placed as to direct a current of air on to the inner surface of the flame at a point some distance above its base. Professor Barff has stated that the prismatic spectrum of the light emitted by this burner is nearly identical with that of the solar ray; it should, therefore, allow nearly all shades of color to be distinguished as in daylight.* The Silber burner with central tube was patented in April, 1873, and the claim specified is for "the improved burner hereinbefore described, in which there are one or more air-tubes receiving atmospheric air through apertures in their sides or peripheries at the lower part thereof, substantially as described." Two years previously Mr. Silber patented a lamp provided with an annular air-space passing vertically through the body of the lamp between the wick chamber and the oil reservoir. Oil was supplied to the wick through several small tubes connecting the base of the oil reservoir with the wick case, and thus the main body of the oil was kept cool, while the

* This remark would, no doubt, be equally applicable to the light given by other mineral oil lamps of modern construction.

small quantity supplied to the wick became considerably heated.

The lamp which has been recently introduced by Messrs. J. Defries & Sons, has several valuable characteristic features. It is on the Argand principle, and is the invention of Mr. Sepulchre. The air passes to the interior of the flame through the base of the lamp, and the wick is contained in an annular space formed by the air-tube (which passes completely through the oil reservoir) and an outer tube attached to the burner collar. The latter tube reaches nearly to the bottom of the oil reservoir, and, being slightly longer than the wick, is always sealed by the oil. Thus the passage of flame from the burner to the air space of the oil reservoir is prevented, and the oil cannot flow out in the event of the lamp being overturned.

The "Lampe Belge" has a similarly placed central air-tube, but is not provided with the long outer wick-tube. The "Excelsior" lamp has an Argand burner with two flat wicks, which, meeting in the wick case, furnish a tubular flame. The wicks are fixed in wick-holders sliding in the wick-tube, and are raised or lowered by a rack and pinion.

The "Waterbury" lamp has an Argand burner provided with an ingenious arrangement for facilitating the insertion of the wick, and with an equally ingeniously contrived extinguisher, to which I must again refer. The "Star" lamp is also on the Argand principle, and has the annular air-space, surrounding the wick tube and passing through the oil reservoir, already described as having been patented by Mr. Silber several years ago. It is an objection to lamps so constructed that the oil creeps over the upper edge of the wick-tube, and it has accordingly been found necessary to provide a drip-cup in the base of the lamp. A later form of the "Star" lamp manufactured by Holmes, Booth, & Hayden Co., New York, has a good extinguisher. One of the Argand burners (patented by J. Funck in 1882) has a long inner wick-tube, extending almost to the bottom of the cylinder, which serves as an outer wick-case. The wick is held in another long tube of thin metal, to which is attached a stud working in a spiral groove made in the fourth tube extending downwards from the collar which supports the cone. The tube which holds the wick is revolved by a pinion working in teeth cut in the lower edge of the cone; and through the action of the spiral groove, the wick is thus raised or lowered. Of the various flat-wick burners the "Sun-hinge" is so made that, without removing the chimney, the cone can be raised like the hinged lid of a box, for trimming the wick or lighting. Another, the "Manhattan," an exceedingly good burner, giving a tall, well-shaped flame, is provided with two cones. The principal general features of the American flat-wick burners are the comparative thinness of the metal of which they are constructed, and the shortness of the wick tubes.

Both in this country and in England flat-wick burners have hitherto been far more largely used than Argand or round burners. On the European continent, on the other hand, flat-wick burners are rarely employed. The very commonest form of German round burner is that which is known as the "Cosmos." This burner has neither the additional inner tube nor the button, and accordingly it is necessary to use with it a chimney much constricted a short distance from the base. Better results, especially with the larger sizes, are obtained with the improved burners supplied by Messrs. C. H. Stobwasser & Co., Messrs. Wild & Wessel, and Messrs. Schuster & Baer, under the names of the "Victoria," the "Phœnix," the "Moon," the "Helios," and the "Solar-oil" burners. These improved burners differ from the old form of "Cosmos" burner principally in being provided with an air tube within the inner wick tube, or with a button to deflect the inner air current.

The Russian burners differ only in details of construction from those already described. One of the Argand burners and the flat-wick burner are intended for use with the heavier oils. The latter burner has a short but capacious wick tube, and takes a wick of unusual thickness. The former burner has a slightly conical chimney held in position by a metal collar fitting over its base. In 1884, the Committee of the Russian Chemical and Physical Society awarded to Kumberg the premium which had been offered for a lamp suited to Caucasian oils of specific gravity .865 to .875.

In the construction of all mineral oil lamps, the principal points aimed at are the production of a current of air passing into the burner with suitable velocity; and the direction of this air current on to the flame in a manner best adapted to secure the proper combustion of the oil. The heated chimney or other arrangement induces the required flow of air, but if in the case of an Argand lamp the chimney be cylindrical and the burner merely two tubes to hold the wick, the air would not do what is required of it, and the lamp would burn with a flame of comparatively little luminosity. In the simplest forms of flat-wick burners the metallic dome which surrounds the top of the wick tube serves to cause the air current to impinge upon the flame, the base of the burner being fitted with a disk of perforated metal to moderate the velocity of the current. In the best round burners the result is attained by the use of a metallic disk or other contrivance, sometimes in conjunction with a cone surrounding the wick tube; or as in the Silber lamp, and other lamps, by the use, in addition to the cone, of an inner air tube of suitable size and form. The "air diffuser" of the Defries lamp (Sepulchre's patent) may be described as a combination of the button and a perforated tube closed at the top, while the air diffuser of the "Rochester" lamp and of Young's "Champion" burner consists of a cylinder closed at the top and with perforated walls. The action of the button or tube is aided by the employment of a chimney formed with a shoulder, and if the chimney be constricted just above the top of the burner, the use of the button or tube may in fact be dispensed with. The upper part of the Bayle chimney is in the form of a truncated cone, the chimney practically consisting of two cones united at their smaller ends. It is claimed that the employment of this form of chimney causes the outer air current, entering between the glass and the wick tube of an Argand burner, to pass upwards with the same velocity as that of the inner current which supplies the center of the flame with air. The use of the double cone of the anucapnic lamp as a substitute for the chimney, has been referred to. Lamps are made in which the air current is supplied by a revolving fan, driven by clockwork in the base of the lamp; this method of construction being illustrated in the lamp made by Messrs. Gardners. Martin Rae, in 1861, patented the use of a small lamp in the base of the lamp proper to create a current of air, the use of a flame "of the size of a common pea" being, he states in his specification, "sufficient to rarefy the air of a lamp with a flame of two inches square."

The "blast lamp," patented by Robert Lavender in 1875, and introduced by Young's Paraffine Oil Company for use in illuminating large spaces in the open air, was provided with an arrangement for introducing a jet of steam into the chimney, on the principle of the "blast" employed in locomotives, and thus producing a strong upward current of air, suitable for the combustion of the heavier mineral oils.

In the case of Argand oil burners, it may be said that there are four principal points at which the air currents impinge upon the flame. Thus as regards the interior surface of the flame, the current of the air first comes into contact with the base of the flame, while a portion is, by the use of a deflector or central tube, or other contrivance, caused to strike the flame at a higher point. Similarly as regards the outer surface of the flame a portion of the air current meets the flame at its base, and another portion comes into contact with the flame surface higher up. As we shall presently see, when considering the subject of lighthouse illumination, Sir James Douglass's mineral oil burner has a cone provided with three openings for air, at gradually increasing heights from the base, and the air is thus supplied to the exterior of the flame in comparatively small quantities at different elevations.

Scarcely less important than the production and direction of the air current is the maintenance of a proper supply of oil to the flame. With most mineral oil lamps this is effected through the unaided capillary attraction of the wick, and it is obvious that the quality of the wick is a point of great importance. In the student or reading lamp the action of the wick is aided by maintaining a constant level of oil on the principle of the bird fountain already mentioned. The principle of the "Moderator" lamp is also sometimes applied to lamps for domestic use, as in the Peigniet-Changeur lamp shown at the International Health Exhibition, the oil pumped up being, however, allowed to overflow at a lower level in the wick tube than in the case of colza oil. Mr. Silber has proposed to lay on a supply of oil to the various burners throughout a dwelling house from a reservoir on each floor, kept filled from a storage tank, the supply being regulated by the use of ball valves. Peter Brash and William Young patented a similar arrangement in 1867, and Mr. D. C. Defries has recently patented a method of arriving at the same result. Messrs. Hinks some years ago manufactured a lamp in which the oil container from which the wick drew its supply could be caused to descend into a well or reservoir forming the base of the lamp, and could thus be refilled. In some lamps the action of the wick proper is aided by the provision of a "wick feeder," consisting of a thick and loosely woven wick attached to the under surface of the burner, in contact with the wick proper, and dipping into the oil.

The wick is usually raised or lowered in the wick case by the action of toothed wheels pressing lightly against it, the revolution of the wheels being effected by turning a button on the end of a spindle which carries them. In some instances, however, the wick is held in a tube, or frame, which is raised or lowered by a rack and pinion, or by a worm cut on the burner tube, and actuated by revolving the burner, or, as in the "Rochester" lamp, by means of a vertical rod attached to the wick frame. The flame has always hitherto been produced from the extremity of the wick, but an arrangement for presenting a fold of a continuous flat wick as the burning surface was shown in the International Inventions Exhibition. The burner thus fitted was provided with a device for causing the wick to travel through the burner so that a fresh portion of wick could be exposed when desired.

The wicks at first employed in lamps for burning fixed oils were of the nature of a loosely woven cord or solid cylinder. In 1773, Leger used a flat wick, and a few years later Argand adopted a tubular wick. Ditmar and others have used two wicks; one to bring the oil up to the burner, and the other to burn it. With a large number of the round burners of the present day, a flat wick of such breadth that the edges meet in the annular wick space is employed, and in some instances two flat wicks are similarly used. The "Mitrailleuse" burner is, however, furnished with a number of solid cylindrical wicks, arranged in a circle, and held in a frame, which is raised or lowered by a rack and pinion. Messrs. Browne & Co., and Mr. Rettich, manufacture this form of burner. The Rettich "Mitrailleuse" burner has an air deflector of improved form. The "Sirius" burner, patented by Morrison & Smith, and one form of the "Martin" burner, are provided with two concentric wicks; but compound Argand burners are, for the most part, used only for lighthouse illumination.

Considerable attention has for some years been paid to the construction of wicks in the United States. The various operations, in the order in which the cotton is subjected to them, are in the United States termed:—(1) opening; (2) lapping; (3) carding; (4) railway drawing; (5) doubling and first drawing; (6) doubling and second drawing; (7) slubbing and roving; (8) speedy roving; (9) spinning; (10) twisting, which makes the yarns ready for the looms.

It is important to dry the wick before it is used, and wicks are frequently found to have absorbed from 4 to 6 per cent. of their weight of moisture, and to the extent to which this moisture is present, the capillary attraction of the wick when used in the lamp is impaired. The following results of experiments which have been made with wicks of various qualities in common use, clearly indicate the importance of employing a wick of good quality. The figures indicate the relative quantities of a given oil of good quality drawn through wicks of the same width, by capillary attraction in a given time:

Wick of best quality............. 198
Wick of medium quality........ 100
Wick of inferior quality......... 76

The extent to which the behavior of the lamp is affected by the quality of the wick, especially with oils that do not flow very freely under the influence of capillary attraction, is strikingly shown by the following results which the author obtained under otherwise similar conditions:

	Wick of best quality.	Wick of ordinary quality.	
Maximum illuminating power............	10.43	9.99	Standard candles.
Minimum illuminating power after six hours' burning	9.63	7.64	Standard candles.
Average illuminating power during six hours' burning......	10.14	8.99	Standard candles.
Diminution in illuminating power, per cent....	7.6	23.5	
Oil consumed per hour.	529	500	Grains
Oil consumed per candle light per hour.......	52.17	55.61	Grains

Many of the complaints of unsatisfactory burning quality of oil have undoubtedly arisen from the use of inferior wicks.

As an illustration of the ignorance which frequently prevails as to the importance of using a good wick, it may be mentioned that an American, engaged in the petroleum trade, being unable to account for the reiterated statements of a customer that the oil supplied would not burn, caused an examination to be made of the lamp in which the oil was used, and found that the wick having become short the complainant had ingeniously lengthened it by attaching with two pins a strip torn from an old flannel garment. This arrangement appeared to have answered the purpose fairly well until one of the pins fell out unperceived, when the surfaces of contact of the flannel and wick were no longer sufficiently large, and the lamp having ceased to burn, the oil was hastily assumed to be in fault.

In certain cases, however, it is found that a wick gives satisfactory results for several days and then appears to become choked. Even in such cases, however, the use of a sufficiently good wick overcomes the difficulty, as is shown in the following tabular statement of the results of some experiments made two years ago. For convenience of comparison the illuminating power is expressed at the commencement of the experiment as 100 in each case:

	Wick of best quality.		Wick of ordinary quality.
Maximum illuminating power when the wick was new......	100	..	100
Maximum illuminating power after the wick had been used for a total of 21 hours on 3 successive days..............	—	..	58.5
Maximum illuminating power after the wick had been used for a total of 32½ hours on 5 successive days..............	—	..	17.8
Maximum illuminating power after the wick had been used for a total of 50 hours on 7 successive days..............	93.8	..	—

Mr. Nakamura formed the opinion that this choking results from the deposition of water in the wick, since the wick recovers its capillary power on drying. Among those who have experimentally investigated the subject of the diminution in illuminating power in petroleum lamps are Colonel Junker, director of the Test

Bureau of the Bremen Petroleum Börse, Mr. L. Schmelk, chemist to the Norwegian Sea-lighting establishment, and Dr. J. Biel, of St. Petersburg.

While on the subject of wick manufacture, it may be pointed out that it is much to be desired that lamp manufacturers would adopt standard gauges for the wick tubes. At the present time an unnecessarily large number of wicks, varying in thickness and in width by sixteenths of an inch, have to be made and kept in stock, and since the nominal widths of the wick tubes sometimes differ to a considerable extent from the actual widths, it frequently results that the wick supplied does not fit the tube properly. The wicks in use in England with mineral oils range in width from $\frac{1}{4}$ of an inch to 5 inches, the greatest difference in width between any two of the intermediate sizes being $\frac{1}{4}$ of an inch, and the difference being in many cases as little as one-sixteenth of an inch. There is also considerable variation in different burners in regard to the thickness of the wick the holder will properly take. If the wick is too narrow, the lamp will not burn well, and its use may even be dangerous. If the wick be too thin, it is deficient in capillary attraction, and if too thick it will not move freely.

Several kinds of incombustible wicks have at various times been introduced. The wick patented in 1876, and in an improved form in 1877, by Heinrichs, consists of a lower portion of felt, an intermediate portion of mineral wool, and an asbestos top or ring. In the International Inventions Exhibition last year, a lamp with an asbestos wick patented by Messrs. Flatau and Turner was shown. One of the claims in the patent specification relating to this lamp is for the division of the wick horizontally into two portions, one of which can be moved up or down so as to be put into or out of contact with the other portion. The inventors appear to prefer that the upper part of the asbestos wick should be a fixture in the wick tube and that the lower part should be moved downwards out of contact with the upper part when it is desired to extinguish the lamp.

It is now usual to fit the larger burners with some form of extinguishing apparatus. The earliest attempt to fit an extinguisher was probably that made in the case of the improved "Brighton" burner, patented in 1862. This burner has an air deflector or button, the stem of which rests upon a pin passing horizontally through the burner. On withdrawing the pin, the button drops on the wick and extinguishes the flame. In the "Waterbury" burner, the dropping of the button is also effected by drawing out a pin, but the action compresses a spring and the button resumes it normal position on the pin being released. The button extinguisher of the new "Star" lamp is brought into action by depressing a thumb plate, and in this case also the button returns to its original position when the pressure is removed. The "Duplex" burners of Mr. James Hinks & Son, Messrs. Wright &

Butler, and others, are fitted with ingeniously contrived extinguishing apparatus, which, on depressing a lever, bring a pair of metallic plates into contact over the top of each wick tube. In one of the "Duplex" lamps made by Messrs. Wright & Butler, the extinguisher is automatically brought into action as soon as a weighted rod suspended beneath the burner passes to any material extent out of a line perpendicular to the base of the lamp. It is therefore impossible for the lamp to become tilted when falling without the flames being extinguished. An automatic extinguisher has also been patented by Messrs. King & Godfrey.

Two of the "Duplex" burners and Rettich's "Mitrailleuse" burner are provided with mechanical arrangements for raising the gallery carrying the chimney and globe, so that the wicks may be conveniently lighted. In Wright & Butler's "Duplex" the gallery is supported on levers, which, on turning a key, not only raise the chimney and globe, but also move them to some extent horizontally.

In Hinks' "Duplex" the movement of the gallery, effected by turning the key, is vertical only. In Rettich's "Mitrailleuse" there is no key action, but the gallery slides up to an extent sufficient to admit of inserting a lighted taper.

Messrs. C. H. Stobwasser & Co., of Berlin, have recently adopted a process for preventing the oil from "creeping" over the edge of the burner collar and soiling the exterior of the reservoir. The process consists in placing in the collar, between the edge of the reservoir and the plaster of Paris which is used to attach the collar, a layer of some compound which looks like a mixture of gelatine and glycerine. The oil will pass through the plaster, but is arrested by the compound referred to. The upper surface of the collar of the lamp is also made slightly conical, and at its inner and lower edge, at the junction between the collar and the burner, a small hole communicating with the oil reservoir is made. Any oil, therefore, which drops from the burner returns to the reservoir.

On the pin of the wick winder is soldered a small star shaped wheel, the points of which are over the conical collar. Oil passing along the pin is stopped by the star wheel, and drops from its lowest point on to the collar.

We have now to consider the principles of construction of mineral oil lamps in relation to the question of safety. It is well known that accidents in the use of mineral oil lamps are, unfortunately, of by no means rare occurrence, though the number bears a very small proportion to that of the lamps in use. The attention of authorities and experts in the United States has long since been directed to the comparative frequency of such accidents, and Dr. Chandler, of New York, as long ago as 1871, published a report of a lengthy series of experiments which he had undertaken with the object of ascertaining the conditions under which the accidents occurred. It seems, however, to have been somewhat hastily assumed that the accidents were the results of explosions of the mixture of petroleum vapor and air formed in the upper part of the oil container, and the experiments were therefore chiefly directed to ascertaining the relation between the flashing point of the oil and the temperature to which the oil was raised when burning in various forms of lamps. Commenting on these experiments, Mr. Peckham very properly points out in his census report that, although explosions undoubtedly sometimes break lamps, the danger arises principally from the risk of overturning and breaking the lamp.

In a lecture, delivered at the Royal Institution eleven years ago, Sir Frederick Abel stated that a large proportion of the accidents arising out of the use of mineral oil lamps were not actually due to the occurrence of explosions; and in a subsequent lecture he added, that instances might be quoted in which the breaking out of a fire, or the destruction of or injury to life, which had evidently been caused by upsetting or allowing to fall a mineral oil lamp, had been erroneously ascribed to an explosion. There are, however, as Sir F. Abel said, numerous cases of accidents which have been caused by explosions in lamps, followed by the ignition of the oil. The experiments which have been made by Sir Frederick Abel and the author, with the valuable aid of Dr. W. Kellner, Assistant Chemist of the War Department, have enabled them to arrive at several definite conclusions with respect to the immediate causes of lamp explosions, and to certain circumstances which may tend to favor the production of such explosions. These conclusions were so clearly set forth by Sir Frederick Abel, which is here quoted verbatim:—

"If the lamp of which the reservoir is only partly full of oil, be carried or rapidly moved from one place to another, so as to agitate the liquid, a mixture of vapor and air may make its escape from the lamp in close vicinity to the flame, and, by becoming ignited, determine the explosion of the mixture existing in the reservoir. This escape may occur through the burner itself, if the wick does not fit the holder properly, or through openings which exist in some lamps in the metal work, close to the burner, of sufficient size to allow the flame to pass them readily. A sudden cooling of the lamp, by its exposure to a draught, or by its being blown upon, may give rise to an inrush of air, thereby increasing the explosive properties of the mixture of vapor with a little air contained in the reservoir, and the flame of the lamp may at the same time be drawn or forced into the air-space filled with that mixture, especially if the flame has been turned down, as the latter is thereby brought nearer to the reservoir. The sudden cooling of the glass, if it had become heated by the burning of the lamp, may also cause it to crack if it is not well annealed, and this cracking, or fracture, which may allow the oil to escape, may convey the idea that an explosion has taken place. If the evidently common practice is resorted to of blowing down the chimney with a view to extinguish the lamp, the effects above indicated as produceable by a sudden cooling may be combined with the sudden forcing of the flame into the air space, and an explosion is thus pretty certain to ensue, especially if that air space is considerable. If the flashing point of the oil used be below the minimum (73° Abel) fixed by law, and even if it be about that point or a little above it, vapor will be given off comparatively freely if the oil in the lamp be agitated, by carrying the latter, or moving it carelessly; the escape of a mixture of vapor with a little air from the lamp, and its ignition, will take place more readily, but, on the other hand, it will probably be feebly explosive, because the air will have been expelled in great measure by the generation of petroleum vapor. If the flashing point of the oil be high, the vapor will be less readily or copiously produced, under the conditions above indicated, but, as a natural consequence, the mixture of vapor and air existing in the lamp may be more violently explosive, because the proportion of the former to the latter is likely to be lower and nearer that demanded for the production of a powerfully explosive mixture. If the quantity of oil in the lamp reservoir be but small, and the air-space consequently large, the ignition of an explosive mixture produced within the lamp will obviously exert more violent effects than if there be only space for a small quantity of vapor and air, because of the lamp being comparatively full. If the wick be lowered very much, or if for some other reason the flame becomes very low, so that it is burning beneath the metal work which surrounds and projects over the wick holder, the lamp will become much heated at those parts, and the tendency to the production of an explosive mixture within the space of the lamp will be increased, while, at the same time, heat will be transmitted to the glass, and it will be correspondingly more susceptible to the effects described as being exerted by its sudden exposure to a draught. Experiments have demonstrated that a lamp containing an oil of high flashing point is more liable to become heated than if it contained a comparatively light and volatile oil, in consequence of the much higher temperature developed by the combustion, and of the comparative slowness with which the heavy oil is conveyed by the wick to the flame. It therefore follows that safety in the use of mineral oil lamps is not to be secured simply by the employment of oils of very high flashing point (or low volatility), and that the use of very heavy oils may even give rise to dangers which are small, if not entirely absent, with oils of comparatively low flashing points."