CANADA

DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; R. W. BROCK, DEPUTY MINISTER.

MINES BRANCH

EUGENE HAANEL, PH.D., DIRECTOR.

Petroleum and Natural Gas Resources of Canada

IN TWO VOLUMES

VOL. I.

TECHNOLOGY AND EXPLOITATION

BY

Frederick G. Clapp,
and Others

OTTAWA

GOVERNMENT PRINTING BUREAU

1914

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PREFACE.

Arrangements were made with Mr. F. G. Clapp, of Pittsburgh, Pa., in April, 1912, to prepare this monograph on Petroleum and Natural Gas with special reference to Canada. It was proposed that the monograph should contain a general summary of all the information that was available with respect to the present or prospective Petroleum or Natural Gas fields in all the provinces of the Dominion. In addition, chapters on special subjects, such as the Technology of the Natural Hydrocarbons; Methods of Prospecting for Oil and Gas; Drilling Equipment; Development of Petroleum and Natural Gas fields; and related matters, were to be included in the monograph.

Mr. Clapp, and his assistant—Mr. L. G. Huntley—each spent about three months during the seasons of 1912 and 1913 on field work in connexion with this report. In November, 1913, before the manuscript was complete, Mr. Clapp accepted private contracts which necessitated his leaving for China. With the consent of the Director of the Mines Branch, he made personal arrangements with certain gentlemen, named below, to prepare special chapters of this report. He also arranged with Dr. David T. Day, of the United States Geological Survey, to assemble the whole report, and to forward it to this office when completed.

Under the arrangements made by Mr. Clapp, the following gentlemen have contributed chapters or sections of this report:—

1. Marius R. Campbell, of the United States Geological Survey, chapter IV, vol. I, on Theories as to the Origin of Petroleum and Natural Gas and their Migration in the Rocks of the Earth's Crust.

2. James H. Gardner, Lexington, Ky., contributed the sections of chapter VI, vol. I, dealing with the Surface Indications Useful in Exploration for Petroleum and Natural Gas.

3. Ralph Arnold and V. R. Garfias contributed the sections of chapter VI, vol. I, dealing with the subject of Casing of Oil Wells and the Exclusion of Water from Oil Wells.

4. Forrest M. Towl contributed chapter VIII, vol. I, on the Transportation of Oil and Gas.

5. T. T. Gray contributed chapter IX, vol. I, on the Utilization of Petroleum and Its Products.

6. Roswell H. Johnson contributed the sections in chapter X, vol. I, discussing Efficiency in the Extraction of Oil and Gas.

7. Mr. L. G. Huntley was associated with Mr. Clapp in much of the field work and is largely responsible for work in Ontario and on the lower Athabaska river. He also assisted in much of the office work.

The completed report was assembled by Dr. David T. Day in Washington, and reached this office in December, 1913. An examination of the text by several qualified officers of this Department indicated that there were a number of places where changes and corrections in matters relating to Canadian geology and geography were desirable. Since Mr. Clapp was absent in China, to return the report was impossible, as there is a pressing need for its publication, and the return would have involved too great a delay. The only alternative seemed to be to place the revision in the hands of a qualified engineer within the Department, and accordingly, Dr. Alfred W. G. Wilson, of the Mines Branch staff, was assigned the task of making whatever revision seemed necessary.

Dr. Wilson was placed in entire charge of the report, and in addition to the revision mentioned below, has supervised the preparation and assembling for publication of all the maps, sections, and drawings, which accompany this report. All the introductory sections in chapter V which deal with the geology of the various provinces have been revised and most of them have been re-written. Such changes as were necessary in matters of geological nomenclature, and Canadian geography, have also been made in the text. No changes, beyond minor editorial corrections, have been made in any of the chapters dealing with theories, or the technology of the subject. The geological nomenclature has been made to conform with that of the Canadian Geological Survey; while the geographic names and boundaries are those having official sanction. Three geological maps have been reprinted by the Geological Survey branch of the Department, for issue with this report. The three other maps which accompany it were compiled by the Chief Draughtsman of the Mines Branch—under the general supervision of Dr. Wilson—from data obtained from publications of the Geological Survey, and other sources, also from data supplied from Mr. Clapp's office. The numerous plates showing well logs were compiled in Mr. Clapp's office from various sources, and were transmitted to this office in the form of blue prints. These have all been re-drawn as accurately as possible; but the original geological nomenclature has been retained, because, in the majority of cases, it is that which was used on many of the original sections prepared by officers of the Geological Survey and others many years ago. In the text, however, particularly with reference to the geology of the Ontario peninsula, the nomenclature used is that officially adopted by the Geological Survey, on the basis of recent work by officers of the Survey, and others. The principal changes, so far as nomenclature is concerned, are the use of Beekmantown instead of Calciferous; Lorraine for Hudson River; and Onondaga for the Corniferous of the older geologists, together with the recognition of the occurrence of the Munroe formation above the Salina.

Since it has been impossible to submit the revised portions of the text to Mr. Clapp, before publication, all essential changes or additions which have been made by Dr. Wilson, or under his supervision, have been signed by him, or have been indicated by footnotes. All the proofs have also been read by Dr. Wilson as well as by the staff of the editor's division of the Department of Mines.

It has been found necessary to publish this report in two volumes, the first being devoted chiefly to the technology of petroleum and natural gas and to the methods of exploitation, the second dealing with the occurrences of petroleum and natural gas throughout the provinces of Canada. This latter volume is further divided, for convenience of distribution, into Part I, Eastern Canada, and Part II, Western Canada.

(*Signed*) **Eugene Haanel,**
Director Mines Branch,
Department of Mines.

Ottawa, Aug. 1, 1914.

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Letter of Transmittal.

Dr. Eugene Haanel,
Director Mines Branch,
Department of Mines,
Ottawa,
Canada.

Sir,—I have the honour to transmit, herewith, the manuscript—consisting of text and illustrations—of a report on the Petroleum and Natural Gas Resources of Canada, to be published by the Mines Branch. This is a broad discussion, prepared during the past few months, of the subject as it pertains to the Dominion as a whole, with such general chapters added as are important to give a general understanding of the Petroleum and Natural Gas industry, and of its various phases. The report is not intended to enter into exhaustive discussions of individual fields, or to solve all the complicated problems regarding petroleum and natural gas in various parts of the Dominion, since such an undertaking would be a matter of years of study and work, but as much detail is included as has been possible in the time allotted, I trust that the publication may be of some value in the development of the Dominion's resources.

Very respectfully,

(*Signed*) **Frederick G. Clapp.**

Pittsburgh, Pa., U.S.A., March 1, 1914.

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CONTENTS.

TABLES.

ILLUSTRATIONS

Photographs.

Drawings.

Note.—The author is indebted to his students, Mr. G. W. Meyers for figures 16, 18, 19, and 20; Mr. F. A. Johnson for figure 17; and Mr. W. E. Bernard for figures 21, 22, 23, and 24, which are taken from their note-books in the Oil and Gas Laboratory of the University of Pittsburgh.

Map

Petroleum and Natural Gas Resources of Canada

Vol. I.

ERRATA

On page 136 is a copy of *The Petroleum Bounty Act, 1904:* this should have been supplemented by the amending Act assented to 4th May, 1910; which specifically defines the conditions controlling the bounty on the production of crude petroleum, not only from wells, but also from "shales and other substances" mined in Canada.

A copy of The Petroleum Bounty Act, 1909, will be found as an appendix to Volume II, p. 367.

On page	iii—	line 18	from	bottom,	read	Monroe, not "Munroe."
"	v—	" 6	"	" ,	"	period, " "comma."
"	ix—	" 5	"	" ,	"	Geanticlinal, not "Geoanticlinal."
"	5—	" 8	"	" ,	"	Petrolia, not "Petrolea."
"	63—	" 8	"	" ,	"	ethane, not "ephane."
"	72—	" 6	"	" ,	"	hydrolyzed, not "hycrolyzed."
"	94—	" 8	"	" ,	"	geanticlinal, not "geoanticlinal."
"	100—	" 3	"	" ,	"	" " "
"	100—	" 2	"	" ,	"	geanticline, " "geoanticline."
"	104—Figure 7 is inverted.					
"	106—	line 1	from	bottom,	read	artificially, " "artifically."
"	109—	" 5	"	" ,	"	trachyte, not "trachite."
"	111—	" 6	"	top ,	"	carburetted, not "carburretted."
"	133—	" 9	"	bottom,	"	two, not "three years."
"	181—	" 15	"	top ,	"	gauge, not "guage."
"	269—	" 4	"	bottom,	"	Mariotte's, not "Mariott's."
"	286—	" 15	"	" ,	"	Jan. 25th., not "15th."
"	286—	" 13	"	" ,	"	1903, not "1893"
"	287—	" 17	"	" ,	"	£3 not "£1 3s."
"	291—	" 12	"	top,	"	reverberatories, not "reverboratories."
"	339—	" 6	"	" ,	"	integration, not "intergration."
"	340—	" 3	"	bottom,	"	carbureter, not "carboreter."
"	342—	" 16	"	" ,	"	mantle, not "mantel."
"	346—	" 7	"	top ,	"	Abitibi, not "Abittibi."
"	357—	" 1	"	bottom,	"	Vermilion, not "Vermillion."
"	359—	" 10	"	top,	"	" " "
"	364—	" 6	"	" ,	"	hydrocarbon, not "hydrocarbons."
"	372—	" 10	"	bottom,	"	mantle, not "mantel."
"	375—	" 26	"	" ,	"	Herzegovina, not "Herzegovnia."

PETROLEUM AND NATURAL GAS RESOURCES OF CANADA

IN TWO VOLUMES

VOL. I.

HISTORY, GEOLOGICAL OCCURRENCE, TECHNOLOGY, AND EXPLOITATION

PETROLEUM AND NATURAL GAS RESOURCES OF CANADA.

VOL I.

CHAPTER I.

HISTORY AND DISTRIBUTION OF PETROLEUM AND NATURAL GAS.

INTRODUCTION.

IMPORTANCE OF PETROLEUM AND NATURAL GAS.

Petroleum is the most important of the bitumens, and, next to coal, the most important of all carbon compounds. Although the first commercial development of significance took place barely half a century ago, the production has increased by tremendous strides until to-day the output has reached enormous proportions. There is no sea whose waters are not churned by the propellers of oil-burning steamships, no country whose roads have not seen the petrol-driven motor car, and no village in the civilized world in which the flame of kerosene or other form of petroleum does not illuminate some house. Thousands of miles of highways are kept free from dust or otherwise improved by the use of petroleum oil.

Wherever petroleum occurs in nature, there also, as a rule, natural gas is likewise found. But gas is less restricted in distribution than oil, and hundreds if not thousands of good gas wells are found where no petroleum occurs. Although its physical character makes it somewhat inadapted to transportation and limits to a certain extent the range of its use, it is, nevertheless, conducted by a vast number of pipe-lines—some of which are hundreds of miles in length—to a great number of towns and cities, as well as to numerous glass and iron works and scores of other classes of industrial plants. It furnishes the cheapest and most convenient fuel and illuminant to many thousands of people in the different countries in which it occurs.

Both petroleum and natural gas are among the great industrial resources of the world and the countries possessing them in large quantities are fortunate indeed. The fact that they have not yet been developed in a locality is rarely a proof of their absence. No year passes without the discovery of some new and often unsuspected field. No stratified rock is so young, and scarcely any so old that the occurrence of oil in it is impossible.

The production of petroleum has advanced steadily in recent years, even in long settled regions, and there is no reason to believe that the maximum output has been reached. The new fields that are discovered each year and the old fields which are extended into new territory more than counterbalance, up to the present time, the losses due to exhaustion of older territory. Any country in which the geological conditions are favourable is, therefore, warranted in exerting every effort to investigate and determine its resources in petroleum and natural gas.

FORMS OF BITUMENS.

Petroleum (from the Latin meaning rock-oil) is the best known of the various natural hydrocarbons of the bitumen series. It is the *erdöl* or *steinöl* of the Germans and the *pétrole* of the French and other nations of southern Europe. The relation of petroleum and natural gas to allied bitumens is indicated in the following classification:—

Classification of Bitumens.

NAMES.

FORM	English	German	French	Spanish
Solid...............	Asphaltum	Asphalt Erdharz	Asphalte	Brea Chapapote
Semi-fluid..........	Maltha		Goudron minéral	Brea
Fluid...............	Petroleum Naphtha	Erdöl or Steinöl	Pétrole	Aciete
Gaseous.............	Natural gas	Natur gas	Gaz natural	Gas natural

EARLY KNOWLEDGE OF THE BITUMENS.

The bitumens were not only known but were probably fairly familiar to mankind before the beginning of the historic period. "The vale of Siddim was full of slime pits" (Genesis, XIV, 10). "Slime had they for mortar" (Genesis, IX, 3) in the building of the tower of Babel. "Oil out of the flinty rock" is mentioned in Deut., XXXII, 13, and in Job, XXIX, 6, "the rock poured me out rivers of oil."

Maccabees, II, 18-22, gives an account of the hiding of the fires from the altar in a deep pit with water by the Priests of the Sun, where, when Nehemiah was sent to investigate in later years, "they found no fire, but thick water." On placing this upon sacrifices and wood on the altar, the sun appeared from behind a cloud and "there was a great fire kindled, so that every man marvelled."

The pits dug for the collection of the oil were called by the Jews *nephtar* or *nephtoj* (nafta of the Persians), from which is derived the word naphtha of to-day.

Bitumen was used in ancient Nineveh and Babylon to cement the bricks and tiles of the temples, and in their grand mosiac pavements, the material probably coming from the Springs of Hit on the Euphrates. These later became famous as the springs of Oyum Hit or Fountains of Hit of the Arabs or the Cheshmeh Kir or Fountains of Pitch of the Persians. To the Turks the pitch was known as Hara saker.

Another important use of the bitumen or pitch in early times was in making tight the seams of vessels. Noah was commanded (Genesis, VI, 14): "Make thee an ark of gopher wood, rooms shalt thou make in the ark, and shalt pitch it within and without." Its use in boats on the Euphrates and in Egypt continues to this day.

Semi-fluid bitumen was also used by the ancients for lining cisterns and granaries, as is indicated by ruins still existing in Mesopotamia, Syria, and Egypt. In the latter country, bitumen was also extensively used in embalming, and to it we owe to a considerable extent the high state of preservation of the mummies.

At a very early period the Persians made pilgrimages to the "fire-temple" at Baku, the flames in which were fed with petroleum and natural gas from the vicinity. Practically down to the present day, it has been similarly visited by the followers of Zoroaster in India. A similar temple, known as Jawalàmŭhki, is said to exist near Kangra in the Punjab.

A more practical use of petroleum by the Persians was for domestic purposes. Long strips of dried dung were dipped in the oil and burned both for illumination and for heating and cooking. Special chimneys were required to remove the intolerable fumes. A light coloured, transparent oil was used for medicinal purposes (Ritter, Erdkunde, II, 578).

The manner of collecting the petroleum at the close of the fifth century before Christ is thus described by Heroditus, a contemporary Greek historian:—

At Ardericca is a well which produces three different substances, for asphalt, salt, and oil are drawn up from it in the following manner: It is pumped up by means of a sweep, and, instead of a bucket, half a wine skin is attached to it. Having dipped down with this, a man draws it up, and then pours the contents into a reservoir, and being poured from this into another, it assumes three different forms; the asphalt and the salt immediately become solid, but the oil they collect . . . It is black and emits a strong odor.

Another reference to the knowledge of petroleum by the ancients is found in Sir Thomas North's translation of Plutarch's Lives (1631, p. 702), where there is reprinted a tradition of a Macedonian in charge of Alexander's effects in the wars of the fourth century before Christ, who dug for water on the banks of the Oxus. "There came out, which differed nothing from natural oile, having the glosse and fatness so like there could be discovered no difference between them."

Plutarch also described the strong impression made upon Alexander when in the district of Ecbatana (Kerkuk) he looked on a "gulf of fire, which streamed continually as from an inexhaustible source. He admired also a flood of naphtha not far from the gulf, which flowed in such abundance that it formed a lake. The naphtha in many respects resembles the bitumen, but it is much more inflammable. Before any fire reaches it, it catches fire from a flame at some distance, and often kindles all the immediate air. The barbarians, to show the king its force and the subtilty of its nature, scattered some drops of it in the street that led to his lodgings, and standing at one end applied their torches to some of the first drops, for it was night. The flame communicated itself quicker than thought, and the street was instantly all on fire."

In the days of the Roman Empire the occurrence of both semi-fluid and liquid bitumen were well-known. The Greek historian Dioscorides Pedanius described the use of petroleum in lamps before the birth of Christ, and Pliny mentions the use of oil for lighting in Agrigentum in Sicily. Stabo writing in the same period, describes the rise of pitchy substances to the surface of the waters of the Dead Sea, where they formed floating masses resembling islands.

The same writer (Strabo) also refers to asphalt deposits near Selenitza, which are to-day still unexhausted.

In the confusion attending the later days of the Roman Empire, and accompanying the rise of Mohammedanism, comparatively little was written of petroleum by Europeans, although the oil pits and springs of the Caspian region and of Persia were well known to the Arabs. Many of the travellers to India in the days before the development of the Cape of Good Hope route, however, brought back accounts of the oil or pitch encountered in the overland journey. Of these, the best known is that by Marco Polo, who travelled extensively in the region in the thirteenth century. To him we are indebted for an account of one of the early conflagrations of oil upon the surface of the ground near Baku, of streams of flaming oil, and of great explosions of natural gas.

The nature of the geographical names of many localities shows more clearly even than the references in literature the general prevalence of the bitumens. Besides the well known Oil City and Petrolea of America, there are several Pitchfords in England. In Germany, Pitchelbronn near Hagenau is named for pitch. Neft and Neftiano, referring to oil, are similarly used in Russia, while the Spanish colonial names Brea, La Brea, and Breaita again refer to pitch. In Persia, Kir (pitch) is used as a part of many place names, and in Burma Yenang (earth oil creek) is the root of Yenangyaung and Yenangyat (earth oil place), the names of important oil districts.

So general is the distribution of petroleum and natural gas that comparatively few countries are entirely lacking in signs of their existence. Such indications have long been known to the inhabitants in their vicinity and many references to them are found in literature. Petroleum, because of the more conspicuous character of its "shows" and its greater ease of utilization, has more frequently attracted attention than has natural gas, and search for it has been more vigorous.

Since the introduction of modern methods of drilling, about 1860, prospecting has been conducted in almost every part of the world, and although much of it has been misdirected, petroleum in paying quantities has been developed in scores of places, including localities in every continent, in the East and West Indies, and Oceania. Natural gas is of even more widespread occurrence, but owing to the lack of available markets in the vicinity of many of the fields, has been comparatively neglected outside of America. Here, however, its production is an industry of very great importance.

In the following summary of the petroleum and natural gas industries in foreign countries the number of scattering references made use of is so great as to make it impracticable to quote all authorities. The chief sources of information are the report of S. F. Peckham on "The Production, Technology, and Uses of Petroleum and its Products," in volume 10 of the 10th Census of the United States, pp. 1-319; "Petroleum, its History, etc.," translated from the German of Wilhelm T. Brannt, 1895, 715 pp.; "Petroleum," by Boverton Redwood, 1896, 2 vols.; "Petroleum Mining and Oil Field Development," by Arthur Beebe Thompson, London, 1910, 362 pp.; and the annual statistical reports in the Mineral Resources series of the U. S. Geological Survey, by S. H. Shotwell, Joseph D. Weeks, F. H. Oliphant, W. T. Griswold, and David T. Day.

Europe.

GREAT BRITAIN.

As early as 1667 Thomas Shirley described (Phil. Trans., II, 482) gas from a spring near Wigan, in Lancashire, some of which he successfully collected and burned. In 1739 Rev. John Clayton described (Phil. Trans., XLI, 59) a ditch in the same locality, "the water in which would seemingly burn like brandy, the flame being so fierce that several strangers boiled eggs over it." Noticing coal in the vicinity, he distilled considerable gas from it. This is apparently the pioneer attempt at distillation and was the forerunner of the commercial processes of to-day.

In 1864, naphtha or liquid bitumen was described as collecting on the surface of the water of a spring near Pitchford, in Shropshire, by Dr. Plot (Phil. Trans., XIV, 806). The petroleum of this locality later became well known and was used for medicinal purposes.

In later years petroleum has been reported from numerous other localities. In Scotland, petroleum is reported from Orkney mainland, from the Carboniferous at Dysart (Fife), Broxburn (Linlithgowshire), and Liberton (Edinburgshire). In Wales, it has been noted in the Permian, at Ruabon (Denbighshire).

In England, the greater part of the petroleum indications have been found in the Coal Measures, or limestones of the Carboniferous. The localities include Whitehaven (Cumberland), Clowne and Alfreton (Derbyshire), Worsley (Lancashire), Langton (North Staffordshire), and Coalbrookdale, Coalport, and Pitchford (Shropshire). From 70 to 100 gallons a day are pumped with the water from a depth of 960 feet in the Southgate colliery, Clowne. Other petroleum bearing formations are the Upper Devonian shales at Barnstaple (North Devonshire), and the Liassic in the Bristol district (Gloucestershire-Somersetshire). At Ashwick (Somersetshire) several barrels of petroleum entered a well following a slight earthquake in 1892.

Notwithstanding the general distribution of petroleum indications, oil has not yet been discovered in commercial quantities at any point in Great Britain. The $5,000,000 worth of petroleum produced annually all comes from the distillation of bituminous shales, the greater part coming from Scotland, with a little from Wales, but practically nothing from England.

Natural gas has been reported from the Weald clays, near Petworth, West Sussex, from mines in the Lower Silurian in Montgomeryshire, and from the Triassic salt beds of Cheshire. Sufficient quantities to cause an explosion were encountered in the construction of the Thames tunnel. In 1893 considerable amounts were struck in a well in the Jurassic at Heathfield, and in 1896 the South Coast Railway Company secured in the same locality a larger supply under a pressure of 150 pounds per square inch, from a depth of 377 feet. This is utilized for illuminating and heating purposes at a rate of 1000 cubic feet daily. Later wells have secured still larger quantities, most of which are utilized.

NORWAY AND SWEDEN.

No petroleum or natural gas in appreciable quantities is known in Norway. In Sweden natural gas is of somewhat widespread occurrence at a number of horizons, especially in Silurian, Liassic, and Miocene rocks, but the volume is usually small. Petroleum indications are less common, but oil-filled fossil cavities have long been known in the Silurian, and led in 1867-1869 to the sinking of several borings on the flanks of Mt. Osmund, of Delarne, 35 miles north of Falun. Although drilling was carried to 900 feet, only traces of oil were found. Later drilling at Nullaberg and elsewhere has been equally unsuccessful. Petroleum resulting from the decomposition of sea weed is found in small quantities along the coast near Lund.

NETHERLANDS AND BELGIUM.

Practically no indications of petroleum have been noted in the Netherlands, although an oily liquid is reported from a well in chalk near Maestricht. In Belgium, traces of petroleum are found at a number of points in the coal fields, especially in iron concretions and in fossil cavities. Oil shows are also reported in the Eocene (?) at Bourlers, near Chimai, and in the Liassic shales of Jamoigne.

FRANCE.

Indications of oil, gas, or other bitumens have long been known in France. The natural gas of the "burning fountain," at La Gua, near Grenoble, Department of Isère, was described as early as 1618. At this date, or even earlier, petroleum was collected from the surface of a spring at Gabian, Department of Hérault, on the Gulf of Lyons, and used for medicinal purposes. A recent boring sunk to a depth of 1350 feet at this point in the Miocene or Triassic beds was, however, without result. Small oil seeps are reported from grey Miocene marls, limestones, and sandstones at depths of from 125 to 425 feet at Clermont-Ferrand, Puy de la Poix, Malintrat and Coeur in the plain of Limagne, Puy de Dôme, between the ranges of Puy de Dôme and Forests in southeastern France, and at Châtillon on the flanks of the Alps in Savoy. A deep boring at Macholle, near Riom, found, in 1896, a few gallons of oil mixed with brine at a depth of nearly 3500 feet. Other borings have been equally unsuccessful.

SWITZERLAND.

Traces of petroleum have been found in the bituminous Miocene limestones near Mathod, Orbe, and Chavornay, Vaud, while natural gas has been encountered in the Liassic rock salt of Bex and at Montreux, Vaud.

SPAIN AND PORTUGAL.

Petroleum indications are apparently limited in Portugal to certain calcitic amygdules in basalt at Sicario, near Cintra. In Spain, on the other hand, surface indications are found at a number of points, and small quantities have been collected in tunnels at Huidsbro, 30 miles north of Burgos. Although wells were drilled to a depth of over 1500 feet, only traces of oil were encountered. A few gallons were found in a mine shaft in the Eocene shales at Conil near Cadiz, but drilling was unsuccessful, as was likewise a boring sunk in similar beds near Algar, 38 miles E.N.E. of Cadiz. Other localities which have afforded petroleum indications, but which have not yielded oil in commercial quantities, are Cueva de la Pez near Bayarque, Liguenza and Molina in Guadaljara, Soria Girona, and San Lorenzo de la Muga and Pont de Molins lying to the west and north of Figueras.

ITALY.

The use of petroleum under the name of "Sicilian Oil" for illuminating purposes at Agrigentum, Sicily, before the beginning of the Christian Era was, as has been noted, described by Strabo and Pliny. The burning gas springs of northern Italy led in 1226 to the adoption by the town of Salsomaaggiore of a salamander surrounded by flames as its official emblem. In 1400 a concession for the collection of petroleum in Miano di Medesano was granted by the Ducal Chamber. The petroleum of Modena, used for lighting, medicinal, and other purposes, was discovered in 1640. Oil was collected early in the 18th century from Monta Chiaro near Piacenza and at Montechino. Genoa was lighted in 1802 by petroleum from the wells of Amiano.

Petroleum and gas indications are too numerous for enumeration. Oil in commercial quantities has been developed in Eocene, Miocene, and Pliocene beds of complicated structure in the Emilian provinces northeast of the Gulf of Genoa, in Eocene beds in the valley of Pescara, in the province of Chieti, in Central Italy, and in Eocene shales in the valley of the Liri near San Giovanni Incarico, midway between Rome and Naples. The Emilia production, after fluctuating between 2 and 30 metric tons annually for 20 years began to increase in 1880, reaching a maximum of 3532 metric tons in 1895. The yield of the Pescara district has been highly irregular, varying from nothing to 363 metric tons. The San Giovanni Incarico field reached a maximum of 600 metric tons in 1878, but was practically exhausted by 1890. Recent years have witnessed renewed activity in Italy and the production is increasing. In 1910 the yield was 7,069 metric tons for the country as a whole.

GERMANY.

The oil springs near Walsbron, Lorraine, were famous in the middle ages, and were even known to the Romans, whose coins have been found in the vicinity. Petroleum was medicinally used in Germany as early as 1436 under the name "St. Quirinus Oil," the supply coming from the Tegernsee district of Bavaria. Oil was discovered at Pechelbronn in Elsass in 1498, and shafts were early dug for its collection. Later, petroleum indications were found in Hanover, Prussia, Hildesheim, Luneburg, and elsewhere,

The commercial developments, which date back less than half a century, include the following districts: (1) North German field, (2) Elsass, (3) Bavaria (Tegernsee district). The North German or Prussian field is described as a belt lying between the Wesser and Elbe rivers north of the Hartz mountains and including the Wietz, Steinförde, Oelheim, and other pools of Hanover, etc. The petroleum, the production of which on a commercial scale dates from 1889, is said to come chiefly from limestones and sandstones of the Upper Jurassic or from transitional beds between the Jurassic and Cretaceous.

Elsass became a producer of petroleum in 1745, the oil being distilled from Tertiary sandstone mined by shafts near Pechelbronn. The production continued negligible until the introduction of machine drilling in 1881. Petroleum is also found at Lobsann and Schivabweiler near Strassburg in Lower Elsass, at Olhungen and Woerth, and at Altkirch near Basle in Upper Elsass.

The petroleum of the Bavarian field is from the Eocene marls and sandstones. The production is very light.

The total production of Germany in 1910 was 1,032,522 barrels, of which four-fifths came from the Prussian field with most of the balance from Elsass.

AUSTRIA-HUNGARY.

Galicia or Austrian Poland is the most important of the various provinces from the standpoint of petroleum indications and production. The "earth-balsam" was used medicinally in

1506. In 1810 oil from the Drohobycz district was distilled on a small scale and used for lighting the Alstetterung at Prague. Refining on a commercial scale dates from 1852. In 1853 petroleum was substituted for candles in the stations of Emperor Ferdinand's North Railroad, and in 1854, five years before the drilling of the Drake well of Pennsylvania, it was an article of commerce in Vienna.

The first systematic development in Galicia was in the Bobrka field in 1854, at which time considerable quantities were collected from trenches and shallow wells. The introduction of drilling in 1885 was accompanied by a rapid increase in production. The development of other fields followed in quick succession, more than a dozen distinct districts being recognized. Many of the wells were remarkable producers, yields of from 1,000 to 3,000 barrels per day not being uncommon. The "Jacob well" in the Boryslaw district is reported to have afforded between 6,000 and 7,000 barrels a day. The record spouter, however, appears to have been the "Oil City Well," struck July 4, 1908, at Tustanowicz in the same field.

The Galician oil field forms a belt 50 miles wide and 200 miles long, lying on the north flank of the Carpathian mountains. The geology is complex, the rocks being characterized by sharply compressed, irregular overthrust folds. The petroleum bearing formations are nearly destitute of fossils, but appear to include Lower and Upper Cretaceous, Eocene, Oligocene, and Miocene. The Eocene, which is very persistent, produces the largest quantities. Lithologically, the rocks are largely shales and sandstones, with some conglomerate and more rarely limestone. Beds of identical character occur at different horizons, adding greatly to the complexity of the geological problems.

The production of the province of Galicia increased from 4,300 barrels in 1878 to 15,000,000 barrels in 1909, but the following year saw the beginning of a marked decline and in 1911 the production was only 10,500,000 barrels.

In the Croatia-Slavonia district oil springs have been noted in the Pliocene shales at Ludbreg, 60 km. northeast, and at Lepavina, 15 km. south of Agram. Borings have obtained small yields at Ribejak, while natural gas has been found near Ivanich. A thick tarry oil exudes from the Miocene marls near Kutina in the Moslalvina Hills, at Bacindol, and at Petrovoszelo.

A strike of oil-gas has been made at Kalusz, in East Galicia. At the depth of 600 meters a strong flow of natural gas was encountered, which Dr. Zuber thinks is a favourable indication of deeper-lying oil sand. The Kalusz Petroleum Gesellschaft was founded with Dr. Zuber at the head of it, the object being to deepen the bore hole to 1,000 meters and develop the oil resources, if any. At a depth of 870 meters strong gas was struck. The rush was so violent that the water in the bore hole, sand, and stones were hurled over the derrick top. At first the volume of the gas escaping was measured as 200,000 cubic feet per hour. After some weeks a second gage showed a volume of 160,000 cubic feet per hour. Boring was continued, and at 890 meters a bituminous shale was met with which was recognized as the Menilite, so closely associated, as all Galician oil operators are aware, with the petroleum formations of that country. The boring is proceeding.

In Hungary, oil has been found in small amounts in Pliocene shales in the hills near Styria and Zala, from both Miocene and Pliocene at Szelnica and Peklenica on the Murakoz peninsula, in ryolite tuffs at Recsk, Heves, and in complexly folded Cretaceous, Eocene, and Oligocene beds at various points in the Carpathian mountains. In Transylvania, natural gas is given off from the Miocene salt-marls of Vizakna and Thorda, and from the Eocene beds in the valley of the Greater Kobel, and there are prospects of important developments in the near future. Petroleum is reported from the Eocene at Kovacs and Monostor, and from the Neocomian (Lower Cretaceous) along the Roumanian frontier. Producing wells have been secured in the Oligocene or Cretaceous at Sösmezö in the Ojtoz.

In Bukowina, oil has been found along the three major anticlines of the Cretaceous series, as well as in several minor folds in the same district. Traces are also reported in Silesia, Moravia, Bohemia, and the Tyrol.

GREECE.

In addition to the oil springs described by the ancients as emerging from the Tertiary deposits on the island of Zante, petroleum has been reported from the Miocene on the island of Antipaxos, in springs from Cretaceous limestone at Dremisou Maurolithari, in the Parnassid and at Galaxidi near Delphi, in seeps from lignitic Miocene strata near Lintzi (the ancient Cyllene) and from several localities on the island of Milo. Some of the earthquakes have been accompanied by discharges of oil, and petroleum and natural gas are known to rise in small quantities from beneath the sea.

RUSSIA.

The great rival of America in the production of petroleum is Russia. The oil and gas of Baku have been known from the earliest times, and up to the date of the Saracenic conquest in A.D. 636, the city was the principal point of pilgrimage of the Persian and Hindoo fire-worshippers and was visited by thousands of devotees annually. As late as 1880, according to a U.S. consular report, the Temple of Surakhani, for centuries the seat of the Sacred Fire, was still attended by priests from India.

Marco Polo, writing in the 13th century, says of the Baku springs: "There is a fountain from which oil springs in great abundance, inasmuch as a hundred shiploads might be taken from it at one time. . . People come from vast distances to fetch it, for in all the countries round there is no other oil." (The Book of Ser Marco Polo the Venetian, Ed. by Col. Yule, London, 1871, I, 4).

An inscription on a stone in an old pit indicates that the oil was worked as early as 1600. Olearius, who accompanied a German embassy to Persia in 1656, saw over 30 petroleum springs near the modern Schemakha, west of Baku. John Hanway, in his "Historical Account of the British Trade over the Caspian Sea" (London, 1754, K, 263 and 381), says of the region of the fire temples: "The earth around the place, for about two miles, has the surprising property that, by taking up two or three inches of the surface and applying a live coal, the part which is so uncovered immediately takes fire, almost before the coal touches the earth." The natural gas, to the ignition of which the flame was due, has been used for burning lime and brick from that day to this.

Speaking of the petroleum on the island of Wetoy (Sviatoi), the same writer says: "The Persians load it in bulk in their wretched vessels, so that the sea is covered with it for leagues together. When the weather is thick and hazy (low barometric pressure) the springs boil up the higher, and the naphtha often takes fire on the surface of the earth, and runs in a flame into the sea in great quantities, to a distance almost incredible. In clear weather the springs do not boil up above 2 or 3 feet. . . The people carry the naphtha by troughs into pits or reservoirs, drawing it from one to another, leaving in the first reservoir the water or heavier part."

Peter the Great, realizing the value of its petroleum, seized the Baku district from Persia in 1723, but later restored it. It was reannexed by Russia, however, in 1806. The monopoly of working the springs was sold to the highest bidder in 1820, the contract extending to 1834. From 1834 to 1850 the Government itself worked the springs, but from 1850 to 1870 they were again leased to private parties.

The collection of oil first took on business proportions in 1832, but as the Government refused to permit the use of tools and as its charges for the privilege of collecting the petroleum were exorbitant, the industry was effectively throttled. Only about 400 pits and dug wells were in existence in 1872 when the fields were put into the hands of a Government Commission. This commission divided the field into lots of 25 acres each, which were sold by sealed bids. High prices were realized. Machine drilling was introduced in 1871, but high taxes, however, prevented profitable exploitation until 1878 when they were removed. From this date the production advanced by leaps and bounds. Many gushers, some with jets from 200 to 400 feet in height, were struck. A single well yielded nearly 7,000 bbls. per day. Immense quantities were wasted, large volumes flowing off over the surface. The oil spray from certain wells was blown as much as 8 miles through the air. The maximum production in the field was reached in 1901 when an output of 80,637,300 barrels was derived from the several thousand producing wells then existing. From this quantity the yield declined to 49,791,336 bbls. in 1905, then rose again to 59,764,971 barrels in 1910, at which time a second decline set in.

The wells were originally from 400 to 800 feet in depth, but many have subsequently been deepened. The Russian developments are remarkable in being confined to small areas. The gas pressure behind the Baku wells is as great as the greatest pressures recorded in the Pennsylvanian fields. The Baku field lies on the Apscheron peninsula and has an area of 9 square miles. The oil is derived chiefly from the Oligocene series, here consisting of alternating beds of shaly marls and fine-grained calcareous sands or sandstone. Their upturned edges are covered with Pliocene or later deposits, also somewhat disturbed, and sometimes containing oil derived from the underlying Oligocene.

Other producing districts of importance are the Grosny and Maikop fields. The Grosny field lies on a sharp anticline of Miocene beds about 500 miles N.W. of Baku and north of the Caucasus range. (Lat. 43° 30′ North, Long. 44° 45′ East). It was worked by pits as early as 1823, but its modern development begins with the first drilled well in 1893. Several immense wells were obtained, one being a lake deep enough to float a steamboat. The yield of the field at one time reached nearly 300,000 barrels daily. The production has increased fairly steadily to a total of 75,189,591 barrels in 1911.

The Maikop field lies on the north flank of the Caucasus mountains in Kuban province, N.W. of the Black sea. The rocks are Miocene, the oil bearing series, about 1,000 feet in thickness, consisting of dolomitic limestone grading downward into shales and sandstone. The dip is commonly 45°—60° to the N.E. but considerable variation exists in the eastern part. Oil in large quantities was first produced in 1910 when the output was 156,640 barrels. The following year, however, the yield jumped to 952,453 barrels.

Oil shows exist in a large number of localities in Russia, Permian indications being noted in Finland, Vologda province, Central and Southern provinces, in Caucasia, Crimea, Taman peninsula, Terek, and Daghestan territories, Kutais, Tifles, etc. Several of the districts are commercially productive, the aggregate yield of the scattered localities being 4,066,782 barrels in 1911.

Notwithstanding the increasing yield of the Grosny, Maikop and scattering fields the production of Russia as a whole has declined since 1910. This is in part due to the retarding of developments in new territory resulting from the lack of transportation facilities, and in part to the Government ownership of some of the most promising territory. Its resources, however, are by no means approaching exhaustion.

The Russian gas fields are co-extensive with its oilfields, but practically none of the gas is utilized and little is known of its volume and pressure beyond the fact that the yield is great and the pressure high. At present nearly the whole is allowed to go to waste.

ROUMANIA.

Petroleum has long been known in Roumania, as is indicated by the frequent occurrence of the village name Pacureti, derived from the Wallachian word *pacura*, meaning petroleum. As early as 1750, travellers reported its use in treating diseases of cattle, lighting courtyards, and as wagon grease.

Modern activity in the development of petroleum began after the redistribution of lands by the government in 1866, but for 15 years the wells were dug by hand. The years 1880-1887 witnessed the first successful drilling. Thereafter progress was steadily forward.

The Roumanian oil district is continuous with that of Galicia, and lies along the south and southeast flanks of the Carpathian mountains, the principal centres of production being Prahova, Dimbovitza, Bacau, and Buzeu districts. The oil is chiefly from the Miocene and Pliocene, with subordinate quantities from the Eocene and Oligocene and possibly from the Cretaceous. The rocks are mainly shales occurring in alternations with sands and sandy clays, with some limestone, gypsum and salt, the whole compressed into a succession of sharp, narrow, and irregular folds associated with some faulting.

The increase in yield has been fairly steady from small beginnings to 11,101,878 barrels in 1911. Of this 90 per cent came from Prahova, 4 per cent each from Dimbovitza and Buzen, and 2 per cent from Bacau.

BOSNIA AND HERZEGOVINA.

No petroleum has yet been found in these districts, although asphaltic indications have been noted at a number of points.

MONTENEGRO.

Petroleum, associated with salt water and gas, has been reported as seeping from the Triassic shales at Bukowik, southwest of the head of Scutari lake.

EUROPEAN TURKEY.

Oil has been found in the sandy Miocene deposits bordering the sea of Marmora west of Gamos, and on the island of Koraka, opposite Salagora in the gulf of Arta. There are also more or less indefinite reports of its occurrence in the Miocene near Feredzik on the Maritza, and in the Jewish quarter of Constantinople.

Asia.

CHINA.

Oil occurs chiefly in Shensi province, China, and has been obtained in small quantities there for centuries. At present small amounts are obtained by antiquated methods and used locally. Kerosene is also found in small quantities in Shansi, Szechuan, and Kansu provinces. At Yenchang, in eastern

Shensi, are oil wells worked with rudimentary machinery under Japanese supervision. The yield of the wells now operated is small, owing to the methods in use. Petroleum, natural gas, and salt brine deposits are reported by travellers in the vast interior of the Chinese empire. However, this great empire will, for many years to come, depend upon the petroleum developed by other countries for its supply.

For many centuries in the province of Szecheun, wells have been drilled by a most primitive and laborious method from 2,500 to 3,000 feet in depth that have produced large quantities of salt brine, and natural gas and petroleum in limited quantities, the natural gas being used extensively as fuel to evaporate the salt brine. The petroleum obtained from the wells is of four different qualities. The first is of a very light colour, and is used in its natural state for burning with refined petroleum in special lamps; the second is of a very greenish colour, and is less valuable than the first; the third is of a yellow colour; and the last is black, very thick and viscous. The oil first mentioned is also employed by the Chinese for medical purposes for various diseases, especially for skin diseases and rheumatism. The temperature of the petroleum and salt water, as they come from the wells, is about 250°C., while the temperature of the atmosphere is only about 40°C.

The presence of petroleum in the salt wells and its use as fuel in obtaining the salt, makes it impossible to separate the two subjects in writing of them. In general, petroleum occupies second place. Salt production is ancient—it is a developed industry. Petroleum production is only of recent date and only exists as a side issue of the salt industry. It belongs to the future. The few wells drilled solely for petroleum may be considered the first efforts toward this new industry. The refining processes are rudimentary where they exist at all, and the oil is not sold commercially for illuminating purposes.

Many of the wells are on the side of a hill which permit of the utilizing of the natural fall, whether it be for running off the salt water into the reservoir and pans for the evaporation of the salt by solar evaporation, or whether for conducting the gas which is given off from the salt wells, which serves like petroleum for fuel. All the conduits for water, gas, and oil are bamboo. The work of drilling the wells is conducted in the following manner: An ordinary pit is dug until it reaches hard clay, which is usually found at a depth of about 200 to 300 feet. In this a wall is built cone-shaped at the top and with an opening large enough to admit the passage of the cable of a drill. Starting with the first hard layer, the drilling is carried on with a drill the width of a section 5 inches by 2½ inches and 20 feet long and weighing a little over 130 pounds. The strikes are 30 blows to a minute, falling each time 16 inches. The last layer before reaching the salt water stratum is granite and very hard. In some mines the salt water is thrown high in the air when the last layer is pierced, but only for a short time. Any natural gas found with the water is separated and sent by a main pipe to be divided to various salt pans for heating. Certain wells strike rock salt—then a second well is drilled alongside and sweet water sent down to dissolve the salt.

The largest, and one of the oldest of the springs of natural gas is that at Tse-liu-tsin, close to the mountain of the same name; while that of Chu-pai-ching has been in operation day and night for forty years. As much as 400 or 500 pounds of fetid oil, which burns on water, may be obtained from a well in a single day. When a well produces petroleum alone, the oil is conveyed to special reservoirs, but where it is found mingled with the brine it floats on the top of the liquid amd is skimmed off. Where gas is the chief product of a brine-well, all the others are neglected. The gas appears to come from two separate horizons—one comparatively near the surface and the other at a depth of about 720 yards.

According to mining regulations established in March, 1904, the Chinese government reserves for itself 25 per cent of the profits of all mines.

JAPAN.

The main supply of petroleum thus far developed in the Empire of Japan is found on the island of Nippon, in the province of Echigo, on the northwestern coast, about 200 miles northwest of the city of Tokyo. There are other localities on this island where some petroleum has been produced, namely, in the province of Ugo, in the extreme northern portion, and in the province of Totomi, about 150 miles southwest of Tokyo.

The island of Hokkaido, or Ezo has produced some superior grades of crude petroleum, in a limited way, near the western flank of the foothills of the great mountain chain running to the north, in the provinces of Mikawa and Ishikari. During 1903 and 1904 several wells were drilled in the Ishikari district which indicated the presence of petroleum in quantity; later tests, however, have given rather discouraging results. There are indications of petroleum scattered over a large portion of this northern island of Japan, and there are also indications of petroleum on the island of Formosa, and some small production in a primitive way. Oil was recently struck on this island at a depth of 810 ft.

The production in Echigo and the indications elsewhere are usually in the middle and newer Tertiary formation. Their individual occurrence is invariably on the flanks or along the crest of well-marked anticlinals. Generally these anticlinals are of comparatively short extent, as they suddenly burst out of the level newer formations, run their course, with slight undulations for from half a mile to 2 or 3 miles, and then suddenly plunge under the level surface of the plain. There are other cases where the ridge of an anticlinal can be traced 10 or 15 miles continuously.

There are usually steep dipping flanks on both sides of the anticlinals, which soon carry the oil-bearing strata to depths too great to be reached by the drill, or at which the strata are saturated with water. The depth of the wells is from 750 to 1,800 feet, and probably 80 per cent of the production comes from drilled wells. The remainder is from dug wells or shafts which range in depth from 200 to 500 feet.

The present production is maintained by the deepening of many of the wells that have exhausted the upper pay.

The formation holding the crude petroleum is generally a loosely cemented sandstone of a bluish cast, with more or less small crystals of pure silica, and in some cases with pebbles interspersed; the formation varies from 5 to 40 feet in thickness.

There are usually beds of blue shale or clay capping the sandstone, and in many wells they follow each other in succession.

The life of the average well is not long—it requires the constant drilling of new wells and the deepening of others where lower productive strata have been developed to keep up the production in most of the fields.

During the last six or eight years, the greater portion of the production has been secured by regularly cable-drilled wells, and some wells were drilled by the Canadian rod system. In 1912 and 1913 the California modifications of the rotary system were adopted with great advantage and the prospect that considerably increased production would result. It is rather surprising that the workmen of Japan should so soon have acquired the knowledge that enables them to drill wells where there are serious difficulties encountered, and a very large amount of skill is required to accomplish the end. In several of the fields, the improved methods of pumping wells in clusters by wire rope and solid connexions is used.

Natural Gas.—The banks of Lake Suwa are said to contain a large amount of natural gas, and the use of this supply for various purposes has been greatly extended with the advance of knowledge among the people there. The present consumers number more than 100, and certain villages there have been developing this industry systematically since 1911 with good results. The present output comes from four wells.

INDIA.

Almost the entire production of India is in Burma.

There are in Burma, as a matter of fact, two quite distinct oilfields, which are in process of being worked, for besides the main field in Upper Burma, there is a small field near the Aracan coast, on the islands of Ramree and Cheduba, but the output from that region per annum is only about 55,000 gallons. There appeared to be little probability of an enhanced production from this field, which seems to be of no commercial importance.

The Burma oilfield proper is situated in four sections on opposite sides of the Irrawaddy, about midway between Rangoon and Mandalay. It begins at Minbu, on the west bank of the river, just above the twentieth parallel of latitude, and about eighty miles above the old military station of Thayetmyo, and ceases for practical purposes, so far as at present known, a few miles north of Yenangyat, on the same bank, about seventy miles farther up and a few miles below Pagan, the famous old capital of Burma. Far the greater part of it, however, lies on the east bank, that portion being divided into the Yenangyaung field, twenty-six miles above Minbu, and that at Singu, about twenty miles higher up.

Petroleum is found in Assam in coal-bearing strata of Eocene age. These are exposed near the foot of the Naga hills to the southwest of the river Bramapootra. There is a line of outcrops on the northwestern slopes of the Tipham hills, a low range running from north-northeast to south-southwest and intersected by Dihing river near Jaipur and farther to the southwest by the Disang. Another line of outcrops, known as the Makum coal field, is met with farther to the east, running east-northeast and west-southwest, roughly parallel to and south of the Dihing river. It is intersected by the Tirap, Namdang Makum, and Dirah rivers, all tributaries of the Dihing, and then sinks below the alluvium near the Tipham hills. Some 40 miles farther to the southwest the coal and oil bearing strata reappear and are exposed in the beds of the Dikhu, Tanji, and Disa rivers.

Oil-bearing strata in Punjab are found among the Eocene rocks. There are two lines of outcrop running roughly east and west, one near Rawal Pindi, the other north of Shahpur. The only locality that has been worked to any extent is Gunda or Sudkal, about 23 miles west of Rawal Pindi. Oil wells were first dug in 1861. The principal well yielded at first only 5 gallons a day; on deepening the amount was increased, but it never yielded more than 50 gallons in one day, and in one hundred and ninety-eight days in 1870 only 1,963 gallons were obtained. About 1880 the total annual yield was rather more than 2,000 gallons. In March, 1888, a concession was granted to an American oil refiner, who does not appear, however, to have been very successful. In 1889 the yield was only

2,873 gallons, which appears to be the maximum amount obtained in any one year. A limited supply of oil is yet obtained. It appears to be employed in gas-making at Rawal Pindi.

PERSIA.

The Persian petroliferous region extends along a line northeast and southwest, starting at Shanku, on the Turco-Persian frontier, and ending on the eastern side of the Persian gulf.

The northern part of this basin has its center at Kasharashirin, near Shahku. Around this village are numerous pits of a depth of about 32 feet. This deposit is situated on an Eocene axis of sand and marl, and the Kurds exploit it in a most primitive manner, contenting themselves with collecting the oil from the pits every four or five days. An average output of 10 barrels is collected each time. The petroleum is very fluid and of a greenish colour and is refined on the spot. In the center of the Persian basin, parallel to the Bakhtiari mountains, there is the petroliferous district of Lauriston. This district, like that of Kasharashirin, is characterized by the same blue clays which are found in Galicia. The petroleum deposits are in the neighbourhood of important salt and sulphur deposits.

The existence of petroleum is also shown in a most conspicuous manner at Chouster, where the inhabitants collect it on the surface. The Chouster oil is of a special quality, being of a yellow colour, very clear and almost transparent, and having a specific gravity of 0·773.

South of this station and a few kilometers from Ram-Armuz are the natural springs of Chardin, one of which has a regular output of about 22 gallons per day.

Natural petroleum springs also exist near the Persian convent of Nuanzady at Haf-Cheide. These springs, which have an output of about 1 barrel per day, produce an oil of a greenish colour and of a specific gravity of 0·927.

Pacific Islands.

PHILIPPINE ISLANDS.

Oil indications are found at many points in the Philippines, especially in Luzon (southern part), Panay, Negros, Cebu, Bohol, where small amounts have been collected for nearly fifty years. Productive wells, presumably in the Tertiary, have existed for some years at Toledo on the west coast of Cebu. The belt in which these occur is probably represented on Panay, Guimaras, and Negros islands on the west and on Leyte on the east. Oil indications are also reported on Mindanao.

BORNEO, JAVA, AND SUMATRA.

Oil shows are numerous in the Tertiary coal-bearing series from the northwest part of the island of Borneo southwestward through the British possessions to Sarawak and on the adjacent islands of Labuan and Mengalon, but although some wells have been drilled, no developments of importance have resulted. In the Dutch possessions on the southeast coast, on the other hand, borings have been more successful. Since the beginning of drilling, about 1896, several hundred wells have been sunk and production has risen gradually to over five and one-half million barrels (1911). The oil is found mainly in Miocene sandstones along long narrow anticlines, and is associated with heavy gas pressures. Most of the wells are gushers. In recent years kerosene has been discovered in large quantities in Sumatra. The oil of Sumatra is of a better quality than that of Borneo, and this island produces a much larger quantity than the other two islands of the group. In Java petroleum is found at a depth of from 150 to 600 meters. There are no springs, but there are a few flowing wells, though the majority must be pumped.

Africa.

EGYPT.

Petroleum indications along the borders of the Red Sea have been known since ancient times, the Romans giving the name Mons Petrolius (Oil Mountain) to the elevation near which it was found at Jebel Zeit near the mouth of the Gulf of Suez. Pronounced oil indications have also been noted at Gemsah, 13 miles south of the first locality, but although borings were carried in 1885 to a depth of over 2,000 feet only small seeps were obtained. The rocks consist of Upper Miocene limestones, clays and gypsum, which form a belt extending from Ras El Gharib on the north to Abu Shaar on the south. Oil indications also occur in the Upper Cretaceous sandstones and limestones along a ridge parallel to the coast and lying west of the Miocene series. Oil under heavy gas pressure was found in a boring at Zafarana, while surface seeps have been noted on the Jebel Atakah, southwest of Suez. Oil indications are also reported at El Hamman (Mokattam) in the Eocene in the hills 20 miles inland from Suakin, and on the upper Nile. Although there has been considerable activity in prospecting, the production so far has been negligible. Considerable natural gas was encountered in a number of the wells, but is not utilized.

TUNIS AND ALGERIA.

Seeps of heavy asphaltic oil are reported from supposed Cretaceous limestones and shales near Testour, about 70 kilometres southwest of the capital of Tunis. In Algeria the presence of petroleum has been known since the time of the Romans, the principal occurrences being on the south flank of the Dahra range, in the Department of Oran. An attempt to collect the oil by tunnelling was made in 1877, and in 1892 test wells were drilled without much result. In 1895, however, small quantities were obtained in wells in a series of alternating Miocene marls, clays, gypsum, and limestone in the same province. Oil indications have also been reported from Cape Ivi, near La Stidia, at

Bel Hacel, on the Oued Kalaa, from Port-aux-Poules near Arzeu, in the valley of Oued-Ouarizane in the province of Constantine. Elsewhere no material production has been anywhere developed in Algeria.

EAST COAST.

Traces of petroleum are said to occur near the juncture of the Umzingwani and Limpopo rivers in Matabeleland, and Livingston reported seeps of a paraffin oil on the shores of Lake Nyanza. Cretaceous shales with shows of oil occur in Gasa Land. In Madagascar oil is reported from the Eocene on the west side in Mesozoic rocks in the valley of the Ranobe and Mananubolo rivers, and in the Jurassic coal fields of Ambavatoby on the northeast coast.

SOUTH AFRICA.

Traces of petroleum are associated with igneous intrusions in bituminous Triassic beds at several points, and gas has been reported from Upper Silurian and Devonian rocks in the Bokkeveldt (Ceres district), 90 miles northeast of Cape Town, and at Mossel bay. In Orange River Colony petroleum indications are again associated with igneous intrusions in bituminous shales. In Transvaal oil shows are reported in the hills 20 miles inland from Suakim, and on the upper Nile. Also 60 miles northwest of Potchefstroom and in Lower Mesozoic shales in a belt extending across the Wakkerstroom, Piet Retief, and Ermelo districts, mostly in association with or exuding from igneous intrusions. No commercial developments are reported.

WEST AFRICA.

Oil rises from the sea bottom off the Cape de Verde island. On the mainland the principal occurrences are in the local Cretaceous areas along the western flanks of the crystalline highlands. Among the localities from which it has been specifically reported are Portuguese Guinea, Gold Coast, island of St. Thomas, Cameroons, French Congo, and Angola. Some drilling has been done, but has not resulted in commercial production.

Australia and New Zealand.

WEST AUSTRALIA.

Petroleum seeps are reported near the mouths of Warren and Donnelly rivers on the southwestern coast. Inland, oil shows are found in the Permo-Carboniferous shales and sandstones near Fly brook and Lake Jasper. No developments have been made.

SOUTH AUSTRALIA.

Petroleum indications are reported in the Miocene shales on Leighs creek (Lat. 31° S.) and in the Gawler between Kapunda and Adelaide. Small quantities have also been noted in boring on Salt creek near Meningie and at Bordertown. Oil springs occur near Yorktown. There have been no commercial developments.

VICTORIA.

Traces of solid bitumens occur at numerous points and oil seeps have been found near Bridgewater, 100 miles northwest of Melbourne, but no occurrences of economic value have been discovered as yet.

NEW SOUTH WALES.

Tertiary lignites saturated with oil occur on the coast north of Cape Horne, at Twofold bay and Bonda, and at Kiandra in the interior, while oil-bearing shales are extensively mined at various points along the borders of the productive coal measure basin. There is no commercial production of petroleum other than derived from the distillation of the shales. Natural gas has been found in considerable quantities in Triassic rocks at Grafton in the northeastern part of the State.

QUEENSLAND.

Oil shales occur in the Tertiary basin of Dawson river and on the north flank of the McPherson range near the border of New South Wales; natural gas has also been found in the Triassic. No natural petroleum is produced.

TASMANIA.

Oil shales are found in the Carboniferous strata south of Table cape in the northern part of the island, and in a belt extending from the Don valley past the Mersey Run to the Tamar estuary. Some petroleum is secured from the distillation of the shales, but there is no natural production.

NEW ZEALAND.

Oil and gas indications have long been known in the North Island of New Zealand, especially at New Plymouth and on adjacent islands on the west coast, and in a belt extending from the vicinity of East Cape Waiapu to the Okahuatin block, 30 miles west of Gisborne on Poverty bay. The first drilled wells were sunk in 1865 near New Plymouth, but only a few gallons were secured. Later wells sunk near New Plymouth, at Poverty bay and on the Waiapu river, have found a little oil, but have not produced in commercial quantities.

Small showings of oil have been found in borings near Brunner, 21 miles east of Greymouth on the west coast, South Island.

Central America.

In recent years there has been an extensive search in Mexico and adjacent countries and in the West Indies, and in South America, for fuel oil, with special regard to the possible future supply of fuel for the great navies of the world. The occurrence of petroleum in these countries is therefore of special interest in considering the resources of these great powers.

MEXICO.

The coast states bordering on the Gulf of Mexico, Tamaulipas, Vera Cruz, and Tabasco, have been known for many years to contain very large deposits of bitumen, sometimes in the form of asphalt of sufficient purity to be mined and used as such, in other cases, bituminous limestone or sandstone, occasionally used for road purposes, etc. One deposit near the Tuxpan river, about 80 miles from its mouth, was worked for many years and probably thousands of tons were dug out, hauled to the head of navigation and shipped down the Tuxpan river.

When Capt. A. F. Lucas developed asphaltic oil at Spindle Top in Texas in 1901, Mr. E. L. Doheny, an oil operator in Los Angeles, California, conceived the idea that these large deposits of asphalt in Mexico represented old dried up oil seepages, and he drilled for oil at Ebano, about 50 miles from Tampico on the railroad line leading to San Luis Potosi. Wells were very successful and production from them still continues.

Soon after this S. Pearson and Son bought a small oil development in Tabasco, and also developed oil near Minatitlan, in southern Vera Cruz. They developed a refinery at this place and organized a general campaign for oil throughout Vera Cruz. This resulted in the development, first, of the wells at San Cristobal, then the great gusher at Dos Bocas, and finally a well with the largest daily capacity that has ever been recorded was developed at Potrero del Llano, about 40 miles north of the Tuxpan river in Vera Cruz.

The Pearson interest, now known as the Mexican Eagle Company, have developed several other fields and have pipe lines to Tuxpan bar and to Tampico. Meanwhile the Doheny interest, known as the Mexican Oil Company, have also developed a large field at Juan Casiana, north of Potrero del Llano, and other pools have been developed at Panuco and Topila on the Panuco river, not far from Tampico. Production is developing rapidly from the two large companies, and many other small companies. Refineries are being built and a large fleet of about forty of the largest sized tank steamers is being developed for the export trade in the crude oil and its products. At this time production amounts to about 20 to 25 million barrels a year.

HONDURAS.

In the republic of Honduras, indications of petroleum are reported in limestone (presumably of Neocomian age) near Comayagua, in the Guare mountains.

PANAMA.

Oil fields have been reported in the Province of Chiriqui, in the republic of Panama. No survey or drilling work has yet been done, so that the extent of the fields is uncertain.

GUATEMALA.

Oil seepages have been found in the northwestern part of Guatemala and on the Atlantic coast side of that republic.

COSTA RICA.

Indications of oil have been found on the Altantic side of the republic of Costa Rica, not far from the port of Limon.

West Indies.

CUBA.

There are numerous indications of petroleum in Cuba, with a range in gravity from that of naphtha to solid bitumen, but as yet there has been no commercial development. There are numerous deposits of asphaltum, and shales highly charged with hydrocarbons are found scattered over nearly all of the provinces in the island. There seems to be a peculiar condition brought about by the volcanic heat that has partially distilled the bitumens, whose lighter products have been condensed in the crevices of the higher and cooler portions of the strata where they are now found. However, there seems to have been little real work done in a systematic manner by persons who understand how to make a thorough test of the many localities where there are surface indications of both petroleum and natural gas.

PORTO RICO.

Exudations of petroleum are said to occur at several points on this island, possibly derived from the beds of bituminous lignite which are found in the Tertiary beds at the southwest corner of the island.

SANTO DOMINGO.

Recent explorations have, it is reported, confirmed the existence of crude petroleum on this island. The petroleum was found in pits and along the dry beds of streams near the old town of Azua, 4 miles from the harbor of Tortugerre.

BARBADOS.

The petroleum deposits of Barbados are almost entirely confined to the Scotland district, on the eastern side of the island, the petroliferous rocks being a series of Miocene sandstones and shales, known locally as the Scotland beds. The most northerly occurrence is that of the Morgan-Lewis estate, about $1\frac{1}{2}$ miles north of St. Andrews, shallow wells have yielded a small quantity of petroleum, as is the case on the Turner's Hall Wood estate, about 3 miles to the southwest. Tarry Gully, a short distance south of the latter, derives its name from the quantities of petroleum-saturated earth found here. Oil is also produced in the Baxters district from shallow wells, and on the Friendship and Groves estates, a short distance to the southwest. On the latter, a large quantity of "manjak" or desiccated tar occurs at or about 4 feet from the surface. A little heavy oil has been obtained on Barrow Gully, about three-quarters of a mile farther south, while manjak and oil occur at Springfield, in the Lloyd wells on the coast, and at St. Joseph farther inland. Manjak is also found at Burnt Hill on Conset bay, some distance to the south, outside the Scotland district, in shales of like age.

The deposits which yield this tar occur in the Scotland district, which includes the parishes of St. Joseph and St. Andrew. The rocks in the district consist of thick-bedded sandstones, coarse grits, bituminous sandstones and shales, and dark grey and mottled clays. The strata are much disturbed, and are broken by many faults, being in some instances vertical, while close by they may be seen at an angle of 13° to 15°.

TRINIDAD.

The oil fields of Trinidad are situated mainly in the southern part of the island, and are now being energetically worked. It is as yet impossible, however, to foresee what will be their ultimate extent and importance.

Oil has been known to exist in Trinidad for a number of years, but it is only of late that it has been produced in commercial quantities, and the production now is not large. The oil is of very low specific gravity and has an asphalt base.

The formation here is somewhat similar to that of the Gulf Coast country. The surface is a rich alluvium, running off into a red sandy clay for some thirty feet, when a soft blue shale, which is a little harder than the clay, is struck. The shale, geologically speaking, seems to be young, and is streaked with seams of sand, in which the oil is found at various depths of from 300 to 700 feet. The pay sands do not lie in regular strata and there is no certainty of a well from one location to another, only a few feet distant. All the wells have some gas, but not sufficient for fuel purposes.

South America.

ARGENTINE.

There can be distinguished to-day in Argentine four different oil-bearing regions, namely: (1) The eastern border of the Andes in the provinces of Salta, Jujuy and Tucuman, (2) the limited deposit of Cacheuta near Mendoza, (3) a long zone of seepages on the eastern border of the Andes in the Province of Mendoza and in the territory of Neuguen, and (4) the deposit of Comodoro Rivadavia on the Atlantic coast. Almost always the oil or its derivatives, often in the form of asphalt (albertite), occurs in Mesozoic deposits. At a few places where one finds it in Tertiary formations, the deposits are secondary.

BOLIVIA.

Seepages of petroleum have long been known in Bolivia in a belt of country traversing diagonally the eastern provinces of Santa Cruz, Sucre, and Tarija and extending to the Argentine boundary at Yacuiva.

BRAZIL.

Thus far no deposit of petroleum is known to exist in Brazil, though very extensive deposits of hydrocarbon shales, containing 33 per cent of volatile matter, are known to exist.

CHILE.

Official confirmation has been given to the report that petroleum deposits have been discovered on the island of Chile. The governor of the colony there has reported that oil in quantity has been found in a shallow well. Arrangements are being made to investigate the mineral resources of this island.

COLOMBIA.

Known deposits of oil exist in many parts of Colombia and are found on the plains near the seacoast of the Atlantic, in the river valleys, along the foothills of the mountains, and at various points in the western chain of mountains (beyond the Magdalena river), where the beds overlying the cretaceous system are also found.

From the Magdalena river to the Atrato river there are indications of oil along the Atlantic seaboard. Many springs of natural gas and oil seepages are among the indications. For some distance up the Atrato river oil is found on the surface at many points.

ECUADOR.

The oil fields of Santa Elena lie between 50 and 80 miles westward of the port of Guayaquil. The principal surface indications occur at San Raimondo, on the coast; at Santa Paula, about 3 miles inland, and at Achaigan, 2 miles northeast of Santa Paula; but traces exist for 30 miles eastward of Point Santa Elena, and southward to Puna island. Oil is said to exude from dioritic rocks, a days' journey northward of Quito, and on the east flank of the Andes an oilspring is reported as found on the southern side of the Pastazza river, about 130 miles east-by-north of Guayaquil. Asphalt is raised on the Cojitambo hill, some 13 miles northeastward of Cuenca.

PERU.

The chief producing district for Peru is at Negritos, the port of shipment being Talara, a few miles distant.

The second district in importance is the Lobitos field, situated at Lobitos, a little north of Talara. The third producing district is at Zorritos. Another district, situated near Lake Titicaca, is being developed, and although some good wells have been struck no large sales or export of oil have been undertaken. These fields, with the exception of that near Lake Titicaca, have increased in production steadily for the last decade.

VENEZUELA.

There are five petroleum districts in or bordering on Venezuela as follows: Mara, where seepages of petroleum were found near the Limon River asphalt lake; Bella Vista, near Maracaibo; the district of Sucre, where seepages are found over a large area, together with asphalt deposits; Sardinate, on Sardinate river in Colombia, near the Venezuelan frontier, where the oil is used locally; Colon, in the state of Zulia, south of Lake Maracaibo.

United States.

In the United States, the greatest producer of oil during the last few years has been California, Oklahoma ranking second among the states in 1912, Illinois coming third, West Virginia fourth, Texas fifth, and Louisiana sixth. The production of California has been enormous, having produced more oil than any entire nation outside the United States. If Russia and the United States be omitted, California has produced more oil than all the rest of the world put together.

Canada.

As in America generally, references to the occurrence of oil, asphalt, and natural gas date back to the earliest history of Canada. Thus Sir Alexander Mackenzie noted the tar springs of the Athabaska region in the "Voyages through North America to the Frozen and Pacific Oceans," 1789, 1793. From that time until the present these tar springs havę been commented upon by all the explorers of that region. Meanwhile, as far back as 1830, the settlers in the neighbourhood of Enniskillen in Lambton county, in the extreme western part of Ontario, noted the presence of oil in the swamps of that region. The presence of "gum oil" as the material in these swamps was called, was sufficient to seriously detract from the value of the land. Oil was developed from these swamps in 1857, when Mr. Shaw dug a shallow well near Enniskillen, at a place which became known as Oil Springs. In fact, not only does the actual use of oil in Canada antedate the drilling of the Drake well in Titusville, Pennsylvania, in 1859, but in 1857, a Mr. Williams drilled a deep well in Ontario with successful results.

Drake's lucky find caused great excitement in the Oil Springs region in Ontario. This caused careful search to be made for oil indications. By 1860 hundreds of derricks had been erected at Black creek in the township of Enniskillen. The wells were all shallow, the oil being obtained at 100 feet more or less. The first flowing well was struck in 1862 by Mr. Shaw at Oil Springs, at a depth of 160 feet, described by Mr. J. T. Henry in the "Early and Later History of Petroleum." This well was struck on January 11, 1862, and before October not less than 35 wells were producing. In spite of the better known development of western Pennsylvania, there is probably no quarter of the world where the production developed so rapidly in these early days as on Black creek, Ontario, in 1862, on account of the shallow depth at which large gushers were obtained. Several yielded as high as 3,000 barrels per day, three produced 6,000 barrels per day, and the Black and Matthewson wells flowed 7,500 barrels per day, according to Henry.

Shortly after the excitement of Oil Springs, another large oil deposit was struck at Bothwell in Kent county, about 30 miles to the southeast, and in 1865 Petrolia, 7 miles north of Oil Springs, developed a larger field, which led to the desertion of Oil Springs, in 1867, and has been a principal contributor to the Canadian oil industry ever since.

As far back as 1844, Sir William Logan noted the presence of several petroleum springs near the extremity of Gaspé in the Province of Quebec.

The history of the development of the Canadian oil and gas deposits has been given quite fully in the various reports of the Geological Survey of Canada.[1] In this report the further description of the development of Canadian oil and gas resources will be given in connexion with the description of each Province.

Statistics of Production.

PETROLEUM.

In addition to the historical review which has been given in the preceding sections, of the development of the world's oil industry, the following pages will present in condensed, tabular form the actual amount of crude petroleum produced by each nation. The unit used will be the barrel of 35 imperial gallons, which is the unit of measurement adopted in Canada. The imperial gallon contains 277·27 cubic inches. In the United States, the unit of measurement is the barrel of 42 American gallons, each of 231 cubic inches. The imperial gallon, therefore, is about one-fifth larger than the American gallon, but 35 imperial gallons, constituting the Canadian barrel, is the same in capacity as the American barrel of 42 American gallons—that is, to within

[1]Summary Reports of the Geological Survey of Canada for the years 1888 and 1889 (Montreal, 1890); in the "Report for 1889 of the Division of Mineral Statistics and Mines of the Geological Survey of Canada," (Montreal, 1890), and "Report for 1898," (Montreal, 1899), by E. D. Ingall; in "Report on Natural Gas and Petroleum in Ontario prior to 1891," (Ottawa, 1892), by H. P. Brumell; in "Report on the Mineral Resources of the Province of Quebec," 1890, by R. W. Ells.

less than one-tenth of one per cent. Therefore, the American barrel and the Canadian barrel can be used interchangeably.

Up to the close of the year 1912, the world's production of petroleum had amounted to 4,804,715,214 barrels, or 647,483,340 metric tons, and at this time, March 1914, the total production of the world has passed five billion barrels, three-fifths of which has been contributed by the United States. Canada, meanwhile, has also contributed over 23,000,000 barrels, as shown in the following table, in which the petroleum producing countries of the world are grouped by seniority, beginning with Roumania where production began in 1857, and ending with Mexico where production on a considerable commercial scale only dates back to 1907.

The world's total production has increased annually since 1906, and there is every prospect that the total production for the next few years to come must show an annual increase of which Canada bids fair to show a greater percentage of increase than most other countries, with the possible exception of Mexico, on account of the energy with which petroleum exploitation is being carried on in Alberta. It is interesting to note that the production of Canada dates back to 1862, in fact, that—leaving out Italy as one of the minor producers—there are only two countries, Roumania and the United States, which have been petroleum producers for a greater period of time. Canada produced petroleum before there is any record of a Russian production.

The figures in this table are taken in great part from the various reports of the Mineral Resources of the United States Geological Survey, where the foreign figures are obtained chiefly by direct correspondence with the officials of the governments concerned, and also from the Moniteur du Petrole Roumain, the Petroleum Review of London, the Petroleum of Berlin, the Petroleum World of London, and the Rivista del Servizio Minerario of Italy.

The following table gives the world's production of petroleum for the years 1857-1912 inclusive, by countries, in barrels of 35 imperial gallons:—

World's productImperial gallons.

Year.	Roumania.	United States.	Mexico.	Other.	Total.
1857	1,977	......	......	......	1,977
1858	3,560	......	......	......	3,560
1859	4,349	2,000	......	......	6,349
1860	8,542	500,000	......	......	508,578
1861	17,279	2,113,609	......	......	2,130,917
1862	23,198	3,056,690	......	......	3,091,692
1863	27,943	2,611,309	......	......	2,762,940
1864	33,013	2,116,109	......	......	2,303,780
1865	39,017	2,497,700	......	......	2,715,524
1866	42,534	3,597,700	......	......	3,899,278
1867	50,838	3,347,300	......	......	3,708,846
1868	55,369	3,646,117	......	......	3,990,180
1869	58,533	4,215,000	......	......	4,695,985
1870	83,765	5,260,745	......	......	5,799,214
1871	90,030	5,205,234	......	......	5,730,063
1872	91,251	6,293,194	......	......	6,877,267
1873	104,036	9,893,786	......	......	10,837,720
1874	103,177	10,926,945	......	......	11,933,121
1875	108,569	8,787,514	......	......	9,977,348
1876	111,314	9,132,669	......	......	11,051,267
1877	108,569	13,350,363	......	......	15,753,938
1878	109,300	15,396,868	......	......	18,416,761
1879	110,007	19,914,146	......	......	23,601,405
1880	114,321	26,286,123	......	......	30,017,606
1881	121,511	27,661,238	......	......	31,992,797
1882	136,610	30,349,897	......	......	35,704,288
1883	139,486	23,449,633	......	......	30,255,479
1884	210,667	24,218,438	......	......	35,968,741
1885	193,411	21,858,785	......	......	36,764,730
1886	168,606	28,064,841	......	......	47,243,154
1887	181,907	28,283,483	......	......	47,807,083
1888	218,576	27,612,025	......	......	52,164,597
1889	297,666	35,163,513	......	......	61,507,095
1890	383,227	45,823,572	......	......	76,632,838
1891	488,201	54,292,655	......	......	91,250,347
1892	593,175	50,514,657	......	......	89,139,219
1893	535,655	48,431,066	......	......	92,038,127
1894	507,255	49,344,516	......	......	89,335,697
1895	575,200	52,892,276	......	......	103,662,510
1896	543,348	60,960,361	......	......	114,159,183
1897	570,836	60,475,516	......	......	121,948,575
1898	776,238	55,364,233	......	......	124,924,682
1899	1,425,777	57,070,850	......	......	131,143,742
1900	1,628,535	63,620,529	......	......	149,132,116
1901	1,678,320	69,389,194	......	a20,000	167,424,089
1902	2,059,935	88,766,916	......	a26,000	181,965,876
1903	2,763,117	100,461,337	......	a36,000	194,804,294
1904	3,599,026	117,080,960	......	a40,000	218,078,766
1905	4,420,987	134,717,580	......	a30,000	215,040,917
1906	6,378,184	126,493,936	......	a30,000	212,912,860
1907	8,118,207	166,095,335	1,000,000	a30,000	264,240,318
1908	8,252,157	178,527,355	3,481,610	a30,000	285,089,815
1909	9,327,278	183,170,874	2,488,742	a30,000	298,326,073
1910	9,723,806	209,557,248	3,332,807	a30,000	327,482,746
1911	11,107,450	220,449,391	14,051,643	a200,000	345,545,624
1912	12,991,913	222,113,218	16,558,215	a250,000	351,213,520
Total..	91,616,808	2,820,426,549	40,913,017	752,000	4,804,715,214

a Estimated.

Note: In Canada the unit for me nsists of 42 gallons, and 231 cubic inches to the gallon. The In within less than 1-10 per cent.

TABLE I.

World's production of Petroleum for the years 1857-1912, inclusive, by countries, in barrels of 35 Imperial gallons.

YEAR.	Roumania.	United States.	Italy.	Canada.	Russia.	Gallicia.	Japan.	Germany.	India.	Dutch East Indies.	Peru.	Mexico.	Other.	Total.
1857	1,977													1,977
1858	3,560													3,560
1859	4,349	2,000												6,349
1860	8,542	500,000	36											508,578
1861	17,279	2,113,609	29											2,130,917
1862	23,198	3,056,690	29	11,775										3,091,692
1863	27,943	2,611,309	58	82,814	40,816									2,762,940
1864	33,013	2,116,109	72	90,000	64,586									2,303,780
1865	39,017	2,497,700	2,265	110,000	66,542									2,715,524
1866	42,534	3,597,700	992	175,000	83,052									3,899,278
1867	50,838	3,347,300	791	190,000	119,917									3,708,846
1868	55,369	3,646,117	367	200,000	88,327									3,990,180
1869	58,533	4,215,000	144	220,000	202,308									4,695,985
1870	83,765	5,260,745	86	250,000	204,618									5,799,214
1871	90,030	5,205,234	273	269,397	165,129									5,730,063
1872	91,251	6,293,194	331	308,100	184,391									6,877,267
1873	104,036	9,893,786	467	365,052	474,379									10,837,720
1874	103,177	10,926,945	604	168,807	583,751	149,837								11,933,121
1875	108,569	8,787,514	813	220,000	697,364	158,522	4,566							9,977,348
1876	111,314	9,132,669	2,891	312,000	1,320,528	164,157	7,708							11,051,267
1877	108,569	13,350,363	2,934	312,000	1,800,720	169,792	9,560							15,753,938
1878	109,300	15,396,868	4,329	312,000	2,400,960	175,420	17,884							18,416,761
1879	110,007	19,914,146	2,891	575,000	2,761,104	214,800	23,457							23,601,405
1880	114,321	26,286,123	2,035	350,000	3,001,200	229,120	25,497	9,310						30,017,606
1881	121,511	27,661,238	1,237	275,000	3,601,441	286,400	16,751	29,219						31,992,797
1882	136,610	30,349,897	1,316	275,000	4,537,815	330,076	15,549	58,025						35,704,288
1883	139,486	23,449,633	1,618	250,000	6,002,401	365,160	20,473	26,708						30,255,479
1884	210,667	24,218,438	2,855	250,000	10,804,577	408,120	27,923	46,161						35,968,741
1885	193,411	21,858,785	1,941	250,000	13,924,596	465,400	29,237	41,360						36,764,730
1886	168,606	28,064,841	1,575	584,000	18,006,407	305,884	37,916	73,864						47,243,154
1887	181,907	28,283,483	1,496	525,655	18,367,781	343,832	28,645	74,284						47,807,083
1888	218,576	27,612,025	1,251	695,203	23,048,787	466,537	37,436	84,782						52,164,597
1889	297,666	35,163,513	1,273	704,690	24,609,407	515,268	52,811	68,217	94,250					61,507,095
1890	383,227	45,823,572	2,998	795,030	28,691,218	659,012	51,420	108,296	118,065					76,632,838
1891	488,201	54,292,655	8,305	755,298	34,573,181	630,730	52,917	108,929	190,131	a150,000				91,250,347
1892	593,175	50,514,657	18,321	779,753	35,774,504	646,220	68,901	101,404	242,284	a400,000				89,139,219
1893	535,655	48,431,066	19,069	798,406	40,456,519	692,669	106,384	99,390	298,969	600,000				92,038,127
1894	507,255	49,344,516	20,552	829,104	36,375,428	949,146	171,744	122,564	327,218	688,170				89,335,697
1895	575,200	52,892,276	25,843	726,138	46,140,174	1,452,999	141,310	121,277	371,536	1,215,757				103,662,510
1896	543,348	60,960,361	18,149	726,822	47,220,633	2,443,080	197,082	145,061	429,979	1,427,132	47,536			114,159,183
1897	570,836	60,475,516	13,892	709,857	54,399,568	2,226,368	218,559	165,745	545,704	2,551,649	70,831			121,948,575
1898	776,238	55,364,233	14,489	758,391	61,609,357	2,376,108	263,389	183,427	542,110	2,964,035	70,905			124,924,682
1899	1,425,777	57,070,850	16,121	808,570	65,954,968	2,313,047	536,079	192,232	940,971	1,795,961	89,166			131,143,742
1900	1,628,535	63,620,529	12,102	913,498	75,779,417	2,346,505	866,814	358,297	1,078,264	2,253,355	274,800			149,132,116
1901	1,678,320	69,389,194	16,150	756,679	85,168,556	3,251,544	1,110,790	313,630	1,430,716	4,013,710	274,800		a20,000	167,424,089
1902	2,059,935	88,766,916	18,933	530,624	80,540,044	4,142,159	1,193,038	353,674	1,617,363	2,430,465	286,725		a26,000	181,965,876
1903	2,763,117	100,461,337	17,876	486,637	75,591,256	5,234,475	1,209,371	445,818	2,510,259	5,770,056	278,092		a36,000	194,804,294
1904	3,599,026	117,080,960	25,476	552,575	78,536,655	5,947,383	1,419,473	637,431	3,385,468	6,508,485	345,834		a40,000	218,078,766
1905	4,420,987	134,717,580	44,027	634,095	54,960,270	5,765,317	1,472,804	560,963	4,137,098	7,849,896	447,880		a30,000	215,040,917
1906	6,378,184	126,493,936	53,577	569,753	58,897,311	5,467,967	1,710,768	578,610	4,015,803	8,180,657	536,294		a30,000	212,912,860
1907	8,118,207	166,095,335	59,875	788,872	61,850,734	8,455,841	2,001,838	756,631	4,344,162	9,982,597	756,226	1,000,000	a30,000	264,240,318
1908	8,252,157	178,527,355	50,966	527,987	62,186,447	12,612,295	2,070,145	1,009,278	5,047,038	10,283,357	1,011,180	3,481,610	a30,000	285,089,815
1909	9,327,278	183,170,874	42,388	420,755	65,970,350	14,932,799	1,889,563	1,018,837	6,676,517	11,041,852	1,316,118	2,488,742	a30,000	298,326,073
1910	9,723,806	209,557,248	50,830	315,895	70,336,574	12,673,688	1,930,661	1,032,522	6,137,990	11,030,620	1,330,105	3,332,807	a30,000	327,482,746
1911	11,107,450	220,449,391	74,709	291,096	66,183,691	10,519,270	1,658,903	1,017,045	6,451,203	12,172,949	1,368,274	14,051,643	a200,000	345,545,624
1912	12,991,913	222,113,218	a86,286	243,614	68,019,208	8,535,174	1,671,405	1,031,048	7,116,672	10,845,624	1,751,143	16,558,215	a250,000	351,213,520
Total	91,616,808	2,820,426,549	747,933	23,051,003	1,492,378,967	119,022,121	22,370,771	10,974,039	58,049,770	119,106,327	10,255,909	40,913,017	752,000	4,804,715,214

a Estimated.

NOTE: In Canada the unit for measuring oil is one barrel of 35 Imperial gallons; the gallon contains 277.27 cubic inches, while in the United States the barrel consists of 42 gallons, and 231 cubic inches to the gallon. The Imperial gallon is therefore about 1-5 larger than the American gallon, although the barrel at either place has the same capacity within less than 1-10 per cent.

Year.	
1859....	
1860....	
1861....	
1862....	
1863....	
1864....	
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1904....	
1905....	
1906....	
1907....	
1908....	
1909....	
1910....	
1911....	
1912....	
Total.	

Productic of 42 gallons.

Year.	Pennsylvania and New York.	Ohio.	W	Louisiana.	United States.	Total value.
1859....	2,000	....	...	....	2,000	$32,000
1860....	500,000	....	...	....	500,000	4,800,000
1861....	2,113,609	....	...	....	2,113,609	1,035,668
1862....	3,056,690	....	...	....	3,056,690	3,209,525
1863....	2,611,309	....	...	....	2,611,309	8,225,663
1864....	2,116,109	....	...	....	2,116,109	20,896,576
1865....	2,497,700	....	...	....	2,497,700	16,459,853
1866....	3,597,700	....	...	....	3,597,700	13,455,398
1867....	3,347,300	....	...	....	3,347,300	8,066,993
1868....	3,646,117	....	...	....	3,646,117	13,217,174
1869....	4,215,000	....	...	....	4,215,000	23,730,450
1870....	5,260,745	....	...	....	5,260,745	20,503,754
1871....	5,205,234	....	...	....	5,205,234	22,591,180
1872....	6,293,194	....	...	....	6,293,194	21,440,503
1873....	9,893,786	....	...	....	9,893,786	18,100,464
1874....	10,926,945	....	...	....	10,926,945	12,647,527
1875....	8,787,514	....	...	....	8,787,514	7,368,133
1876....	8,968,906	31,763		....	9,132,669	22,982,822
1877....	13,135,475	29,888		....	13,350,363	31,788,566
1878....	15,163,462	38,179		....	15,396,868	18,044,520
1879....	19,685,176	29,112		....	19,914,146	17,210,708
1880....	26,027,631	38,940		....	26,286,123	24,600,638
1881....	27,376,509	33,867		....	27,661,238	23,512,051
1882....	30,053,500	39,761		....	30,349,897	23,631,165
1883....	23,128,389	47,632		....	23,449,633	25,740,252
1884....	23,772,209	90,081		....	24,218,438	20,476,924
1885....	20,776,041	661,580		....	21,858,785	19,193,694
1886....	25,798,000	1,782,970		....	28,064,841	20,028,457
1887....	22,356,193	5,022,632		....	28,283,483	18,856,606
1888....	16,488,668	10,010,868		....	27,612,025	17,950,353
1889....	21,487,435	12,471,466		....	35,163,513	26,963,340
1890....	28,458,208	16,124,656		....	45,823,572	35,365,105
1891....	33,009,236	17,740,301	2,	....	54,292,655	30,526,553
1892....	28,422,377	16,362,921	3,	....	50,514,657	25,906,463
1893....	20,314,513	16,249,769	8,	....	48,431,066	28,950,326
1894....	19,019,990	16,792,154	8,	....	49,344,516	35,522,095
1895....	19,144,390	19,545,233	8,	....	52,892,276	57,632,296
1896....	20,584,421	23,941,169	10,	....	60,960,361	58,518,709
1897....	19,262,066	21,560,515	13,	....	60,475,516	40,874,072
1898....	15,948,464	18,738,708	13,	....	55,364,233	44,193,359
1899....	14,374,512	21,142,108	13,	....	57,070,850	64,603,904
1900....	14,559,127	22,362,730	16,	....	63,620,529	75,752,691
1901....	13,831,996	21,648,083	14,	....	69,389,194	66,417,334
1902....	13,183,610	21,014,231	13,	548,617	88,766,916	71,178,910
1903....	12,518,134	20,480,286	12,	917,771	100,461,337	94,694,050
1904....	12,239,026	18,876,631	12,	2,958,958	117,080,960	101,175,455
1905....	11,554,777	16,346,660	11,	8,910,416	134,717,580	84,157,399
1906....	11,500,410	14,787,763	10,	9,077,528	126,493,936	92,444,735
1907....	11,211,606	12,207,448	9,	5,000,221	166,095,335	120,106,749
1908....	10,584,453	10,858,797	9,	5,788,874	178,527,355	129,079,184
1909....	10,434,300	10,632,793	10,	3,059,531	183,170,874	128,328,487
1910....	9,848,500	9,916,370	11,	6,841,395	209,557,248	127,899,688
1911....	9,200,673	8,817,112	9,	0,720,420	220,449,391	134,044,752
1912....	8,712,076	g8,969,007	12,	9,263,439	222,113,218	163,802,334
Total.	736,205,411	415,444,184	238,	3,087,170	2,820,426,549	2,337,934,607

TABLE II.

Production of Petroleum in the United States, 1859-1912, by years and by states, in Barrels of 42 gallons.

Year.	Pennsylvania and New York.	Ohio.	West Virginia.	California.	Kentucky and Tennessee.	Colorado.	Indiana.	Illinois.	Kansas.	Texas.	Missouri.	Oklahoma.	Wyoming.	Louisiana.	United States.	Total value.
1859	2,000														2,000	$32,000
1860	500,000														500,000	4,800,000
1861	2,113,609														2,113,609	1,035,668
1862	3,056,690														3,056,690	3,209,525
1863	2,611,309														2,611,309	8,225,663
1864	2,116,109														2,116,109	20,896,576
1865	2,497,700														2,497,700	16,459,853
1866	3,597,700														3,597,700	13,455,398
1867	3,347,300														3,347,300	8,066,993
1868	3,646,117														3,646,117	13,217,174
1869	4,215,000														4,215,000	23,730,450
1870	5,260,745														5,260,745	20,503,754
1871	5,205,234														5,205,234	22,591,180
1872	6,293,194														6,293,194	21,440,503
1873	9,893,786														9,893,786	18,100,464
1874	10,926,945														10,926,945	12,647,527
1875	8,787,514														8,787,514	7,368,133
1876	8,968,906	31,763	120,000	12,000											9,132,669	22,982,822
1877	13,135,475	29,888	172,000	13,000											13,350,363	31,788,566
1878	15,163,462	38,179	180,000	15,227											15,396,868	18,044,520
1879	19,685,176	29,112	180,000	19,858											19,914,146	17,210,708
1880	26,027,631	38,940	179,000	40,552											26,286,123	24,600,638
1881	27,376,509	33,867	151,000	99,862											27,661,238	23,512,051
1882	30,053,500	39,761	128,000	128,636											30,349,897	23,631,165
1883	23,128,389	47,632	126,000	142,857	4,755										23,449,633	25,740,252
1884	23,772,209	90,081	90,000	262,000	4,148										24,218,438	20,476,924
1885	20,776,041	661,580	91,000	325,000	5,164										21,858,785	19,193,694
1886	25,798,000	1,782,970	102,000	377,145	4,726										28,064,841	20,028,457
1887	22,356,193	5,022,632	145,000	678,572	4,791	76,295									28,283,483	18,856,606
1888	16,488,668	10,010,868	119,448	690,333	5,096	297,612									27,612,025	17,950,353
1889	21,487,435	12,471,466	544,113	303,220	5,400	316,476	33,375	1,460	500	48	20				35,163,513	26,963,340
1890	28,458,208	16,124,656	492,578	307,360	6,000	368,842	63,496	900	1.200	54	278				45,823,572	35,365,105
1891	33,009,236	17,740,301	2,406,218	323,600	9,000	665,482	136,634	675	1,400	54	25	30			54,292,655	30,526,553
1892	28,422,377	16,362,921	3,810,086	385,049	6,500	824,000	698,068	521	5,000	45	10	80			50,514,657	25,906,463
1893	20,314,513	16,249,769	8,445,412	470,179	3,000	594,390	2,335,293	400	18,000	50	50	10			48,431,066	28,950,326
1894	19,019,990	16,792,154	8,577,624	705,969	1,500	515,746	3,688,666	300	40,000	60	8	130	2,369		49,344,516	35,522,095
1895	19,144,390	19,545,233	8,120,125	1,208,482	1,500	438,232	4,386,132	200	44,430	50	10	37	3,455		52,892,276	57,632,296
1896	20,584,421	23,941,169	10,019,770	1,252,777	1,680	361,450	4,680,732	250	113,571	1,450	43	170	2,878		60,960,361	58,518,709
1897	19,262,066	21,560,515	13,090,045	1,903,411	322	384,934	4,122,356	500	81,098	65,975	19	625	3,650		60,475,516	40,874,072
1898	15,948,464	18,738,708	13,615,101	2,257,207	5,568	444,383	3,730,907	360	71,980	546,070	10		5,475		55,364,233	44,193,359
1899	14,374,512	21,142,108	13,910,630	2,642,095	18,280	390,278	3,848,182	360	69,700	669,013*	132		5,560		57,070,850	64,603,904
1900	14,559,127	22,362,730	16,195,675	4,324,484	62,259	317,385	4,874,392	200	74,714	836,039	a1,602	6,472	5,450		63,620,529	75,752,691
1901	13,831,996	21,648,083	14,177,126	8,786,330	137,259	460,520	5,757,086	250	179,151	4,393,658	a2,335	10,000	5,400		69,389,194	66,417,334
1902	13,183,610	21,014,231	13,513,345	13,984,268	185,331	396,901	7,480,896	200	331,749	18,083,658	a757	37,100	6,253	548,617	88,766,916	71,178,910
1903	12,518,134	20,480,286	12,899,395	24,382,472	554,286	483,925	9,186,411		932,214	17,955,572	a3,000	138,911	8,960	917,771	100,461,337	94,694,050
1904	12,239,026	18,876,631	12,644,686	29,649,434	998,284	501,763	11,339,124		4,250,779	22,241,413	a2,572	1,366,748	11,542	2,958,958	117,080,960	101,175,455
1905	11,554,777	16,346,660	11,578,110	33,427,473	1,217,337	376,238	10,964,247	181,084	b12,013,495	28,136,189	a3,100	(c)	8,454	8,910,416	134,717,580	84,157,399
1906	11,500,410	14,787,763	10,120,935	33,098,598	1,213,548	327,582	7,673,477	4,397,050	b21,718,648	12,567,897	a3,500	(c)	d7,000	9,077,528	126,493,936	92,444,735
1907	11,211,606	12,207,448	9,095,296	39,748,375	820,844	331,851	5,128,037	24,281,973	2,409,521	12,322,696	a4,000	43,524,128	e9,339	5,000,221	166,095,335	120,106,749
1908	10,584,453	10,858,797	9,523,176	44,854,737	f727,767	379,653	3,283,629	33,686,238	1,801,781	11,206,464	a15,246	45,798,765	e17,775	5,788,874	178,527,355	129,079,184
1909	10,434,300	10,632,793	10,745,092	55,471,601	f639,016	310,861	2,296,086	30,898,339	1,263,764	9,534,467	a5,750	47,859,218	e20,056	3,059,531	183,170,874	128,328,487
1910	9,848,500	9,916,370	11,753,071	73,010,560	f468,774	239,794	2,159,725	33,143,262	1,128,668	8,899,266	a3,615	52,028,718	e115,430	6,841,395	209,557,248	127,899,688
1911	9,200,673	8,817,112	9,795,464	81,134,391	f472,458	226,926	1,695,289	31,317,038	1,278,819	9,526,474	a7,995	56,069,637	e186,695	10,720,420	220,449,391	134,044,752
1912	8,712,076	g8,969,007	12,128,962	86,450,767	f484,368	206,052	970,009	28,601,308	1,592,796	11,735,057	(h)	51,427,071	e1,572,306	9,263,439	222,113,218	163,802,334
Total	736,205,411	415,444,184	238,985,483	542,887,881	8,068,961	10,237,571	100,532,249	186,512,968	49,422,978	168,721,719	54,077	298,267,850	1,998,047	63,087,170	2,820,426,549	2,337,934,607

a Includes the production of Michigan.
b Includes production of Oklahoma.
c Included with Kansas.
d Estimated.
e Includes the production of Utah.
f No production in Tennessee recorded.
g Includes production of Michigan.
h No production in Missouri.

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There are no reliable statistics of production in Canada prior to 1886, but the following are the estimates of parties intimately connected with the industry:

TABLE III.

Production of Crude Petroleum in Canada from 1862 to 1885.[1]

Years	*Barrels*	*Years*	*Barrels*
1862	11,775	1874	168,807
1863	82,814	1875	220,000
1864	90,000	1876	312,000
1865	110,000	1877	312,000
1866	175,000	1878	312,000
1867	190,000	1879	575,000
1868	200,000	1880	350,000
1869	220,000	1881	275,000
1870	250,000	1882	275,000
1871	269,397	1883	250,000
1872	308,100	1884	250,000
1873	365,052	1885	250,000

Min. Rev. U. S. 1887, pp. 456–8.
" " U. S. 1907, p. 86.
" " U. S. 1909, pp. 88–90.
Geol. Survey, Canada.

The following figures of production of the entire province are given in reports of the Geological Survey of Canada prior to 1908, and in the reports of the Mines Branch, Department of Mines, since 1908:

TABLE IV.

Production, Value, and Average Price Per Barrel of Petroleum in Canada, from 1886 to 1912, inclusive.

Year	*Quantity-Barrels*[1]	*Value*	*Average Price Per Barrel.*
1886	584,061	$525,655	$ 0.90
1887	525,655	556,708	0.78
1888	695,203	713,695	1.02⅔
1889	704,690	653,600	0.92¾

[1] Barrels of 35 imperial gallons.

Year	*Quantity-Barrels*[1]	*Value*	*Average Price Per Barrel.*
1890	795,030	902,734	1.18
1891	755,298	1,010,211	1.33¾
1892	779,753	984,438	1.26¼
1893	798,406	874,255	1.09½
1894	829,104	835,322	1.00¾
1895	726,138	1,086,738	1.49⅔
1896	726,822	1,155,647	1.59
1897	709,857	1,011,546	1.42½
1898	758,391	1,202,020	1.40
1899	808,570	1,151,007	1.48⅔
1900	913,498	1,479,867	1.62
1901	756,679	1,225,820	1.62
1902	530,624	951,190	1.79¼
1903	486,637	1,048,974	2.15½
1904	552,575	984,310	1.78
1905	634,095	856,028	1.35
1906	569,753	761,760	1.337
1907	788,872	1,057,088	1.34
1908	527,987	747,102	1.41½
1909	420,755	559,604	1.33
1910	315,895	388,550	1.23
1911	291,096	357,073	1.23
1912	243,614	345,930	1.42

[1] Barrels of 35 imperial gallons.

The production prior to 1895 was sold at prices established by the Petrolia Oil Exchange—now the producers make sales direct to the refiners.

In the following table will be found a statement of the production of petroleum from each producing state of the United States from the year 1859 to and including the production of the year 1912:—

[illegible]

TABLE V.

Producers of Natural Gas in Canada.

Arranged according to Provinces and Counties

(From lists in the office of the Division of Mineral Resources and Statistics, Mines Branch, Ottawa)

Name of Company	*Address*	*Location of Wells*	*No. of Producing Wells as on Dec. 31, 1913*	*Representative or Manager*
Maritime Oil Fields, Ltd.	Moncton, Box 196	Albert co., N.B., Stony Ck. Dist.	31	A. Crichton.
The Canadian Natural Gas Co.	St. Hyacinthe, Que.	St. Hyacinthe co., Que., St. Barnabé	1	
The Provincial Natural Gas and Fuel Co. of Ontario, Ltd.	Niagara Falls	Welland co., Ont	212	D. A. Coste, Supt.
Bertie Natural Gas Co., Ltd.	Ridgeway	" " Bertie tp.	11	A. H. Kilman, Secy.
Empire Limestone Co.	Buffalo, 4th and Virginia	" " Humberstone tp.	17	J. N. Morris, Asst. Treas.
Niagara Nat. Gas and Fuel Co., Ltd.	Sherkston	" " " " II, 4, 5	3	B. F. Mathews, Pres.
Humberstone Mutual Nat. Gas and Fuel Co.	Humberstone	" " " "	2	L. R. Snyder, Secy.-Treas.
Miner and Mekelenbacker	"	" " " "	1	O. P. Miner.
Industrial Natural Gas Co.	Port Robinson	" " " and Crowland	43	Thos. Coulter, Mgr.
The United Gas Companies, Ltd.	St. Catharines, 45 King	" " Wainfleet tp.	39	P. I. Price.
J. A. Coleman	Wellandport	" " "	4	
Welland County Lime Works, Ltd.	Port Colborne	" " " and Humberstone tp.	32	D. Alair, Secy.
Sterling Gas Co., Ltd.	"	" and Haldimand co.	45	C. E. Steele, Mgr.
The Dominion Natural Gas Company.	Buffalo, 842 Marine Bk. Bldg.	Haldimand, Norfolk, Elgin, Lincoln, and Wentworth cos.	406	Art. J. Devlin.
F. R. Lalor	Dunnville	Haldimand co., Moulton tp.	5	H. E. Arderlay, Secy.
J. J. Lawson	Stromness	" "	3	
Buffalo and Dunnville Oil and Gas Co.	Dunnville	" "	5	Jesse Kittinger, Pres.
Canboro Nat. Gas Co., Ltd.	Canboro	" Canboro tp.	1	N. R. Teeft, Secy.-Treas.
Chippewa Oil and Gas Co.	Tavistock	" "	2	A. E. Ratz, Secy.
Moote, Melick and Lymburner	Canboro	" "	10	Robt. J. Melick.
Aikens and Kohler	Dunnville	" "	17	W. J. Aikens.
Lint and Emmerson	Attercliffe Sta.	" "	4	Jno. W. Lint.
Melvin G. Hart and Co.	"	" "	2	
Aikens, Beck and Lalor	Dunnville	" Cayuga South	21	W. J. Aikins.
F. L. Snively	" Box 232	" Cayuga South and Rainham	27	
The Waines and Root Gas Co., Ltd.[1]	"	" Cayuga S., Rainham, Dunn, Canboro, Walpole	71	
The Midfield Nat. Gas Co.	Hamilton, 32 Stinson	" Cayuga North	7	Walter Armstrong, G. Mgr.
Canfield Natural Gas Co., Ltd.	Canfield	" " "	3	W. M. Thompson, Secy.
Azoff Gas Co., Ltd.	"	" " "	1	Wm. Thompson.
Sundy Gas Well Co.	Dunnville	"	2	Jas. Ralton and Bennett.
Port Maitland Nat. Gas Co.	Port Maitland	" Dunn tp.	1	Ed. Martin.
The Dunn Nat. Gas Co., Ltd.	Dunnville	" "	16	W. J. Aikins.
The Eastside Gas Co.	Port Maitland	" "		
Jas. S. Jones	"	" "	4	
Lalor, Aikins and Smith	Dunnville	" " and Sherbrooke	16	W. J. Aikins.
The Home Natural Gas Co., Ltd.	Hamilton, 18 Cottage Ave.	" Oneida tp.	4	Robt. H. Foster.
The Aldrich Gas and Oil Co., Ltd.	"	" Rainham tp.	10	W. Aldrich, Mgr.
David E. Hoover	Selkirk	" "	8	J. A. Norrington.
D. E. and A. E. and M. Hoover	Rainham Centre	" "	7	
D. Kindy and Sons	Selkirk	" "	7	
Kindy Gas Company	Rainham	" "	3	Josiah Kindy.
North Shore Gas Co., Ltd.	Hamilton, Bk. of Hamilton Bldg.	" "	14	S.C. Macdonald, Sec.-Treas.
Fisherville Gas Co.	Fisherville	" "	2	Chris. Held.
National Gas Co., Ltd.	Rainham Centre	" " and Seneca tps.	72	R. F. Miller, Gen. Mgr.
The Producers Natural Gas Co., Ltd.	Buffalo, 842 Marine Bank Bldg.	" " and Walpole tps.	80	Art. J. Devlin, Agent.
The Holmes Gas Co., Ltd.	Selkirk	" " "	30	W. C. Holmes, Secy.
Port Colborne—Welland Natural Gas Co.	Port Colborne	" Seneca tp.; also Brant co., Onondaga tp.	25	Geo. H. Smith, Secy.-Treas.
Lime and Cement Works	Hamilton	" Seneca tp.	24	Jas. Marshall, Hamilton.
J. E. Hoover	Selkirk, Box 18	" Walpole tp.	6	
Lalor and Vokes	Dunnville	" "	11	H. E. Arderlay, Secy.
Nanticoke Natural Gas Co., Ltd.	Cheapside	" "	2	S. A. Thompson.
M. Wederick	"	" "	1	
Regal Natural Gas Company	Hagersville	" "	4	Howard Hager.
Cheapside Natural Gas Co., Ltd.	Cheapside	" "	3	Geo. E. Pond.
Alfred Lamb	Selkirk	" "	14	
Walter B. Lamb	Nanticoke	" "	11	
Enterprise Gas Co., Ltd.	Buffalo, 842 Marine Bank Bldg.	Norfolk co., Middleton tp. (Delhi)	9	Art. J. Devlin, Agent.
The Norfolk Gas Co., Ltd.	" " "	" Woodhouse tp. (Pt. Dover)	11	Art. J. Devlin, Secy.-Treas.
Port Rowan Natural Gas Co.	" " "	" Walsingham tp. (Pt. Rowan and St. Williams)	10	"
North Western Gas Co., Ltd.	Erie, Pa., 611 Masonic Temple	Brant co.	4	J. S. Owen, Secy.-Treas.
Standard Natural Gas Co., Ltd.	Dunnville	" Onondaga tp.	30	W. J. Aikins.
The Onondaga Oil and Gas Co.	Brantford	" "	12	Jas. C. Spence, Secy.-Treas.
Telephone City Oil and Gas Co., Ltd.	"	" "	4	B. Forsayerth, Secy.-Treas.
Commonwealth Oil and Gas Co.	Hamilton, 165 Bay N.	" "	2	Geo. Schuabel, Pres.
The Crystal Oil and Gas Co., Ltd.	Paris, River St.	" "	4	Jas. R. Inksater.
Grand River Oil and Gas Co., Ltd.	Brantford, 116 Dalhousie	" "	5	Alf. J. Wilkes, Secy.
D. Danskin	Cainsville	" "	1	
A. W. VanSickle	Onondaga	" "	3	
Wentworth Natural Gas Co., Ltd.	Hamilton	" "	2	M. Westcott.
Thomas Walker	Caledonia, R.R. No. 2	" Tuscarora tp.	1	
Oxford Oil and Gas Co., Ltd.	Brantford, 17 Albion	Oxford co., East Zorra tp.	3	J. J. Howey.
The Medina Natural Gas Co., Ltd.	Chatham, 40 Fifth St.	Elgin co., Bayham tp.	18	W. C. Ryan, Mgr.
The Union Natural Gas Co. of Canada, Ltd.	Niagara Falls	Kent co., Romney, Raleigh, and Tilbury E.	88	D. A. Coste, Secy.
The Canadian Gas Co., Ltd.	Detroit, Mich., 1426 Dime Bk Bldg.	Kent and Essex co., Romney, Mersea, and Gosfield S.	20	W. H. Beamer, Pres.
The Beaver Oil and Gas Co., Ltd.*	Brantford, 66½ Market	Kent co., Romney	14	
The Maple City Oil and Gas Co., Ltd.	Buffalo, 842 Marine Bank Bldg.	" Romney and Tilbury tps.	3	F. M. Lowry, Gen. Mgr.
Glenwood Natural Gas Co., Ltd.	" " "	" Raleigh tp.		" " "
Oil Springs Oil and Gas Co., Ltd.	Oil Springs	Lambton co., Euphemia tp.	2	A. W. Parks, Pres.
William Hawkin	Warwick	" Warwick tp., Egremont Rd., III. 7		
Corporation City of Medicine Hat	Medicine Hat, Alta	Medicine Hat, Alta., Tp. 12	11	J. W. Craft, Supt., Box 265.
Canadian Pacific Railway	" "	" " (2) Carlstadt. (1). Tp. 15 Suffield (1) Tp. 14.	4	R. S. Winter, Gas Inspector
Medicine Hat Brick Co., Ltd.	" "	Medicine Hat	1	A. P. Pashouse, Secy.
The Alberta Rolling Mills Co., Ltd.	" "	" "	1	J. L. Pollock, Pres.
Redcliff Brick and Coal Co., Ltd.	Redcliff, Alta	Redcliff, Alta., Tp. 13	2	E. R. Sellhorn.
The Redcliff Light and Power Co., Ltd.	" "	" " "	4	H. O. Wheeler, Secy.
Dominion Glass Co., Ltd.	" "	" " "	1	Geo. Lydiatt.
Redcliff Rolling Mills and Bolt Co., Ltd.	" "	" " "	1	John Husband, Mgr.
Canada Cement Co.	Montreal, Herald Bldg	Medicine Hat, Alta., (6 mi. south). Tp. 12	(Drilling)	H. L. Doble, Comptroller.
Dunmore Dev. Company, Limited	Medicine Hat, Alta.	Dunmore, Alta.	1	W. T. Black.
The Can. Western Nat. Gas L. H. and P. Co., Ltd.	Calgary, Alta.	Bow Id. (16) Tp. 10, Brooks (2) Tp. 18, Dunmore Tp. 12	19	Eug. Coste, Man. Dir.
Town of Bow Island	Bow Island, Alta.	Bow Island, Alta.	(Drilling)	W. A. Bateman, Secy.
Irvine Light and Power Co.	Irvine, Alta.	Irvine, Tp. 11, R. 2	"	S. W. Arbuckle.
High River Oil and Gas Co., Ltd.	Calgary, Box 18	High River, Alta. Tp. 19, R. 28	1	Geo. E. Mack.
The Calgary Pet. Producer Co., Ltd.	Calgary, Alta.		2	A. W. Dingman.
Lacombe Brick and Tile Co.	Lacombe, Alta.	Lacombe, Alta. Tp. 40. R. 27		W. L. Crane, City Eng.
City of Wetaskiwin	Wetaskiwin, Alta.	Wetaskiwin, Alta. Tp. 46. R. 24	1	L. B. Browne, Secy.
Municipality of Castor	Castor, Alta.	Castor, Alta. Tp. 37. R. 13	1	L. P. Browne, Secy.
Municipality of Tofield	Tofield, Alta.	Tofield, Alta. Tp. 50. R. 19	(Drilling)	J. W. McMullen, Sec.
Municipality of Vegreville	Vegreville, Alta.	Vegreville, Alta. Tp. 52. R. 14	1	H. R. Pozer, Secy.
Athabasca Natural Gas Co., Ltd.	Athabaska, Alta	Athabaska, Alta. Tp. 66	(Drilling)	A. A. Greer, Pres.

[1]Present address, 842 Marine Bank Bldg., Buffalo, N.Y.

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NATURAL GAS.

Canada.

The preliminary report on the mineral production of Canada for 1912, published by the Mines Branch, Department of Mines, states:—

"While the production of petroleum has been declining, the output and use of natural gas has been steadily increasing. The southern portion of Ontario has for many years been the principal source of gas, but the Albert County field in New Brunswick is now an important producer, while large developments are taking place in Alberta with such a rapid increase in output of gas that this Province may soon take first place as a producer.

"The total production of natural gas in Canada in 1912 was approximately 15,286,803,000 cubic feet, valued at $2,362,700, and includes 12,529,463,000 cubic feet in Ontario, valued at $2,036,245, and 2,583,437,000 cubic feet in Alberta, valued at $289,906. New Brunswick production was 173,903,000 cubic feet. The production in 1911 was reported at 11,644,000,000 cubic feet, valued at $1,917,678, including 10,864,000,000 cubic feet in Ontario, valued at $1,807,513, and 780,000,000 cubic feet in Alberta, valued at $110,165. These values represent as closely as can be ascertained the value received by the owners or operators of the wells for gas produced and sold or used. The values do not represent what consumers have to pay since in many cases the gas is resold once or twice by pipe-line companies before reaching the consumer."

The following table gives the value of natural gas produced in Canada each year since 1892, by Provinces:—

TABLE VI.

Value of Natural Gas produced in Canada, by Provinces, 1892-1912.

Year[1].	Alberta.	Ontario.	Total Canada.
1892	....	$150,000	$150,000
1893	....	238,200	238,200
1894	....	204,179	204,179
1895	....	282,986	282,986
1896	....	276,710	276,710
1897	....	308,448	308,448
1898	....	301,599	301,599
1899	....	440,904	440,904
1900	....	392,823	392,823
1901	....	342,183	342,183
1902	....	195,992	195,992
1903	*a*5,675	196,535	202,210
1904	*a*74,852	253,524	328,376
1905	*a*63,085	316,476	379,561
1906	*a*50,077	533,446	583,523
1907	*a*68,533	746,499	815,032
1908	*a*24,044	988,616	1,012,660
1909	61,722	1,145,307	1,207,029
1910	75,168	1,271,303	1,346,471
1911	110,165	1,807,513	1,917,678
1912	*a*326,455	2,036,245	2,362,700

a Alberta and other.

[1] The first year in which records of natural gas were kept was 1892.

Italy.

The *Rivista Minerario* gives the production and value of natural gas in Italy from 1903 to 1912, as follows:—

TABLE VII.

Production and value of Natural Gas in Italy, 1903-1912.

Year	*Quantity (cubic meters)*	*Value*
1903	2,255,596	$15,024
1904	2,551,396	16,715
1905	3,092,000	19,310
1906	5,723,469	32,394
1907	5,710,000	32,279
1908	6,737,500	33,809
1909	8,268,000	42,287
1910	8,840,000	73,301
1911	9,021,000	74,174
1912	Not available	Not available

United Kingdom.

The annual report of the British home office gives the statistics of the production and value of natural gas in the United Kingdom for the years 1902 to 1912 as follows:

TABLE VIII.

Production and value of Natural Gas at Heathfield, (a) **England, 1902-1912.**

Year	*Quantity cubic feet*	*Value*
1902	150,000	$146
1903	972,460	944
1904	774,800	754
1905	(b)	(c)
1906	(b)	(c)
1907	(b)	(c)
1908	(b)	(c)
1909	236,800	(c)
1910	262,000	(c)
1911	221,400	(c)
1912	(d)	(c)

(a) Heathfield in Sussex county.

(b) None reported. The railway station at Heathfield, however, is lighted with it, but the quantity is not ascertained.

(c) Not stated.

(d) Not available.

TABLE IX.

Distribution of Gas consumed for industrial purposes in the United States.[1]

TABLE IX.

Distribution of Gas consumed for industrial purposes in the United States.[1]

The following table gives the distribution of gas consumed for industrial purposes in 1912, by States.

State.	Industrial consumers.			Gas consumed.			Gas consumed.					
				Manufacturing.			Other industrial (power).			Total industrial.		
	Manufacturing	Other industrial	Total.	Quantity (M cubic feet).	Cents per M cubic feet.	Value	Quantity (M cubic feet).	Cents per M cubic feet.	Value.	Quantity (M cubic feet).	Cents per M cubic feet.	Value.
Pennsylvania	1,987	1,455	3,442	114,617,963	11.45	$13,127,440	9,706,948	12.42	$1,205,608	124,324,911	11.53	$14,333,048
Ohio	2,768	1,646	4,414	43,300,321	12.86	5,568,386	16,403,594	13.46	2,207,690	59,703,915	13.02	7,776,076
West Virginia	888	1,065	1,953	59,189,820	5.07	2,998,754	20,031,650	5.35	1,071,949	79,221,470	5.14	4,070,703
Kansas	959	145	1,104	32,353,405	6.94	2,246,186	3,143,299	8.19	257,309	35,496,704	7.05	2,503,495
Oklahoma	288	1,363	1,651	20,915,974	4,56	954,498	14,133,367	6.41	905,984	35,049,341	5.31	1,860,482
Louisiana }	550	882	1,432	2,992,216	8,38	250,803	8,628,773	8.01	691,311	11,620,989	8.11	942,114
Alabama }												
California	....	232	232	....	....	....	8,379,632	7.27	609,028	8,379,632	7.27	609,028
Texas	(a)	329	329	(a)	....	(a)	5,128,745	9.72	498,665	5,128,745	9.72	498,665
Illinois	26	186	212	948,415	10.00	95,088	3,418,791	6.71	229,392	4,367,206	7.43	324,480
New York	11	794	805	354,333	16.51	58,518	1,243,454	18.09	224,889	1,597,787	17.74	283,407
Kentucky	19	84	103	1,671,287	7.97	133,220	669,083	14.66	98,098	2,340,370	9.88	231,318
Indiana	20	120	140	223,547	18.19	40,675	404,882	15.16	61,368	628,429	16,24	102,043
Arkansas }												
Colorado }	(a)	103	103	(a)	....	(a)	870,751	6.93	60,315	870,751	6.95	60,315
Wyoming }												
South Dakota }	....	3	3	....	....	....	9,900	54.55	5,400	9,900	54.55	5,400
North Dakota }												
Missouri	....	11	11	....	....	....	7,600	26.97	2,050	7,600	26.97	2,050
Michigan	....	2	2	....	....	....	900	50.00	450	900	50.00	450
Total	7,516	8,420	15,936	276,567,281	9.21	$25,473,568	92,181,369	8.82	8,129,506	368,748,650	9.11	33,603,074

a Included in other industrial.

[1] B. Hill. The Production of Natural Gas in 1912. Min. Res. of U.S. for 1912, pp. 9-10.

TABLE X.

Value of Natural Gas produced in the United States, 1882-1912, by States.

State.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.
Pennsylvania	$75,000	$200,000	$1,100,000	$4,500,000	$9,000,000	$13,749,500	$19,282,375	$11,593,989	$9,551,025	$7,834,016	$7,376,281
New York				196,000	210,000	333,000	332,500	530,026	552,000	280,000	216,000
Ohio				100,000	400,000	1,000,000	1,500,000	5,215,669	4,684,300	3,076,325	2,136,000
West Virginia				40,000	60,000	120,000	120,000	12,000	5,400	35,000	70,500
Illinois				1,200	4,000			10,615	6,000	6,000	12,988
Indiana					300,000	600,000	1,320,000	2,075,702	2,302,500	3,942,500	4,716,000
Kansas					6,000			15,873	12,000	5,500	40,795
Missouri								35,687	10,500	1,500	3,775
California								12,680	33,000	30,000	55,000
Kentucky								2,580	30,000	38,993	43,175
Tennessee											
Texas								1,728			100
Alabama											
Louisiana											
Arkansas								375		250	100
Wyoming											
Colorado											
Utah											
South Dakota											
North Dakota											
Indian Territory											
Oklahoma											
Oregon											
Iowa											
Michigan											
Other	140,000	275,000	360,000	20,000	32,000	15,000	75,000	1,6[illegible],175	1,606,000	250,000	200,000
	$215,000	$475,000	$1,460,000	$4,857,200	$10,012,000	$15,817,500	$22,629,875	$21,107,099	$18,792,725	$15,500,084	$14,870,714

State.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
Pennsylvania	$6,488,000	$6,279,000	$5,852,000	$5,528,610	$6,242,543	$6,806,742	$8,337,210	$10,215,412	$12,688,161	$14,352,183
New York	210,000	249,000	241,530	256,000	200,076	229,078	294,593	335,367	293,232	346,471
Ohio	1,510,000	1,276,100	1,255,700	1,172,400	1,171,777	1,488,308	1,866,271	2,178,234	2,147,215	2,355,458
West Virginia	123,000	395,000	100,000	640,000	912,528	1,334,023	2,335,864	2,959,032	3,954,472	5,390,181
Illinois	14,000	15,000	7,500	6,375	5,000	2,498	2,067	1,700	1,825	1,844
Indiana	5,718,000	5,437,000	5,203,200	5,043,635	5,009,208	5,060,969	6,680,370	7,254,539	6,954,566	7,081,344
Kansas	50,000	86,600	112,400	124,750	105,700	174,640	332,592	356,900	659,173	824,431
Missouri	2,100	4,500	3,500	1,500	500	145	290	547	1,328	2,154
California	62,000	60,350	55,000	55,682	50,000	65,337	86,891	79,083	67,602	120,648
Kentucky	68,500	89,200	98,700	99,000	90,000	103,133	125,745	286,243	270,871	365,356
Tennessee										300
Texas	50	50	20			765	8,000	20,000	18,577	14,953
Alabama										
Louisiana										
Arkansas	100	100	100	60	40					
Wyoming										
Colorado		12,000	7,000	4,500	4,000	3,300	1,480	1,800	1,800	1,900
Utah	500	500	20,000	20,000	15,050	7,875				
South Dakota							3,500	9,817	7,255	10,280
North Dakota										
Indian Territory										360
Oklahoma										
Oregon										
Iowa										
Michigan										
Other	100,000	50,000	50,000	50,000	20,000	20,000				
	$14,346,250	$13,954,400	$13,006,650	$13,002,512	$13,826,422	$15,296,813	$20,074,873	$23,698,674	$27,066,077	$30,867,863

State.	1903.	1904.	1905.	1906.	1907.	1908.	1909.	1910.	1911.	1912.
Pennsylvania	$16,182,834	$18,139,914	$19,197,336	$18,558,245	$18,844,156	$19,104,944	$20,475,207	$21,057,211	$18,520,796	$18,539,672
New York	493,686	522,575	623,251	672,795	766,157	959,280	1,222,666	1,678,720	1,418,767	2,343,379
Ohio	4,479,040	5,315,564	5,721,462	7,145,809	8,718,562	8,244,835	9,966,938	8,626,954	9,367,347	11,891,299
West Virginia	6,882,359	8,114,249	10,075,804	13,735,343	16,670,962	14,837,130	17,538,565	23,816,553	28,435,907	33,349,021
Illinois	3,310	4,725	7,223	87,211	143,577	446,077	644,401	613,642	687,726	616,467
Indiana	6,098,364	4,342,409	3,094,134	1,750,715	1,572,605	1,312,507	1,616,903	1,473,403	1,192,418	1,014,295
Kansas	1,123,849	1,517,643	2,261,836	4,010,986	6,198,583	7,691,587	8,293,846	7,755,367	4,854,534	4,336,635
Missouri	7,070	6,285	7,390	7,210	17,010	22,592	10,025	12,611	10,496	11,576
California	104,521	114,195	133,696	134,560	168,397	307,652	446,933	476,697	800,714	1,134,456
Kentucky	390,301	322,104	237,290	287,501	380,176	424,271	485,192	456,293	407,689	497,909
Tennessee	300	300	300	300	300	350	350	300	300	375
Texas	13,851	14,082	14,409						1,014,945	1,405,077
Alabama				150,695	178,276	236,837	453,253	956,683	858,145	1,747,379
Louisiana			1,500							
Arkansas	2,460	6,515	21,135	34,500						
Wyoming					126,582	164,930	226,925	301,151	295,858	309,816
Colorado	14,140	14,300	20,752	22,800						
Utah										
South Dakota	10,775	12,215	15,200	15,400	19,500	24,400	16,164	31,999	16,984	30,412
North Dakota					235	2,480	3,025	7,010	5,738	
Indian Territory	1,000	49,665	130,137	259,862	417,221	860,159	1,806,193	3,490,704	6,731,770	7,334,599
Oklahoma					100	250	50			
Oregon						93	50	40	70	120
Iowa							255	820	1,330	1,470
Michigan										
Other										
	$35,807,860	$38,496,760	$41,562,855	$46,873,932	$54,222,399	$54,640,374	$63,206,941	$70,756,158	$74,621,534	$84,563,957

CHAPTER II.

PHYSICAL PROPERTIES OF PETROLEUM.

COLOUR.

The colour of a crude oil is usually taken by reflected light, although where the oil is translucent the colour by transmitted light is usually recorded also.

Colour by transmitted light: While most crude oils are opaque, except in very thin layers, when they are brown, many of the thinner grades of Pennsylvania oils and oils lately found in Alberta vary in colour from a pale straw to various shades of yellow, red, brown, and deepening shades of brown to black.

Colour by reflected light: Crude oils have usually a green cast by reflected light. Otherwise they vary in colour from yellow to black—the same as when seen by transmitted light. The greenish colour by reflected light is an important characteristic of crude oils. It is a case of dichroism, differing from the bluish florescence of refined oils. It is frequently a convenient means of distinguishing between crude oils and those which have been manufactured.

Dark crude oils can be deprived of their colour by filtration through Fuller's earth or clay. This is probably what happens in earth where white oils are found.

White oils are not common in America, but are sometimes found. Some cases have been noted in the Los Angeles field, California, which had a specific gravity of 0·810; some in the Placenta Canon district, California, which had a specific gravity of 0·740; some at Butler, Ohio, with a specific gravity of 0·7407.

There are black oils in Mexico, Wyoming, Texas, etc. One Wyoming oil had a specific gravity of 0·966.

The following is a table showing specific gravity, flashing point, and the colour of various Canadian oils, taken from Sir Boverton Redwood's Treatise on Petroleum, Volume One:

Physical Properties of Crude Petroleums in Canada.

Locality	Specific Gravity	Flashing Point (AbelTest.) F	Colour
Canada:			
Petrolia	0·858	....	Dark brown
New Field	0·840	Below 60°	Reddish brown
Gaspe—1	0·881	180°	Brown
2	0·856	65°	Brown
3 (2,057 feet)	0·853	54°	Dark brown
4 (906 feet)	0·877	90°	Dark brown
5	0·939	280°	Black
6	0·921	210°	Brown
7	0·948	....	Brown
8	0·871	104°	Brown
9	0·894	....	Brown
10 (2,361 feet)	0·847	46°	Brown
11	0·844	60°	Brown
12 (1,946 feet)	0·861	183°	Brown
13	0·795	20°	
14	0·828	Below 0°	
New Brunswick—1	0·857	40°	
2	0·852	Below 50°	Reddish brown
3	0·862	95°	
4	0·855	84°	
5	0·838	Below 60°	Dark reddish brown

ODOUR.

Oils from various regions are so well distinguished by odour, that it is frequently quite possible to note the origin of an oil in this way. Thus, the Pennsylvania oils have a peculiar odour described as gasoline odour. On the other hand, the oils of California, while having much less odour, have an aromatic smell somewhat like that of coal tar oils. The oils of Texas and Russia smell very much alike, and it is easy to detect an odour similar to oil of cedar in the petroleum from the East Indies. Frequently these characteristic odours are clouded by the strong disagreable odour of hydrogen sulphide. Other organic sulphur compounds give a peculiar, disagreeable character to the odour of much of the oil from Ontario which is like that of the oils of Ohio and Indiana.

In order to determine the characteristic odour of an oil, three samples should be prepared in narrow bottles, carefully stoppered, and half filled with the oil. The oil is shaken vigorously so as to impart its odour to the air above the oil in the bottle and, if this gives the odour of hydrogen sulphide, five cubic centimeters of a fairly strong solution of caustic potash should be added and the oil shaken until the odour of sulphide of hydrogen disappears. In the case of many of the California oils, the shaking with caustic potash solution will give an odour of pyrridine. In a second sample, the odour should be noted after similar treatment of five cubic centimeters of dilute sulphuric acid.

SPECIFIC GRAVITY.

All varieties of petroleum are lighter than water, except when contaminated with finely suspended mineral matter; therefore the specific gravity, *i.e.* its weight, compared with water as one, is expressed as a decimal ranging usually between 0·780 and 1·0. Petroleum lighter than 0·780 is rarely found. More commonly, the specific gravity of petroleum ranges between 0·85 and 0·94. It becomes denser on exposure to air.

On account of the inconvenience of using a decimal fraction as an expression of specific gravity, another system is used—the Baume scale which, while entirely arbitrary, is very convenient. The standard hydrometer scale is known as the specific gravity scale, and has as its initial point distilled water, which on the scale reads 1·000 or 1,000. It is divided decimally above this for liquids heavier than water and below for liquids lighter than water; all oils come under the latter. If an oil is 25 per cent lighter than water, it will therefore read 0·750 specific gravity; 15 per cent lighter than water 0·850 specific gravity, etc. This scale is used by the oil trade in England, France, Germany, Austria, and in fact nearly all of the continental countries. The oil industry in this country, however, has adopted and always used a scale known by its author's name, the Baume or Beaume, both spellings being extensively used.

Antoine Baume first published his table for liquids lighter than water about 1768. He derived his values from solutions of salt and water, and as his methods were what would now be known as crude, his errors were so large that an exact duplicate of his original solutions is impossible. Since the appearance of this first table there have been some fourteen different tables, all by good authorities, each known as the Baume table. Lately the United States Bureau of Standards has adopted the following relation of Baume scale to specific gravity: If 140 is divided by the specific gravity of the liquid taken at 60° and compared with water at 60° and 130 be subtracted, the result is the corresponding number of degrees Baume or

$$\text{Degrees Baume} = \frac{140}{\text{Specific Gravity}\ \frac{60^\circ}{60^\circ}\ \text{F.}} - 130.$$

The following table shows the specific gravity of the liquid and the pounds in a gallon for each degree Baume:—

Equivalents of the Baume Scale and Specific Gravity.

Baume	Spec. Gravity	Lbs. Per Gal.	Baume	Spec. Gravity	Lbs. Per Gal.
10	1·0000	8·33	61	0·7329	6·11
11	0·9929	8·27	62	0·7292	6·07
12	0·9859	8.21	63	0·7254	6·04
13	0·9790	8·16	64	0·7217	6·01
14	0·9722	8·10	65	0·7179	5·98
15	0·9655	8·04	66	0·7143	5·95
16	0·9589	7·99	67	0·7107	5·92
17	0·9524	7·93	68	0.7071	5·89
18	0·9459	7·88	69	0.7035	5.86
19	0·9396	7.83	70	0·7000	5.83
20	0·9333	7.78	71	0·6965	5·80
21	0.9272	7·72	72	0·6931	5·78
22	0·9211	7·67	73	0·6897	5·75
23	0·9150	7·62	74	0·6863	5·72
24	0·9091	7·57	75	0·6829	5·69
25	0·9032	7·53	76	0·6796	5·66
26	0·8974	7·48	77	0·6763	5·63
27	0·8917	7·43	78	0·6730	5·60
28	0·8861	7·38	79	0·6698	5·58
29	0·8805	7·34	80	0·6666	5·55
30	0·8750	7·29	81	0·6635	5·52
31	0·8696	7·24	82	0·6604	5·50
32	0·8642	7·20	83	0·6573	5·48
33	0·8589	7·15	84	0·6542	5·45
34	0·8537	7·11	85	0·6511	5·42
35	0·8485	7·07	86	0·6481	5·40
36	0·8433	7·03	87	0·6451	5·38
37	0·8383	6·98	88	0·6422	5·36
38	0·8333	6·94	89	0·6392	5·33
39	0·8285	6·90	90	0·6363	5·30
40	0·8235	6·86	91	0·6335	5·28
41	0·8187	6·82	92	0·6306	5·25
42	0·8139	6·78	93	0·6278	5·23
43	0·8092	6·74	94	0·6250	5·21
44	0·8046	6·70	95	0·6222	5·18
45	0·8000	6·66	96	0·6194	5·16
46	0·7955	6·63	97	0·6167	5·14
47	0·7909	6·59	98	0·6140	5·11
48	0·7865	6·55	99	0·6113	5·09
49	0·7821	6·52	100	0·6087	5·07
50	0·7777	6·48	101	0·6060	5·05
51	0·7735	6·44	102	0·6034	5·03
52	0·7692	6·41	103	0·6008	5·00
53	0·7650	6,37	104	0·5983	4·98
54	0·7609	6·34	105	0·5957	4·96
55	0·7568	6·30	106	0·5932	4·94
56	0·7527	6·27	107	0·5907	4·92
57	0·7487	6·24	108	0·5882	4·90
58	0·7447	6·20	109	0·5858	4·88
59	0·7407	6·17	110	0·5833	4·86
60	0·7368	6·14			

All densities taken at temperatures of 60°F and referred to distilled water at 60°F as standard.

The most practical instrument for testing the specific gravity of an oil is the hydrometer, which is undoubtedly familiar to all interested in the testing of oils. For the benefit of any who are interested in this subject and have not had actual use of the instruments, we will describe a hydrometer as an instrument composed of a long cylindrical body with tapering ends; on the upper end is mounted a stem, which stands at right angles to the diameter of the body; this stem contains the scale showing the gravity readings. At the lower extremity of the body is attached a small bulb or body, containing a weighted substance, usually mercury or lead shot, and adjusted so as to make the instrument float with the stem always perpendicular to the surface of the liquid. Hydrometers are nearly always made of glass, although there are a few metal forms on the market, and are made either with or without a thermometer placed inside the body, in the latter form enabling one to take the exact temperature of the oil at the time the gravity test is being made.

The important features in the handling and use of the hydrometer are: always have the instrument clean, as dirt will either weigh it down or buoy it up; see that the surface of the oil is free from dirt, dust, and air bubbles, and do not force the instrument down or allow it to sink more than an eighth or at the most a quarter of an inch over the point at which it will float, as the oil clinging to the stem will give it extra weight and cause inaccurate readings. With ordinary care in making the test, a hydrometer will give readings of the highest accuracy.

FRACTIONAL DISTILLATION.

While separation of oils into their individual constituent hydrocarbons is possible, it is never carried out, and the oil is separated merely into such portions as will best fill the requirements of trade, which in the past have been simple. These requirements depend chiefly upon the boiling point (volatility) of the products. Thus internal combustion engines require oils (grouped as naphtha, benzine, gasoline, motor spirit, etc.) which will easily vaporize and mixing with air explode easily in an automobile cylinder. Illuminating oils require that these explosive portions shall be removed so the oil will burn safely in lamps. Again, lubricating oils must be still more difficultly vaporized, so that by separating the oils into these three classes each one is better by being separated from the other.

The tables above show that oils with low specific gravity have correspondingly low boiling points, for members of the same series. When the crude oil is heated the most volatile oils are first to distil over. They are condensed by cooling and run into tanks by themselves as naphtha or crude gasoline until the gravity of the succeeding distillates shows that they are free from gasoline and safe for lamps. These are separated as "burning oil distillate," until the specific gravity becomes too heavy for the oils to rise freely in a wick, and the next products are set aside as gas oils because too thick for lamp oils and too thin for lubricants. The distillation continues at progressively high temperatures until various grades of lubricating oils have been distilled off and only a small percentage of coke is left in the still.

In examining a specimen of crude petroleum it is customary to distill 100 cubic centimeters in a glass flask of special dimensions, and at a specified rate heating prescribed by Engler and Ubbelohde and described in the rules offered by the International Petroleum Commission With American and Canadian, and most other petroleums, the distillate distilling over below 150° centigrade is taken as naphtha, and that between 150° and 300° as crude burning oil for lamps—with some Roumanian and other petroleums the burning oil fraction must be limited to 250°C. Higher products detract from the good quality of the oil.

By so distilling an oil a fair idea may be obtained as to what it will yield in a refinery, although by redistillation and the use of steam, much better separations can be made.

VISCOSITY.

The viscosity of oils increases as the specific gravity increases. It is measured by the time of flow of a given quantity through a small orifice in one of several types of viscosimeters. It is of value in determining the facility with which the oil can be pumped with or without heat through pipe lines. There is no dividing line between thick viscous oils and Maltha Brea and soft asphalt. The viscosity of paraffine oils usually increases quite rapidly with the lowering of temperature on account of amorphous wax contained.

The relation between Engler and Saybolt viscosimeters, which are frequently used in the examination of petroleum products, is thus given by Dr. S. W. Stratton, Director of the United States Bureau of Standards:

If E_t = time in secs. for outflow of 200cc with Engler
S_t = " " " " " 60cc " Saybolt
then $E_t = S_t\,F$
and $S_t = \frac{E_t}{F}$

where the conversion factors F have the values given in the following table:—

E_t *Secs.*	S_t *Secs.*	F *Conversion Factors*
65	37·8	1·72
70	41·7	1·68
80	50·0	1·60
90	58·1	1·55
100	66·2	1·51
125	86·2	1·45
150	106·4	1.41
175	125·9	1·39
200	146·0	1·37
2400	1765	1·36

Example 1. Suppose the observed time of outflow of 60cc with the Saybolt Universal viscosimeter was 1000 seconds. The conversion factor corresponding to $S_t = 1000$, taken from the above table, is about 1·365. Hence the corresponding Engler time is $1000 \times 1{\cdot}365 = 1365$ seconds.

Example 2. Suppose the observed time of outflow of 200cc with the Engler viscosimeter was 185 seconds. The conversion factor corresponding to $E_t = 185$, taken from the above table, is about 1·38. Hence the corresponding Saybolt time is

$$\frac{185}{1 \cdot 38} = 134 \text{ seconds.}$$

The above table was found to hold for all the oils tested ranging from light machinery to heavy cylinder oils, and at all temperatures, 70° to 210° F. The table must not be used below $E_t = 65$ seconds, as none of these viscosimeters are adapted to low viscous oils, as e.g. illuminating oils.

In the use of the Engler instrument, the so-called Engler numbers are very often used instead of the time in seconds. The Engler number is the time of outflow of 200cc of the oil at the test temperature divided by the time of outflow of 200cc of water at 20°C. With Engler instruments, having the standard dimensions specified for these instruments, and in which the variations do not exceed the specified limits, the time of outflow of 200cc of water at 20°C is between 50 and 52 seconds.

Example. Suppose the observed Engler time (for 200cc of oil at the test temperature) is 1000 seconds, and that the time of outflow of 200cc of water at 20° has been found to be 51 seconds. Then the corresponding Engler number is

$$\frac{100}{51} = 1 \cdot 96$$

The above conversion table is given for the time of outflow of 200cc of oil, which is the standard method of using the Engler instrument. When viscous oils are tested at low temperatures, however, the time consumed for the outflow of 200cc is very long. The test can be very much abbreviated by observing the time of outflow of 50cc or of 100cc and multiplying by a suitable factor to reduce to the equivalent time for 200cc, in the way explained by Holde in his book on "Untersuchung der Mineralöle und Fette," 2nd ed. 1905, published by Julius Springer, Berlin.

A very complete investigation of the effect of small variations in the standard dimensions of the Engler viscosimeter is given by Meisener[1]. The same author has also published a paper in the same journal for January, 1912, giving the results of intercomparisons of one Universal Saybolt, one Redwood, and two Engler viscosimeters, with formulæ for reducing to absolute viscosities in dynes per square centimeter.

COEFFICIENT OF EXPANSION.

The coefficient of expansion of petroleum and its products varies not only with the density but with the locality from which oils are obtained. The following table, published by Dr. C. Engler[2] shows the coefficient of expansion of oils from various localities:—

Coefficients of Expansion of Crude Petroleum.

Origin	Coefficient of expansion × 1,000,000	Specific Gravity at ? °C × 1,000
Pennsylvania	840	816
Canada	843	828
Schwabweiler (Elsass)	843	829
Virginia	839	841
Schwabweiler (Elsass)	858	861
Wallachia	808	862
Eastern Galicia	813	870
Rangoon	774	875
Caucasus	817	882
Western Galicia	775	885
Ohio	748	887
Baku (Benkendorf property)	784	890
Oedesse (Hanover)	772	892
Pechelbronn—Pit oil	792	892
Wallachia	748	901
Oberg (Hanover)	662	944
Weitze (Hanover)	647	955

[1]Chemische Revue Uber die Fett-und Harz-Industrie, Heft 9, seite 202-209.

[2]Zeitangew. Chem. xxi, 1585-1597 (1908) Jour. Soc. Chem. Ind. xxvii, 643.

Höfer[1] gives the following co-officients of expansion for various oils:—

Relation of Coefficient of Expansion to Specific Gravity.

Origin	Density × 1,000 at 0° C.	Density × 1,000 at 50° C.	Coefficient of Expansion × 100,000.
West Virginia (White Oak)	873	853	46
(Burning Spring)	841	808	81
Pennsylvania (Oil Creek)	816	784	82
Canada	870	851	44
Burma (Rangoon)	892	861	72
Russia (Baku)	954	920	71
Eastern Gallicia	870	836	81
Western Gallicia	855	852	77
Rumania (Ploiesti) 1	862	829	80
(Ploiesti) 2	901	869	73
Italy (Parma, Neviano de Rossi)	809	772	96
Hanover (Oberg)	944	914	66
Elsass (Pechelbronn)	912	880	73
France (St. Gabian)	894	861	69
Zante	952	921	67

OPTICAL ACTIVITY.

The optical characteristics which are of value in connexion with the study of petroleum are:—

Index of Refraction; Petroleums from different fields vary in their refractive indices, and a study of this property is of frequent value in identifying the source of crude petroleums.

The following table, taken from Redwood, shows the relation of specific gravity to refractive index, in various petroleum derivatives from different localities:—

Refractive Indices of Petroleum Distillates.

	Fraction 140°–160°.		Fraction 190°–210°.		Fraction 240°–260°.		Fraction 290°–310°.	
	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.	Sp. Gr.	Ref. Ind.
Tegernsee	0·7465	1·427	0·7840	1·437	0·8130	1·451	0·8370	1·465
Pechelbronn (Elsass)	0·7550	1·421	0·7900	1·440	0·8155	1·454	0·8320	1·462
Oelheim (Hanover)	0·7830	1·435	0·8155	1·450	0·8420	1·468	0·8620	1·480
Pennsylvania	0·7550	1·422	0·7860	1·439	0·8120	1·454	0·8325	1·463
Baku	0·7820	1·436	0·8195	1·454	0·8445	1·467	0·8640	1·475

[1] Das Erdöl, etc., 1888.

Optical Activity.—It has been found that many varieties of crude petroleum show double refraction. They usually rotate the plane of polarization to the right but many authorities have found a number of varieties of crude petroleum optically inactive while a few, particularly those in the East Indies, rotate the plane of polarization to the left. The optically inert petroleums are usually light paraffin oils from which various bodies known to be optically active have been removed by the natural process of diffusion and absorption. Just, as with the index of refraction, this variation in power to rotate the plane of polarization (polarized light) is useful in deciding upon the place of occurrence of crude petroleums.

THE CHEMICAL COMPOSITION OF PETROLEUM.

GENERAL COMPOSITION.

The varieties of petroleum found in different oil fields over the world are so different in their general composition as to present really almost continuous gradation from oils containing hydrocarbons of the paraffin series (with the general composition C_nH_{2n+2}) through the many series of hydrocarbons to oils which consist almost entirely of liquid asphaltum. Nevertheless, the predominance of one or another series of hydrocarbons in each field makes it possible to give a rough classification of the oils from different regions.

NATURE OF BASE.

The difficulty in refining oils which contain asphaltic bodies has led to a common division of petroleums into those which contain paraffin hydrocarbons alone—so-called "paraffin base" oils, and those which also contain asphaltic material—so-called "asphaltic base" oils.

HYDROCARBONS.

The oils which were first carefully studied were found in Pennsylvania and West Virginia, and were shown to consist chiefly of the members of the paraffin or methane series. Almost all the members from CH_4 (gaseous) to $C_{33}H_{68}$ (solid paraffin wax) were found. The study of Russian petroleum showed that this oil, while containing the paraffine series of hydrocarbons, also contains another series called napthenes which are hydrogen addition products of the benzol or aromatic series. An examination of the oils from the Gulf region of Texas and Louisiana showed the presence of small proportions of these same napthenes together with a considerable proportion of asphaltic bodies, but again containing a large proportion of paraffin hydrocarbons and even paraffin wax itself. A study of California oils showed that, while containing the same series of hydrocarbons found in Russian, Pennsylvanian, and Texas oils, also contain considerable proportions of the benzol or aromatic series. The examination of oils from Borneo and Sumatra brought to light still other hydrocarbons in addition to the ever-prevalent members of the paraffin series.

The following table gives a list of the individual hydrocarbons which have been found in petroleums in Canada:—

Canadian Hydrocarbons which have been identified.

Formula	Boiling Point	Specific Gravity at 20 ° C.
$C_{12}H_{24}$	216°	......
$C_{13}H_{26}$	228°–230°	0·8087
$C_{14}H_{28}$	141°–143 50mm	0·8096
$C_{15}H_{30}$	159°–169° 50mm	0·8192

Individual Hydrocarbons known to exist in Petroleum.

Prof. Hans Hofer states that members of the following groups of hydrocarbons have been identified in petroleum:—

Hydrocarbons

C_nH_{2n+2}
C_nH_{2n}
C_nH_{2n-2}
C_nH_{2n-4}
C_nH_{2n-6}
C_nH_{2n-8}
C_nH_{2n-10}
C_nH_{2n-12}

Cn H_2n+_2 Hydrocarbons.

Composition	Spec. Gravity	Refractive Index	Boiling Point	Pressure	Melting Point	Authority
C_4H_{12}Iso.			0°	760 mm		Mabery
C_5H_{12}Nor.	0·6250 25/25°		36·3	"		Young
	0·6261 0/4°					"
	0·6454 "					"
" Iso.	0·6392 "		27·95	711 mm		"
C_6H_{14}Nor.	0·6771 "		68·95	"		"
" Iso.	0·6730 "		61·00	"		"
C_7H_{16}Nor.			98·40	"		"
" Iso.	0·6969 0/4°		90·30	"		"
C_8H_{18}Nor.	0·7188 20/20°		125·00	760 mm		"
" Iso.	0·7190 "		119·50	"		Mabery
C_9H_{20}Nor.			151·00	"		"
$C_{10}H_{22}$Nor.	0·7479 "		163–164	"		"
" Iso.	0·7467 "		173–174	"		"
$C_{11}H_{24}$	0·7581 "		196–197	"		"
$C_{12}H_{26}$Nor.	0·7676 "		214–216	"		"
$C_{13}H_{28}$	0·7834 "	1·451	226	"		"
$C_{14}H_{30}$	0·7814 "	1·436	236–238	"		"
$C_{15}H_{32}$	0·7896 "	1·4413	256–257	"		"
$C_{16}H_{34}$	0·7911 "	1·4413	274–275	"		"
$C_{17}H_{36}$	0·8000 "	1·4435	288–289	"	10	"
$C_{18}H_{38}$	0·8017 "	1·440	300–301	"	20	"
$C_{19}H_{40}$	0·8122 "	1·4522	210–212	50 mm	33—34	"
$C_{21}H_{44}$			230–231	"	40—41	"
$C_{22}H_{46}$	0·7796 15°		240–242	"	44	"
$C_{23}H_{48}$	0·7900 60°		258–261	"	45	"
$C_{24}H_{50}$	0·7902 "		272–274	"	48	"
$C_{25}H_{52}$	0·7941 "		280–282	"	53—54	"
$C_{26}H_{54}$	0·7977 "		292–294	"	58	"
$C_{31}H_{64}$	0.7992 70°		328–330	"	66	"
$C_{28}H_{58}$	0·7945 "		310–312	"	60	"
$C_{32}H_{66}$	0·8005 75°		342–345	"	68	"
$C_{34}H_{70}$	0·8009 80°		366–368	"	72	"
$C_{35}H_{72}$	0·80052 "		380-384	"	76	"

Monocyclic Polymethylenes—Cn H_2n.

Composition	Spec. Gravity	Boiling Point	Pressure	Authority
C_5H_{10} Penthamethylene	0·70000 04°	50°	760 mm	Young
C_6H_{12} Methylpentamethylene	0·7660 04°	72	"	"
C_6H_{12} Hexamethylene	0·7722 04°	80·6	"	"
C_7H_{14} Dimethylpentamethylene	0·7543 20/4°	94	"	"
C_7H_{14} Methylhexamethylene	0·7964 20/4°	102	"	"

Hydrocarbons Cn H_2n.

Composition	Spec. Gravity	Refractive Index	Boiling Point	Pressure	Authority
$C_{21}H_{42}$	0·8424 20/20°				
$C_{22}H_{44}$	0·8262 "	1·454	240-242°	50 mm	Mabery
$C_{23}H_{46}$	0·8569 "	1·4714	258-260	"	"
$C_{24}H_{48}$	0·8598 "	1·4726	272-274	"	"
$C_{26}H_{52}$	0·8580 "	1·4725	280-282	"	"

Hydrocarbons Cn H_2n $-_2$.

Composition	Spec. Gravity	Refractive Index	Boiling Point	Pressure	Authority
$C_{27}H_{52}$	0·8688 20/20°	1·4722	290-294°	50 mm	Mabery
$C_{28}H_{54}$	0·8694 "	1·4800	310-312	"	"

Napthenes from Petroleum.

Formula	Formation and Occurrence	Boiling Point °C.	Spec. Grav. °C./°C.
C_6H_{12}	Hexahydrobenzene (Kijner) Russian petroleum	69°	0·7539
C_7H_{14}	Hexahydrotoluene (Lossen) Russian petroleum	97°	0·772
	From the products of dry dis-colophony (Renard)	95° to 98°	0·742 20°/20°
C_8H_{16}	Hexahydro-m-xylene (Wreden)	115° to 120°	0·777
	Russian petroleum (Wreden)	122° to 124°	0·7835
	From colophony	120° to 123°	0·764 19°/19°
C_9H_{18}	Hexahydromesitylene (Bayer)	135° to 138°	
	Hexahydro—×—cumene (Knowaloff)	135° to 138°	0·7812
	From petroleum	135° to 136°	0·7808
	Hexahydropropylbenzene (Tchitchibabin)	140° to 142°	0·7811
$C_{10}H_{20}$	Dodecahydroronaphthalene (Wreden)	153° to 158°	0·802
	From petroleum	160° to 162°	0·7808 17·40°/40°
	From petroleum	168° to 170°	0·8073 to 0·814 15°/15°

Napthenes from Petroleum (continued.)

Formula	Formation and Occurrence	Boiling Point °C.	Spec. Grav. $\frac{°C.}{°C.}$
	From menthene	168·5° to 170°	$0{\cdot}797\frac{15°}{15°}$
	From terpene hydrate	168·5° to 170°	0· "
	From camphor (Starodubsky)	167° to 169°	$0{\cdot}8114\frac{0°}{0°}$
	Tetrahydroterpene (Orloff)	162° to 167°	$0{\cdot}806\frac{0°}{0°}$
$C_{11}H_{22}$	From petroleum	179° to 181°	$0{\cdot}8019\frac{16{\cdot}2°}{40°}$
$C_{12}H_{24}$	From petroleum	197°	$0{\cdot}8120\frac{18{\cdot}4°}{40°}$
$C_{14}H_{28}$		240° to 241°	$0{\cdot}8215\frac{18{\cdot}6°}{40°}$
$C_{15}H_{30}$		246° to 248°	$0{\cdot}8210\frac{18{\cdot}8°}{40°}$

OCCASIONAL CONSTITUENTS OF PETROLEUM.

While petroleum, when pure, consists of various compounds of carbon and hydrogen, it frequently contains in solution other compounds of carbon, hydrogen and nitrogen, or carbon, hydrogen and oxygen, or carbon, hydrogen and sulphur, and besides it contains sometimes hydrogen sulphide or elementary sulphur in solution. The nitrogen present varies from 0·2 to more than one per cent. High percentages have been found in California oils. Of these oils, the nitrogen compounds are usually easily removable by sulphuric acid, and some of them have been isolated as alkaloidal bases. These alkaloidal bases are particularly evident in oils from shale where the distillation has been carried on in an atmosphere of hydrogen, and especially under pressure.

Sulphur exists in petroleum in the three forms already mentioned—these are hydrogen sulphide, free sulphur, and organic sulphur compounds. The oils of Mexico contain much sulphur in solution and in the form of hydrogen sulphide, and this is true of the oils in the Gulf region of Texas and Louisiana. Sulphur is comparatively easily removed by distillation, and this is true also with the smaller percentages of sulphur found in California oils. The sulphur in the oils of Lima, Ohio, and in the corresponding limestone oils in Ontario is present, however, in the form of organic sulphur compounds which distil over, particularly in the burning oil fraction, and are removed with great difficulty, the successful method consisting in exposing a large surface of copper oxide to the vapor of the oil during the distillation, by this means the sulphur compounds are broken up with the formation of copper sulphide from which copper oxide can easily be regenerated and used repeatedly. A considerable percentage of sulphur is a frequent characteristic of thicker asphaltic oils. Sometimes the sulphur is partly replaced by oxygen. The percentage of sulphur in the so-called sulphur oils usually varies between 0·5 and two per cent, but oils have been found in Mexico containing more than five per cent of sulphur. It is, however, more difficult to remove sulphur from Ohio oils containing not more than 0·6 per cent than from Mexican oils containing four per cent. The sulphur petroleums in Canada contain more sulphur than the Ohio oils. Maberry found 0·98 per cent of sulphur in addition to that present as hydrogen sulphide. Maberry and Quayle[1] separated the following sulphur compounds from Canadian petroleums:—

Sulphur Compounds	*Boiling Point*
$C_7H_{14}S$	71°— 73°
$C_8H_{16}S$	79°— 81°
$C_8H_{16}S$	97°— 98°
$C_9H_{18}S$	110°—112°
$C_{10}H_{20}S$	114°—116°
$C_{11}H_{22}S$	129°—131°
$C_{14}H_{28}S$	168°—170°
$C_{18}H_{36}S$	198°—200°

These boiling points are all at a pressure of 50 mm.

[1]Journal Society Chemical Industry 1900, p. 505.

The substances thus far mentioned as accompanying petroleum are such as will not settle on standing or can not be filtered from the petroleums. Ordinarily many of the varieties of petroleum contain mineral matter in suspension, and this increases as the oil increases in viscosity. The percentage of clay which can remain suspended or emulsified in an oil seems to depend on the proportion of water. If the water is removed, the clay will settle out—vice versa, if the clay is removed the water will likewise settle out.

ANALYSES.

It is unfortunate that so few analyses are existent of Canadian oils. In the early days some of the refineries and other companies had analyses made, but it was thought that they were of no particular value and the principle was largely discontinued. Few of the analyses are now available. Some of the old analyses are reported in the chemical dictionary published by Lippincott and referred to in the British Encyclopædia, 9th Edition.

In general the oils in Nova Scotia and New Brunswick are associated with thick beds of shale and consequently nearly free from sulphur and asphalt. They consist chiefly of paraffin hydrocarbons rich in gasoline, lamp oils, and paraffin wax and are associated with large supplies of natural gas which is likewise quite pure methane.

In Ontario, on the other hand, the oils are associated with limestones, and are characterized, as at Petrolia, by sulphur compounds including hydrogen sulphide which smells so strong that it can be recognized throughout the field. The crude petroleum contains less illuminating oil than Pennsylvania crude oil or than the Canadian oils farther east, or those near Calgary in Alberta. The Ontario oils are rich in lubricating oils and show good yields of paraffin wax. The Lambton county oil is dark brown in colour and has a gravity of 31 to 35 Baume. Its sulphur content is much higher than in the United States; the latter containing seldom more than 0·55 of sulphur, whereas the Canadian oil runs as high as 2½ per cent, making refining difficult except by the most modern methods.

The following table shows the yield of crude oils from various fields:—

Unsaturated hydrocarbons

TABLE XI.

Analyses of Petroleum from various fields.

No.	LOCATION.	Depth of Well (feet).	Physical Properties. Gravity at 60° F. Specific.	Gravity at 60° F. Baumé.	Colour.	Odour.	Distillation by Engler's Method. Begins to boil at ·C.	By volume. To 150° C. C. C.	To 150° C. Specific gravity.	150°–300° C. C. C.	150°–300° C. Specific gravity.	Residuum. C. C.	Residuum. Specific gravity.	Total. C. C.	Sulphur (per cent).	Paraffin (per cent).	Asphalt (per cent).	Water (per cent).	Unsaturated hydrocarbons (per cent). Crude.	Unsaturated hydrocarbons (per cent). 150°–300°	REMARKS.
	Canada:																				
	Ontario, Lambton County—																				
1	Petrolia		.8580	33.0				2.50		57.50		a40.00		100.00							aIncludes 4.08% coke.
2	Other							12.5	.7350	35.80	.8260	a48.70		97.00		3.00					aIncludes 43.7% lubricating oil 5% coke and loss.
3	"							20.0	.7940	50.00	.8370	a30.00		100.00							aIncludes 2.2% lubricating oil 8% tar, coke and loss.
	Quebec—																				
4	Gaspé No. 1.		.8470	35.0				8.75		48.00		a42.75		99.50							aIncludes 2.75% coke.
5	" No. 2.		.7950	46.0				22.10		34.30		a42.80		99.20							aIncludes .8% coke.
6	" No. 3.		.8280	39.0				15.90		41.30		a41.90		99.10							aIncludes 1.4% coke.
	United States:																				
	Pennsylvania—																				
7	Perry County—Millerstown		0.7900	47.2				17.00	0.6930	43.00	0.7650	40.00		100.00							Percentages 17, 43, 40 are approximate.
8	Venango County		.8820	28.7	Dark brown			8.55		a42.78		b48.67		100.00							a150°–270° C.; bIncludes loss and water.
	Kentucky—																				
9	Allen County—Petroleum	810	.8490	34.9	Brown	Like Pa. oil	71	12.50	.7373	41.00	.8144	45.30	0.9162	98.80		3.65	2.10	Trace.	18.8	7.0	
	West Virginia—																				
10	Ritchie County—Harrisville	1,850	.7977	45.5	Dark amber	"	93	17.00	.7265	42.00	.7770	40.90	.8485	99.90		5.32	.00		5.6	4.0	
11	Wood County—Parkersburg	350	.8750	30.0	Dark green	"	165			16.00	.8356	82.40	.8872	98.40			.00	Much.	21.6	5.0	
	Ohio—																				
12	Morgan County—Milner pool	325	.8046	44.0	"	"	74	14.50	.7137	38.50	.7815	43.60	.8669	96.60		5.36	.00		11.6	5.0	
13	Fairfield County—Bremen pool	2,462	.7848	48.4	Medium green	"	68	15.00	.7036	40.00	.7698	42.00	.8557	97.00		8.33	.00	None.	11.6	4.0	
14	Northwestern Ohio—Trenton limestone		.8284	39.0				15.00		33.00		51.46			.34						
	Illinois—																				
15	Lawrence County—Bridgeport Twp	1,700	.8289	38.9	Dark green	Sulphur	73	12.00	.7230	35.00	.7874	49.20	.9067	96.20		4.31		Trace.			
	Indiana—																				
16	Vigo County—Terre Haute		.8790	29.3						39.60	.8254	60.40		100.00	.72						300°–350° C., 14.8%; sp. gr., 0.867; 350°–390° C., 40.6%; sp. gr., 0.879.
	Kansas—																				
17	Allen County—Chanute pool	751	.8647	31.9	Dark green		109	5.00	.7350	36.00	.7993	57.80	.9223	98.80		4.25	1.23				
	Oklahoma—																				
18	Creek County—Glenn pool	1,500	.8459	35.5	Black		105	8.50	.7566	42.00	.8001	49.90	.9032	100.40		6.98	.45				
	Texas—																				
19	Hardin County—Sour Lake pool	1,020	.9352	19.7	Dark green	Sulphur	170			23.00	.8750	76.70	.9569	99.70		.00	.00		59.6	11.0	
	Louisiana—																				
20	Caddo Parish	1,620	.8723	30.5	Black		210			28.00	.8299	69.50	.8895	97.50			.14				
21	Marion County, Texas (Caddo pool)	*2,300	.8065	43.6	Brown	Like Pa. oil	100	6.00	.7305	50.50	.7646	42.90	.8739	99.40		7.02			12.8	5.0	
	California—																				
22	Fresno County—Coalinga		.9590	16.0						14.50		85.50		100.00			9.50				Flash point 120° C.
23	" "		.8459	35.5	Greenish			33.06	.7829	57.85	.8608	9.09		100.00	.21						Combustion gives carbon 86.24%, hydrogen 13.08%, bromine absorption 9.07%.
24	Kern County—Kern river		.9673	14.7	Black			1.00		a28.99		71.01		100.00	.95		21.25				a150°–350° C. 350° C. to asphalt, 48.13%. B. t. u. 10,471. Viscosity at 15.5° C.–274.35; at 85° C.–3.35.
25	Los Angeles Co.—Los Angeles city	1,060	.9706	14.2						26.30	.8852	73.70		100.00	1.18		25.30				Gravities at 15° C. 300° C. to asphalt, 44.2%. Calorific value per c. c., 10,073. Viscosity by Redwood viscometer over 1,800 at 150° C.
26	" Newhall district		.8107	42.7				51.00	.7830	43.00	.8333	6.00		100.00							150°–270° C.; above 270° C., 4%; loss 2%.
27	" "	662	.9474	17.8				1.20	.7790	40.20	.8723	58.60		100.00	.49		22.70				300° C. to asphalt, 34.8%. Gravities at 15° C. Calorific value per c. c., 9,911. Viscosity by Redwood viscometer 1,355 at 150° C.
28	" Whittier field		.9396	19.0				5.00		a20.00		75.00		100.00	.70		37.00				a150°–270° C; above 270° C 38%. Maumene No. 0.335. Nitrogen 0.669; oil at 19° C.
29	Santa Barbara Co.—Santa Maria field	1,600	.8882	27.6				25.90	.7460	30.60	.8469	44.50		101.00	1.56		12.00				Gravities at 15° C. 300° C. to asphalt; 29.7%. Calorific value per c.c., 9,364. Viscosity by Redwood viscometer, 90 at 15° C.
30	" "							12.00		12.00		76.00		100.00			16.00				No temperature given. Gas oil, 10%, lubricating oil, 50%.
	Colorado—																				
31	Mesa County	150	.8345	37.8	Yellow	Aromatic	145	1.00		42.00	.7188	56.50	.8427	99.50		19.65			12.4	4.0	
32	Fremont County—Florence	2,455	.8750	30.0			122	1.50		27.00	.7988	70.20	.9079	98.7		9.23					
	Wyoming—																				
33	Fremont County—Lander field	965	.9126	23.4	Dark brown		105	1.50		24.00	.8018	73.9	.9605	99.40		.90	11.04		58.0	4.0	
34	Natrona County—Salt creek		.8563	33.5	Dark green		126	1.00		36.00	.7854	62.4	.9032	99.40		5.63	.00		13.2	4.0	
	Utah—																				
35	San Juan County—Goodridge	225	.8363	37.4	Black		90	10.00	.7375	38.00	.7967	51.60	.8974	99.60		7.31		Trace.			
	New Mexico—																				
36	Eddy County—Dayton pool	914	.9109	23.7	Black	Sulphur	142	1.00		31.00	.8417	68.10	.9390	100.10	(a)	.00	3.91		25.6	14.0	aNot determined.
37	Trinidad No. 1.		a.9000	26.0				19.00		39.00		b42.00		100.00	.44						aSp. gr. at about 28° C. bIncludes 34% lubricating oil and 8% residue and loss.
38	No. 2.		a.8930	27.0				19.50		38.00		b42.50		100.00							aSp. gr. at about 28° C. bIncludes 36.5% lubricating oil and 6% residue and loss.
	Peru—																				
39	Zorritos		.8480	35.0	Dark brown			25.00		28.5 35.0		a17.00					31.00				aLubricating oil.
	Russia—																				
40	Baku		.8800	29.0				.63	.7620	37.28		a62.09		100.00							aIncludes 57.97% distillate above 300° and 4.12% residue and loss.
41	Roumania		.8460	35.0				10.00		81.88		5.89		97.77		2.23					
	Japan—																				
42	Formosa, Shinkkoko		.8284	39.0				10.00	.7880	80.00	.8350	a10.00	.8760	100.00							aIncludes heavy oil and paraffin.
	New Zealand—																				
43	Gisborne district		.8642	32.0	Green	Aromatic	210			43.00	.7300	57.10	.8923	100.10		8.88		Trace.			
44	Tarauaki district		.8495	34.8	Brown	"	97	10.00	.7805	50.00	.8281	39.90	.8969	99.90		14.78		Trace.			
	Spain—																				
45	Province of Cadiz No. 1.		.7973	45.6	Amber	"	87	27.50	.7375	53.00	.8088	18.40	.8727	98.90		2.52	.00	0	5.6		
46	" " No. 2.		.8018	44.6	"	"	108	19.00	.7414	60.00	.8000	21.80	.8708	100.80		3.20	.00	0	7.6		

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TABLE XII.

Analyses of Natural Gases from various fields.

LOCALITY.	CONSTITUENTS. Methane.	Carbon Monoxide.	Carbon Dioxide.	Nitrogen.	Oxygen.	Hydrogen.	Ethylene Series.	Carbonic Acid.	Hydrogen Sulphide.	Inert Media.	Other Hydro-carbons.	Other Constitu-ents.	REMARKS.	ANALYST.
Canada.														
Ontario—Welland County	a96.57 (mostly methane)			2.69					.74					F. C. Phillips.
Kent County—New Tilbury and Romney	92.20 (mostly methane)	.21	1.40	5.59	trace	.40			.20					
Alberta—Medicine Hat	99.49								.51					
British Columbia—Vancouver	93.56		.14	6.30										F. C. Phillips.
United States.														
California—Fresno County—Coalinga Field	88.00		11.10	.90									Collected by G. H. Salisbury, June 10, 1910.	G. A. Burrell.
King County—Sunset Field	87.70		10.50	1.80									Collected by I. C. Allen, July 16, 1909.	"
Los Angeles County—West Los Angeles	91.00		1.00	5.20	.10						2.70	......	Collected by I. C. Allen, July 23, 1909.	"
Santa Barbara Co.—Santa Maria Field	62.70		15.50	1.40	.20						20.20	......	Collected by I. C. Allen, Aug. 5, 1909.	"
Kansas—Allen County—Iola	94.50			5.08	.23							H–Trace. He– .18	Collected June 10, 1906.	Hamilton P. Cody and David F. McFarland.
Chase County—Elmdale	78.60		.15	12.13	.30						8.26	He– .56	Depth, 152 ft.; pressure 45 lbs.; collected Oct. 6, 1906.	"
Louisiana—Caddofield	95.00		2.34	2.56								.01		F. C. Phillips.
New York—Chautauqua Co.—Fredonia	90.05		.41	9.54										"
Pennsylvania—McKean County—Kane	90.38		.21	9.41	Tr.									"
Washington County—Houston	84.26		.44	15.30	Tr.								Contains also trace of ammonia.	"
Westmoreland Co.—Murrysville	97.70		.28	2.02	Tr.									"
West Virginia—Marion County—Fairmont	81.60	.40	.10	3.21	.20	.20					14.29			C. C. Howard.
Austria. Wels	97.10		1.30	1.00	.60								Specific gravity—(air=1.) 0.5667	
Germany. Neuengamme near Hamburg	91.50		.30	4.60	1.50						2.10			
Hungary	92.05		.65	7.30										
Russia. Samara	53.35		1.17	40.86	4.22						.40			
Daghestan	65.84		12.82									Ethane 19.92		
Tchelcken	77.30	3.50	3.60	8.90	1.80							Olefines 4.80		
Caspian Region	93.07		2.18	.49		.98						Olefines 3.26		
Baku (Peninsula of Apscheron)	92.89		.93	2.13		.34						Olefines 4.11		
England. Staffordshire—Charlemont	99.60		.30	.10										
Sussex—Heathfield	93.16	1.00		2.90								Ethane 2.94		

a Including minor amounts of other hydrocarbons.

[illegible]

[illegible]

[illegible]	[illegible]

[illegible]

CHAPTER III.

NATURAL GAS.

GENERAL COMPOSITION.

The gaseous members of the petroleum series are referred to as natural gas. Practically all oil pools contain the gaseous members dissolved in the liquid portion and usually under such high pressure that large quantities of gas are thus stored. In drilling into the deposit, if the highest point in the oil reservoir is tapped, the gas is liberated and a gas well is obtained whereas if the reservoir is tapped farther down the slope of the dome or anticline in which the oil is stored the pressure of the gas above presses out the oil inside, and an oil well is the result. It is this gas pressure which causes the oil to flow into wells, and produces flowing wells, and even the oils that are pumped owe their productivity to the pressure of dissolved gas which forces the oil slowly through the porous rock into the well cavity. Occasionally dry gas is obtained—that is gas which is not connected with any oil pool. Such gas can be distinguished from the gas from oil pools because it consists chiefly of methane, the first member of the series, and is comparatively free from the higher members such as ephane, propane, butane, pentane. The latter are vapours which are easily condensed under pressure and cold to produce a very volatile grade of gasoline known as natural gas gasoline. Natural gas is very commonly found issuing in sufficient quantities to be dangerous in coal mines and occasionally in mines of other minerals.

In composition, natural gas—from whatever source it is obtained—is to a large extent methane, the porportion of this frequently reaching 95 to 98 per cent, while the remainder is ethane, nitrogen, etc., as shown by the following analyses:—

Canadian Natural Gas.[1]

	Methane CH_4	Ethane C_2H_6	Carbon dioxide CO_2	Oxygen O_2	Nitrogen N_2	Other gases	Authority
Ontario	92·6	—	0·3	0·3	3·6	H_2 = 2·2, CO = 0·5, H_2S = 0·2, C_2H_4 = 0·3	Tassarts (*a*)
Vancouver, B.C.	—	93·6	0·1	—	6·3		Phillips (*b*)
Sedgewick, Alberta	66·9	—	1·1	3·9	28·1		Stansfield (*c*)
Calgary, Alberta	91·6	—	0	0·2	8·2		Carter (*c*)
Mayton, Alberta	93·9	—	0·2	1·1	4·8		Carter (*c*)

(*a*) Exploit du petrol. 1908, 302.
(*b*) Amer. Chem. Jour. 16, 416, 1894.
(*c*) Fuel Testing Division, Mines Branch, Ottawa.

In the above analyses methane is not distinguished from its higher homologues ethane, propane, etc.; in the last three it was found that the amount of these homologues was small, certainly less than 1 per cent. That the higher hydrocarbons are not always so low is shown by Burrell and Seibert (Jour. Amer. Chem. Soc. 1914, 1538); they made a complete analysis of Pittsburgh natural gas by means of fractional distillation at the low temperatures attainable by the use of liquid air, and obtained the following results:—

Methane	=	84·7%
Ethane	=	9·4%
Propane	=	3·0%
Butane	=	1·3%
Nitrogen	=	1·6%

Stansfield and Carter have examined a Canadian natural gas from the Dingman well, Calgary, in which there were present considerable quantities of higher hydrocarbons; 1 litre of the gas at N.T.P. was found to contain 0·565 grams of carbon and

[1] This table and the following table of analyses of natural gas from foreign countries, and the accompanying notes were prepared by Dr. F. E. Carter, Mines Branch, Ottawa.

0·175 grams of hydrogen; if the gas were all methane the carbon hydrogen ratio would be 2·98, if it were all ethane the ratio would be 3·97. The actual ratio of this gas was 3·23, which shows that it was similar to that examined by Burrell and Seibert for which the ratio was 3·24 (calculated from above analysis). The so called "wet" natural gases contain higher percentages of ethane, propane, etc., and correspondingly less methane than the "dry" gases.

Some further analyses are given of natural gas in other countries:—

	Methane CH_4	Ethane C_2H_6	Carbon dioxide CO_2	Oxygen O_2	Nitrogen N_2	Other gases	Authority
United States:—							
Wyoming	81·7	17·4	0·2	0	0·7		Burrell (*d*)
Pennsylvania	92	·6	0·3	0	7·1		Phillips (*e*)
New York	90·1	—	0·4	trace	9·5		Phillips (*f*)
Cleveland, Ohio	93·5	—	0·2	0	6·3		Phillips
Indiana	77·4	14·2	0·7	0	6·6	$C_2H_4=0{\cdot}9$, $He=0{\cdot}2$	Cady and MacFarland (*g*)
Kansas	90·6	—	1·0	0·6	7·1	$C_2H_4=0{\cdot}2$, $Co=0{\cdot}5$	Cady and MacFarland (*g*)
California	83·7	0	6·7	2·8	6·3	$C_2H_4=0{\cdot}2$, $CO=0{\cdot}3$	Cady and MacFarland (*g*)
Russia:—							
Ssurachany	94·0	—	4·0	0·4	0·6	$C_2H_4=1{\cdot}0$	V. Herr (*h*)
Bibi-Eibat	86·3	2·8	10·0	0·2	0·7		V. Herr (*h*)
Baku	91·2	1·3	1·8	1·2	4·5		V. Herr (*h*)
Galicia:—							
Tustanowice	86·5	—	—	1·0	3·8	heavy hydrocarbons = 8·7	Grusciewicz and Hausmann (*i*)
Hungary:—							
Seibenburgen	91·0	—	0·2	0·3	1·4	heavy hydrocarbons = 1·1 unstated 6·0	Zeller (*k*)
Kissarmas	99·0	—	—	0·4	0·2	$H_2=0{\cdot}4$	Czako (*l*)

(*d*) Bureau of Mines, Tech. Paper 57.
(*e*) Amer. Chem. Jour. 16, 416, 1894.
(*f*) Chem. Centralblatt, 1887, 1524.
(*g*) Jour. Amer. Chem. Soc. 29, 1523, 1907.
(*h*) Trudy, 1908.
(*i*) Petroleum 6, 2245, 1911.
(*k*) Petroleum, 1906, 297.
(*l*) Jour. Für Gasbeleuchtung, Dec. 1911.

In Kansas a natural gas well has been found which consists largely of nitrogen while, on the other hand, many gas wells, especially those connected with a large petroleum supply, are largely made up of gasoline vapours—so as to be largely condensible into natural gas gasoline. Various methods have been given for the analysis of natural gas to ascertain the quantity of natural gas gasoline which can be extracted under pressure and cold. The simplest of these is to pass the gas through an absorbent, such as a heavy petroleum, and note the gain in weight, or to afterwards distil off the gasoline absorbed by the heavier material. More direct and, perhaps, more satisfactory methods consist in the actual condensation of the gasoline by means of pressure and cold. Where liquid air is accessible, condensation by this agent is most satisfactory.

SWAMP GAS.

In many stagnant pools, bubbles of gas are noticed frequently in considerable quantities. This gas, if collected, usually burns although sometimes the quantity of nitrogen and carbon dioxide prevents. In many places where large quantities of vegetable matter, trees, etc., are buried fifty or a hundred feet underground, as on the sea coast or any flood plain of a large river, wells drilled into this vegetable mass yield swamp gas under considerable pressure. Notable examples of this are on the west coast of Washington and Oregon and in Louisiana near the mouth of the Mississippi river. In the latter place, gas sufficient for lighting several houses has been obtained for years. This gas can be readily distinguished from the usual deep-seated natural gas by its odour of decaying vegetable matter whereas in some cases dry natural gas has no odour; however in the far greater number of cases it has the odour of gasoline or crude petroleum.

Frequently natural gas is largely contaminated by hydrogen sulphide, as in Mexico.

In the limited amount of gas which is found in the Petrolia field, Ontario, a considerable proportion of hydrogen sulphide is present; consequently, the government gas inspector has notified the company and consumers that gas must not be used for illuminating purposes in Petrolia, unless it be first purified. In Chatham and in some other localities purification is accomplished by the companies through the use of individual purifiers in each house.

CHAPTER IV.

Geological Occurrence of Petroleum and Natural Gas.

ORIGIN OF PETROLEUM.

By Marius R. Campbell.

Although petroleum or its residual products have been known from very early times, little progress has been made in determining its ultimate source and its mode of origin. It is true that many suggestions have been made and many hypotheses have been advanced with great zeal by their originators and ardently supported by their advocates, yet none of them has been universally accepted and they have never passed beyond the stage of theory pure and simple. Most of the theories are based on chemical evidence and so are difficult to prove or disprove, as Nature in her world-wide laboratory has been able, in the long eons of time since first the world began, to accomplish many things that are impossible to the limited facilities and the short space of time available to man.

Under such conditions the writer prefers to make a simple statement of the principal theories and of the strongest arguments that have been adduced in their support, and to leave the reader to select that which seems to him most reasonable or which appears to fit most of the facts in the field with which he is familiar.

Many students of petroleum have taken the position that the ultimate source of the oil and its mode of origin are unimportant to the practical geologist or oil operator, and that all that is necessary is to understand the forces which have caused the oil to move in the rocks and the conditions which have affected its accumulation. It is true that, from the standpoint of the man searching for oil, these are the important factors, but can he really be sure of finding an accumulation of oil without knowing something of the source from which it may have been derived and the extent of its migration? In many cases the geologist can, in advance of exploration with the drill, point out geologic structures favorable for the accumulation of oil, but unless there are some surface indications of the oil itself, he knows no more of its actual presence in the rocks below than the merest tyro. He must advise the oil man to test the ground with the drill to see if oil is present or not, and even then he has no idea, if the location is in entirely new territory, how deep he will have to go to make a thorough test. As the geologist does not know from whence the oil may come, he cannot set a limit beyond which it is fruitless to continue the search. In other words, the practice of exploration for oil to-day is largely governed by chance, but it is confidently believed that much which is now uncertain could be eliminated were the source of the oil well known and its mode of origin understood. The geologist cannot afford to ignore this phase of the question, for so long as he does he is obliged to confess that much of his work is unscientific and that the presence or absence of oil in any locality is, so far as he is concerned, a matter of accident about which he can only make a guess at the best. Let us hope that geologists and oil chemists the world over will be constantly on the watch for evidence upon which to settle this important question.

Although many theories have been proposed to account for the origin of petroleum, none have been well established and consequently public sentiment varies from time to time regarding them. At one time a certain theory may be generally accepted, but the discovery of new facts or the appearance of a new advocate may change the tide of public opinion and some other theory may be the one generally accepted. Such will naturally be the case until more positive proof can be obtained regarding the mode of origin that is at present available, and then it may be found that petroleum has been produced in various ways and that many of the theories advanced have an element of truth in them, but that no particular theory has universal application.

The theories of origin so far propounded may be separated broadly into two groups: (1) those ascribing to oil an inorganic origin, and (2) those ascribing to it an organic origin.

INORGANIC ORIGIN.

The theories ascribing to oil an inorganic origin have been propounded alone by chemists who necessarily know little of the geologic conditions under which oil occurs in various parts of the world. So far as the writer is aware, no geologist has yet publicly advocated such a theory. It would therefore seem that the geologic conditions do not favour such an hypothesis, else men familiar with them would rally to its support. This would seem to militate against such a theory, for the true explanation of the origin of oil must fit all the facts, both chemical and geologic, and neither set should be disregarded in attempting to solve the problem.

It seems to be unnecessary here to review all of the steps leading up to what may be considered the present accepted version of the theory of the inorganic origin of petroleum. It was extremely crude when first proposed, but has been modified from time to time as chemical knowledge increased.

The first suggestion that deserves the name of theory regarding the inorganic origin of petroleum was advanced by the distinguished French chemist, Berthelot, in 1866. He supposed that the alkali metals, potassium and sodium, exist uncombined and at high temperature in the interior of the earth. Whenever water carrying carbonic acid in solution finds access to these metals a series of hydrocarbon compounds would result. According to this theory the formation of oil and gas would take place deep in the earth without the intervention of organic matter of any kind, and the process, if not continuous, would be active whenever water penetrated to this part of the globe.

The theory of the inorganic origin of petroleum, in the minds of most people, is associated with the name Mendeljieff, the great Russian chemist, who in 1877 advanced the following theory. He supposed the interior of the earth to contain large masses of metallic iron and also metallic carbides all at a high temperature. The contact of water with these bodies would, according to his theory, generate metallic oxides and hydrocarbons and thus by these simple reactions petroleum would be produced. If this is accepted as the true mode of origin, it naturally follows that the process is continuous or intermittent and will continue in operation as long as the supply of metallic carbides exists. It is true that the rate of production is not known and it may be much slower than that of the removal of the oil by the hand of man, but the very fact that the process must be in a measure continuous would mean that the supplies of oil though exhausted to-day may be renewed to-morrow, and thus we are in little danger of a lack in our fuel supply. This is certainly a most consoling idea, much more so than the advocacy of a theory which provides only for a stored supply and little or no prospect of its replenishment, but despite this advantage the theory has not attracted many adherents, and few geologists familiar with field conditions have had the hardihood to advocate it or to apply it in the solution of the problems that confront them in the practical development of an oil field.

This feeling had grown so strong that seldom was any explanation of the origin of petroleum put forward, except the organic theory, until 1903 when an ardent advocate of the inorganic theory, Eugene Coste, appeared upon the scene and presented a fairly able defense of the theory. He claimed to have applied the principles of this theory in the practical development of several oil and gas fields, and he expressed full confidence that it applied to all occurrences of such hydrocarbons. Mr. Coste presented no new evidence and consequently made no addition to existing knowledge. He attempted to explain every phenomenon connected with an oil field by volcanic or solfataric action, but unfortunately most of his evidence was derived from the reports of others and he was apparently deceived by the term mud volcanoes, thinking them phenomena of true vulcanism.

If petroleum originated from inorganic material, then it should have been in the process of formation since the earliest geologic times and presumably it should permeate the oldest rather than the youngest formations, except as it has migrated through the rocky crust of the earth. It should also be found in igneous as well as sedimentary rocks; in fact, it seemingly should be more abundant in the former than it is in the latter. It should be most in evidence in regions of greater disturbance and faulting and least known in little disturbed and thick sedimentary formations. Its occurrence throughout the habitable globe is under conditions diametrically opposed to those which should prevail according to theory. It is true, however, that oil has been found in igneous rocks in many places, but the amount is small and its presence can be easily accounted for on the assumption that it has migrated from some sedimentary formation which is or has been in contact with the igneous rock.

Some of the phenomena encountered on the Gulf Coastal Plain in Mexico and the United States, such as the association of the oil with salt, sulphur, and hot water, and the presence in many places of dikes and plugs of igneous rock, are puzzling and may be interpreted as an argument for the inorganic origin of the oil, but even if this be granted it explains only its origin in a limited area and the arguments which may be good here do not apply in the great majority of fields throughout the world.

THEORIES OF ORGANIC ORIGIN.

Since 1803, when Leopold von Buch suggested that the bitumen of the Würtemberg Liassic shales was derived from animal remains in the rock, many theories to account for the vegetable or animal origin of petroleum have been advanced. As in the case of the inorganic origin, most of the theories have been put forward by chemists, and geologists have been backward in expressing views upon the subject. This may be accounted for largely by the conditions which prevail in most oil fields and which do not permit of a close examination of the oil-bearing strata, at least in the area in which the oil occurs. It may also be partly explained by the lack of knowledge regarding the laws that control the migration of hydro-carbons through the rocks, for until that question is settled it is extremely difficult to say where the oils have originated and what were the conditions surrounding them.

Most of the oil of the world occurs in formations having a marine origin, and hence it is commonly believed that marine organisms have supplied the material from which it was derived. This view has been greatly strengthened by the demonstration in 1865, by Warren and Storer, that fish oil on distillation would yield hydrocarbons similar to petroleum, and by similar though more elaborate experiments along the same line by Doctor Engler at a later date.

Many chemists and geologists have contributed to the literature on the subject, arguing for the origin from animal or vegetable remains, but the name that now stands out most prominently as having contributed materially to the knowledge of the origin of petroleum is that of Doctor Engler, although the names of Potonié, Orton, Pickham, Höfer, etc., are closely associated with this subject.

The details of the various advances that have been made, and the names of the scientists to whom credit should be given, are ably presented by Redwood in his latest edition ("A Treatise on Petroleum," London, 1913), and by Dalton in "Economic Geology" (Economic Geology, vol. IV, pp. 603-631, 1909), but it seems unnecessary here to do more than attempt to summarize the recent and most important conclusions of the men who have been most active in attempting the solution of the problem.

Engler's statement of the various stages in the process of the formation of petroleum from organic matter, as given by Dalton,[1] is as follows:—

(1) Putrefaction, or fermentation, by which albumen and cellulose, etc., are eliminated. Fatty matter (and waxes), with a small quantity of other durable material and possibly fatty acids from the albumen remain.

(2) Occurs partly during the first stage; saponification of the glycerides and production of free fatty acids, either from action of water or ferments, possibly both. The waxy esters are either wholly or partly hycrolyzed. The residues from many crude oils are probably due to lack of completion of these actions.

(3) CO_2 is eliminated from the acids and esters, water from the alcohols, oxy-acids, etc., leaving hydrocarbons of higher molecular weight containing oxy-compounds, c.f. the intermediate product like ozokerite of Krämer and of Zalo-

[1]Op. cit., p. 625.

ziecki, who also regarded that mineral as representing an early stage in the formation of oil.

(4) Formation of liquid hydrocarbons and violent reaction, with "cracking" into light or gaseous products=formations of petroleum.

He adds, in regard to all these stages, that he is assuming that time and temperature compensate one another, though pressure had no action beyond raising the temperature slightly, and it is in no way equivalent to it. He considers that with moderate temperatures and pressures oil of intermediate grade will be found, while increase of either tends to form light oils. Polymerization and addition products are formed after the completion of stage 4.

He further suggests that the various hydrocarbons are formed as under:—

Methanes—as direct products from the "bitumen," that is, the fats of stage 1 and heavy hydrocarbons of stage 3.

Olefines—directly formed by splitting up of saturated chains of hydro-carbons of the paraffin series.

$$C_{2}n\ H_{4}n+_{2} = Cn\ H_{2}n+_{2}+Cn\ H_{2}n.$$

These would afterwards polymerize to form simple methanes, etc., but they are probably partly reformed in distillation, especially at high temperatures as in the cracking process.

Naphthenes—perhaps from the decomposition of aromatic acids or esters, or from the isomeric olefines under the influence of heat and pressure.

Lubricants—formed directly from the original fats, at low temperatures.

Benzine, etc.—from the decomposition of the fats at comparatively high temperatures.

So far the evidence presented here has been almost entirely chemical. Geologists generally have favoured the theory of the organic origin of oil, probably because in most fields they found the oil contained in or associated with thick masses of sedimentary rock, fossils of which might easily have supplied the original material from which the oil was derived, but unfortunately the conditions have generally been such that no positive evidence could be obtained. The facts, so far as the geologists could observe them, were generally interpreted as favouring the organic as against the inorganic origin, but after all it was a matter of interpretation or personal bias and had little or no real foundation. Thus in the great Appalachian oil and gas fields, geologists have assumed that the great masses of Devonian shale in which the oil sands are imbedded were the source of the oil, but even on that assumption they were compelled to admit migration to its present resting place. The question then naturally arose, if the oil has migrated from the shale into the sandstones, what is to prevent its migration from underlying rocks, and if from underlying rocks, may it not have come from deep in the crust of the earth? It must be admitted that while such a migration is possible, it seems like carrying the movement to the extreme, and few geologists have been willing to admit even its possibility.

In probably every known field in the world there are fossiliferous rocks to appeal to as a source of origin, but the conditions are such that it is extremely difficult to prove such a source of origin. The writer is familiar with only one case in which the conditions are such as to offer almost positive proof not only of the particular formation in which the oil originated, but also the kind of organisms that furnished the raw material. This case is the oil fields of southern California as interpreted by Arnold and Anderson.[1] It would be impossible in this paper to review all of the evidence, but briefly summarized it is as follows:—

Several of the formations in this region are diatomaceous, in fact, one formation 2,500 feet thick (the Monterey shale) is made up almost exclusively of the casts of diatoms. The diatom-bearing formations do not as a rule contain oil to-day, but they bear inherent evidence of having contained it in times long past. The oil is now found in sandstone reservoirs, but only in those that are adjacent to the diatomaceous material either through faulting, through conformable disposition, or through unconformable deposition. This association of the oil-bearing rocks to the diatomaceous shale has been found to

[1]In various bulletins issued by the U.S. Geological Survey.

hold true throughout practically all of the fields of southern California and in case the Monterey or main diatom-bearing bed is barren of diatoms, as in certain parts of the field, the oil sands cease to follow it, but are associated with another diatomaceous shale lower in the series. The relationship is so constant that it has proved to be a reliable guide in new territory in determining whether or not the rocks contain oil.

The writer regards the assumption that the diatoms furnished the original material from which the oil has been found, so strong that it practically amounts to proof, and offers it as one case in which the geologic relations point unmistakably toward the origin of the oil. It seems probable also that in such fields as the oil shales of Utah and Colorado it may be possible by geologic studies to definitely determine the kind of material that furnished the supply of organic matter, and also to locate its position in the geologic section. It is to be hoped that similar proofs may be obtained in other fields so that the chemical results may be checked by geologic observations in order to completely establish the source and mode of formation of the oil.

Before concluding this brief resumé of the theories propounded and the generally accepted beliefs of to-day, it is important to consider the optical investigations and the light they throw on this important question.

Although it has been known since 1835 that the polarized ray was rotated by petroleum, it was not until 1904 that Rakusin suggested that this property of rotation was due to cholesterol, an element found only in animal fats. Later, Doctor Lewkowitsch pointed out that the rotation of the polarized ray could be produced not only by cholesterol from animal fats, but also by phytosterol from vegetable oils. On applying this optical test it was found that many crude petroleums possessed the rotary power, but that oil derived from inorganic materials was entirely inactive. On the basis of such tests Dalton[1] states: "There seems to be no reasonable room for doubt that the optical activity of petroleum is due to cholesterol and phytosterol...... Not only do they establish beyond question the organic origin of

[1]Op. cit.

petroleum, but also since the alcohols in question occur in the fatty parts of the animals and vegetables, it confirms Engler's hypothesis that these parts play the principal role in the formation of mineral oils." He also concludes his review with the following comprehensive statement: "One is led, therefore, to regard the great majority of oils as derived from the decomposition, during long ages, at comparatively low temperatures, of the fatty matters of plants and animals, the nitrogenous portions of both being eliminated by bacterial action soon after the death of the organism. The fats and oils from terrestrial fauna and flora may have taken part in petroleum formation, but the principal role must, from the nature of most petroliferous deposits, have been played by marine life."

In attempting to sum up the evidence presented herewith, and other evidence which the present paper affords no opportunity to present, three propositions seem to be established.

(1) The evidence available at the present time favours the animal origin of most petroleum.

(2) A certain amount has probably been derived from the fatty portions of plants.

(3) The optical and geologic evidence is decidedly against the inorganic origin of petroleum, but the association of oil and gas with volcanic features in certain fields suggests that there may have been a relationship of cause and effect in the associated phenomena.

MOVEMENT OF OIL THROUGH THE ROCKS AND CONDITIONS OF ACCUMULATION.

In considering the manner in which oil has moved through the rocks and the conditions that have led to its accumulation in the vast pools that have been found by the drill, it is immaterial what has been its source of origin or its mode of formation. Almost all geologists who have written upon the subject are agreed that, in general, oil has not been formed in the rocks in which it now occurs, but that it has migrated from its place of formation. Whether this movement has been from vents where volcanic emanations have come up through the strata, or from areas in which the oil has been produced from organic matter, is of little consequence. The fact of prime importance to the working geologist is that it *has migrated* from the place where it was formed and that it *has accumulated* where local conditions have been such as to interfere with its further movement. In most cases migration must be understood as preceding accumulation, but there are apparent exceptions which will be mentioned later. According to the generally accepted idea, there could have been no accumulation into pools without previous movement; therefore the first part of the problem to be considered is the migration of oil through the rocks, the cause of the movement, and the various geologic conditions that may have affected it and modified the results.

Migration.—There are three forces which, under certain conditions, tend to produce movement of oil in the rocks. These are (1) gravitation, (2) capillary attraction, and (3) difference in specific gravity of oil and water.

Gravitation.—Oil, in common with all other substances, is affected by gravitation, but as the attraction of gravitation is the weakest of the forces enumerated above, it operates only where the conditions are such that the others are inactive. This is when the rocks are dry and of an open porous character. As the pull of gravitation is towards the center of the earth the movement of the oil under such conditions is always downward, but its course is probably not direct and the movement is one of dispersion rather than concentration. This is due to the ready response of the moving oil to the inequalities and irregularities of the pore spaces in the rock and to the surface tension of the oil.

Owing to the vicissitudes encountered by the particles of oil moving alone under the influence of gravity, the movement is weak and probably has played only a small part in the great migration of oil from its point of origin to the pool in which it is found.

Capillary attraction.—The capillary attraction of oil is much more powerful than the pull of gravitation, but it is entirely overcome in the presence of water by the greater surface tension of the latter liquid. Therefore capillarity can produce movement of oil only in dry rocks, and as it operates in material having extremely small pores, it follows that it is not a factor of movement in open porous rocks but in fine-grained rocks. Day[1] has shown that petroleum will diffuse readily in all directions through dry clay and shale and that in the diffusion the oil will be separated into fractions of very different specific gravities. From this he concludes that most crude oil has been diffused through such material and that capillary attraction is the cause of much of the movement of oil in the crust of the earth. Day also proves that moist clay and shale are impervious to oil and hence that a cap rock of such material is the one best fitted to hold the oil after it has accumulated.

The diffusion of oil through dry shale or clay would seem to offer a plausible explanation of the manner in which the oil has migrated across the planes of stratification from its place of origin. If it originated from inorganic substances then the oil has migrated upward by capillarity with the porous strata in which it is now found, and if it originated from organic matter it passed from the shale in which it originated in all directions until it found a resting place in a more porous rock.

While this explanation seems plausible it is based solely upon the assumption that the rocks were dry, else the movement could not have taken place. As all of the sedimentary rocks were laid down by or in water it would mean that all of this original water must have departed before the migration occurred. Also if the oil diffused so readily through the dry clay or shale why should it accumulate in the open porous rocks? As the open rocks are bounded by fine-grained rocks, would not the oil continue to migrate rather than to accumulate? It is true that water could be appealed to as one agent for stopping the forward movement of the oil, but if water were present at any place in the rocks, why with its superior capillary attraction should it not have filled the rocks before the advent of the oil?

Although capillary attraction is doubtless an active force in the movement of oil under special conditions, it seems probable that the conditions have been neither sufficiently wide-

[1]Am. Phil. Soc. of Phil., Proc., vol. 36, No. 154, pp. 112-155, Jan. 1897; also Am. Inst. Min. Eng. Trans., vol. 41, pp. 219-224, March 1910.

spread, nor continuous in the past to make it an all-important factor in the problem of the broad migration of oil. The first step as stated above is the concentration of the oil in the porous strata, and in this movement capillarity may have played an important part. Its migration after it has reached such a stratum is almost entirely controlled by the water contained therein, and consequently the great movement of the oil is due to the next cause.

Difference in specific gravity of oil and water.—As both of the forces just mentioned presuppose the existence of special conditions, it is generally agreed that water has been and still is the great medium for the migration of oil through open porous rocks. As the latter substance is lighter than water it is forced upward by the pressure of the water toward the surface. This would cause movement up the rise of inclined porous beds that are saturated with water, but would not produce migration down the dip or in a horizontal direction.

Recently Munn has argued that movement was not produced by the difference in specific gravity of the oil and water, but by a definite circulation of the water itself. The particles of oil would, according to this hypothesis, be carried along by the moving water and the direction and extent of the movement would be controlled entirely by the movement of the interstitial water. This hypothesis, however ingenious, has not met with general acceptance and hence the theory attributing the movement to difference in specific gravity is regarded as having better standing and will be treated here as the one commonly accepted.

When the anticlinal theory was first propounded it seems to have been taken for granted that all rocks composing the outer crust of the earth are saturated with water, but recently deep drilling has shown that whereas such is generally the condition of the rocks for a few hundred feet below the surface, at great depths the rocks are generally dry, or at least in certain localities they are so dry that water must be pumped into the hole in order that the drilling may proceed.

Another factor, which undoubtedly has played an important part in this problem and which should be taken into account in attempting to explain the presence of oil in any particular locality, is the change of water level in the saturated rocks that may have taken place as a result of orogenic movements in the crust of the earth. If, therefore, such changes of level be postulated, it is evident that rocks which to-day are saturated may have been dry at some previous geologic epoch, and, conversely, rocks which to-day are dry may at some other time have been completely saturated. Knowledge regarding the circulation of water in the earth's crust and the factors which control its height at any particular point or any particular time is too meagre to warrant more than a reference, but evidence has accumulated that seems to prove that different conditioms have prevailed in the past and that these conditions must be considered in attempting to interpret the data available at the present time.

If, therefore, the extensive migration of oil through dry rocks is ruled out of the problem, the question again reverts to water as the medium for general migration. The rate of movement and the volume of oil depend upon the porosity of the rocks and the time during which the migration has been going on. The most porous of the clastic rocks are sandstone and conglomerate, hence these are generally the formations through which the oil has travelled, but in certain cases dolomitic limestone where formed largely of interlocking crystals, as is the condition of the Trenton limestone of the Ohio and Indiana fields, has afforded an open passage for the oil. It must not be assumed, however, that ail beds of sandstone or all parts of any particular bed are permeable to oil. If the grains of sand are closely cemented the rocks may be practically impervious but if the grains have little cementing material between them the sandstone or conglomerate offers an easy passageway for the oil and also a reservoir for its accumulation if other conditions are favourable.

In a lesser degree joint cracks and fractures afford avenues for the movement of the oil, but such fractures are not formed until the rocks have received a certain degree of induration, which in all probability follows rather than precedes the main migration. Again, geologists and physicists generally maintain that open fissures are not possible at any great depth in the crust of the earth and therefore that they afford opportunity for movement only near the surface. With all due respect to the eminent authorities who have presented such an argument the writer maintains that it is based entirely on theoretical grounds which are not borne out by facts revealed by the drill, as will be noted on another page.

Dike walls and faults in many cases afford opportunity for the circulation of liquids in the earth's crust, but here again there may be great exceptions. In very much indurated rocks, fractures of any kind may constitute open avenues for the migration of oil, but in slightly indurated rocks, and especially those that contain an appreciable amount of argillaceous material, a fault may have the opposite effect, or act as a barrier to the movement of liquids or fluids. The reason why faults in such rocks form barriers is that in the slight movement back and forth that has undoubtedly occurred along most fault planes the clay contained in the sandstone has become plastered over its face, effectually sealing it to the further progress of gas and oil. Such barriers not only play an important part in preventing migration, but they also cause the oil to accumulate behind them and thus form pools, as will be explained later.

Persons in search of oil or gas should thoroughly understand the effect of faults and fractures on the movement and accumulation of oil, and when they understand it they will not look for large supplies of oil or gas in greatly disturbed rocks, especially if the rocks are geologically very old and greatly indurated, but where the opposite conditions of structure and character of rocks prevail they will find that such structures are no bar to the formation of large pools. These conditions are well illustrated by the different conditions which characterize the Appalachian and California oil fields. In the former, large accumulations occur in the great synclinal trough which coincides roughly with the coal fields. In this trough the rocks are gently flexed into a number of folds, but none are of such a magnitude as to have produced appreciable fractures in the rock. The belt of oil pools is abruptly terminated on the east by the line which marks the boundary between the gentle and the pronounced structures, and little or no oil or gas has been found east of that line. In California some of the largest pools are associated with the most pronounced folds and faults, and geologic structure and fractures cannot be said to be controlling factors in the case.

Accumulation.—The discussion so far has been confined to the migration of oil through the rocks and it has been shown that water is the medium by which this movement is largely effected. It now remains to consider the conditions which interfere with such a movement and which cause the oil to accumulate in the so-called pools.

Urged on by the difference in specific gravity the oil will rise through the interstitial pores in the rock. If the rock consists of a great mass of sandstone the oil will be forced to the top of the bed unless it has been arrested in transit by a barrier of impervious sand or a clay-sealed fault. After reaching the top of a particular "sand," be it thick or thin, the oil, if still forced by the water behind, will seek to escape into the overlying bed, but if this bed be composed of impervious clay or shale the oil will be confined to the one stratum. When so confined, its movement will depend almost entirely upon the attitude of the bed or, in other words, upon the geologic structure. If the bed lies nearly horizontal there is manifestly no place to which the oil can migrate and then it collects in the uppermost layers of the sand. Beds of rock, however, seldom retain their horizontality for any great distance. If they rise, the oil will tend to move in this direction, but whether this tendency develops into actual motion will depend largely upon the degree of inclination of the bed. If the dip is slight the pressure resulting from the difference in specific gravities of the water and oil may not be sufficient to drive the oil through the open sand, but in case the bed is sharply tilted the oil will move freely, provided that the sand maintains its open, porous character. This fact explains one of the conditions controlling accumulation of oil—a condition that is probably most marked in the case of the Ohio-Indiana pools in the Trenton limestone.

In the development of oil and gas in western Ohio and in Indiana, it was found that the oil occurred in pools on the flanks of a broad gentle dome in the Trenton limestone, not at its top, but on its sides and with little regularity regarding their positions on the dome. At first this was very puzzling as it seemed to be totally different from the conditions in other fields, but after considerable drilling had been done, and the position of the oil-bearing limestone determined, it was found that the pool marked a sort of structural shelf or terrace or area of arrested dip. In other words, the limestone rises gradually toward the centre of the dome, but in places this rise is not maintained and over a considerable area the rock is nearly flat. Beyond this flat the bed rises once more toward the axis of uplift.

The oil on being forced up through the interstitial spaces in the limestone finally arrived at the structural terrace and there the pressure was not sufficient to force it through the many miles of horizontal rock and it accumulated and was held in place by a large body of water behind it. Under such conditions the oil occurs near the outer edge of the terrace, because it is in that place that it is brought to a stop. If the oil had been moving down it would have accumulated at the inner edge of the terrace. The position, therefore, of the oil pool is a good indication of the direction in which the oil is moving.

Assuming again a single porous stratum thoroughly saturated with water, the oil would be forced to rise until it could go no farther. This arrest of motion might be due to (1) the oil reaching the limit of the bed of sand, (2) to a change in the character of the rock by which it becomes impervious, (3) to a barrier such as a clay-sealed fault, (4) to a change in the attitude of the sand (geologic structure), or (5) to the oil reaching the upper limit of the water. Conditions 1, 2 and 3 are simple and need no further explanation. Conditions 4 and 5 are those which control the locations of nine-tenths of the pools of the world and call for a more detailed discussion.

As the rock strata of the earth's crust are generally thrown into more or less strongly marked folds, it follows that in most cases where oil is migrating up a sloping bed of rock it will encounter a more or less well developed arch or anticline. If the fold is in an incipient stage it may take the form of an "arrested dip" or "structural terrace," as already described, or it may take a variety of irregular forms, almost all of which tend to produce pools of oil, for their effect is that of barriers and they make it impossible for the water to force the oil to a higher level. If the anticline is well developed and lies entirely below the level of ground water the oil will migrate to the crest where movement will be arrested by the dip of the bed in the opposite direction. In such folds, therefore, there is a tendency for the oil, or if gas be present, as it is in almost all cases, for the gas and oil to occupy the highest part of the crest of the fold floating on the water which had forced them and still holds them in this position.

This conception of the relation of gas, oil, and water to the crest of the anticline has been widely known as the anticlinal theory. Although the close association of the oil pools and anticlines has long been recognized and has been commented on by Hunt, Höfer and others, it was not until 1885 that it took the definite form of a theory. In that year it was first definitely stated by I. C. White[1] but since then if has been modified in many respects as knowledge has been acquired regarding the conditions below the surface of the ground. Many have combatted this theory, but to-day it stands as the theory most generally applicable to the oil fields of the world and most generally accepted by geologists familiar with oil conditions.

The case noted above as typical of the effect of anticlines on the accumulation of oil is simple in the extreme. In many places the structure, although generally anticlinal, may be so irregular that it bears little resemblance to the type, but in all cases of this kind each minor fold is controlled by the same conditions as the major fold and may be marked by small pools on the outskirts of the larger one.

Condition 4 also in many places tends to complicate the situation, for frequently the water line instead of being entirely above the anticline may cut it below the summit and at various angles to the axis of the fold. As there is no tendency for the oil to rise above the surface of the water it will accumulate in the rocks along the water line, and as the water line laps around a pitching fold so may the oil pools change in direction corresponding to the change in strike of the rocks.

[1]White, I. C., The geology of natural gas: Science, vol. 6, June 26, 1885.

If a pool is formed in the crest of an anticline or at the water line along the flanks of the fold and then the water level for this stratum is lowered, it is manifest that the oil would not remain at the point where it accumulated in the presence of water, but gradually under its own weight it will move downward, but it will lack the power of the water behind it as in its ascent, and also it will become more or less diffused through the porous stratum without a large quantity at any given point. Hence, under such conditions many small pools may be formed, but they will be so irregularly disposed and so widely scattered that their discovery will be largely a matter of accident. This is purely an assumed case, but the writer is familiar with areas in the Appalachian region which can be explained only on such an hypothesis. It seems probable that since conditions in the earth's crust have not remained constant throughout geologic time, that many changes in water level may have occurred throughout the crust of the earth and that similar results may be found in many oil fields.

As most of the oil has migrated up monoclinal slopes or up the limb of a syncline from the bottom of the basin, it follows that in any minor folds or wrinkles on these major structures, the oil will accumulate in the top of the fold if that is below water level, or if it projects above the surface of the water then the oil will tend to accumulate on that side of the anticline which is connected with the long slope down the monoclinal structure or into the centre of the basin. In other words, the large gathering ground of a long slope is more favourable for the formation of an oil pool of considerable magnitude than is the short slope on the other side connected with the slope above. Manifestly, the reverse would be true if the oil were moving in the opposite direction.

In regions of extremely complex geology, as in California, many modifications of the anticlinal theory are necessary, but the underlying principles of migration and accumulation, as outlined above, clearly fit in this region, as well as they do the Appalachian region. In California oil occurs in rocks of Cretaceous, Tertiary and Pleistocene age, but at the present time the great bulk of the product is derived from Tertiary formations.

These formations were laid down in a region where there were many and violent oscillations of level and corresponding changes in geographic conditions. As a result many formations overlie others unconformably and then the whole has been folded and faulted in a most confusing manner. The oil has migrated up saturated sands, but these, owing to the unconformable relations of many of the formations, come into contact with other sands along the line of unconformity. This allows the oil to pass readily from one formation to another lying above and complicates to a great extent the problem of tracing oil to its ultimate source. Again the plane of unconformity may be sealed by clay and thus it may in places serve as a barrier instead of an avenue of escape. Similarly faults in this region are sealed so that they prevent the movement of the oil and cause it to accumulate on the lower side of the fault plane.

In comparing the conditions in California with those in the Appalachian fields it is manifest that time is a large element in the oil problem. In the Palæozoic oil rocks the time since the oil migration has been so great that any avenue of escape however small has been sufficient to allow most of the oil to disappear, whereas in California the time since the rocks were deposited has been so short that even where the oil sands are tilted, eroded and exposed at the surface, the oil has only in part disappeared, but undoubtedly if the time were extended the oil would in a large measure pass off into the atmosphere. It must not be supposed, however, that this failure to escape through the eroded edges of the porous beds is due entirely to lack of time. That is probably the most important element in the problem, but the tendency of such thick asphaltic oils as those of California to part with their lighter constituents where exposed to the air and to clog the sands with the tarry residue, undoubtedly has played a prominent part in preventing the escape of much of the oil.

In some fields the oil finds a reservoir in cleavage joints and fissures in the rock. It matters not whether these occur in pervious or impervious rocks, they serve equally well in storing the oil. The most striking case of this kind with which the writer is familiar is the Florence field of Colorado. There is seemingly reliable evidence to show that in drilling many of the wells of this field the drill has struck open cavities in the shale even at depths of more than 1,000 feet and such cavities apparently contain the oil. The character of this reservoir is still further attested by the linear arrangement of the locations of the best wells and by the effect that the "bringing in" or exhaustion of one well has upon another. Pools of this character are not common, for the effect of fissures is generally to allow the escape of the oil from some reservoirs lower down than to retain the oil as a pool. In the Florence field the oil is apparently held in fissures in shale in a broad open syncline, and the impervious layer that prevents its escape until it is reached by the drill appears to be a zone of water-saturated shale which extends a certain distance below the surface. Day[1] has shown that oil will diffuse readily through dry Fullers earth, but that the moistened earth is absolutely impervious. From this it is seen that the impervious cover over an oil reservoir may be fine-grained rocks so cemented as to prevent the passage of the oil through it, or it may be fine material merely saturated with water.

One of the most striking occurrences of oil, and at the same time the most puzzling, is in the so-called salt domes of the Coastal Plain about the Gulf of Mexico. The salt domes are low mounds on the flat plain composed of enormous masses of salt or sulphur. In some mounds the salt appears at the surface, but in others erosion has not yet exposed the masses of salt which invariably form the cores of the mounds. The rock strata of the plain dip away from these masses in all directions and where not removed by erosion are found arching over its summit. In effect they are true structural domes or anticlines, with the oil occurring on the top or on the flanks of the fold. The occurrence of oil in these domes seems to conform to the anticlinal theory, but whether the pool exists in the bedded rocks near the top of the dome or whether it is derived from a reservoir lower down and merely finds its way upward around the core of salt has not yet been determined. Capt. A. F. Lucas, who first demonstrated the association of large bodies of oil with these salt domes by sinking the original well on Spindletop near Beaumont, Texas,

[1]Day, David T. The conditions of accumulation of petroleum in the earth. Am. Inst. Min. Eng. Trans. vol. 41, pp. 212-224, 1911.

sought to determine the source of the oil by deep drilling, but unfortunately the well had to be abandoned at a depth of about 3,400 feet, and thus the question of the composition of the core at great depth and the possibility of an oil reservoir below those already discovered remains unknown. The question of the origin and mode of accumulation of the oil in these domes is bound up with that of the origin of the domes themselves and the geologists who are most familiar with them do not agree in their explanations. Some have attributed the salt which forms the cores of practically all the mounds to have been deposited by currents of hot water ascending along lines of weakness caused by faults; others have attributed the dome structure itself to the power generated by the growing crystals of salt, while others are certain that the domes are but the surface expressions of laccoliths of igneous rock which do not reach the surface. Naturally, the latter explanation suggests the inorganic origin of the oil, but it is equally possible that the oil originated from inorganic material in the surrounding sedimentary rocks and has merely found reservoirs for its accumulation in the salt domes. The evidence available cannot be regarded as at all conclusive, but until such evidence is obtained it must be admitted that the theory of inorganic origin applies to this field as well as that of the organic origin and may prove to be the correct theory to apply to all fields showing such phenomena.

Although the limits of this paper will not permit of a full discussion of the movement of oil through the rocks and the effect of structure on its accumulation, no account would be complete without a word regarding the oil shales that have been found in many parts of the world. Most of these consist of masses of carbonaceous material, which yield upon distillation oil of various grades, but some are reported in which petroleum seems to exist as free oil that has been derived from the carbonaceous material held by the shale. Such apparently is the case in regard to the oil-shale of Colorado and Utah, and also, according to report, of that of Derbyshire, England. If this interpretation be correct the oil has migrated only a short distance if at all, and most of it is in the place in which it originated.

GEOLOGICAL OCCURRENCES OF PETROLEUM AND NATURAL GAS.

CONDITIONS NECESSARY FOR NATURAL GAS ACCUMULATION.

In any locality, no matter in what part of the world it occurs, at least three conditions are necessary to assure its accumulation at any particular locality. These are

(a) A porous formation to act as a reservoir.

(b) An impervious cover to prevent the gas from escaping.

(c) Some form of geological structure to concentrate it.

Reservoir.—Natural gas and oil occur in rocks of all geological ages. It is the character of the individual formations that is essential to assure a reservoir. The oil or gas rock must be porous; and it generally consists of sand, sandstone, limestone or dolomite, although there are a few known instances where gas exists in shale. The presence of gas in limestone may be due to the natural porosity of the rock, to simple solution, or to chemical changes which result in the formation of dolomite. The possibility of the Trenton limestone holding oil and gas is due to the fact that the limestone has been locally altered to a dolomite, which thereby becomes more porous than a sandstone. The exact point of occurrence may be controlled, therefore, not only by the structure of the rock, but also by its internal characteristics. Since its upper portions correspond with places of change from limestone to dolomite, the highest portion of the anticline is more commonly the region saturated with gas. In the case of sandstone, the occurrence of gas is due not only to structure, but is affected also by the continuity of the stratum. Not all sandstone contains gas, one essential feature being that the individual grains comprising the rock shall be rounded sufficiently to assure a porous bed which forms a reservoir. Well drillers recognize the internal variations when they speak of a sand being "open" or "close," "soft" or "hard," "good" or "poor" in character. An experienced driller can determine the porosity of a sand satisfactorily by an eye examination, but he is unable to determine whether it would be productive without knowing the geological structure of the locality in question. In order to illustrate the wide occurrence of natural gas and oil stratigraphically, the following summary is given of the various horizons at which they are known to exist in the principal fields of the United States and Canada.

Geological Structure of Typical Gas Fields.

Name of Gas Field	Locality	Age of Producing Sands	Type of Geological Structure
Bow island	Alberta	Cretaceous	Crest of geanticline or great arch in strata.
Leamington	Ontario	Ordovician	Northern end of Cincinnati geanticline.
Norfolk and Elgin County fields	Ontario	Ordovician	Pinching out of Clinton and Medina sands.
Central Ohio	Ohio	Ordovician	Pinching out of Clinton sand.
Lima	Northwestern Ohio and northern Indiana	Silurian	Crest of Cincinnati geanticline.
Majority of West Virginia and Pennsylvania fields		Carboniferous and Devonian	Crests of anticline.
Southeastern Ohio	Ohio	Carboniferous and Devonian	Structural terraces, small anticlines, and domes.
Kansas and Oklahoma fields		Carboniferous and Devonian	Crests of domes and pinching out of certain sands.
Caddo	Louisiana	Cretaceous	Crest of the Sabone uplift (geanticlinal).
Transylvania	Hungary	Tertiary	Crests of domes.

Formations Productive of Oil and Gas.

State	Formation	Age
New York	Guelph limestone Niagara limestone Medina sandstone Trenton sandstone	Silurian
	Potsdam sandstone	Cambrian
	Conemaugh Allegheny Pottsville	Carboniferous
Pennsylvania	Pocono	Sub-Carboniferous
	Catskill Chemung	Devonian
	Conemaugh Allegheny Pottsville	Carboniferous
West Virginia	Green Briar limestone Pocono	Sub-Carboniferous
	Catskill	Devonian
	Pottsville	Carboniferous
	Pocono	Sub-Carboniferous
	Corniferous	Devonian
	Niagara Clinton	Silurian
Kentucky	Hudson River Trenton limestone Calciferous	Ordovician
Alabama	Pottsville	Carboniferous
	Claiborne	Tertiary

State	Formation	Age
Louisiana	Nacatoch sand Annona chalk Eagle Ford Woodbine sand	Cretaceous
	Claiborne	Tertiary
Texas	Navarro	Cretaceous
	Permian series	Carboniferous
Colorado	Mesaverde Pierre Mancos Benton	Cretaceous
	Pierre	Upper Cretaceous
	Benton	Upper Cretaceous
Wyoming	Kootenai	Lower Cretaceous
	Embar	Carboniferous
	Fernando	Pliocene Tertiary
	McKittrick Monterey group	Miocene Tertiary
California	Tejon	Eocene Tertiary
	Chico Knoxville	Cretaceous
	Conemaugh Allegheny Pottsville	Carboniferous
Ohio	Ohio shales	Devonian
	"Clinton sand"	Silurian
	Trenton limestone	Ordovician

State	Formation	Age
Indiana	Huron sandstone	Sub-Carboniferous
	Corniferous limestone	Devonian
	Trenton limestone	Ordovician
	McLeansboro, Carbondale, Pottsville	Carboniferous
Illinois	Chester, St. Genevieve	Sub-Carboniferous
	Niagara limestone	Silurian
Kansas	Pleasonton shale, Cherokee shale	Carboniferous
	Trinity	Cretaceous
Oklahoma	Cisco, Cherokee, Atoka, Winslow	Carboniferous

Cap Rock.—Ordinarily the bed of impervious rock overlying a "sand "which holds oil or gas is known as the "cap rock." It is frequently very hard, though not always, and generally consists of limestone or shale. One of the most widespread formations overlying gas and oil sands is the Utica shale above the Trenton limestone in the Ohio-Indiana fields. The Clinton sand of central Ohio is overlain in a similar way by the Clinton shale. The numerous oil and gas sands of Pennsylvania and West Virginia are all overlain by impervious shales. In the Louisiana fields a very hard stratum of limestone acts as a cap-rock overlying a more pervious portion of the same formation. In fact cap rocks may consist of almost any material other than sandstone.

TYPES OF GEOLOGICAL STRUCTURE NECESSARY FOR OIL AND NATURAL GAS ACCUMULATION.

In order to consider the various geological structures in which oil and natural gas are known to exist, the writer has had occasion to classify them. The original classification was published in Economic Geology[1] and it referred to accumulations of oil as well as of gas.

CLASSIFICATION OF OIL AND GAS ACCUMULATIONS.

The structure of the productive stratum itself must be considered independently of the configuration of structure of any surface formation.

In order to illustrate the difference in geologic conditions, a tentative classification of fields has been made. There is no attempt made to distinguish oil structures from gas structures, nor between the different kinds or ages of productive formations.

The object of the tentative classification is to show that accumulations of oil and gas can be grouped into classes, each division of which follows a special rule of structure, and all of which have certain aspects in common.

The classification proposed is as follows:—

- I. Where anticlinal structure exists.
  - (a) Strong anticlines standing alone.
  - (b) Well-defined anticlines alternating with synclines.
  - (c) Structural terraces.
  - (d) Accumulations on monoclines due to thinning out or change in texture of the sand as it rises toward the nearest anticline.
  - (e) Broad geoanticlinal folds.
  - (f) Overturned folds.
- II. Quâquaversal structures.
  - (a) Anticlinal bulges.
  - (b) Stratigraphic domes.
  - (c) Saline domes.
- III. Sealed faults.
- IV. Oil and gas sealed in by asphaltic deposits.

[1]Econ. Geol., vol. IV, 1909, pp. 565-570.

V. Contact of sedimentary and crystalline rocks.
VI. In joint cracks.
VII. Surrounding volcanic vents.
VIII. Where there is no particular gas structure, but the gas is associated with adjacent oil pools.

Class I. *Where anticlinal and synclinal structure exists.*—This is the type of oil and gas accumulation with which we are most familiar. It includes a large majority of the known oil fields of the world. The Appalachian, Mid-Continent, Illinois, Indiana, Wyoming, Colorado, northern Louisiana, and northern Texas, and some of the California fields in this country, and the Russian, Austrian, Burma, and Borneo fields in the eastern hemisphere, all belong to this class. It is divided into five subclasses, in order to distinguish between various structural relations in which oil is found in connexion with anticlines and synclines.

Subclass (a). *Where strong anticlines exist standing alone.*—In this division I would include fields that bear a direct relation to *very pronounced* uplifts, easily recognizable, and which constitute a marked geologic feature of the region. The only prominent example in the eastern fields of the United States is the famous Eureka-Volcano Burning Springs anticline in West Virginia, which is 25 miles in length, ranging in direction from North 10 degrees West to North 20 degrees East, being from an eighth of a mile to half a mile broad on its flat crest, and having side-dips of from 20 to 60 degrees. This differs somewhat in direction from the main Appalachian folds, and was probably produced at a different time. It is one of the earliest recognized anticlines in the country, and probably has had as many wells drilled on it as any other anticline. It has been described by White[1], Andrews, and Evans. Some of the California fields having sharp anticlines probably belong to this class. Possibly the Baku field of Russia may also belong here.

Subclass (b). *Where well-defined alternating anticlines and synclines exist.*—This is really a composite of sub-class (a). With minor exceptions it includes the entire Appalachian field in

[1]I. C. White, Bull. Geol. Soc. Am., vol. 10, 1899, p. 29.

Pennsylvania, West Virginia, and eastern Kentucky, southern Indiana and Illinois, the Oklahoma fields and the Caddo field in Louisiana, the north Texas fields, and those of Colorado, Wyoming, and Montana.

The Caddo field has nothing in common with the Beaumont and Jennings fields and other fields of the Coastal Plain of Louisiana and Texas, but it is very similar in structure to the fields of Pennsylvania, West Virginia, and Illinois. The proper structure in northern Louisiana is afforded by the Sabine uplift. The final distribution of oil and gas in the Caddo field is presumably due to slight anticlines and synclines and differences in porosity of the Upper Cretaceous formations which exist there.

Several of the oil fields of California also belong in this class Examples are the Coaling field and the Los Angeles field, according to descriptions by Eldridge,[1] and by Arnold and Anderson.[2] In 1895 Noettling established the fact that the oil fields of the Irrawaddy, in Burma, correspond with the structural theory; and I believe they belong in this subclass. The oil and gas in those fields are directly related in their accumulation to anticlines and domes in the Miocene sandstone.

The rocks in the fields comprised in subclass (b) are folded into alternating anticlines and synclines, bounded by moderate dips, seldom more than 30 degrees from the horizontal. This is the subclass to which the anticlinal theory as originally propounded applies strictly; the gas occurs in the upper part of individual sands or "pay streaks," the oil occurs somewhere below the gas, while salt water, if it occurs at all, fills in the remaining space in the sand (if the latter is uniformly porous), or occurs in the separate "pays" (where the sand as a whole has not a high degree of porosity), all these deposits being controlled mainly by the force of gravity. Where oil or salt water occurs higher in the sand than gas, it is presumably due to sharp changes in the dip, or to a multiple nature of the "pay streaks."

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[1]Geo. H. Eldridge, Bull. 213, U.S. Geol. Survey, pp. 306-321, 1902.

[2]Ralph Arnold and Robert Anderson. Bull. 357, U.S Geol. Survey, pp 70-71, 1908.

Subclass (c). *Terrace structures are an exaggerated form of the flattenings of dip, included in subclass (d).*—As a rule where gas occurs, it is found on the outside of the terrace and

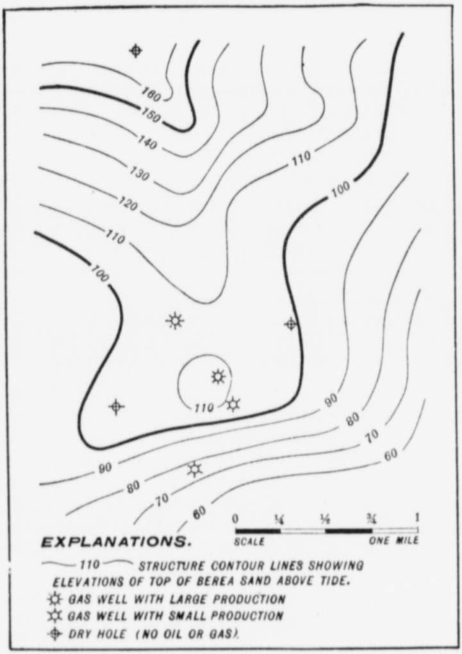

Fig. 1. Occurrence of natural gas on a structural terrace in Ohio.

oil on the inside, though this is not an infallible rule. The change in the rate of dip, forming a local interruption, seems to be the essential factor. An example of a structural terrace in southwestern Ohio is shown in Fig. 1.

The effect of terrace structure was first explained and illustrated by Edward Orton in 1886[1]. The terraces described by him were in the Trenton limestone fields of northwestern Ohio. In the Findlay field the oil and gas were found in two terraces, separated by a monoclinal dip. The upper terrace yielded dry gas, the lower terrace yielded oil and water.

Orton gave the name "arrested anticlines" to structural terraces, and cites the Macksburg field of southern Ohio as an example.[2] The terrace structure of the Macksburg field was first recognized and described by Newhall in the same volume.

During the past decade hundreds of similar terrace structures have been discovered throughout southeastern Ohio and to some extent in adjacent states, and most of them are available for oil and gas development. Generally, though not always, the structure can be determined from the geology of the surface without the need of borings until one is ready to make his test. Other good examples of terrace structures and relations of oil to them were shown by Griswold and Munn in Jefferson co., Ohio.[3]

Subclass (d). *Where there are monoclinal dips; i.e., where he rocks dip in one general direction throughout (although the dip may vary in steepness).*—The majority of the oil and gas pools in southeastern Ohio belong in this division. Definite anticlines are not so common in Ohio as in Pennsylvania and West Virginia, as the prevailing dip of the formations is all in one general direction (toward the southeast). However, the application of the structural theory, properly understood, is almost as certain of profitable results as it is in Pennsylvania, because the dip is not uniform, but varies from flat to over 5 degrees from the horizontal. Rounded or somewhat elongated semi-anticlines of subclass (b) are occasionally found.

Oil and gas can be predicted in subclass (c) through recognition of the principle that any change in the rate of dip is to be considered as a possible place of accumulation; and that such a

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[1]Science, vol. 7, p. 563.
[2]"Geology of Ohio," vol. 6, p. 94, 1888.
[3]Bull. 318, U.S. Geol. Survey, 1907.

place of accumulation once discovered, the pool can be easily extended (within structural limits) by following lines of horizontality in the sand.

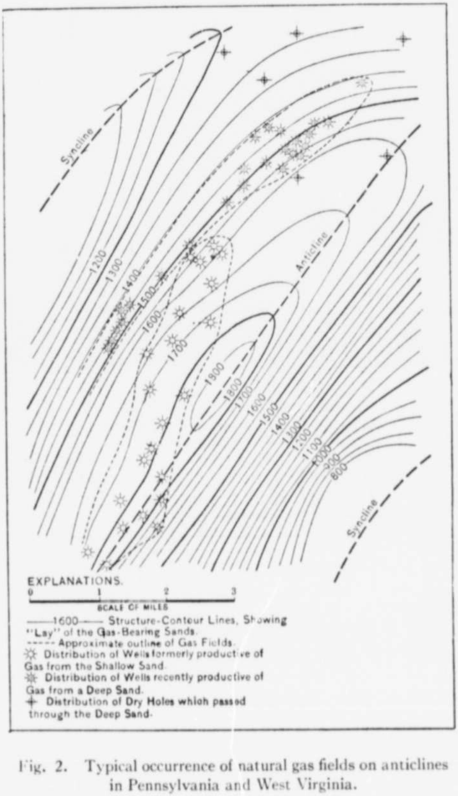

Fig. 2. Typical occurrence of natural gas fields on anticlines in Pennsylvania and West Virginia.

To this subclass may also belong (in part at least) the Florence oil-field in Colorado, where the oil exists in beds having a dip of less than 5 degrees, lying between dips as great as 20

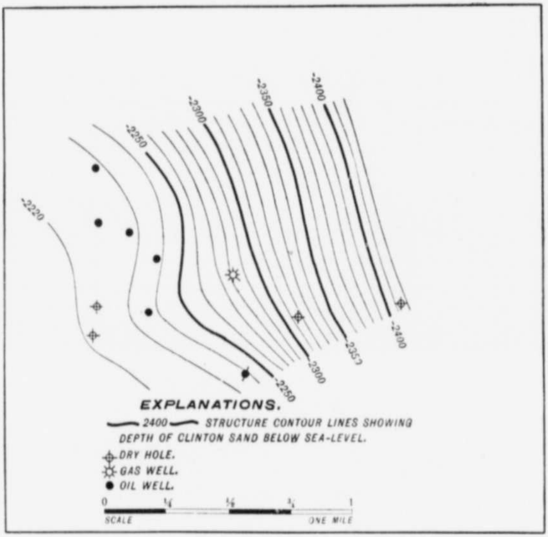

Fig. 3. Example of sub-class I (c.). An oil pool coincident with a change in monoclinal dip, in the Clinton sand of Southern Ohio. Structure map of the sand in a small area determined by the convergence method.

degrees (according to Fenneman), and occupying a portion of a structural slope where the sands locally are rather flat for a few miles, being a semi-terrace in the formation. In this field the beds carry little water.

Subclass (e). *Broad geoanticlinal folds.*—This is an extreme type of I(a). By a geoanticline is meant an anticline which is extremely long and broad, and constitutes more than

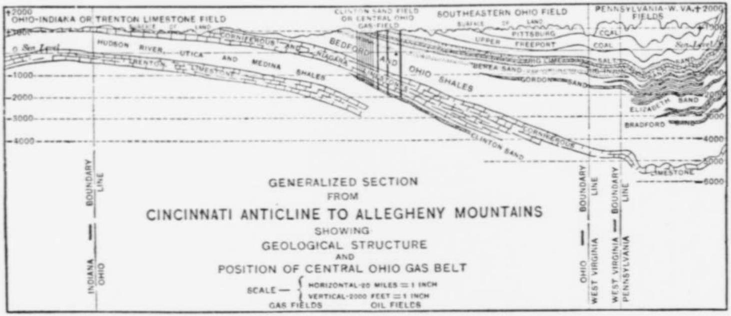

Fig. 4. Generalized cross-section from Cincinnati anticline to Allegheny mountains, showing relative positions and geological structure of the various Ohio and Pennsylvania gas fields.

a local feature, extending over thousands or tens of thousands of square miles. One of the best examples in this country is the Cincinnati anticline, in which immense reservoirs of oil and gas have been developed and exhausted, the oil and gas being contained mainly in the Trenton limestone. Owing to the broad areas under which oil and gas are found in the Cincinnati anticline the chances of success in drilling were originally much better than in other fields. The decline of the Trenton limestone fields was largely due to wastefulness of the gas before people in general understood that the fields were subject to exhaustion. Most of the pools in the Clinton sand in Ohio are situated along the eastern flank of the Cincinnati anticline, but these pools belong under subclasses (c) and (d), of the classification.

Subclass (f). *Overturned folds.*—Examples of oil and gas occurring in connexion with overthrust folds are not common but some such cases are conspicuous in California, as shown by Arnold and Johnson[1].

Class II. *Domes, or quaquaversal structures.*—Certain types of anticlines developed as well-marked domes might be classed here; but since they are included in subclasses (a) and (b) of Class I, the domes here considered will be limited to those which are not part of any well-developed anticline, and are thus susceptible of a different classification. The conspicuous examples of the occurrence in this country are in the fields of the Coastal Plain of Texas and Louisiana, described by Hayes and Kennedy[2], Fenneman[3], Harris[4] and others. Some of the best known instances are Spindletop, Sour lake, and Batson. The mounds in which gas and oil exist may not show as such at all on the surface. They do, however, appear *in some cases* as circular elevations, covering several hundred to several thousand acres and rising 50 to 100 feet above the surrounding plain, in which case they can, of course, be easily recognized. They are frequently

[1]Ralph Arnold and Harry R. Johnson, Bull. 406, U.S. Geol. Survey, 1901, p. 97.

[2]C. W. Hayes and Wm. Kennedy, Bull. 212, U.S. Geol. Survey, 1903.

[3]N. M. Fenneman, Bull. 282, U.S. Geol. Survey, 1906.

[4]G. D. Harris, Geol. Survey of La., Bull. No. 7, 1908.

known as "salines," on account of containing deposits of rock salt. Underneath the surface the whole body of strata have a mound-like shape, containing, in addition to the ordinary formations, limestone, salt, gypsum, and other minerals, all of

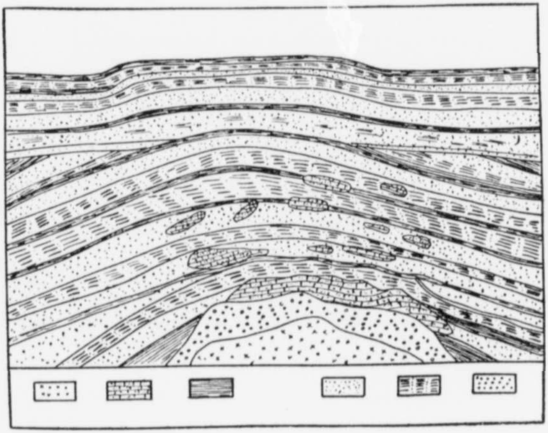

Fig. 5. Cross section of typical saline dome oil field, Texas (after Hager).

which have been passed upwards in approximately circular outlines. Fig. 5 shows a cross section of a typical saline according to the ideas of Harris.

Class III. *Along sealed faults.*—The known examples of this class consist of some of the pools in the Los Angeles field and some of those in the Lompoc field in California described by Arnold. In these cases the highly inclined oil sands are cut off abruptly below ground by a fault, thus sealing in the oil and gas and preventing their escape to the surface. Some of the other fields in California probably belong to this class. To show the probability that such cases are more frequent than known, it may be worth while to mention that oil springs frequently, and perhaps generally, occur along fault lines. Some of these instances exist in British Columbia and others in Gaspé, Quebec.

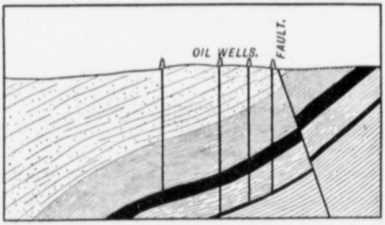

Fig. 6. Example of class III. An oil pool in California sealed in by a fault line. (After Arnold, Bull. 309, U.S. Geol. Survey, Plate 20, 1907.)

Class IV. *Oil and gas sealed in by asphaltic deposits.*—Certain examples of this class, like the last, are few, and not well known, but they may be exemplified by the Pitch lake of Trinidad, where small quantities of oil and gas are reported. Some of the oil found near the vein of grahamite at Ritchie mines,

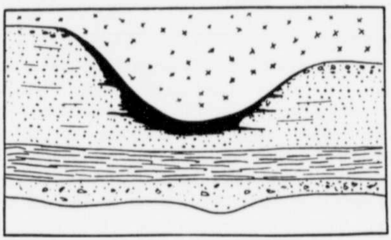

Fig. 7. Theoretical example of class V. A gas pool in the arkose zone between granite and Potsdam sandstone, in Province of Quebec.

West Virginia, described by White[1], may belong in this class, although these deposits are also dependent in their original accumulation upon anticlinal and synclinal structure, as in Class I.

[1] I. C. White, Bull. Geol. Soc. Am., vol. 10, 1899, pp. 277-284.

Class V. *At the contact of sedimentary and crystalline rocks.*—The principal known examples of this class are in the Provinces of Quebec and northern Ontario, and have not been much studied. It is probable that gas occurs at some places in northern New York state in this way. No records are at hand of *oil* occurring in such a position, but gas occurs in commercial quantities. It is held in the zone of the lower Potsdam sandstone, which is of arkose nature, and rests directly upon the underlying granite or gneiss. The deposits seem, so far as the writer has been able to learn from men who know the fields, to occur on top of prominent knobs of the granite. The occurrence may be somewhat as in Fig. 7.

Class VI. *In joint cracks.*—According to descriptions of Mr. H. S. Gale, some of the oil in the Florence field in Colorado occurs in joint cracks in shale. Other examples of this nature are believed to exist elsewhere.

Class VII. *Surrounding volcanic vents.*—This class seems to be illustrated by certain Mexican fields. It may be considered an exaggerated form of Class II.

Although most fields are susceptible of classification according to the foregoing plan, some of them do not fit in easily. It is believed that if all the causes and effects, and the internal character of the sands, were known in every case, the fields could be classified. Another factor of importance in the position and distribution of all types of oil and gas accumulations is the ... n explained[1], ... some persons ... y pools have ... oil lies below ... l.

ERRATUM :—

FIG. 7 IS UPSIDE DOWN.

To accompany report on "Petroleum and Natural Gas Resources of Canada," vol. I, p. 104.

... ught lessons which operators and geologists took years to learn, but now that they have been learned, they are becoming productive of good results. For instance, in pools where the oil occurs in thin "paystreaks," there are sometimes dry areas several square miles in extent, which lie directly "down-dip" from important pools of

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[1]Econ. Geol. vol. IV, 1909, pp. 565-570.

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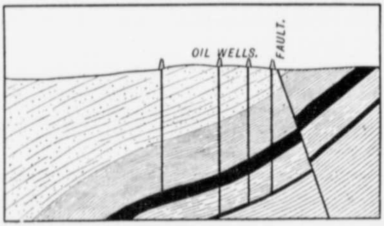

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Although most fields are susceptible of classification according to the foregoing plan, some of them do not fit in easily. It is believed that if all the causes and effects, and the internal character of the sands, were known in every case, the fields could be classified. Another factor of importance in the position and distribution of all types of oil and gas accumulations is the degree of saturation of the sand; although, as has been explained[1], the position of the water line is not so important as some persons have supposed. In the Berea grit, for instance, many pools have been found, and are still being tapped, where the oil lies below the water line in neighbouring pools in the same sand.

Some of the newer oil developments have taught lessons which operators and geologists took years to learn, but now that they have been learned, they are becoming productive of good results. For instance, in pools where the oil occurs in thin "pay-streaks," there are sometimes dry areas several square miles in extent, which lie directly "down-dip" from important pools of

[1]Econ. Geol. vol. IV, 1909, pp. 565-570.

oil or of water or of both. Near the corner of Brighton, Chippewa and South Beaver townships, in Beaver county, Pa., is a small pool in which the production of the wells is very light, which is bordered on the northeast, southeast, and south by a number of strong salt water wells. The "pay" here, as in the majority of pools in the Berea sand, is near the top of the sand. The salt water in close proximity to the pool occupies a definite structural position with reference to it, occurring on all sides of the pool except on the up-dip side. However, this water was not found to extend far down-dip from the oil-pool, several wells between there and the Ohio river, four miles southeast, having been dry of both water and oil. Similar occurrences are found repeatedly in the Berea sand in Beaver county, Pa., and in neighboring counties and the Pan-Handle of West Virginia and in Ohio, where dry areas of the sand occur on the down-dip sides of several pools of oil and salt water.

The point to be noted is that the lowest oil-pool in a stated group of pools in the Berea sand is successively higher above sea-level going from southwest to northeast parallel with the Ohio river. Near Steubenville and Mingo, in Jefferson county, Ohio, the lowermost elevation at which oil has as yet been discovered in this sand is 600 feet below sea-level; at Holidays Cove, West Va., it is about 400 feet below sea-level; on the West Virginia-Pennsylvania line near the southwestern corner of Beaver county it is 250 feet below; at Hookstown and Smiths Ferry, Beaver county, it is at sea-level; while near the corner of Brighton, Chippewa and South Beaver townships, in the pool first mentioned, it is 200 feet *above* sea-level. The progressive rise toward the northeast is explained in part by the greater general height of the anticlinal folds and the lesser depth of the adjacent synclinal depressions in the sand in that direction.

The fact that a so-called pay-streak lying down-dip from a known pool may be dry of both water and oil does not disprove the structural theory of the accumulation in its proper application; but the position of the dry area is due to the fact that whatever water and oil may once have occupied the pay-streak have been drained out, segregated elsewhere naturally or artifically, or the pay-streak is in reality not so porous as would seem from the size of the grains in the sand-pumpings. Moreover, many apparently dry areas are due to a change in the character of the sand, by which it becomes practically non-oil bearing or non-water bearing.

The fields in the deeper sands frequently do not correspond structurally with those in the shallow sands, even where the sands are parallel, and this is one reason why the deeper fields are not discovered more rapidly. As a rule, the shallows sands are productive of gas near the crests of anticlines, where anticlines occur, as in Classes I (a) and I (b), and are frequently confined to domes, in these crests, *while the deeper sands may be*, and frequently *are*, barren on the crests and productive of gas on the flanks of the anticline where it is dipping moderately steeply towards the adjacent syncline. This is generally due to the non-parallelism of the deeper sands. And since the size of pools is approximately inversely proportional to the steepness of the dips, these deep-sand pools commonly take the longest to be discovered by the drill.

THE GEOLOGICAL CONDITIONS GOVERNING THE OCCURRENCE OF PETROLEUM AND NATURAL GAS.

In applying the principles governing the accumulation of oil deposits which have been dwelt upon in the preceding pages, to the principal oil fields of Canada and the United States, it will be evident that in developing any new field, a thorough knowledge of the geological structure is necessary for any decision as to whether oil is likely to be found, and if so to locate the most profitable sites for drilling.

BASIS OF GEOLOGICAL KNOWLEDGE.

While it is true undoubtedly that the great majority of the oil fields of Canada, especially in Ontario, as in some other parts of the world, have been discovered by random drilling, it can be said on the other hand that many pools have been found on the basis of geological structure. For instance, in the Raleigh township field in Kent county, the logs of water wells, which have been drilled, showed the presence of an anticline, and Mr. A. T. Gurd, of Petrolia, who happened to be travelling through the region, became familiar with this fact, and with the presence of an oil scum on the water. In view of these facts the first well was drilled, which was known as the "Gurd gusher." After drilling operations had begun and more holes had been drilled for oil, additional information was available by which the anticline could be outlined accurately.

The following table shows the oil and gas formations in Canada in which oil and gas deposits have been found.

Table of Oil and Gas Producing Formations in Canada.

Period	*Formation*	*Productive Locality*
Devonian	Hamilton limestone	Upper showing at Petrolia and Oil Springs.
	Onondaga limestone	Oil Springs and Petrolia fields
	Oriskany sandstone	Euphemia, Lambton county.
Silurian	Guelph limestone	Three horizons in Essex and Welland counties.
	Niagara limestone	Not known to be productive in Ontario; locally productive in New York and Indiana.
	Clinton limestone	Welland county.
	Medina red sand	Welland county. Also in New York state.
	White Medina sands[1]	Welland and Brant counties. Also in New York state.
Cambro-Silurian	Trenton limestone	Showings of gas in Welland county. This is extensively productive in Ohio and Indiana.
	Beekmantown and Potsdam sandstone	St. Catharines, Ontario. Also reported[2] productive locally in New York state.
Cambrian	Quebec group	Reported productive in Newfoundland.

ASSOCIATION OF BITUMENS WITH OIL AND GAS.

The source of the grahamite dike in Richie county, West Virginia, is believed to have been the Cairo oil sand, at a depth of about 1,300 feet from the surface.

[1] The so-called Clinton sandstone of Ohio is probably equivalent to this sand.

[2] Reported by Eugene Coste.

Similarly, the source of the albertite dike in Albert county, New Brunswick, is believed to have been oil intruded from petroliferous strata in the Albert shales.[1] Albertite is a hydrocarbon filling a large vertical fissure and column, in a fine-grained dark grey to black shale of lower Carboniferous or Devonian age. The albertite fissure was as much as seventeen feet wide in some places, and was mined to a depth of 1,300 feet. It also fills many branch veins in the wall rock. Albertite is also reported in the pre-Cambrian metamorphic slates, in the overlying Coal Measures, and as veins in the gypsum at the Hillsboro quarries.

The uintaite (gilsonite) of Utah has been shown by Mr. Eldridge to occupy a fractured zone in the central Uinta synclinal basin. There are many parallel vertical veins of gilsonite from one-sixteenth of an inch to eighteen feet in width, and from a few hundred yards to eight or ten miles in length: paralleling the mountains which border the basin.

To illustrate the importance of such bitumen dikes as indications of oil and gas, it may be said that the grahamite dike of West Virginia is in the center of one of the greatest oil and gas regions in the world; that the albertite of New Brunswick is only a few miles from the Stony Creek oil and gas field; and that the uintaite dikes of Utah lead, in a general direction, toward the oil which is found over the boundary in Colorado.

THE OCCURRENCE OF OIL IN IGNEOUS ROCKS.

Petroleum and solid bitumen have often been noticed by various observers in traps, basalts, and other igneous rocks. An interesting instance was mentioned by Sir William Logan[2] in a greenstone dike at Tar Point, Gaspé, in the province of Quebec.

Another instance is reported by Rateau in trachite in Galicia.[3]

An instance from the United States was mentioned by Arthur Lakes[4] in the volcanic dike in Archeluta county, Colorado.

[1]Bailey, Geol. Survey Canada, 1876-77, p. 354 et seq.
[2]Geology of Canada, 1863, pp. 400-789.
[3]Annales des Mines, 8th series, Vol. XI, pp. 150, 152.
[4]Mineral Resources of the U. S., 1901, p. 561.

Another unpublished instance contributed by D. T. Day refers to a boulder of vesicular basalt from Colorado in which the vesicles were filled with oil. In order to prove whether the oil had filtered in from exterior sources, a fragment was boiled with benzol until no more oil could be extracted, and the basalt still contained much oil. It was shown, however, that the cavities had been sealed by a secondary deposit of carbonate of lime and that by removing this the oil could all be extracted and the basalt left intact. Thus the exterior origin of the oil was rendered probable.

In the vicinity of Binny Craig, Scotland, a volcanic neck or pipe was encountered in an oil shale working; this dike consisting of trap, and containing cavities in which mineral wax, pitch or paraffine were found.[1]

A still more radical instance was noticed by the undersigned in extensions of basalt cones in the coastal plain in the oil fields of Vera Cruz, Mexico, where a very viscous oil was seen running down the slope of the cone from a point perhaps about one hundred feet above its face. This and the other instances are not, however, in the opinion of the undersigned, due to the oil having had an igneous origin, but are accounted for by the fact that the volcanic rock was intruded from below into the sedimentary formation which contained oil, and consequently must have absorbed large quantities of bitumen in ascending to the surface. Moreover, in an instance like that in Mexico there are a great many crevices in the circumference of volcanic necks, and these are sufficient to allow oil to enter them from the surrounding Tertiary and Cretaceous formations, and to ascend to the surface in that way.

However, it is fair to say that no conclusive argument has ever been advanced, either for or against any theory of the origin of bitumen, except certain arguments which will apply in particular instances. As a rather convincing argument, Mr. Coste derives evidence from the eruption of Mt. Pelee in Martinque, where an immense quantity of gas swept down from the crater,

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[1]Henry M. Cadell, oil-shale holdings of the Lothians, Transactions of the Inst. of Min. Eng., Vol. 22, Pt. 3, pp. 347-353.

killing many thousands of people and animals. It was inferred that the gas consisted mainly of hydrocarbons.

On the other hand, the opponents of the volcanic theory advocate the fact that the gas originating from volcanoes, wherever it has been collected and tested, consists mainly of carbonic acid, and the proportion of carburretted hydrogen is only from one to four per cent.

MUD VOLCANOS AS EVIDENCES OF NATURAL GAS.

One of the foremost localities in the world for mud volcanos is situated in Asia Minor at both extremities of the Caucasus mountains at Taman-Kertch, between the Black sea and the Sea of Azof, and also at Baku on the Caspian sea, in which mud volcanos have been known for centuries and having been associated with large quantities of natural gas and petroleum. The height of the mud volcanos from the Apcheron peninsula near Bakou is very great, sometimes being as much as 1,300 feet; while the mud volcanos of Hungary, on the other hand, are seldom over thirty feet in height.

EXUDATION OF OIL.

In past times rivers of oil have been known to boil out from beneath the Caspian sea, and natural explosions of burning oil have taken place, throwing masses of clay and stones into the air, uplifting the bottom of the sea locally and giving rise to small islands in the vicinity of Bakou.[1]

ASSOCIATION OF OIL AND GAS WITH SALT AND SULPHUR.

In a large number of American and foreign oil fields an association of salt and sulphur and hydro-carbons is found. This is true in Russia, Sumatra, Java, Japan, China, Roumania, Germany, and Hungary. Gypsum and zinc blend are also found associated with these deposits, and pyrites and galena are reported by at least one writer.

[1]A De Lapparent, Traite de Geologie, 1883, p. 490.

CHAPTER V.

PREPARATION FOR DEVELOPMENT.

CHOICE OF TERRITORY.

Whether the question is one of "wild-catting" for oil—prospecting for petroleum outside of all known oil pools—or whether it is the development of what is known as "proved" territory, it is possible at the present time to lessen the expense of the enterprise very greatly by giving careful geological study to the problem of selecting the sites for drilling.

More frequently than otherwise an incentive to drilling is given by the discovery of seepages of thick asphaltic oil or dried asphalt, or by the occurrence of a steady flow of gas from water. All of these bespeak the broken crest of an anticline from which oil is escaping, or similar escape from a fault or fissure. Care must then be taken to drill far enough away from the line of fracture so as to penetrate the oil-bearing stratum at a depth sufficient to secure a supply. The distance from the seepages depends very much upon the dip of the rocks; the greater the dip, the greater the depth at which the oil rock should be struck in order to secure a good supply. From a thousand to two thousand feet is the best range of depth at which to strike the oil-bearing stratum where the dip of the rocks is comparatively great. Where the beds have only a slight dip, the oil can be struck to advantage at 500 to 1000 feet below the surface.

Where the oil is sought in what has been known to be an unbroken anticline, or dome, the first well may be drilled to advantage as near the crest as possible, for while this well may develop nothing but gas, it gives valuable information for subsequent wells, and any enterprise must be prepared for drilling a number of holes in the development of a new field.

This subject, including a discussion of the best location for wells, spacing of wells, and the importance of geological examination of the territory, is given careful consideration in the chapter by Prof. Roswell H. Johnson.[1]

[1]Chapter x.

LAWS AND REGULATIONS FOR ACQUIRING PUBLIC OIL LANDS.

The policy of the different provinces of Canada with regard to the granting or reservation of minerals, both precious and base, in public lands when these were sold, has not been uniform. Under the regalian principle of the common law, although not expressly reserved in the grant, the right to the precious mineral was reserved if no mention was made of it.

The title to all the land, as well as all contained minerals, within the present Dominion of Canada was vested originally either in the King of France or in the English crown. As regards the part originally belonging to France, a grant of the land did not convey the right to the minerals without special words of conveyance regarding this right.

The common law of England, unless modified by statutes, is in force, however, in all the territories and provinces of Canada except Quebec, where the old French law is the basis of the legal system. By the theory of the common law in Canada, gold and silver mines belong to the crown in all land whatsoever, unless they have been expressly severed therefrom and granted by the crown.[1] By the British North American Act, under the provisions of which the Dominion of Canada came into existence, exclusive jurisdiction was given to the several provinces to make laws in relation to the management and sale of public lands within their boundaries. In general all the public lands within the different provinces had been granted by the crown to the provinces,[2] and this grant included the regalian right to gold and silver. The House of Lords has decided that in provinces such as British Columbia, which were not specially mentioned in said Act, but were admitted afterwards, the assignment of the regalian right to gold and silver to the provinces took effect upon their joining the Dominion.[3] In the case of British Columbia, however, this was only a recognition

[1]McPherson and Clark, "Law of Mines of Canada," p. 28.

[2]British North American Act of 1867, sec. 1904, Law Reps. 1867 (30-31 Vict.), ch. III, p. 5.

[3]Attorney-General of British Columbia vs. Attorney-General of Canada, 14 Appeal Cases, 295 (304).

of the rights which said province held in the lands, precious minerals, etc., previously. In this province the policy of late has been to reserve all minerals when public land is sold, together with right of entry for working it.

Acting under the powers conferred upon them by Sec. 97 of the British North American Act, 1867, the provinces of *Quebec, Nova Scotia, New Brunswick, Ontario and British Columbia* have by their Legislatures enacted laws dealing with mines and minerals, including, in most cases, specific provisions for the development of petroleum and natural gas deposits.

By the provisions of section 109 of this Act and subsequent Orders of Council, these provinces possess, subject to the administration and control of their several legislatures, the right to dispose of the public lands within their boundaries, excepting such portions as are reserved to the Dominion for public works and undertakings or are required for purposes of defence.

Although *Prince Edward Island* was admitted to the Dominion by authority of this Act it was not affected by the provisions of section 109 since at that time it embraced no public lands.

Public lands in *Manitoba, Alberta, Saskatchewan, Northwest Territory, and Yukon* are subject to administration by the Governor in Council by authority of the Acts admitting these provinces to the Dominion (Rupert's Land Act 1868 Imperial and Order of Her Majesty in Council, dated July 31, 1880), or by Acts of the Dominion Parliament establishing them (Manitoba Act, 1870), Alberta and Saskatchewan Acts assented to July 20, 1905, and Yukon Act, R.S.C. Ch. 63, 1906.

Unappropriated Dominion lands located in the above mentioned provinces and territories are open for petroleum prospecting by any individual or company under the following Petroleum Regulations approved by Order in Council dated March 11, 1911:

Regulations for the disposal of Petroleum and Natural Gas rights, the property of the Crown, in Manitoba, Saskatchewan, Alberta, the Northwest Territories, the Yukon Territory, the Railway Belt in the Province of British Columbia, and within the tract containing three and one-half (3½) million *acres of land acquired by the Dominion Government from the Province of British Columbia, and referred to in subsection (b) of section 3 of the Dominion Lands Act,* ***approved*** *by Orders in Council dated 11th day of March, 1910,* ***(re-*** *established by Order in Council 12th Aug., 1911),* ***and Order*** *in Council dated the 11th day of March, 1911.*

Minister shall mean the Minister of the Interior of Canada.

1. The petroleum and natural gas rights which are the property of the Crown, in Manitoba, Saskatchewan, Alberta, the Northwest Territories, the Yukon Territory, the Railway Belt in the Province of British Columbia, and within the tract containing three and one-half (3½) million acres of land acquired by the Dominion government from the Province of British Columbia, and referred to in subsection (b) of section 3, of the Dominion Lands Act, may be leased to applicants at a rental of twenty-five (25) cents an acre for the first year, and for each subsequent year a rental at the rate of fifty (50) cents an acre, payable yearly in advance. The term of the lease shall be twenty-one years, renewable for a further term of twenty-one years, provided the lessee can furnish evidence satisfactory to the Minister to show that during the term of the lease he has complied fully with the conditions of such lease and with the provisions of the regulations in force from time to time during the currency of the lease.

2. No applicant shall be allowed to lease the petroleum and natural gas rights under an area of more than 1,920 acres.

3. If the tract applied for is situated in surveyed territory, it shall consist of sections, or legal subdivisions of sections, but the several parcels comprising the tract shall be adjoining, the length of the tract not to exceed three times its breadth. In unsurveyed territory, if at least one of the lines bounding the section of part of section applied for has been surveyed, and such survey has been duly approved, an application for a lease of the petroleum and natural gas rights under such section or part of section may be considered under the provisions of this section of the regulations.

4. Application for a lease of the petroleum and natural gas rights on surveyed lands shall be filed by the applicant in person with the Agent of Dominion Lands for the district in which the rights applied for are situated, or with a sub-agent for such district, for transmission to the agent, but priority of application shall be based upon the date of the receipt of such application in the office of the Agent of Dominion Lands for the district.

5. In case the surface rights of the tract applied for have been patented, or have been disposed of by the Crown under any Act or Regulation which contemplates the earning of patent for such surface rights, the lease shall not authorize entry thereon except with the written consent of the owner or occupant being first had and obtained. In the case of a timber license, grazing or coal mining lease, mining claim or other form of terminable grant which does not contemplate the issue of patent, the permission of the Minister to enter upon the land must first be obtained, which permission will be made subject to such conditions for the protection of the rights of such lessee or licensee as it may be considered necessary to impose.

6. If the rights applied for are situated in unsurveyed territory, application for a lease shall be made by the applicant in person to the Agent of Dominion Lands for the district in which the rights applied for are situated, or to a sub-agent for such district, for transmission to the agent.

7. Applications for a location situated in unsurveyed territory shall contain a description by metes and bounds of the location applied for, and shall be accompanied by a plan showing the position of such location in its relation to some prominent topographical feature or other known point. The plan shall contain sufficient data to admit of the position of the location applied for being definitely shown in the records of the department. The location must be rectangular in form, except where a boundary of a previously located tract is adopted as common to both locations, the length not to exceed three times the breadth.

The application shall be accompanied by evidence, supported by affidavit of the locator, to show that the following requirements have been fully complied with:—

(a) That the location applied for has been defined on the ground by the locator in person by planting two wooden posts, at least four inches square, and standing not less than four feet above the ground—such posts being numbered '1' and '2' respectively. The distance between post No. '1' and post No. '2' shall not exceed 15,840 feet, and upon each post shall be inscribed the name of the locator and the date of the location. Upon post No. '1' there shall be written, in addition to the foregoing the words 'initial post,' the approximate compass bearing of post No. '2' and a statement of the number of feet lying to the right and to the left of the line between post No. '1' and post No. '2'. Thus—(initial post, direction of post No. '2' is............feet lie to the right and............feet to the left of the line between post No. '1' and post No. '2'). (O. in C., 11 March, 1911.)

When the tract which an applicant desires to lease has been located, he shall immediately mark the line between post No. '1' and post No. '2' so that it can be distinctly seen, in a timbered locality, by blazing trees and cutting underbrush, and in a locality where there is neither timber nor underbrush he shall set posts of the above dimensions or erect mounds of earth or rock not less than two feet high and two feet in diameter at the base in such a manner that the line may be distinctly seen.

(*b*) All the particulars required to be inscribed on posts No. '1' and No. '2' shall be set out in the application and shall be accompanied by a plan showing the position of the tract in its relation to some prominent topographical feature or other known point, such plan to contain sufficient data to admit of the location being shown definitely on the record of the Department.

(*c*) The locator shall post a written or printed notice on a conspicuous part of the location applied for, setting out his intention to apply within thirty days from the date of such notice for a lease of the petroleum and natural gas rights under the said location.

(*d*) The application shall be accompanied by evidence, supported by the affidavit of the locator, in due form, to show that the above requirements of the regulations have been fully complied with.

8. In case the tract applied for is located in unsurveyed territory on the margin of a river or lake, it shall not include more than one mile in direct distance along such water frontage, and shall extend back therefrom as far as may be necessary to include a total area of not more than 1,920 acres, the length of the location, however, not to exceed three miles. The tract shall be marked on the ground by two legal posts firmly fixed in the ground, one at each end of such front boundary. The posts shall be numbered '1' and '2' respectively. It shall not be lawful to move post No. '1', but post No. '2' may be moved by a Dominion Land Surveyor if the distance between the posts exceed the length prescribed by these regulations, but not otherwise. The side boundaries shall be parallel lines drawn from each end of the front boundary at right angles to the base line of such river or lake established or to be established, by the Department. In the event of the base line not being established, the side boundaries of the location shall be drawn at right angles to the general direction of the valley of the river, or the margin of the lake. The required notice of application shall be posted conspicuously on the location near the margin of the lake or river on which it fronts.

The boundaries of claims situated on the margin of a lake or river, and any disputes which may arise in connection therewith, shall be subject to final adjustment by the Minister. (O. in C., 11 March, 1911.)

9. Application for a lease of the petroleum and natural gas rights under lands situated in unsurveyed territory shall be made by the locator in person to the Agent of Dominion Lands for the district in which the tract applied for is situated, or to a sub-agent for such district, within thirty days from the date upon which the tract applied for was staked as above provided, if it is situated within one hundred miles of the office of the Agent or Sub-Agent otherwise it will not be considered. One extra day, however, shall be allowed for every additional ten miles or fraction thereof that the location is distant more than one hundred miles from the office of the Agent or Sub-Agent.

10. Where two or more persons lay claim to the same location, or to portions of the same locations, situated in unsurveyed territory, the right to the lease shall be in him who can prove to the satisfaction of the Minister that he was the first to take possession of the tract in dispute by staking in the manner prescribed in these Regulations, and that he made application for a lease within the specified time.

11. As soon as the survey of a township has been confirmed, all petroleum and natural gas leases embracing any portion of such township so surveyed and confirmed, shall be made to conform to the Dominion Lands System of Survey if the Minister so decides, by the substitution of a new lease describing by sections, legal subdivisions of sections, or regular portions of legal subdivisions—as nearly as may be the tract embraced in the leasehold in so far as the township so surveyed is concerned. If any part of the leasehold is in territory which remains unsurveyed, it shall continue to be described as in the lease originally issued, until such portion is included in a confirmed survey.

12. As soon as the survey of a township has been confirmed, all petroleum and natural gas leaseholds embracing any portion of the township so surveyed and confirmed, shall be subject to the withdrawal forthwith from the lease, without compensation to the lessees, of any portions which, in accordance with such confirmed survey, are found to be the property of the Hudson's Bay Company.

13. The lease shall bear date from the day upon which the application is granted and the rental for the first year at the rate of twenty-five (25c.) cents an acre shall be paid within thirty

days from such date otherwise the application shall absolutely lapse and the rights applied for shall become available for other disposition. If during the term of the lease the lessee shall fail to pay the rental in advance for each subsequent year, at the rate of fifty (50c.) cents an acre per annum, within thirty days after the date upon which the same becomes due, the lease shall be subject to cancellation in the discretion of the Minister and to the immediate forfeiture of all the rights which the lessee had in the said lease.

Provided that if the lessee, in consideration of the expenditure to be incurred by him in actual boring operations upon his leasehold, makes application, at or before the beginning of the second and third years, respectively, of the term of the lease, for an extension of time within which to pay the rental when due, or becoming due, the Minister may grant such extension of time in writing, and if the lessee, before the end of the year in respect of which application was made, submits evidence to the Land Agent, or Sub-land Agent, of the district in which the leasehold is situated, in the form of affidavits by himself and two reliable witnesses, that during such year actual boring operations have been prosecuted upon his leasehold, as required by Section 15 of these Regulations, the amount expended in such boring operations, exclusive of the cost of machinery and casing, may be deducted from the rental which became due at the beginning of the said year. The balance of rental due, if any, shall be paid at the same time as the evidence in regard to work done is submitted, as above required. Failure to submit such evidence, or to pay the balance of rental due, will render the lease liable to cancellation, as hereinbefore provided.

14. The lessee shall, within one year from the date of the lease, have upon the lands described therein such machinery and equipment suitable for carrying on prospecting operations as the Minister may consider necessary, and he shall within the same period furnish evidence, supported by affidavit, showing the character, quantity and value of the machinery so installed and the date of its installation. If the required machinery is not installed within the period specified, and if evidence of its installation is not furnished within the prescribed period, the lease shall be subject to cancellation in the discretion of the Minister. Provided, however, that the Minister shall not require that the value of the machinery so installed shall exceed the sum of five thousand ($5,000) dollars.

15. The lessee shall commence boring operations on his leasehold within fifteen months of the date of his lease, and he shall continue such boring operations with reasonable diligence, to the satisfaction of the Minister, with a view to the discovery of oil or natural gas. If the lessee does not commence boring operations within the time prescribed, or if having commenced such operations he does not prosecute the same with reasonable diligence, to the satisfaction of the Minister, or if he ceases to carry on the same for a period of more than three months, the lease shall be subject to cancellation, in the discretion of the Minister, upon three months' notice to this effect being given to the lessee. Provided, however, that if satisfactory evidence is furnished to show that the sum of at least two thousand ($2,000) dollars has been expended in actual boring operations, by recognized methods, upon the leasehold in any year, such expenditure shall be accepted as compliance with this provision for the year during which such expenditure was incurred.

16. The lease shall in all cases include only the oil and natural gas rights, which are the property of the Crown, but the lessee may, upon application, be granted a yearly lease at a rental of one ($1) dollar an acre per annum, payable yearly in advance, of whatever area of the available surface rights of the tract described in his petroleum and natural gas lease the Minister may consider necessary for the efficient and economical working of the rights granted him.

17. Should oil or natural gas in paying quantity be discovered on the leasehold, and should such discovery be established to the satisfaction of the Minister, the lessee will be permitted to purchase at the rate of ten ($10) dollars an acre whatever area of the available surface rights of the tract described in the lease the Minister may consider necessary for the efficient operation of the rights granted him.

18. If it is not established to the satisfaction of the Minister that oil or natural gas in paying quantity has been discovered on the leasehold, the lease shall be subject to termination upon two years' notice in writing being given to the lessee by the Minister.

19. The boundaries beneath the surface of a location shall be vertical planes or lines in which their surface boundaries lie.

20. A fee of five ($5) dollars shall accompany each application for a lease, which will be refunded if the rights applied for are not available, but not otherwise.

21. The lease shall be in such form as may be determined by the Minister of the Interior, in accordance with the provisions of these Regulations.

22. The lessee shall not assign, transfer or sublet the rights described in his lease, or any part thereof, without the consent in writing of the Minister being first had and obtained.

23. No royalty shall be charged upon the sales of the petroleum acquired from the Crown under the provisions of the Regulations up to the 1st day of January, 1930, but provision shall be made in the leases issued for such rights that after the above date the petroleum products

of the location shall be subject to whatever regulations in respect of the payment of royalty may then or thereafter be made.

24. A royalty at such rate as may from time to time be specified by Order in Council may be levied and collected on the natural gas products of the leasehold.

25. At the end of each year of the term of the lease the lessee shall furnish a statement supported by affidavit, showing the number of days during the year that operations were carried on upon the location; the number of men so employed; the character of the work done; the depth attained; the total expenditure incurred; a detailed statement setting out fully the purpose for which such expenditure was incurred; the quantity of crude oil or natural gas obtained, and the amount realized from the sale thereof. Failure to furnish such yearly return will render the lessee subject to a fine of ten ($10) dollars a day for each day's delay in furnishing the sworn statement, and after three months' delay the lease shall be subject to cancellation.

These regulations are extended and applied to lands included in the railway belt in the province of British Columbia. (Order in Council, 11th of March, 1911.)

Western Canada School Land Leases.—By ruling of the Dominion Government in 1913, school land reserves in the west can be leased for petroleum and natural gas purposes to applicants, at a rental of 25 cents per acre for the first year, and 50 cents per acre for each consecutive year. The leases are allowed to run twenty-one years, and are renewable at the end of that time. A condition is made, however, that not more than 640 acres will be leased to any one person.

LAWS CONCERNING INDIVIDUAL PROVINCES.

In addition to the laws and regulations quoted above various statutes and regulations apply to individual provinces and are quoted below.

Quebec.

Petroleum and natural gas mining rights in the Province of Quebec are acquired under the provision of the Quebec Mining Law (55-56 Victoria Ch. 20—1892). Specific mention of these minerals is not made in this enactment, but by regulation of the Lieutenant Governor in Council.

All such unwithdrawn public lands or private lands in which the minerals are reserved to the Crown containing them are subject to acquisition for development purposes.

Disposition of mineral lands and mineral rights is vested in the Commissioner of Colonization and Mines who is empowered to sell mining concessions not exceeding 200 acres each in extent at public auction or privately upon application accompanied by plan and field notes of official survey and cash payment at the rate of a certain amount an acre, if the land is more than 20 miles from a railway, which amount is doubled if the tract is less than 20 miles distant.

Lands may also be acquired for mining purposes by occupation and working under a mining license.

For a fee of $10 a miner's certificate good only for the current calendar year may be obtained from the Commissioner, conveying the right to prospect on all unoccupied unwithdrawn public lands and on private lands where minerals are reserved to the Crown in which latter case security is required to answer for any damage to the surface estate. When he makes a discovery the holder of a miner's certificate is allowed to stake and indicate on the ground in a prescribed manner an area not exceeding 200 acres in extent and after filing notice of his discovery is allowed four months in which to apply for a mining license. These are of two kinds (1) Private lands license, where minerals are reserved to the Crown, (2) Public lands license. Mining licenses are granted to holders of mining certificates upon application accompanied by a plan showing clearly the location of the desired claim, by an affidavit that the land sought is enterable and that the claim is properly marked on the ground, by payment of a fee of $10 and an annual ground rental of $1 an acre. Licenses are renewable from year to year upon payment of a renewal fee and an annual rental of $1 an acre subject at the discretion of the Lieutenant Governor to the requirement of a royalty in lieu of such renewal and rental fees. Private land licenses are qualified by provisions for indemnity to the owner of the surface estate for damages resulting from mining operations.

Ontario.

Search for and development of petroleum and natural gas deposits in Ontario is provided for in the Mining Act of Ontario (8 Edward VII, Ch. 21, 1908), amended at various times since its enactment.

Vacant crown lands and patented lands in which the mineral rights are reserved to the Crown are open for prospecting by individuals who hold valid miners' licenses from the Minister of Mines.[1]

Prospectors so qualified may stake in a prescribed manner a compact area not exceeding 640 acres, and by complying with certain regulations as to survey, indemnification for damages to owner of surface estate, etc., and payment of a fee of $100, obtain a boring permit granting exclusive right to prospect for petroleum and natural gas within the desired area for a period of one year.

Before the termination of this permit a sum amounting to not less than $2 an acre in actual development work for oil or gas must be spent in order to qualify the holder for a renewal of his permit, which, if the conditions are fulfilled, is renewable for one year at the same terms as to development work, for a fee of $100.

After a discovery of oil or gas is made the prospector is entitled to apply to the Minister of Mines for a lease of any or all the land involved upon the submission of satisfactory proof that he is the holder of the boring permit affecting the land and that he has discovered oil or gas in commercial quantities within the area. Leases are issued for a term of 10 years at an annual rental of $1 an acre payable in advance, and subject to the expenditure of not less than $2 an acre per annum in obtaining oil or gas, or in actual bona fide operations or works for the purpose of obtaining the same from the lands. The lessee has the right of renewal of his original lease for a second term of ten years at the same rental, and at the expiration of this term the right of a further renewal for twenty years on terms to be agreed upon at the time if not provided by statute or regulation. Every lease is issued subject to such other conditions, stipulations and provisos as the Lieutenant-Governor in Council may prescribe and are forfeitable for non-payment of rent and failure to comply with the prescribed terms.

[1] In the older parts of the province the mining rights have already been transferred from the Crown to the owner of the surface rights. See page 123.

The lease conveys to the lessee the right to enter upon the land described and dig, bore, sink, drive, or otherwise search for and obtain only petroleum, natural gas, coal, and salt. All other valuable minerals are reserved to the Crown and any holder of a miner's license is at liberty to enter the lands, prospect, stake claims and obtain limited patent thereto, provided the lessee is duly compensated for any resulting damage or injury to his interests.

FOREST RESERVES.

Lands embraced in Crown forest reserves in Ontario are open for prospecting by any holder of a miner's license, but are not subject to sale, although a lease permitting mining operations thereon may be granted for a period not exceeding ten years with the right of perpetual renewal for periods of not more than ten years each subject to such regulations as may be made by the Lieutenant-Governor in Council.

British Columbia.

Acquisition of petroleum and gas-bearing lands in the Province of British Columbia is under the Çoal Mines Act, R.S. Ch., 137, and the procedure involved is, briefly, as follows:

Licenses to prospect for petroleum or natural gas over any compact area of public land in the province, not exceeding 640 acres, for a term not exceeding one year, may be granted to any person by the Chief Commissioner of Lands and Works upon the following conditions:—

Applicant must stake the desired area in a prescribed manner and post thereon a notice of his intention to apply for a license, must publish for 30 days a notice of his intention in the British Columbia Gazette and in some newspaper circulating in the local district; and at the expiration of this publication period must make duplicate application in writing, accompanied by a plan and description of the land and a fee of $100 to the local commissioner, for a prospector's license covering that area.

Licenses so granted are subject to two renewals upon payment of a fee of $100 for each renewal and satisfactory showing to the Chief Commissioner or Assistant Commissioner that the licensee has bona fide explored for coal or petroleum during the term of the lease. For purpose of prospecting, provision is made that license holders, not exceeding ten, on adjoining lands may unite in a partnership and proceed as a firm in prospecting one claim, which, if done satisfactorily to the Chief Commissioner, relieves the individual licensee of separate prospecting.

After discovery is made a lease is procurable by an individual or firm from the Lieutenant-Governor in Council, good for five years, subject to the payment of an annual ground rental of 15 cents an acre, and a royalty of 2½ cents a barrel for all crude petroleum obtained from the land, and further subject to continuous and vigorous prosecution of development work.

At the expiration of this lease if all conditions have been faithfully fulfilled the lessee is entitled to purchase the land together with the petroleum therein at the rate of $10 an acre, or in case the land has been alienated, he shall be entitled to obtain a grant of coal and petroleum underlying the land, upon payment at the rate of $5 an acre.

METHODS OF OBTAINING OIL AND GAS RIGHTS FROM PRIVATE LANDS.

In Ontario the surface owner has a title to the oil and gas rights and the companies lease the rights direct from the surface owner. The Canada Company has, however, some land on which the Government still holds the title. The courts have decided that oil is not a mineral. This decision was made in the test case of Farquharson vs. The Canada Land Co. In Northern and Western Ontario the government has reservations.

GAS LEASES.

As a rule the leases give a limited amount of free gas to the owner of the property; formerly it was the custom to give an unlimited amount of free gas. At present they seldom give over 200,000 cubic feet of free gas from the first paying gas well on the property. The rentals are 20 to 25c. per acre for every year after the first year. The companies never pay over 50c. an acre and they generally get one year free lease, They pay $50 for a gas well or give 200,000 cubic feet of free gas and only in a few cases do they do both. In a few instances they pay $100 for a well, but never over this. The leases provide a royalty of one-tenth to one-eighth of the oil to the owner of the surface; all the earlier leases giving one-tenth.

Form of Lease.

A lease form used by one of the prominent Canadian gas companies follows:—

THIS AGREEMENT made in duplicate this..................day of..................

A.D. 190....

BETWEEN..

....

of the Township of ....in the County of..............hereinafter called the Grantor, of the First Part; and

THE COMPANY

hereinafter called the Company of the Second Part.

WITNESSETH that in consideration of the sum of One Dollar, the receipt whereof is hereby acknowledged, and of the rents, royalties and agreements hereinafter contained, the Grantor ha granted and do........hereby grant unto the Company, for the purpose and with the exclusive right of searching for, producing and taking away petroleum and natural gas. All that certain tract of land situated in the Township of....................in the County of.......................................Province of Ontario, described as follows:..

....

....

....

....

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....

....

....

together with all rights and privileges necessary or proper for these purposes, without restricting the generality of the foregoing, the Company shall be deemed to have the right of way over and across said lands; the right to transmit power and gas to and from said premises, for operating purposes and to have sufficient oil, water and gas from said lands to run all machinery necessary to operate the same; the right to bring upon, erect or remove from said lands, any piping, machinery or fixtures and the exclusive right to lay pipes for conveying oil and gas on and across said lands.

TO HAVE AND TO HOLD the said premises for the purposes and with the rights aforesaid, for the term of ten years from the date hereof and as much longer as said premises are operated for the production of oil or gas, or the rental paid thereon.

THE COMPANY AGREES:

1st. To give the Grantor the..............part of all oil produced and saved on the premises.

2nd. If gas is found in sufficient quantities to utilize, that the Grantor shall for the first paying gas well drilled have the privilege of using in his dwelling now on said premises....

............feet of gas each year free of cost or a rental at the rate of.................... dollars a year, payable quarterly in advance so long as gas therefrom is sold off the premises: for all gas used in excess of that amount, the Grantor agrees to pay to the Company the sum of twenty cents per one thousand cubic feet payable on demand: for each subsequent paying gas well drilled the Company agrees to pay at the rate of........................dollars per annum, payable quarterly in advance so long as gas therefrom is being sold off the premises.

3rd. To compensate the Grantor at the rate of twenty dollars per acre for all damage to crops on said lands caused by operating thereon.

4th. To drill no well within two hundred feet of any house or barn now on said lands without the consent of the Grantor.

If no well is commenced within..............................from this date this grant shall become null and void unless the Company shall pay the Grantor a rental quarterly in advance at the rate of ....per year during the remainder of the said term, provided however that such rental shall not in any event be payable after surrender of this lease. Any moneys payable hereunder may be paid to the Grantor in person or by mailing the same in a postpaid envelope directed to him at..........................post office or by depositing the same to his credit in the...............................Bank at..and may be made by cheque, Express Order, Post Office Order or the notes of a chartered bank.

THE COMPANY may at any time surrender this lease whereupon all liability of the Company shall forthwith cease and determine except for moneys due and unpaid at the time of such surrender: such surrender shall be in writing and the same, and any notice required to be given hereunder may be effectually given by delivering the same to the Grantor in person or by mailing the same in a postpaid envelope addressed to the Grantor at.......... ....Post Office.

THESE presents shall enure to the benefit of and be binding upon the parties hereto, their heirs, executors, administrators, successors and assigns respectively.

IN WITNESS WHEREOF the said parties have hereunto set their hands and seals the day and year first above written.

Signed, Sealed and delivered in the presence of

THE....................COMPANY, LIMITED.

...............................Pres.

.......................Sec'y

The following is a form of lease quoted as a typical form used in Canada, by Mr. A. Beeby Thompson in "Petroleum Mining," p. 41.

THIS LEASE, made the...........................day of.....................A.D., between.............................of............................., in the County of ....and Province of Ontario, farmer, hereinafter called the lessor of the first part, and......................., hereinafter called the Lessee, of the second part. In consideration of the agreements herein contained, the lessor does hereby grant and lease unto the lessee, for the term of five years, and so long thereafter as oil or gas is produced from the land leased in paying quantities, the exclusive right to drill for and produce petroleum and natural gas, and the right to conduct all operations necessary for the production, storage, and transportation of oil or natural gas, with the right to use water and gas (if found) for the necessary engines, and to remove all machinery, fixtures, etc., placed by the lessee on the premises, namely:

....................................in the Township of.............................. County of..................................Province of Ontario, being................. acres more or less. No wells to be drilled within............................feet of buildings without lessor's consent. The lessee to deliver to the lessor on the premises, free of cost, the one-tenth part of all petroleum produced and saved from the premises, and to pay one hundred dollars ($100) per annum for each gas well from which the gas is marketed for lighting any village, town or city. If the lessor shall request it, the lessee shall bury all oil and gas lines below plough depth.

Lessee to pay compensation for any actual damage to crops or improvements caused by operations, to keep all gates closed and fences as found, and to pay all taxes rated on any property or effects he may place thereon.

This lease to be null and void and no longer binding on either party if operations for drilling are not commenced on the premises within..................days from this date, unless the lessee shall thereafter pay yearly to lessor twenty-five cents (25c.) per acre for delay.

It is understood between the parties to this agreement that all the conditions between the parties hereunto shall extend to their heirs, executors, administrators, and assigns.

Lessor to have free use of gas (if found) for household purposes on the premises during said terms.

SIGNED and sealed by................................and....................

A form of agreement entered into by individuals and the Dominion Government in leasing oil and gas lands follows, together with the latest regulations approved January 19, 1914, for the disposal of oil and gas rights in certain territories.

Petroleum and Natural Gas Lease No.......
File No..................................

THIS INDENTURE, made in duplicate, this day of in the year of our Lord one thousand nine hundred and BETWEEN HIS MAJESTY KING GEORGE THE FIFTH, represented herein by the Minister of the Interior of Canada, hereinafter called the Minister, of the first part, and hereinafter called the lessee, of the second part.

WHEREAS by Order of the Governor in Council, dated the nineteenth day of January, in the Year of our Lord, one thousand nine hundred and fourteen, regulations were made for the disposal of petroleum and natural gas rights, the property of the Crown in the Provinces of Manitoba, Saskatchewan and Alberta, the Yukon Territory, the Northwest Territories, the Railway Belt in the Province of British Columbia, and the three and one-half millions of acres of land acquired by the Dominion from the Province of British Columbia, and referred to in sub-section (b) of Section 3 of the Dominion Lands Act, Chapter 20, 7-8 Edward VII, a copy of which regulations is hereto appended.

AND WHEREAS the lessee having applied for a lease under the said Regulations of the petroleum and natural gas rights in the lands hereinafter described the Minister has granted such application upon the terms and conditions herein contained.

NOW THEREFORE THIS INDENTURE WITNESSETH that in consideration of the rents and royalties hereinafter reserved and subject to the provisos, conditions, restrictions and stipulations hereinafter expressed and contained, His Majesty doth grant and demise unto the lessee, for the sole and only purpose of mining and operating for petroleum and natural gas, and of laying pipe lines and of building tanks, stations and structures thereon necessary and convenient to take care of the said products.

ALL AND SINGULAR

TO HAVE AND TO HOLD the same unto the lessee for the term of twenty-one years, to be computed from the day of 19 , renewable for a further term of twenty-one years provided the lessee furnishes evidence satisfactory to the Minister of the Interior to show that during the term of the lease he has complied fully with the conditions of such lease and with the provisions of the regulations under which it was granted. Yielding and paying therefor during the first year of the said term unto His Majesty the clear yearly rent or sum of twenty-five cents of lawful money of Canada for each and every acre of land comprised within the said lands, and for each subsequent year of such term the rent or sum of fifty cents, such rent being payable yearly in advance on the day of in each year of the said term, the first of which payments has been made on or before the execution of these presents; and also rendering and paying therefor unto His Majesty a royalty at such rate as may from time to time be prescribed by Order of the Governor General of Canada in Council on natural gas products taken out of the said lands, and also such royalty on petroleum products taken out of the said lands from and after the first day of January in the year 1930 as the regulations then and thereafter in force may prescribe, and such rent and royalty to be free and clear of and from all rates and taxes and assessments and from all manner of deductions whatsoever except as hereinafter mentioned.

PROVIDED ALWAYS that this demise is granted upon and subject to the following provisos, conditions, restrictions and stipulations, that is to say:

1. That the lessee shall and will well and truly pay or cause to be paid to the Minister at Ottawa, the rent and royalty hereby reserved, and shall and will make all returns at the times and in the manner herein or in or under the said regulations prescribed.

2. That the lessee shall and will well, truly and faithfully observe, perform and abide by all the obligations, conditions, provisos and restrictions in or under the said regulations imposed upon lessees or upon the said lessee.

3. That the lessee shall and will keep correct books of such kind and in such form as may be prescribed by the Minister, showing the quantity of petroleum and natural gas taken out of the said lands, and whenever required so to do shall submit such books to the inspection of any officer or person appointed or authorized by the Minister to examine the same for the purpose of verifying the returns made by the lessee.

4. That the lessee shall and will, during the said term, make such provision for the disposal of the earth, rock, waste or refuse of the said lands that the same shall not be an inconvenience, nuisance or obstruction to any railway right of way, roadway, pass, passage, river, creek or place, or to any private, public or Crown lands, or conflict with or embarrass the operating of any other mines on the said lands, or in any manner whatsoever occasion any private or public damage, nuisance or inconvenience.

5. That the lessee shall and will, during the said term, make and deliver to the Minister or to any officer or agent appointed or instructed by him to collect, obtain or receive the same, all such true and proper information of the working and operations of any mines on the said lands (the truth and accuracy of which shall be verified by oath or solemn declaration of the lessee or his manager, agent or employee cognizant of the facts) as the Minister shall from time to time direct.

6. That the lessee shall also make proper and reasonable compensation to any railway company for any damage caused to the right of way or station grounds of the railway or other property of the Company upon the said lands.

7. That the lessee shall and will permit any inspector or other person duly authorized in that behalf, with all proper or necessary assistants, at all reasonable times during the said term, quietly to enter into and upon the said lands, mines and premises, and into all buildings erected thereon, and into any part thereof, and to survey and examine the state and condition thereof, so nevertheless that in so doing no unnecessary interference, is caused with the carrying on of the mining work, of the lessee; and shall and will by all means in his power aid and facilitate such inspector or other person in making such entry, survey and examination.

8. That the lessee shall and will during the said term, open, use and work any mines and works opened and carried on by him upon the said lands in such manner only as is usual and customary in skilful and proper mining operations of similar character when conducted by proprietors themselves on their own lands, and when working the same shall keep and preserve the said mines and works from all avoidable injury and damage, and also the roads, ways, works, erections and fixtures therein and thereon in good repair and condition, except such of the matters and things last aforesaid as shall from time to time be considered by any inspector or other person authorized by the Minister to inspect and report upon such matters and things to be unnecessary for the proper working of any such mine, but so that no casing placed in any mine shall be removed or impaired, and in such state and condition shall and will at the end or sooner determination of the said term deliver peaceable possession thereof and of the said lands to His Majesty.

9. That the lessee shall and will during the said term enclose and keep enclosed all abandoned openings or excavations made in connection with or for the purpose of mining operations on the said lands with fences or walls sufficient to prevent cattle and other animals falling thereinto, such fences or walls to be of a height and character satisfactory to the Minister or to the inspector or other person duly authorized by him as aforesaid, and to comply with any regulations or directions from time to time made or given by the Minister.

10. That no waiver on behalf of His Majesty of any breach of any or either of the provisos, conditions, restrictions and stipulations herein contained, whether negative or positive in form, shall take effect or be binding upon him, unless the same be expressed in writing under the authority of the Minister, and any waiver so expressed shall extend only to the particular breach so waived and shall not limit or affect His Majesty's rights with respect to any other or future breach.

11. That no implied covenant or liability of any kind on His Majesty's part is created by the use of the words "demise" or "lease" herein, or by the use of any other word or words herein, or shall otherwise arise by reason of these presents or anything therein contained.

12. That in case of default in payment of the said rent or royalty for 30 days after the ame should have been paid, or in case of breach or non-observance or non-performance on the part of the lessee of any proviso, condition, restriction or stipulation herein contained, and which ought to be observed or performed by the lessee and which has not been waived by the said Minister, the Minister may cancel these presents by written notice to the lessee, and thereupon the same and everything therein contained shall become and be absolutely null and void to all intents and purposes whatsoever, and it shall be lawful for His Majesty into and upon the said lands (or any part thereof in the name of the whole) to re-enter and the same to have again repossess and enjoy; anything herein contained to the contrary notwithstanding. Provided nevertheless that in case of such cancellation and re-entry the lessee shall continue to be liable to pay and His Majesty shall have the same remedies for the recovery of any rent or royalty then due or accruing due as if these presents had not been cancelled, but remained in full force and effect.

13. That within two months from the termination of this lease from any cause, if all rent and royalty due thereunder shall have been paid, and all provisos, conditions, restrictions and stipulations hereby imposed upon the lessee shall have been duly observed and performed, the lessee may remove from the said lands all tools and machinery, buildings and erections which he may have placed thereon, but shall not remove or impair any of the casing which is necessary to the use and maintenance of the shafts or wells in any mine on the said lands, or any article, matter or thing the removal of which might cause such mine to cave in or give way, and that in default of removal within such period of two months all such tools and machinery, buildings and erections shall be absolutely forfeited and shall become and be the property of His Majesty.

14. Provided that, if in consequence of insufficient survey or of any cause whatsoever the said demised premises are found to include a portion of the petroleum and natural gas rights demised to any other person under the regulations of any Order of the Governor General in Council, the lessee whose application was first recorded in accordance with the provisions of such regulations shall have priority.

15. That if in the opinion of the Minister the said petroleum or its products or any portion thereof should at any time during this demise be required for the use of His Majesty's Canadian Navy, the Minister shall have a right of pre-emption of all crude petroleum oil or its products gotten or won under this demise for such use as aforesaid, the price to be agreed on between the Minister and the lessee or in case of difference to be fixed by the Exchequer Court of Canada.

16. And provided further and it is hereby declared that this lease is subject in all respects to the regulations of the Governor in Council, relating to petroleum, and to any regulations that may be issued in amendment of and in substitution therefor.

Where the context permits the expression "lessee" herein includes the heirs, executors, administrators and assigns of the lessee; the expression "His Majesty" includes the successors and assigns of His Majesty; and the expression "Minister" includes the successors in office of the Minister of the Interior.

IN WITNESS WHEREOF the Deputy of the Minister of the Interior and the Lessee have hereunto set their hands and seals the day and year first above written.

SIGNED, SEALED AND DELIVERED

IN THE PRESENCE OF

....

....
Deputy of the Minister of the Interior.

And by the lessee in the presence of

....
Witness.

....
Lessee.

Regulations for the disposal of Petroleum and Natural Gas rights, the property of the Crown, in Manitoba, Saskatchewan, Alberta, the Northwest Territories, the Yukon Territory, the Railway Belt in the Province of British Columbia, and within the tract containing three and one-half (3½) million acres of land acquired by the Dominion Government from the Province of British Columbia, and referred to in subsection (b) of section 3 of the Dominion Lands Act, approved by Order in Council dated the 19th of January, 1914.

INTERPRETATION

"Minister" shall mean the Minister of the Interior of Canada.

"Adjoining" lands shall be those which are not separated by a section, or by any of the regular subdivisions into which a section may be divided.

"Location" shall mean the tract described in a petroleum and natural gas lease.

"Group" shall mean two or more of the locations described in petroleum and natural gas leases, consolidated for purposes of operation.

"Lessee" means any individual, company, corporation or municipality the holder of a petroleum and natural gas lease in good standing.

"River" shall mean a stream of water the bed of which is of an average width of 150 feet throughout the portion thereof on which the tract applied for fronts.

1. The petroleum and natural gas rights which are the property of the Crown, in Manitoba Saskatchewan, Alberta, the Northwest Territories, the Yukon Territory, the Railway belt in the Province of British Columbia, and within the tract containing three and one-half (3½) million acres of land acquired by the Dominion Government from the Province of British Columbia, and referred to in subsection (b) of section 3 of The Dominion Lands Act, may be leased to applicants at a rental of twenty-five (25) cents an acre for the first year, and for each subsequent year a rental at the rate of fifty (50) cents an acre, payable yearly in advance. The term of the lease shall be twenty-one years, renewable for a further term of twenty-one years, provided the lessee can furnish evidence satisfactory to the Minister to show that during the term of the lease he has complied fully with the conditions of such lease and with the provisions of the regulations in force from time to time during the currency of the lease.

2. The maximum area of a petroleum and natural gas location shall be 1,920 acres, and no person shall be permitted to acquire a greater area except by assignment.

Provided that a person who has been granted a lease for a location, and who subsequently abandons or assigns the same, may, after the expiration of twelve months from the date of the said lease, apply for an area not greater than that abandoned or assigned.

Provided further, however, that such rights shall not be granted unless all payments on account of rent or other liability to the Crown due by such person, have been fully made, up to the date of the registration by the Department of the assignment of his right to such lease, or up to the date upon which the notice of his abandonment of the same was received by the Department.

3. If the tract applied for is situated in surveyed territory, it shall consist of sections, or legal subdivisions of sections, but the several parcels comprising the tract shall be adjoining, the length of the tract not to exceed three times its breadth. In unsurveyed territory, if at least one of the lines bounding the tract applied for has been surveyed, and the returns of such survey have been duly received in the office of the Surveyor General, an application for a lease of the petroleum and natural gas rights under such tract may be considered under the provisions of this section of the regulations.

4. Applications for a lease of the petroleum and natural gas rights on surveyed lands shall be filed by the applicant in person with the agent of Dominion Lands for the district in which the rights applied for are situated, or with a sub-agent for such district, for transmission to the agent, but priority of application shall be based upon the date of the receipt of such application in the office of the Agent of Dominion Lands for the district.

5. If the rights applied for are situated in unsurveyed territory, application for a lease shall be made by the applicant in person to the Agent of Dominion Lands for the district in which the rights applied for are situated, or to a sub-agent for such district, for transmission o the agent.

6. Application for a location situated in unsurveyed territory shall contain a description by metes and bounds of the location applied for, and shall be accompanied by a plan showing the position of such location in its relation to some prominent topographical feature or other known point. The plan shall contain sufficient data to admit of the position of the location, applied for being definitely shown in the records of the Department. The location must be rectangular in form, except where a boundary of a previously located tract is adopted as common to both locations, the length not to exceed three times the breadth.

The application shall be accompanied by evidence, supported by affidavit of the locator, to show that the following requirements have been fully complied with:—

(a) That the location applied for has been defined on the ground by the locator in person by planting two wooden posts, at least four inches square, and standing not less than four feet above the ground—such posts being numbered "1" and "2" respectively. The distance between post No. "1" and post No. "2" shall not exceed 15,840 feet, and upon each post shall be inscribed the name of the locator and the date of the location. Upon post No. "1" there shall be written, in addition to the foregoing, the words "initial post," the approximating compass bearing of post No. "2" and a statement of the number of feet lying to the right and to the left of the line between post No. "1" and post No. "2." Thus—Initial post, direction of post No. "2" is..feet lie to the right and ....feet to the left of the line between post No. "1" and post No. "2."

When the tract which an applicant desires to lease has been located, he shall immediately mark the line between post No. "1" and post No. "2" so that it can be distinctly seen, in a timbered locality, by blazing trees and cutting underbrush, and in a locality where there is neither timber nor underbrush he shall set posts of the above dimensions or erect mounds of earth or rock not less than two feet high and two feet in diameter at the base in such a manner that the line may be distinctly seen.

(b) All the particulars required to be inscribed on posts No. "1" and No. "2" shall be sent out in the application and shall be accompanied by a plan showing the position of the tract in its relation to some prominent topographical feature or other known point, such plan to contain sufficient data to admit of the location being shown definitely on the records of the Department.

(c) The locator shall post a written or printed notice on a conspicuous part of the location applied for, setting out his intention to apply within thirty days from the date of such notice for a lease of the petroleum and natural gas rights under the said location.

(d) The application shall be accompanied by evidence, supported by the affidavit of the locator, in due form, to show that the above requirements of the regulations have been fully complied with.

7. In case the tract applied for is located in unsurveyed territory on the margin of a river or lake, it shall not include more than one mile in direct distance along such water frontage and shall extend back therefrom as far as may be necessary to include a total area of not more than 1,920 acres, the length of the location, however, not to exceed three miles. The tract shall be marked on the ground by two posts firmly fixed in the ground, one at each end of such front boundary. The posts shall be numbered "1" and "2" respectively. It shall not be lawful to move post No. "1", but post No. "2" may be moved by a Dominion Land Surveyor if the distance between the posts exceeds the length prescribed by these regulations, but not otherwise. The side boundaries shall be parallel lines drawn from each end of the front boundary at right angles to the base line of such river or lake, established or to be established by the Department. In the event of the base line not being established, the side boundaries of the location shall be drawn at right angles to the general direction of the valley of the river, or the margin of the lake. The required notice of application shall be posted conspicuously on the location near the margin of the lake or river on which it fronts.

The boundaries of claims situated on the margin of a lake or river, and any disputes which may arise in connection therewith, shall be subject to final adjustment by the Minister.

8. Application for a lease of the petroleum and natural gas rights under lands situated in unsurveyed territory shall be made by the locator in person to the Agent of Dominion Lands for the district in which the tract applied for is situated, or to a sub-agent for such district within thirty days from the date upon which the tract applied for was staked as above provided, if it is situated within one hundred miles of the office of the Agent or Sub-Agent, otherwise it will not be considered. One extra day, however, shall be allowed for every additional ten miles or fraction thereof that the location is distant more than one hundred miles from the office of the Agent or Sub-Agent.

9. Where two or more persons lay claim to the same location, or to portions of the same locations, situated in unsurveyed territory, the right to the lease shall be in him who can prove to the satisfaction of the Minister that he was the first to take possession of the tract in dispute by staking in the manner prescribed in these regulations, and that he made application for a lease within the specified time.

10. As soon as the survey of a township has been confirmed, all petroleum and natural gas leases embracing any portion, of such township so surveyed and confirmed, shall be made to conform to the Dominion Lands System of Survey if the Minister so decides, by the substitution of a new lease describing by sections, legal subdivisions of sections, or regular portions of legal subdivisions—as nearly as may be—the tract embraced in the leasehold in so far as the township so surveyed is concerned. If any part of the leasehold is in territory which remains unsurveyed, it shall continue to be described as in the lease originally issued, until such portion is included in a confirmed survey.

11. As soon as the survey of a township has been confirmed, all petroleum and natural gas leaseholds embracing any portion of the township so surveyed and confirmed, shall be subject to the withdrawal forthwith from the lease, without compensation to the lessees, of any portions which, in accordance with such confirmed survey, are found to be the property of the Hudson's Bay Company.

Provided, however, that upon such withdrawal being made from any location in good standing, the rental paid on the land so withdrawn, in whole or in part, may, in the discretion of the Minister, be refunded to the lessee.

12. The rental for the first year of the location applied for at the rate of twenty-five (25) cents an acre per annum, shall accompany the application filed in the office of the Agent of Dominion Lands for the district in which the rights applied for are situated, and no application for a lease of petroleum and natural gas rights shall be accepted or recorded unless it is accompanied by the full amount of the rental for the first year at the above rate. The lease, when issued, shall bear date from the day upon which the application was filed in the office of the Agent of Dominion Lands. If, during the term of the lease, the lessee shall fail to pay rental in advance for each subsequent year at the rate of fifty (50) cents an acre per annum within thirty days after the date upon which the same became due, the lease shall be subject to cancellation in the discretion of the Minister and to the immediate forfeiture of the rights which the lessee had in the said lease.

13. Provided, that if the lessee, in consideration of the expenditure to be incurred by him in actual boring operations upon his leasehold, makes application, at or before the beginning of the second and third years, respectively, of the term of the lease, for an extension of time within which to pay the rental when due, or becoming due, the Minister may grant such extension of time in writing, and if the lessee, before the end of the year in respect of which application was made, submits evidence to the Land Agent of the district in which the leasehold is situated, supported by affidavit, that during such year actual boring operations have been prosecuted upon his leasehold, as required by section 15 of these regulations, the amount expended in such boring operations, exclusive of the cost of machinery and casing, may be deducted from the rental which became due at the beginning of the said year. The balance of rental due, if any, shall be paid at the same time as the evidence in regard to work done is submitted, as above required. Failure to submit such evidence, or to pay the balance of rental due, with interest, will render the lease liable to cancellation, as hereinbefore provided.

14. The lessee shall, within one year from the date of the lease, have upon the lands described therein such machinery and equipment suitable for carrying on prospecting operations as the Minister may consider necessary, and he shall, within the same period, furnish evidence, supported by affidavit, showing the character, quantity and value of the machinery so installed, the date of its installation and the particular parcel of land upon which it was installed. If the required machinery is not installed within the period specified, and if evidence of its installation is not furnished within the prescribed period, the lease shall be subject to cancellation in the discretion of the Minister. Provided, however, that the Minister shall not require that the value of the machinery so installed on a location shall exceed the sum of five thousand dollars ($5,000).

15. The lessee shall commence boring operations on his leasehold within fifteen months of the date of his lease, and he shall continue such boring operations with reasonable diligence, to the satisfaction of the Minister, with a view to the discovery of oil or natural gas. If the lessee does not commence boring operations within the time prescribed, or if having commenced such operations he does not prosecute the same with reasonable diligence, to the satisfaction of the Minister, or if he ceases to carry on the same for a period of more than three months, the lease shall be subject to cancellation in the discretion of the Minister, upon three months' notice to this effect being given to the lessee. Provided, however, that if satisfactory evidence is furnished to show that the sum of at least two thousand ($2,000.00) has been expended in actual boring operations, by recognized methods upon the leasehold in any year, such expenditure shall be accepted as compliance with this provision for the year during which such expenditure shall have been incurred.

16. The Minister may permit a lessee, who has acquired by assignment or otherwise more than one petroleum and natural gas lease, to consolidate his operations and expenditure, and to install machinery and equipment on one or more of the locations described in the lease affected. Provided that such consolidation or grouping shall apply only to the second and third years of the term of the leases, and shall comprise only such leases as may at the time be included in such consolidation or grouping . Evidence of the installation of machinery on one or more of the locations included in a group shall be that prescribed by Section 14 of these regulations. If the required machinery is not installed on one or more of the locations included in a group within the period specified, and evidence of its installation furnished within the prescribed period, and if boring operations are not commenced and continued on such location or locations in the manner set out in Section 15 of these regulations, the leases included in the group shall be subject to cancellation in the discretion of the Minister.

17. The Minister may, in consideration of the expenditure to be incurred by a lessee in boring operations upon one or more of the locations included in a group, grant an extension of time within which to pay the rental for the second and third years of the term of the several leases so included, and upon receipt of the evidence required by Section 13 of these regulations, he may deduct from the rental which became due at the beginning of the year in respect of the several locations grouped, the amount expended in actual boring operations on one or more of the locations, exclusive of the cost of machinery and casing. The balance of the rental due, if any, shall be paid at the same time as the evidence in regard to work done is submitted, as above required. Failure to submit such evidence or to pay the balance of the rental due, with interest, will render the several leases included in the group liable to cancellation.

18. Provided, however, that the Minister shall not require that the value of the machinery to be installed on any group of locations shall exceed the sum of ten thousand dollars ($10,000) nor shall he require that the expenditure incurred in boring operations thereon in any one year shall exceed the sum of two thousand dollars ($2,000) for each location included in the group.

19. The maximum area of the locations which may be included in one consolidation or group shall not exceed twenty (20) squares miles, nor shall the locations so included be separated one from the other by a greater distance than two miles.

20. The Minister may, upon application, grant a lessee during the second and third years of the term of the lease an extension of time within which to pay the rental and to install the prescribed machinery and equipment, and within which to commence actual boring operations upon the location, or upon a group of locations consolidated under the provisions of these

regulations: Provided that evidence to the satisfaction of the Minister is furnished to show that an expenditure equal to that prescribed by these regulations in respect of boring operations is to be incurred in some other acceptable and necessary form of preliminary development, having for its object the discovery of petroleum or natural gas, by which the interests of the district in which the locations are situated might be materially benefited. Upon receipt of evidence on or before the termination of the year, supported by affidavit and duly corroborated, that such expenditure has been incurred, and that the work done was of a character beneficial to the district, the Minister may deduct the amount of such expenditure from the amount due on account of the rental of the location or locations affected, in the manner prescribed in section 13 of these regulations. In case evidence is not furnished, or, if furnished, is not acceptable to the Minister, the leases shall be subject to immediate cancellation in the discretion of the Minister.

In case an extension of time is granted during the second and third years of the term of a lease within which to install machinery and commence boring operations on any location under the grouping provisions of these regulations, then the provisions of sections 14 and 15 of the regulations shall apply to the fourth year of the term of the lease of such location.

21. In case the surface rights of a petroleum and natural gas location are covered by a timber license, grazing or coal mining lease, mining claim or other form of terminable grant, the lease shall not authorize entry thereon, without the permission of the Minister being first had and obtained, and such permission shall be given subject to such conditions for the protection of the rights of such lessee or licensee as it may be considered necessary to impose.

22. In case the surface rights of a petroleum and natural gas location have been patented, or have been disposed of by the Crown under any act or regulation which comtemplates the earning of patent for such surface rights, and the lessee of the petroleum and natural gas rights cannot make an arrangement with the owner of such surface rights, or with his agent, or the occupant thereof, for entry upon the location, or for the acquisition of such interest in the surface rights as may be necessary for the efficient and economical operation of the rights acquired under his lease, he may, provided the mineral rights in the land affected with access thereto and the right to use and occupy such portion of the land as may be necessary for the effectual working of the minerals therein have been reserved to the Crown in the original grant of the surface rights, apply to the Minister for permission to submit the matter in dispute to arbitration. Upon receiving such permission in writing, it shall be lawful for the lessee to give notice to the owner, or his agent, or the occupant, to appoint an arbitrator within a period of sixty days from the date of such notice, to act with another arbitrator named by the lessee, in order to determine what portion of the surface rights the lessee may reasonably acquire:—

(a) For the efficient and economical operation of the rights and privileges granted him under his lease;

(b) The exact position thereof, and

(c) The amount of compensation to which the owner or occupant shall be entitled.

23. The notice mentioned in this section shall be according to a form to be obtained upon application to the Agent of Dominion Lands for the district in which the land in question is situated, and shall, when practicable, be personally served on the owner of such land, or his agent, if known, or the occupant thereof, and after reasonable efforts have been made to effect personal service without success, then such notice shall be served by leaving it at, or sending it by registered mail, to the last known place of abode or address of the owner, agent or occupant, and by posting a copy of the same in the office of the Agent of Dominion Lands for the district in which the land in question is situate. Such notice shall be ten days if the owner, or his agent, resides in the district in which the land is situate; if out of the district and if in the province or territory, twenty days, and if out of the province or territory, thirty days, before the expiration of the time limited in such notice. If the owner, or his agent, or the occupant of the land refuses or declines to appoint an arbitrator, or when, for any reason, no arbitrator is so appointed in the time limited therefor in the notice provided for by this section, the Agent of Dominion Lands for the District in which the land in question is situate shall forthwith, on being satisfied by affidavit that such notice has come to the knowledge of such owner, agent or occupant, or that such owner, agent or occupant, wilfully evades the service of such notice, or cannot be found, and that reasonable efforts have been made to effect such service, and that the notice was left at the last place of abode or known address of such owner, agent, or occupant as above provided, appoint an arbitrator on his behalf.

24. In case the two arbitrators cannot agree upon the award to be made, they may within a period of ten days from the date of the appointment of the second arbitrator select a third arbitrator, and when such two arbitrators cannot agree upon a third arbitrator, the Agent of Dominion Lands for the district in which the land in question is situate shall forthwith select such third arbitrator.

25. All the arbitrators appointed under the authority of these regulations shall be sworn before a justice of the peace to the impartial discharge of the duties assigned to them, and after due consideration of the rights of the owner and the needs of the lessee, they shall decide as to the particular portion of the surface rights which the latter may reasonably acquire for the

efficient and economical operation of the rights and privileges granted him under his lease the area thereof, and the amount of compensation therefor to which the owner or occupant shall be entitled.

26. In making such valuation the arbitrators shall determine the value of the land irrespective of any enhancement thereof from the existence of minerals thereunder.

27. The award of any two such arbitrators made in writing shall be final, and shall be filed with the Agent of Dominion Lands for the district in which the land is situate, within twenty days from the date of the appointment of the last arbitrator. Upon the order of the Minister the award of the arbitrator shall immediately be carried into effect.

28. The arbitrators shall be entitled to be paid a per diem allowance of $5 together with their necessary travelling and living expenses, while engaged in the arbitration, and the cost of such arbitration shall be in the discretion of the arbitrators.

29. The lessee shall at all times take reasonable measures to prevent the injurious access of water to the oil bearing formation. Upon a well proving to be unproductive, or ceasing to yield oil in paying quantity, or being abandoned for any cause, the lessee shall be at liberty to withdraw the casing from the said well, but in order to prevent water gaining access to the oil-bearing formation, the lessee shall immediately close the well by filling it with sand, clay or other material which may have the effect of preventing water from gaining access thereto.

In case natural gas is discovered through boring operations on a location, the lessee shall take all reasonable and proper precautions to prevent the waste of such natural gas, and his operations shall be so conducted as to enable him, immediately upon discovery, to control and prevent the escape of such gas.

Should salt water be encountered through operations upon the location, the lessee shall immediately and effectively, to the satisfaction of the Minister, close the well at such a depth as may prevent such water from gaining access to the oil-bearing formation.

The Minister may, from time to time, make such additional regulations as may appear to be necessary or expedient governing the manner in which boring operations shall be conducted and the manner in which the wells shall be operated.

Failure on the part of the lessee to comply with the above requirements, or to comply with such other requirements as the Minister may consider it necessary to impose in respect of boring and operating, will render the lease subject to cancellation in the discretion of the Minister.

30. The lessee may be permitted to relinquish at any time the whole or any portion of the location described in his lease, provided he has complied in every respect with the provisions of the regulations, and that all payments on account of rental or other liability to the Crown, due in connection with the lease, have been fully made, and provided the portion of the location which may be retained shall be of the prescribed shape, and shall not be of a less area than forty acres.

31. The lease shall in all cases include only the oil and natural gas rights, which are the property of the Crown, but the lessee may, upon application, be granted a yearly lease at a rental of one dollar ($1) an acre per annum, payable yearly in advance, of whatever area of the available surface rights of the tract described in his petroleum and natural gas lease the Minister may consider necessary for the efficient and economical working of the rights granted him.

32. Should oil or natural gas in paying quantity be discovered on the leasehold, and should such discovery be established to the satisfaction of the Minister, the lessee will be permitted to purchase at the rate of ten dollars ($10) an acre whatever area of the available surface rights of the tract described in the lease the Minister may consider necessary for the efficient operation of the rights granted him.

33. If it is not established to the satisfaction of the Minister that oil or natural gas in paying quantity has been discovered on the leasehold, the lease shall be subject to termination upon three years' notice in writing being given to the lessee by the Minister.

34. The boundaries beneath the surface of a location shall be vertical planes or lines in which their surface boundaries lie.

35. A fee of five dollars ($5) shall accompany each application for a lease, which will be refunded if the rights applied for are not available, but not otherwise.

36. The lease shall be in such form as may be determined by the Minister of the Interior in accordance with the provisions of these regulations.

37. The lessee shall not assign, transfer or sublet the rights described in his lease, or any part thereof, without the consent in writing of the Minister being first had and obtained.

38. No royalty shall be charged upon the sales of the petroleum acquired from the Crown under the provisions of the regulations up to the 1st day of January, 1930, but provision shall be made in the leases issued for such rights that after the above date the petroleum products of the location shall be subject to whatever regulations in respect of the payment of royalty may then or thereafter be made.

39. A royalty at such rate as may from time to time be specified by Order in Council may be levied and collected on the natural gas products of the leasehold.

40. Any company acquiring by assignment or otherwise a lease under the provisions of these regulations, shall at all times be and remain a British company, registered in Great Britain or Canada and having its principal place of business within His Majesty's Dominions and the chairman of the said company and a majority of the directors shall at all time be British subjects, and the company shall not at any time be or become directly or indirectly, controlled by foreigners or by a foreign corporation.

Any alteration in the memorandum of articles of association, or in the constitution of the company, or in the by-laws of the company shall be reported to the Minister, provided that two months' previous notice of the intention to make any alteration which might conceivably affect the British character of the company shall be given in writing to the Minister, and if, in the opinion of the Minister the said alteration shall be contrary to the cardinal principle that the lessee company shall be and remain a British company under British control, the Minister may refuse his consent to such alteration.

If the company which may acquire a location under these regulations shall at any time cease to be a British company, or shall become a corporation under foreign control, or shall assign any of the rights acquired under the lease without the consent in writing of the Minister being first had and obtained the lease shall be subject to immediate cancellation in the discretion of the Minister.

41. The Minister may at any time assume absolute possession and control of any location acquired under the provisions of these regulations, if in the opinion of the Government of Canada such action is considered necessary or advisable, together with all buildings, works, machinery and plant, upon the location, or used in connection with the operation thereof and he may cause the same to be operated and may retain the whole or any part of the output, in which event compensation shall be paid to the lessee for any loss or damage sustained by him by reason of the exercise of the powers conferred by this provision of the regulations, the amount of the compensation, in case of dispute, to be fixed by a Judge of the Exchequer Court of Canada, provided that the compensation in any such case shall not exceed the profit which the lessee would have earned in the working of the location and the disposal of the products thereof, had possession and control of the location and of the buildings, works, machinery and plant not been assumed.

42. If the location described in any lease issued under the provisions of these regulations, shall yield oil in paying quantity, the lessee shall pump and work the wells faithfully and uninterruptedly with due vigour and skill, with good and sufficient machinery and appliances in accordance with the provisions of the regulations and to the satisfaction of the Minister, so long as the said wells continue to yield oil in remunerative quantity.

43. At the end of each year of the term of the lease the lessee shall furnish a statement, supported by affidavit, showing the number of days during the year that operations were carried on upon the location; the number of men so employed; the character of the work done; the depth attained; the total expenditure incurred; a detailed statement setting out fully the purpose for which such expenditure was incurred; the quantity of crude oil or natural gas obtained; and the amount realized from the sale thereof. Failure to furnish such yearly return will render the lessee subject to a fine of ten dollars ($10) a day for each day's delay in furnishing the sworn statement, and after three months' delay the lease shall be subject to cancellation.

44. These regulations shall apply to all applications submitted on and after the first day of August, 1913, in accordance with the provisions of the regulations which were for the time in force.

And that if the rent hereby reserved or any part thereof shall be unpaid for thirty days after becoming payable (whether formally demanded or not), or if any covenant, proviso, stipulation or condition on the part of the lessee herein contained shall not be performed or observed, then and in any of the said cases it shall be lawful for the Minister by notice in writing under his hand to cancel these presents and terminate the estate or term hereby demised, and thereupon these presents and everything therein contained and the estate or term shall, from the time of the giving of such notice, absolutely cease, determine and be void without re-entry or any other act or any suit or legal proceedings to be brought or taken, provided that His Majesty shall nevertheless be entitled to recover from the lessee the rent then accrued or accruing, and moreover that any right of action of His Majesty against the lessee in respect of any antecedent breach of any of the said covenants, provisos, stipulations or conditions, shall not thereby be prejudiced.

And that any notice affecting the tenancy hereunder which the lessor may desire to serve upon the lessee shall be sufficiently served on the lessee if left addressed to him on the demised premises or posted to him addressed to his last known address, or if left at the said address. A notice sent by post shall be deemed to be given at the time when in due course of post it would be delivered at the address to which it is sent.

For purposes of comparison a form of lease used in the United States is given below:—

OIL AND GAS LEASE.

AGREEMENT OF LEASE, made this..........day of..........A.D. 19....between
....
.... Lessor
and ....Lessee

WITNESSETH, that the Lessor in consideration of one dollar, the receipt of which is hereby acknowledged, does hereby grant unto the Lessee for the term of ....years (and so long thereafter as oil or gas is produced from the land leased, and royalty and rentals paid by Lessee therefor) the exclusive right to drill for and produce petroleum and natural gas from and the possession of so much of..
.........................acres of land more or less in..................................
Township...................................County, State of Ohio as may be necessary therefor, with the right of way in and to said premises, the right to use water and gas (if found) for the necessary boilers and engines, and to remove, either during or after the term hereof, all machinery, fixtures, etc., placed by Lessee on the premises. Said land bounded:
North by Land of..
East by Land of..
South by Land of...
West by Land of..
....

No well to be drilled within................feet of the barn or dwelling house without the Lessor's consent.

The Lessee to deliver to Lessor in tanks or pipe line one eighth (⅛) of all petroleum produced and saved from the premises and to pay for each gas well from the time and while the gas is utilized an annual rental of............................Dollars (.......................) payable........................and to pay all damages to growing crops.

This lease to be null and void and no longer binding to either party if a well is not........ ....on the premises within..............................from this date, unless the Lessee shall thereafter pay......................................to Lessor ....dollars ($....................), per.................... for each....................delay in..........................said well. Each payment to extend the time for............................and no longer. A deposit to the credit of the Lessor in............................Bank at............................on or before the date rentals fall due, shall be a good payment of any moneys on this lease.

It is mutually agreed by and between the first and second parties that if second party fails to pay the rental or drill a well, said second party shall have the right to surrender this lease, and all the terms shall cease, determine and become void. Lessor is to have free use of gas for domestic use if found on land covered by this lease, by making his own connections at well.

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And that all conditions, terms and limitations between the parties hereto shall extend to their heirs, successors or assigns.

And for the consideration aforesaid....................of the said.................. joined herein, hereby releases unto the Lessee, the right of dower in and to the granted and leased premises.

WITNESS the hand and seals of the parties hereto, the day and year above written.

Signed in the presence of:

....[SEAL]

....[SEAL]

....[SEAL]

....[SEAL]

DRILLING CONTRACTS.

All wells in Ontario are drilled by contract. The contractors get 90c per foot and pay for their own fuel in western Haldimand county. In eastern Haldimand county the price is less and in Elgin county it is more. The contractors provide their own fuel at $5 per day. Generally 40,000 to 60,000 cubic feet of gas per day is used for drilling. The company provides the casing and the contractor provides the rig and tools.

GOVERNMENT BOUNTY ON OIL.

In August, 1904, an Act was passed by the Dominion government providing for the payment of a bounty on all crude petroleum produced in Canada. The text of this Act, with its provisions, is given below:—

"*An Act to provide for the payment of bounties on crude petroleum from Canadian wells.*"

(Assented to 10th August, 1904.)

His Majesty, by and with the consent of the Senate and the House of Commons of Canada, enacts as follows:

1. This Act may be cited as The Petroleum Bounty Act, 1904.

2. The Governor in Council may authorize the payment out of the Consolidated Revenue Fund of a bounty of one and one-half cent per imperial gallon on all crude petroleum produced from wells in Canada on and after the eighth day of June, one thousand nine hundred and four, the said bounty to be paid to the producer of the petroleum.

3. The Governor in Council may authorize the payment out of the Consolidated Revenue Fund of a bounty of one and one-half cent per imperial gallon on all crude petroleum produced from wells in Canada and held in storage tanks or other storage receptacles on the eighth day of June, one thousand nine hundred and four, the said bounty to be paid to the actual owner of the petroleum on that day.

4. The Minister of Trade and Commerce shall be charged with the administration of this Act, and may, subject to the approval of the Governor in Council, make such regulations as he deems necessary respecting the payment of the said bounties.

5. This Act shall be deemed to have come into force on the eighth day of June, one thousand nine hundred and four."

REGULATIONS.

Regulations under the provisions of the Petroleum Bounty Act, 1904, entitled—

"*An act to provide for the payment of a bounty on Crude Petroleum from Canadian Wells.*"

1. The Minister of Trade and Commerce having been charged with the administration of the Act has, with the approval of the Governor in Council, made the following regulations respecting the payment of bounties.

2. All producers of crude petroleum from wells in Canada who desire to avail themselves of the provisions of the Act above quoted, and to be paid a bounty, before making claim for such bounty, shall notify the Minister of their intentions to claim under the provision of the

Act and shall for registration purposes, declare where or approximately where their wells are situated, the number thereof, their estimated monthly production, the place and names of the purchasers of the crude product, and in the case of a co-partnership the names of the individual partners, and in the case of an incorporated company the names of the President, Secretary and Manager, as well as the name and address of the official authorized to make the claim.

3. The books of the claimants and those of the refineries, tanking companies, gas companies, fuel oil companies and sundry purchasers, shall be at all times open to the examination of the supervising officer and of any officer of the Department of Trade and Commerce who may be detailed by the Minister for such purpose.

4. All claims shall be substantiated by the certificate of the receiving stations, tanking companies, refineries, gas companies, fuel oil companies, manufacturers of lubricating oil, or other purchasers as well as that of the supervising officer.

5. Samples must be taken at time of delivery of all crude oil sold by claimants and a record of same kept by the receivers and buyers.

6. The supervising officer may, at any time, make examination of samples or take samples at any of the receiving stations, fuel oil companies, tanking companies, refineries, gas companies, or at any purchasers or receivers of crude oil.

7. Claims for bounty may be made monthly when amounting to $25 or more per month, and quarterly, when for a less sum.

8. Claims when made and certified as above, shall be forwarded by the supervising officer to the Department of Trade and Commerce for payment.

9. No claim will be recognized or paid unless the claimant has conformed to the requirements of regulation 2, and unless claim is made and substantiated as per regulation 4 and in form hereto attached.

10. *All claims to be made in duplicate.*

Much oil and gas land is owned in fee. The advantages of this form of controlling oil land are mainly in cases where it is non-agricultural and non-mineral land, where this form of ownership may be cheaper in the long run. The disadvantages are that it is not applicable on land on which the government owns the mineral rights.

RENTALS AND ROYALTIES.

In the public lands of the Northwestern Provinces[1] there is a rental of 25 cents for the first year and 50 cents for each subsequent year, payable in advance, for a term of 21 years, and renewable upon fulfilment of certain conditions for a second term. For a tract of land covering more than the actual oil and gas rights, but considered necessary for proper development of the territory, a rental of $1 an acre a year is charged.

In this section of the Dominion of Canada there is no royalty on oil, but a gas royalty is levied, as specified from time to time, by Order in Council.

[1] Manitoba, Saskatchewan, Alberta, Northwest Territory and Yukon.

School lands in this part of the country rent for 25 cents an acre for the first year and 50 cents each succeeding year, the term of lease being 21 years.

In Quebec, a yearly rental of $1 an acre is charged for public oil and gas lands, renewable from year to year and subject to change by the Lieutenant Governor as to royalty at his discretion.

Public oil and gas lands in Ontario may be leased at $1 an acre each year for a term of 10 years, the lease being renewable upon the fulfilment of certain conditions.

In British Columbia a smaller yearly rental of 15 cents an acre is charged, the term of lease being only 5 years, and a royalty on oil is exacted in addition of 2½ cents a barrel.

Private gas lands are leased for 20 to 25 cents an acre after the first year, which is usually given free. A royalty of 10 to 12·5% is also provided. Ontario farmers usually receive 10 per cent royalty on their lands.

CHAPTER VI.

METHODS OF OBTAINING PETROLEUM AND NATURAL GAS.

SURFACE INDICATIONS USEFUL IN EXPLORATION FOR PETROLEUM AND NATURAL GAS.

By James H. Gardner.[1]

Surface indications useful in exploration for petroleum and natural gas may be divided into two general classes. One class includes all the different conditions by which actual signs are evident to the non-scientific or practical man while the other class covers all the various indirect data that enables the technical geologist to map the rock folds from various exposures on the surface. One may be called the "direct" and the other the "indirect" class. In the direct class are included "oil seeps," "oil springs," "outcrops of oil sands," "oil-filled fissures," "asphalt veins," "asphalt lakes," "oil in faults," "escapings of natural gas," etc. These are indications that have a direct bearing on the presence of oil and gas either in small or large quantities in any particular region. But it must be borne in mind that many of the large oil and gas fields of the globe have not shown any of these direct indications previous to drilling. But practically all oil and gas fields show the surface indications that are here classed as the "indirect, "namely: The presence of folding in the rock strata.

The oil and gas bearing folds in the rocks of the earth are of several types; they bear oil and gas under various conditions of water saturation in the sands and under varying amounts of hydraulic and hydrostatic pressure. What is known as the "anticlinal occurrence of oil and gas" in its broad usage includes all the several conditions under which oil and gas are found related to the rock folding. An anticline is what might be termed the ideal condition wherein the strata are arched into

[1]Of Fohs and Gardner, oil geologists, Lexington, Ky., and Tulsa, Okla.

an elongated fold of the nature of an inverted canoe; the rocks dip downward from the main axis while the fold dies out toward the two ends; on such a structure gas, oil and water are separated according to their gravities leaving gas and oil at the crest, and slightly below, and water in the sand down the sides of the fold and in the neighbouring depressions. Gas is often held soluble in oil under pressure as well as usually being entirely separated above the oil on folds. If the upper limit of water is low on a fold, then the oil does not reach to the crest and this permits the volatilization of the lighter constituents of the oil

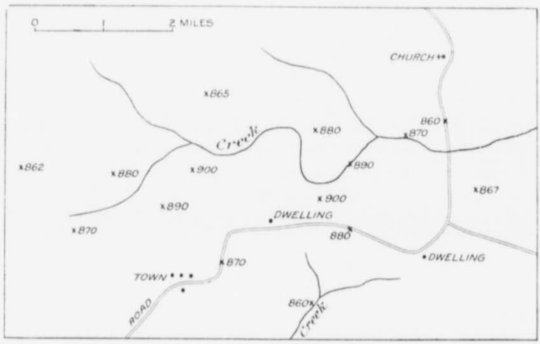

Fig. 8. Sketch map showing numbered elevations on the same outcropping stratum, at different points.

into gas at the crest. Then if later the rock pressure is increased by subsequent folding the oil and gas are put under pressure, in which case the oil absorbs the gas. But in case the salt water limit is near the top of a fold, then oil lies at the crest under pressure with no chance of volatilizing into gas, as in Lawrence county, Illinois, where oil lies at the top of the anticline with no gas of consequence. But where no water is present in the sands the occurrence of oil and gas is quite different, and in that case, as has often been demonstrated in developed fields, the oil lies in the depressions, or synclines, while gas is found along the sides or at the crests of neighbouring anticlines. Oil and gas are found also on monoclines (rises in the strata where normally they lie horizontal) or on terraces (flat places

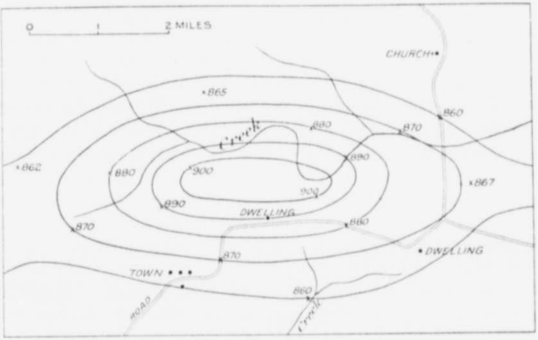

Fig. 9. Same map as Fig. 8, with structure contour lines connecting points of equal elevation, thus outlining an elongated dome or anticline.

in the strata where normally they lie on an inclination) or on domes which are practically circular anticlines. Oil and gas

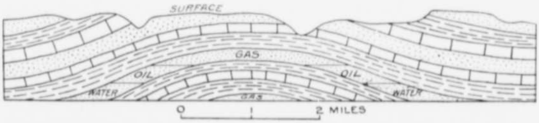

Fig. 10. Lengthwise section of the structure shown in Fig. 9.

accumulations are found on these different types of structure under different conditions that cannot be discussed under the subject of this chapter.

It is sufficient to say that all surface indications in the oil and gas exploration work belong to the domain of geologic science. The use of all surface observations in the selection of favourable territory for drilling belongs especially to that branch of geology known as "applied geology."

The practical oil and gas operator who happens not to be familiar with geology as related to his business is apt to ridicule the application of it. He is likely to be sceptical as to the usefulness of all surface indications in throwing light on what is to be expected at great depths, or else attempt to make use of some appearance of the surface hills and valleys that have no application to the subject. But the operator who has been taught the methods of modern geology in working out the folds in the rocks as shown on the surface, and who understands not only the value but also the limitations of such work is an ardent supporter of having careful structure maps prepared in advance of drilling.

It matters not how little the oil man may use his eyes in noting the outcrops of rocks in ledges, cliffs, etc., and in observing the dips and positions of the same, he will nevertheless find himself, on close analysis, making some slight use of geology. In some manner he feels that the search for oil and gas should not be wholly haphazard and without method. Manifestly every operator owes it to himself to investigate the claims of the oil and gas geologist. He should not be too prone, in his inherited disbeliefs of the old school, to place everyone in the class of "faker" who claims to be able to foretell in some measure what is to be expected in drilling a well. The science of geology is young. But it is evident to the most casual observer that vast sums of money are annually appropriated by legislative bodies all over the world for the purpose of carrying on geological surveys. The advance that has characterized all other sciences including chemistry, medicine, agriculture, etc., has been equally shown in geology. Broadly speaking, there is the scientific and the practical division of all the sciences. The use of surface data in oil and gas exploratory work is a practical division of science. Most of the large operating companies in all portions of the globe where oil and gas are found have their geologic corps of trained men which itself speaks in certain terms of the wisdom of studying the surface carefully in advance of development and along with development.

The search for oil and gas has difficulties peculiarly its own. These substances normally occur in such a manner that they are carefully sealed off from surface escape and for this reason the drill itself must, in every instance, tell the final story of what occurs in the depths that it penetrates. So that the surface indications must be looked upon as forerunners of the drill. They go in conjunction and as a part of the drilling operations. They tell where to place the drill and where not to place it. They point out many places where it would be folly to drill and permit the selection of places where it would be wise to drill. This means the saving of money, time, and labour.

With the foregoing paragraphs made clear at the outset, the writer will attempt in the following pages to outline some of the methods of obtaining information from surface studies. This will be done in terms, so far as possible, that are plain to the practical man.

Oil and gas are found in sedimentary rocks, which are those that have been deposited through the agency of water; in general terms these are limestone, sandstone, and shale. Consequently, in searching for new fields a long distance away from known oil and gas fields, and in areas where geological explorations have not been made, it is first necessary to learn whether sedimentary rocks occur there. In many large areas, the only rocks to be found are metamorphic and igneous rocks, including granite, gneiss, basalt, and related rocks. In such rocks oil and gas do not exist, and it is very exceptional that drilling is done in such areas. Now and then, however, a company is organized and several thousands of dollars are expended in drilling in some such place, in entire ignorance of this plain geological classification.

In a region of sedimentary rocks where suitable rocks do not occur, there are other classifications to be made between favourable and unfavourable territory for testing in search of new fields. This involves the working out of what is called the structural conditions. Areas of great disturbance where the rocks are turned up on edge or closely folded and faulted must be ruled out as being unfavourable, for in such cases all collecting ground has been broken up and any oil or gas that may have previously existed has been given avenues of escape to the surface. Now and then faults are found in near proximity to oil producing territory and in such cases it is very important to locate them as negative ground. But in the selection of favourable territory, there are certain types of rock folds that are known to carry oil and gas in other fields that have been developed. These include anticlines (elongated upward folds), synclines (elongated downward folds), monoclines (folds with only one direction of dip), terraces (flat places along the dip), and domes (upward circular folds as suggested by an inverted wash pan). Now to work out the positions and details of these different folds involves a thorough knowledge of field geology backed by good experience. There are many thorough geologists in the geological surveys and in private practice who are amply capable of working out the details of rock folding. But the practical oil man should exercise care in the investigation of the experience and standing of the men he employs in such work, for like all other professions there are a number of individuals in geologic work who, without ability, are continually thrusting themselves forward on the public only to the slander of the science.

The surface indications utilized in working out the structure of oil and gas fields consist of observations, carefully mapped and recorded, of the outcropping ledges of rock as they occur in place. In most of the oil countries of the globe, there are numerous places where the solid rocks can be found in outcrop, from point to point over the land; in most cases the ravines, gullies and creeks cut into rocks in their natural bedding, or exposures are found along roadways or in railway cuts. These are very valuable in working up data for a structure map. But the compiling of the map from observations at these different points is not so simple as may at first seem. Not only are accurate levels to these different exposures necessary but the intervals across the bedding from one layer of rock to another must be worked out, so as to calculate the levels from one place to another on the same bed. In some fields some certain bed can be picked out and different levels run to this bed over the district that is being worked. This is called the "key bed" or "key horizon" and the various levels on it above some datum plane (usually sea level) will show the points that lie high and those that lie low so that in this manner the details of the folding can be determined. In some areas some one coal bed can be used for this if the territory lies within a coal field. The idea in working out the different levels of some surface beds is to determine the underground variations which usually run parallel with it; the sedimentary rocks of the earth are bedded over one another in a laminated series like the leaves of a book, so that if the top layers are folded the lower ones conform with it. So while an oil sand may lie a thousand feet or more beneath the surface, its rises and depressions can be worked out by a study of the rises and depressions of some one ledge that outcrops over the surface a thousand feet or more above. To fully grasp this idea in all its simplicity is to understand the basic principles of geologic oil work. Now it must be clearly understood that the rises and depressions of the surface itself are not the same as the rises and depressions of the rocks that outcrop over the surface. This point is difficult for many men to grasp though it seems very simple to the student of geology.

It must be borne in mind that vast areas of rocks have been removed from the surface of the earth. Ledges match across valleys from one hill to another so that the mind must restore what erosion has taken away. In discussing this idea recently with an oil man he remarked that the surface of the earth so far as the rocks are concerned reminded him of a human head nearly bald with patches of hair left here and there showing that it once covered the entire scalp. This was a very good illustration.

One hears often some one speak of an anticline when he really means a valley. Ridges, valleys, and plains are the result of erosion and may or may not bear a relation to the folding; they frequently do not in the oil fields, and a ridge in the surface may be a depression in the rocks so that on both sides of the ridge the rocks dip in toward it, the ridge lying in the trough of the strata; or a ridge may be half in a syncline and half in an anticline, or in any conceivable relation to the surface configuration (topography).

In the preceding paragraphs, the writer has purposely omitted the usual notation of the nature of oil and gas origin and accumulation in order not to distract from these other points more in line with the subject matter under discussion.

The oil operators all over the globe have in past years been gathering data with the drill that has taught the nature of oil and gas occurrences. More is known now than ever before in this respect, and for this reason geological work is more valuable than ever before. Then too the methods of modern geological mapping are far in advance of former years. More detail is supplied, and the results are more accurate.

DRILLING FOR PETROLEUM AND NATURAL GAS WELLS.

HISTORY OF EARLY METHODS.

The earliest method of petroleum production appears to have been to skim it off the surface of pools of water, this having been done in many contries. In Galicia and Roumania, as well as in Ontario, wells were dug and timbered in the early days. In Roumania, however, hand-dug wells prevailed long after drilled wells were introduced in Galicia and elsewhere, and even at present many small land owners or leasers develop their properties by this means. Evidences of such workings can still be seen at some localities in America.

American.

Early oil wells in California were hand dug to a depth of 70 feet and curbed with planks.

In Johnson county, Kentucky, according to Prof. Lesley, oil was formerly collected from sands by making shallow canals 100 to 200 feet long, with an upright board and reservoir at one end, from which they obtained as much as 200 barrels per year by striking the sands with a pole. These are known as "stirring places." Similar spots at Burning Springs, West Virginia, were worked in the same way over 100 years ago.

Oriental Methods.

In 1868 a peculiar method of digging was in operation in Japan.[1] The work was done by two men in shifts of 3 hours each, one man working in the well, the other sending down fresh air to him by means of a large bellows, which is operated by walking back and forth along a board covering the bellows. The wells were timbered and cross pieces were attached for assistance in descending into it. The rock and earth was raised by means of rope-nets, pulled by several men. Wells were dug by this method to a depth of 900 feet, at a cost of only $1,000.

In China[2] early in the past century artesian wells for the production of brine were sunk by raising and lowering a rammer of 300 pounds or more in weight, by means of a man dancing on a lever which raised the rammer about two feet and let it fall. The rock was softened by occasionally throwing in buckets-ful of water.

More recently the Chinese have devised a method of drilling for salt which parallels our American standard methods of oil drilling.[3] A pit several feet in diameter is first dug to a depth of about 100 feet. Then the well is walled by blocks of hard stone, giving it a mouth 6 to 9 inches in diameter, the cavity then being filled with earth between the stones and the sides.

The boring machinery consists of a large hoisting drum with wooden axle 7 or 8 feet in length, terminating in an iron pin, and surrounded with an iron framework, forming a skeleton drum, on which the cable winds. In place of the "walking beam" a plank lever, resting on a wooden frame, is used. The boring bits differ somewhat in shape for the upper and lower parts of the well, and are attached to the "sinker-bar" by bamboo strips, allowing for more or less play, as in the case of the "jars" used in American drilling. A safety cord is attached to the bit,

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[1]Lyman, Report on the Geological Survey of the Oil Lands of Japan, 1877, p. 17.

[2]Père Imbert, Ann. Assoc. Propag. Foi., Vol. 3, 1828, p. 369.

[3]Louis Coldre, Annals des Mines, 8th Ser., Vol. XIX, 1891, pp. 441 et seq.

to eliminate the danger of loss if the cable should be broken. The cable is attached to the working lever by means of a swivel, and the length of cable is adjusted so that the lever is horizontal when the bit rests on the bottom of the well. By the process of working the lever by the jumping workmen, 700 to 800 strokes per hour are obtained. The Chinese also have a primitive form of sand-bucket. The oil is raised by long bamboo tubes of much the same proportions as an American bailer.

When it is necessary to tube the well, this is done by means of bamboo stems or hollowed trunks of cypress trees. The tubes are coated first with a canvas wrapping saturated with boiling water. Naturally, fishing tools are used in China, as elsewhere, and some of them resemble American fishing tools, but are constructed of bamboo.

In Burma the modern drilling methods have improved little on those of a hundred years ago.[1] A square hole 5 or 6 feet in diameter is dug, lined with wooden casing of rough stones as the work proceeds. The digging tool in soft ground consists of an iron shoe in the shape of a chisel attached to a wooden handle, which is used like a shovel. In order to drill through hard sandstone beds, a lump of iron of angular shape weighing 150 pounds or more is hung by a rope in the mouth of the well, and then allowed to drop, fracturing the stone. Owing to the presence of oil vapours, a digger can only work in the well for a few minutes at a shift. The earth and rock are raised to the surface by a leather rope pulled by coolies and running over a drum at the well-mouth. Earthern pots are used for raising oil and for conveying it to the river.

European Methods.

The methods used in drilling in Europe are a decided improvement over those of Asia and are more or less similar to those in use in America. The principal European method is the Canadian system and its various modifications, as effected in Galicia and Russia. These methods will be hereinafter described.

[1]Fritz Noetling. Report on the Petroleum Industry in Upper Burma; Rangoon, 1891, and Mem. Geol. Sur. India, Vol. 27, pt. 2, 1897.

Methods in use in Canada.

In Canada, as in all countries, thousands of shallow wells have been sunk by digging by hand. This method has been confined mainly to water wells, but in the Petrolia fields in the early days many oil wells were sunk by hand. Driven, punched, and bored wells are also used to a certain extent for water. The abrasive methods are applied in drilling for coal, iron and sometimes other minerals, and a few diamond drill holes have been sunk in prospecting for oil. But the principal types of drilling used in Canada, as in American and European oil fields, are the percussion or churn drill methods. As yet, hydraulic drilling is little used in Canada; but there is no doubt that in some parts of the west it will prove desirable.

CHOICE OF METHODS.

The choice of drilling method to be used in any part of the country depends on several factors, among which may be mentioned the following:—

(a) Depth of well desired..... { whether 500 feet in Ontario or 5,000 feet in Alberta.

(b) Purpose of well desired.... { oil. gas. water. salt. prospecting.

(c) Character of the materials. { hard or soft. sandy or clayey. porous or close. stratification flat or inclined. similar or changeable. consolidated or unconsolidated.

(d) Amount of water present.

(e) Custom in the particular field.

The advantage of knowing the kind of outfit necessary can be readily understood. In shallow water wells, in superficial deposits, driven or bored wells will generally suffice. In the 500 to 800 foot oil wells of Ontario, wells drilled by the percussion portable rig method are satisfactory and cheapest, while in 2,000 to 3,000 foot wells of New Brunswick or Alberta a heavy Standard drilling rig must be used. It is probable that in the future still deeper wells of Alberta, steel rigs must be used for going to depths of a mile or more; and in some cases rotaries should be procured. The character of the material is important, since this decides whether or not the rotary is necessary, and many other technical questions. The amount of water present is very important, since this has a great bearing on the question of casing. The custom of the field must be considered, since the drillers operating in any field are familiar with and prefer the methods ordinarily in use there, and disaster might be entailed by experimenting with a better, but less understood, method. No method can be said to be best under all conditions.

CLASSIFICATION OF DRILLING METHODS.

There are a great number of drilling methods employed in the oil business. For a full comprehension of drilling methods it is necessary to group them in several classes, as follows:—

1. Digging.
2. Driving.
5. Punching.
4. Boring.
5. Abrasion methods.......
   - a. Diamond drilling.
   - b. Calyx drilling.
   - c. Chilled-shot drilling.
6. Percussion methods.....
   - a. Standard American method.
   - b. Portable drilling machines.
   - c. Pole tool method.
   - d. Self cleaning method.
   - e. California method.
   - f. Canadian method.
7. Hydraulic rotary method.

1. *Dug wells.*—These wells are common in Canada as they are also in all countries, but they have chiefly been sunk for

water. In the Petrolia field in Ontario many of the wells sunk for oil in the early days were dug by hand. Since then this has not been done.

2. *Driven wells.*—Driven wells also are seldom sunk for oil or gas, but frequently for water. These commonly consist of a few feet of iron pipe and a driving point, the well being driven by hand. The pipe is generally one and one-quarter inch in diameter, although sometimes larger pipe is used. The point consists of a perforated gas pipe covered with brass wire cloth, generally from 60 to 100 mesh and protected by a perforated brass jacket. These wells are frequently shallow water wells, operated by a pitcher pump, and common in the United States. Driven wells are sometimes of large size, up to several inches in diameter and 100 feet or more in depth, driven by sledge or steam power, and sunk to the bottom of the unconsolidated deposits.

3. *Punched wells.*—In a few localities where the material is very clayey wells are sunk by a punch instead of an auger. Of this method and its use in Arkansas and Louisiana Veatch says:[1]

"In regions where there are uniform clay beds without rocks or boulders wells are often made with a well punch. This consists of a cylinder of steel or iron 1 to 2 feet long, split along one side and slightly spread. The lower portion is very slightly expanded, sharpened and tempered into a cutting edge. In use it is attached to a rope or wooden poles and lifted and dropped in the hole by means of a rope given a few turns around a windlass or drum. By this process the material is forced up into the bit, slightly springs it, and so is held. When the bit is filled it is raised to the surface and emptied. When working in very dry clay water is sometimes added to aid the bit in picking up the material. Thin sand layers are passed by throwing clay into the well and mixing it with the sand until the bit will take it up."

This process is not very extensively used in this region, and is not so practicable as the Arkansas clay auger.

[1]Veatch, A. C., Geology and underground water resources of a portion of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46, 1906, p. 97.

4. *Bored wells.*—These wells are also used mainly for water, and are bored with an auger, in unconsolidated deposits. A common size for bored wells is 8 inches. They are lined with iron tubing or with wood and the water is raised by a windlass and cylinder bucket having a valve at the bottom. Such methods are still in use in Arkansas and in Florida, in the United States, although this method was in common use in the United States between 1855 and 1885. The augers commonly range in size from 2 to 8 inches.

5. *Abrasive methods.*—The abrasive methods of drilling may be classified as follows:—

a. Diamond.

b. Calyx.

c. Chilled shot.

These are all known commonly as "core drill methods." They are used in prospecting for coal, copper, iron or other metals, and for testing foundations and dam and bridge sites. The advantage is that, in hard formations, a complete core can be preserved of the material penetrated. Core drilling is not employed in drilling for oil or gas; though in certain cases such holes have discovered these substances. In Hungary some cores have been taken of certain strata in gas wells which it was desired to examine for potash salts. Core drilling is accomplished by a circular shoe or bit set on the lower end of a hollow rod, which is rotated by machinery from above. Such holes range in size from one-half inch up to 6 inches or more.

These drills may be operated in all kinds of rock from the hardest trap to the softest shale; but in unconsolidated formations a hydraulic or other attachment must be used. The three classes of abrasive methods have their respective advantages in special instances. The diamond method was used first in 1863, being followed in 1873 by the calyx method. This method differs in the respect that the bit is of hardened tool steel, like the cutting shoe of a hydraulic rotary and has teeth instead of employing diamonds, for this purpose. There are also other minor differences, such as an arrangement for preserving fragments of the material which is ground out in boring. Calyx drill holes are sometimes as much as 15 inches in diameter. In the chilled shot method, the cutting is accomplished by revolving an iron or steel tube on shot poured down the hole. Distribution of the shot in the hole is aided by special shaping of the tube.

In all the abrasive methods a constant stream of water is pumped down the central tube, and, sweeping away the rock cuttings, it passes it to the outside of the pipe in a similar manner to that hereinafter described for hydraulic rotary boring.

6. *Percussion methods.*—The first deep well sunk by percussion methods, and for many years the deepest in the world, was the artesian water well at Grenelle, near Paris, France, completed in 1841 to a depth of 1,798 feet. It required seven years to drill it. One of the earliest wells of this type was the Passy well in Paris, which was completed in 1857 and curbed to a depth of 1,923 feet, having a diameter of $2\frac{1}{3}$ feet and being a flowing artesian water well. Another well, situated at La Chapelle, France, was 1,000 feet deep and $5\frac{1}{2}$ feet in diameter. It was sunk by a drill weighing four tons and operated by a powerful steam engine.

At about the same time deep wells were sunk in the United States at Charleston, South Carolina, Louisville, Kentucky, at St. Louis, Missouri, and in Pennsylvania. Within a few years wells 2,000 to 4,000 feet deep had been drilled in the oil fields of the latter state.

Percussion methods may be classified as follows:—

(a) Standard American.

(b) Portable drilling machine.

(c) Pole tool method.

(d) Self-cleaning method.

(e) California method.

(f) Canadian method.

Drilling Outfit.

Outfit necessary for drilling.—In order that a well may be drilled it is necessary to have an outfit which is frequently very complicated; but which, in all cases, consists of:—

(a) The rig or derrick.

(b) The machinery.

(c) The drilling tools.

(e) The casing.

The derrick or rigs.—By either of these terms is meant the structure with its foundation of heavy timbers, its wheels and reels and fully equipped frame, on which are hung the lines and cables to which the drilling tools are attached. Two kinds of rigs are in use, which are:—

(a) The stationary derrick.

(b) The portable drilling machine.

The first mentioned will be discussed first, and the drilling machine will be taken up in later paragraphs of this chapter.

The derricks or rigs are of various classes, namely:—

(a) The American Standard rig.

(b) The Canadian or Galician derrick.

(c) The pipe derrick.

(d) The structural steel derrick.

The type of derrick which must be used for drilling a well in any locality varies according to the character of the formation to the depth which must be drilled; the weight of the casing required; climatic conditions; and other features.

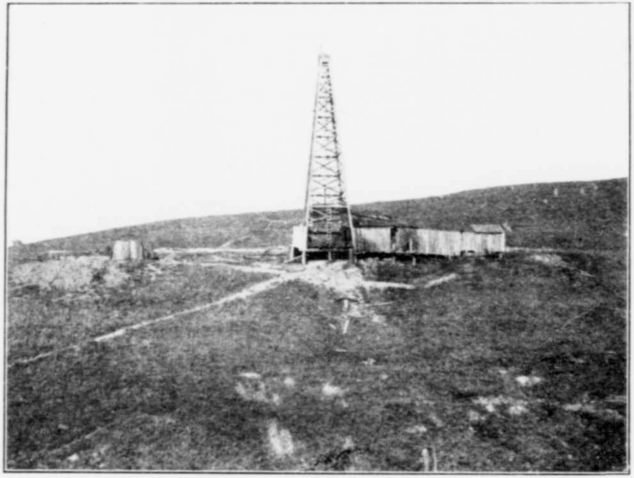
Material for the derrick.—As a rule, the timber and lumber required for a derrick are cut in the immediate vicinity of the hole, wherever such timber is available. The rig irons—which include the irons, nails and bolts and also the special parts for building the wheels and reels—are obtained through a supply company, costing from $50 to $275, according to the size and design. Their weight varies from 1,500 to 8,000 pounds. Where the timber and lumber for erecting a derrick are not available in the vicinity of a well, as is the case in the plains of Southern Alberta and Saskatchewan, it is possible to obtain the entire rig from a supply company ready to erect it; the prices ranging from $600 to $750, and having an average weight of perhaps 60,000 pounds.

AMERICAN STANDARD DRILLING METHOD.

General Description.

The so-called "Standard" rig is that used throughout the American fields for practically all deep wells, with appropriate modifications to suit varying conditions in

PLATE I.



Typical West Virginia (United States) well.

PLATE II.

Typical Ohio (United States) well.

different fields. See Plate I. This outfit acquired its essential features during the early developments in Pennsylvania; but from time to time the tools have been enlarged and several features modified, until the rig has become a very modern and rapid working one. While standard rigs, when completed in any given field, are so nearly alike that a person unfamiliar with the business could hardly detect any difference in detail, the rigs nevertheless generally differ in some particulars to suit varying conditions or the preferences of the drillers. A photograph of a Standard drilling rig is given in Plate II.

Description of the rig.—The most conspicuous part of a drilling outfit is the derrick, which consists, in the Standard method, of a framework of timber, or sometimes steel, from 30 to 110 feet high, erected over the spot at which the well is to be sunk. In warm weather the derrick is generally left open except on one side, which is boarded in to form a shed for storing tools and clothing, and to protect the forge; but in winter the lower part of the derrick is often closed on all sides for protection of the workmen from the severe weather. The essential particulars of the Standard derrick, when completed for use, are shown in Fig. 12, p. 158. The common height of one of these derricks is 72 or 82 feet; but the writer has seen one 110 feet high in Mexico. It is very important that a Standard rig shall contain all of the parts necessary, and they should be of material up to the required specifications and strength.

The Standard derrick.—The derrick has four legs, extending from the ground to its full height, and steadied by girts and braces, and surmounted by what is known as the crown block, in which is set the crown pulley, over which the drilling cable passes. Access to the *crown block* is had by a *ladder* which extends the entire height of the derrick on one side. The derrick has a solid *floor* which rests upon its *foundation posts*, six in number, which are set deep in the ground to render the structure very firm. In some parts of the world, as in Louisiana and Texas, it is necessary to run guy wires from the top of the derrick to some firm object at a distance to act as wind braces. On the floor of the derrick and set even with one of its sides are the *bull wheels*, which consist of a large reel on which the drilling cable is wound; and at each end of which is a wheel which is usually built up of wooden arms and segments, fastened together with wooden pins, and known to the trade as *arms, cants* and *handles.* The entire bull wheel equipment is set firmly into *bull wheel posts,* and strenghthened by the *bull wheel post brace.*

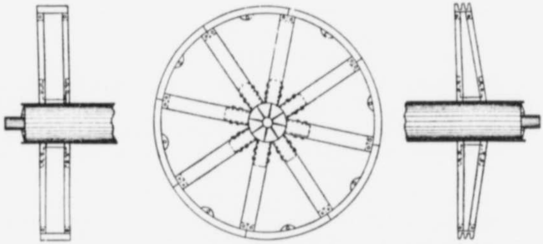


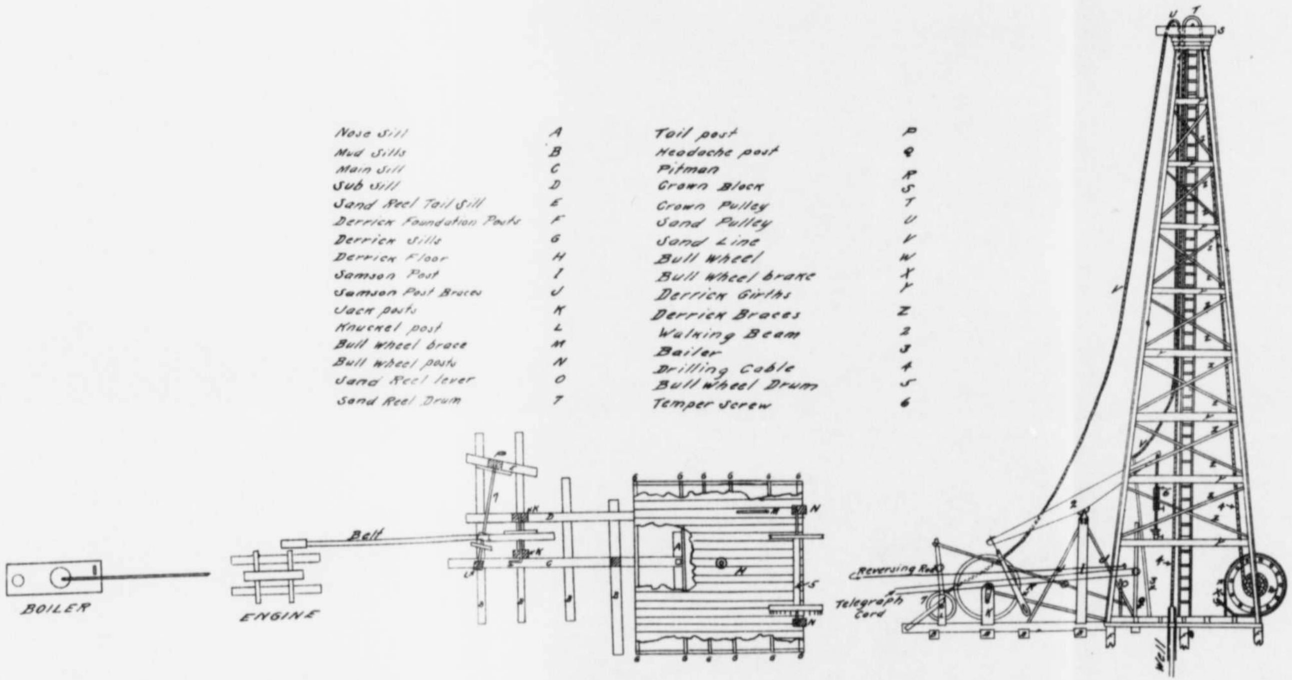
Fig. 11. Detailed drawing of steel bull wheels; consisting of a full side view of the grooved wheel in the centre; on the right, an edge view of the brake wheel, and on the left, an edge view of the tug rope wheel.

The bull wheel is grooved at one end of the reel, in order to hold the bull rope, which acts as a belt in operating the reel. In order to control the movement of the reel there is a brake, which passes over the wheel at the other end of the reel and is controlled by a lever. This brake consists in modern derricks of an iron brake band, although in early rigs rope or belting was used, which was less satisfactory. At the opposite side of the derrick from the bull wheel, and resting on four heavy *mud sills* is a still heavier main sill thirty feet in length, extending nearly that distance outside the derrick towards the engine. At the farther side of the derrick from the bull wheel is set the *samson post,* usually about fourteen feet in length, which rests firmly on the *main sill,* is strongly braced by the *samson post braces,* and supports the *walking beam.* The walking beam is commonly 26 feet in length, and carries the *pitman* at one end and the *temper screw* at the end inside the derrick to which the tools are fastened, which are used in drilling. The pitman is connected by a wrist pin with the crank of the jack or band wheel which is supported on *jack posts* and transmits the power to various parts of the rig. This *band wheel* is set at the farther end of the main sill from the derrick. The power is transmitted from the band wheel to the walking beam by means of crank and pitman and to the bull wheels through the tug wheel and bull rope.

Just behind the band wheel is set the *sand reel,* which is operated by the former through a friction pulley. The sand reel is mounted on a *knuckle post* and is controlled by the *sand-line pulley* from within the derrick and is used in handling the *sand bucket* or *bailer,* which is lowered into the well at necessary intervals to remove the drillings or sediment which accumulate. A modern derrick is not complete without the *headache post,* also called the *life preserver,* which is usually a piece of heavy timber set on the derrick end of the main sill directly under the walking beam, so that in case of accident the latter would only fall a few inches and save the driller from injury to the head. The headache post is also useful when repairs are necessary to the pitman or band wheel and crank, as in such cases a block may be placed between the headache post and the walking beam, enabling the pitman to be easily removed.

In the California type of Standard rig there is an additional reel which is known as the *California or "calf" reel,* which is set even with the side of the derrick opposite the bull wheels, and carries a cable which is used in lowering and pulling the casing, and saves considerable time in deep drilling operations. The *calf reel* is operated by the band wheel through a tug and rope belt, and its operation is controlled by a lever and clutch. For supporting the various wheels and reels and the other parts of the rig, various Standard posts and sills are used which are given appropriate names by the drillers.

Extending from a convenient place on the derrick to the engine some distance away, is the *telegraph cord* used by the driller in controlling the throttle of his engine. This cord consists of a double line of telegraph wire passing over small wheels, Extending from the derrick to the engine is also a reverse lever which is used for reversing the engine. A derrick of the type described can be constructed by three or four skilled workmen in from three to five days; the time depending largely upon the accessibility of the lumber. Such a derrick is commonly put together by nailing and may sometimes be used for three or more wells, but can seldom be used longer for the reason that the timber and lumber become too badly worn to be set up again; hence the advantage of a bolted wooden or steel derrick which is described in a later paragraph.



12

Fig. [redacted] Side Elevation and Ground Plan of Standard Rig.

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The parts needed, illustrated on the accompanying figure by appropriate letters, are as follows: (The references are to Fig. 12).

Specifications for Standard 82-foot Derrick.[1]

Pieces	Size Inches	Length Feet	Name	Illustration Marks
1	16×16	10	Nose sill	A
2	16×18	16	Mud sills	B
2	16×18	20	Mud sills	B
§1	18×18	31	Main sill	C
1	18×18	16	Sub sill	D
1	14×14	16	Sand reel tail sill	E
6	16×18	4	Derrick foundation posts	F
2	10×10	21	Derrick sills	G
20	12×12	20	Derrick floor	H
1	16×16	16	Samson post	I
2	6×8	14	Samson post braces	J
*1	16×18	16	Front and rear jack posts and knuckle post	K L
1	6×8	14	Bull wheel post brace	M
*1	14×14	22	Bull wheel posts	N
*1	9×10	14	Sand reel lever and dead block	O
*1	12×14	5	Tail post	P
1	6×8	14	Headache post	Q
†1	5×12	12	Pitman	R
*1	5×14	16	Crown block	S
1	....	....	Crown pulley	T
*1	3×14	10	Sand sheave pulley block	U
1	....	....	Sand line	V
1	Diam.	10	Bull wheel	W
1	....	....	Bull wheel brake	X
	....	....	Derrick girths	Y
80	1×6	16	Derrick braces and roof batting	Z
‡1	....	....	Walking beam	2
1	....	....	Bailer	3
1	....	....	Drilling cable	4
1	....	....	Bull wheel drum	5
1	....	....	Temper screw	6
1	....	....	Sand reel drum	7

If closed or winter rig is desired, add 500 feet, 1 inch by 18 foot boards.

* These pieces should be oak or other hard wood. If hard wood is not obtainable, sizes must be increased according to quality of material.

§ The main sill may be sawed in two pieces, 16 and 18 feet in length, with 2-foot splice.

† Pitman should be 5 inches square at top, and 5 x 12 inches at bottom.

‡ The walking beam should be 14 inches square at each end, the taper beginning 3 feet on each side from centre.

Estimated weight 67,000 pounds.

[1] Catalogue A. Oil Well Supply Co.

Labour Necessary in Drilling.

The rig is usually erected by carpenters known as rig builders. The rig builder takes entire charge of putting up the derrick and all wood work. He usually employs on the spot such help as he finds necessary. He may or may not install the boiler and engine depending upon whether the well is let by contract or not. If by contract, the boiler and engine may be installed by the contractor in charge of the drilling. The whole care of the drilling is now turned over to the drill crew under the charge of the contractor, or, if the well is drilled by day labour, to the field superintendent who provides for the board and lodging of the drillers, and furnishes all supplies. The actual drilling is in charge of a driller and his assistant, a tool dresser. The driller is in charge of the well and is responsible for the log during his turn of 12 hours, when he is relieved by the night crew, which is the exact duplicate of the day crew and goes on at 6 p.m. and works till 6 a.m. The driller's work requires him to stay in the derrick while the drilling is in actual progress. The tool dresser has charge of the machinery; he fires the boiler and runs the engine while the tools are being drawn from the holes. Many features of drilling are common to all systems and may therefore be stated in connexion with the Standard system.

Fuel.

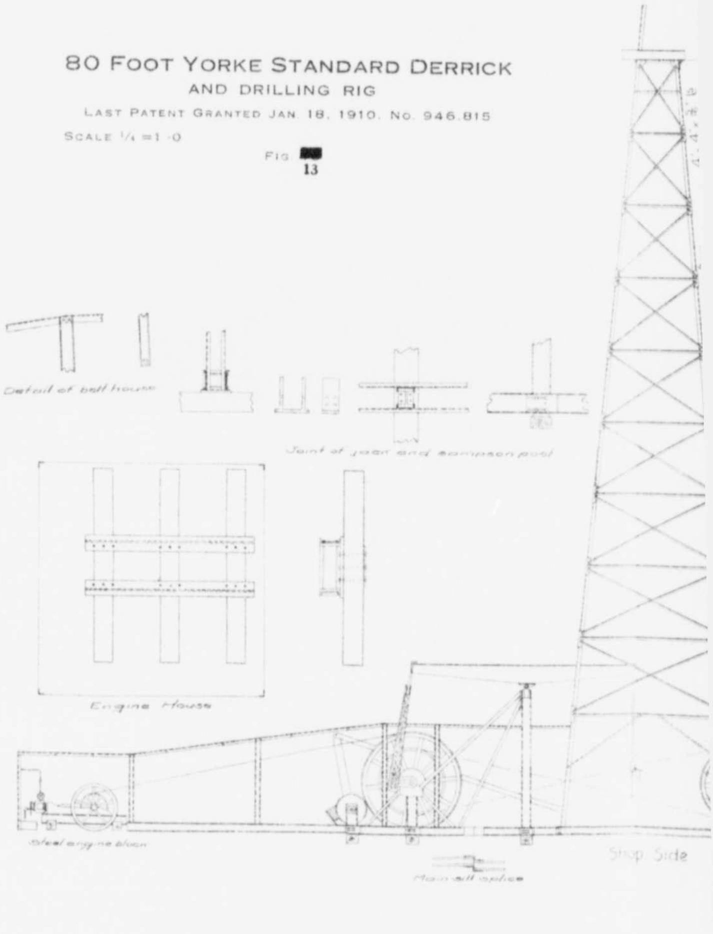
Gas, crude oil, coal, and wood are the fuels in question, for power in drilling, pumping, and cleaning oil wells. They are mentioned in the order of their value. In developed fields gas from some neighbouring well is usually depended upon. It is piped from the well to the boiler at a safe distance from any gas which the drilling well may develop. Gas will undoubtedly be the fuel used in drilling in the western Canadian provinces. The ordinary charge is the flat rate of 5 cents per day per well for drilling purposes. Crude oil is burned under the boilers instead of gas in most drilling operations in California. The amount for drilling, pumping and other field work amounts to between 3 and 4 per cent of the total California product. In the

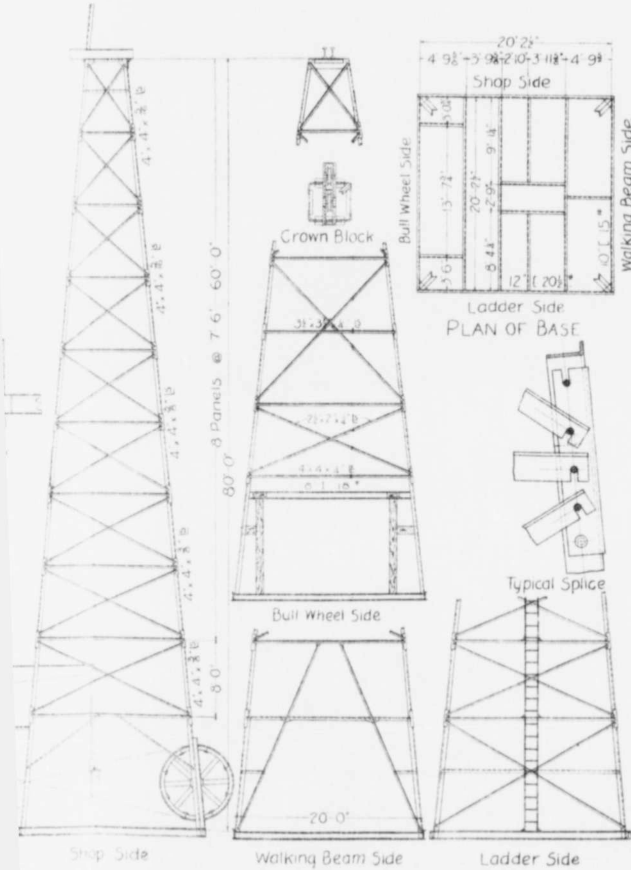
80 Foot Yorke Standard Derrick
and Drilling Rig

Last Patent Granted Jan. 18, 1910. No. 946.815

Scale 1/4 =1 -0

Fig. [redacted]
13





20' 2½"
Shop Side
Bull Wheel Side
Walking Beam Side
Ladder Side
PLAN OF BASE
Crown Block
8 Panels @ 7' 6" 60' 0"
80' 0"
8' 0"
Typical Splice
Bull Wheel Side
20' 0"
Shop Side
Walking Beam Side
Ladder Side

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Midway district and where the gas is available it has promptly supplanted oil.

In wildcatting operations where gas or oil is not available coal is greatly preferred to wood. Relative cost is not nicely measured on account of the steadier, hotter fire which coal maintains.

In California the usual fuels have been supplanted to some extent by electric power even for drilling—this will be considered further on.

The consideration of a supply of water of fair quality for boiler purposes is of greatest importance. In fact drilling operations have been delayed and even totally stopped for important periods in the middle west by the droughts of the past two summers. Usually the wooden or steel tanks, provided for taking care of the first oil struck and located close to the well, are utilized for a considerable water supply.

Where water is so distant that it cannot be pumped economically to the tanks at the rig, and it becomes necessary to drill a water well, this is usually put down before the regular drilling operations are begun. The water well is usually put down under the walking beam about three feet back from the point where the oil well is to be drilled. The water is pumped by the walking beam.

Boiler and Engine.

The boiler used in drilling wells in cases where a stationary rig is erected, ranges from fifteen to forty horse-power, and the engine commonly is from twelve to thirty horse-power. The ordinary cost of this essential is from $500 to $1,000 and the weight is from 8,000 to 16,000 pounds.

Cost of the Drilling Outfit.

The cost of a drilling outfit varies so greatly in different types of wells and in different parts of the country, that it is almost impossible to give any features of the expense. In certain cases a suitable outfit might be obtained at a cost of

$500 or less, while under other conditions an expenditure of ten times that amount may be necessary.

The machinery used in drilling.—In a portable drilling machine which is described in later paragraphs of this report, the machinery is all carried on the portable outfit itself; consequently, it will be discussed later. A stationary rig, however, must be equipped with machinery before the well can be drilled. By machinery is understood, the boiler, engine and their equipment.

The drilling tools include all essential articles used in making the hole in the ground and cleaning out the detritus; and also all special appliances which may be necessary for removing broken tools, or tools which become fastened in the bore hole; also the drilling cable and the sand line with tools for handling the casing used in the wells. The character and type of the drilling tools are very variable, and will be discussed in further detail.

Drilling Tools.

The string of tools[1] used in deep drilling consists of several parts, all of which have certain definite functions and are the outgrowth of years of experience. A full string comprises *rope socket, sinker bar, jars, auger stem,* and *bit.* Whether or not the complete string is used depends on the conditions under which drilling is done.

The *socket* may be fastened to the drilling rope in several ways. It may have a tapered hole in which the rope is secured by knotting; the rope and socket may be riveted together, or the rope may be threaded back and forth through several holes in the socket secured by wedging.

The *sinker bar* is a long, heavy bar, which is used to add weight and length and thus aids in keeping the holes straight. It was formerly thought to be an essential part of the string, but it is now seldom used unless a wet hole (one partly filled with water) is being drilled. It then assists in sinking the cable

[1] Bowman, Isaiah. Well drilling methods. U. S. Geological Survey, water supply paper 257, pages 38-40.

rapidly. If it is placed between the jars and the bit, it adds force to the blow of the latter.

The *jars*, as previously stated, consist of a pair of linked steel bars. When drilling in rocks in which the bit is apt to stick they are necessary to jar the drill loose. The drill responds to the powerful upward blow of the jars as they are jerked violently together by the stroke of the walking beam when it will not yield to the slow and relatively steady pull of the rope. In ordinary brittle rock the jars are now almost universally discarded but they have a very important use in fishing for lost tools; those intended for this purpose are made longer than jars used in ordinary drilling.

The jars in no sense act as a maul to drive the drill into the rock, as many people suppose. In fact, a good driller so adjusts the cable that it is impossible for the upper jar to strike the lower one except when the cable is raised. The only weight which adds effectiveness to the blow of the drill is the weight of the lower jar, the auger stem, and the drill. The weight of these three parts, or of the two last-named parts, makes up three-fourths to seven-eighths of the total weight of the string of tools. This weight, falling through a distance of several feet, is all that the drill can bear. Some inexperienced drill men give the drill too much rope, so that the bottom of the upper jar strikes into the bottom of the slot of the lower jar at each downward stroke, and in a short time the links are seriously damaged. The stroke must be carefully adjusted to the play of the jars, taking into account the stretching of the rope.

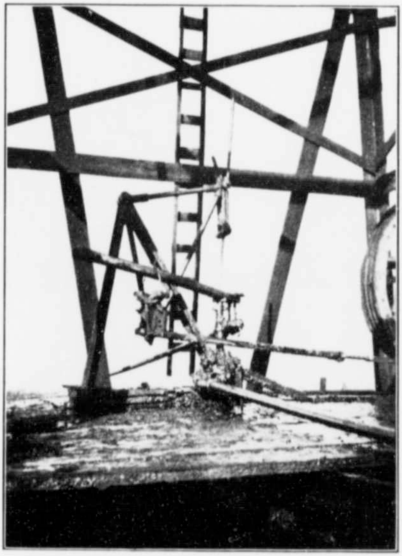
The *auger stem* gives additional weight to the blows that are struck, and also, by increasing the length of the drill, helps to maintain a straight hole. It is of the same shape as the sinker bar, but is considerably shorter.

Various patterns of *drilling bit* are used, according to the character of the rock that is being penetrated. The shape illustrated at the bottom of the string of tools in Plate VIII, is used in moderately hard rock; the "Mother Hubbard" pattern (Plate III) is a similar, but thicker drill that is used in hard, fissured rock; the California pattern, which is concave on the bottom, is much used in the shales of the oil districts in that state. A shorter, lighter bit is used in spudding at the beginning of drilling. Star bits are sometimes used in creviced rock that dips steeply, and more complex shapes are used in reaming and in other special operations.

Bits of good length are very desirable; in the event they are lost from the stem they are not so easily driven into the wall of the hole; when they stand in a perpendicular position they are more easily recovered. It is also desirable that they be so thick as to almost fill the hole which prevents the hole from going crooked in passing through crevices or fissures in the rock. A water course or flutes on the sides of the bit permits the water and drillings to pass up freely past the bit. The tool wrenches vary in weight to meet the judgment and ideas of the different contractors, the average weight being about 300 lbs. each. They are usually made to fit a 5-inch square, which is the size of the square on the larger tools, and by the use of a bushing called a Dutchman, the size of the wrench is made to fit the smaller tools. The wrenches are attached to a balancing weight in the derrick which permits one man to handle them with ease. They are operated by a powerful apparatus called a "jack", which consists of an arc circle of heavy iron which is fastened to the floor around the hole and far enough distant from the hole to catch the extreme end of the wrenches when they are placed in position on the joint. The jack travels on the circle, and while one wrench is firmly held by a wrench post pin, the other wrench is moved around the circle by a ratchet jack.

The *temper screw* consists of two steel reins about 6 feet in length, connected at the top to a steel rod 2½″ in diameter and 16″ in length, upon the top of which is a tee 2½″ in diameter and 14″ in length. On the bottom of the reins is a split box which, when closed, is 2″ in diameter, supplied with a screw 1½ threads to the inch. The temper screw proper is a steel screw 2″ in diameter with 1½ threads to the inch and 6 feet in length; to the bottom of which is attached a C (half circle) which holds the clamps which go around the cable, and which is attached to the screw with a ball-bearing attachment. When the screw is placed in the box on the reins, the box is tightened by a set screw which passes through a band or yoke. When the

PLATE III.



Type of Jack used in pumping oil wells
(Oklahoma fields, etc)

screw is to be raised or lowered, this set is gently loosened, which allows the screw to be turned.

All joints of the string of tools have taper screws, so that only a few turns are required to fasten them together. They are screwed up tightly by heavy wrenches on which great leverage is exerted by means of a ratchet floor circle and jack, or by a simpler arrangement in which the floor circle is an arc of band iron with holes punched in it every 2 or 3 inches. These holes give footing to a bar by which the upper wrench is forced around. The great stress that is thus brought on the screw binds the string of tools together. When first assembled and screwed together tightly each joint of the string may be marked by a cold chisel cut that extends across it, and each time a joint is put together care is taken to see that it is screwed up as far as or a little farther than it was before. If the two halves of the chisel mark fall short of coinciding, sand or mud in the threads may be the cause, and if this material is not removed and the joint screwed together tightly, the sand may work out, leave the joint loose, and cause loss of all tools below the joint.

Both hemp and steel wire ropes are now used for *drilling cables*, the steel wire having come into more general use during the last ten or fifteen years.

The best quality of hemp rope is that made of manila hemp (not common hemp nor sisal) and is hawser laid, that is, it consists of three ropes of three strands each, twisted together into a single rope. In its manufacture a "nap" is formed, of the ends of hemp fibres, nearly all of which point towards one end of the rope. The rock socket should be fastened to the end toward which the fibres point, for although when the tools are attached to this end the fibres spread out and retard the downward stroke in a hole that is partly filled with water, they protect the rope better from being frayed by rubbing against the casing on the upstroke.

Steel wire drilling cable is composed of several strands wound about a hemp core, each strand being formed of several wires. Rope consisting of six strands of seven wires each is a style commonly used.

The advisability of substituting steel wire cable for hemp cable in drilling deep wells has been much discussed, some maintaining that hemp can never be replaced by steel, and others that steel will shortly be used altogether. The importance of the substitution of steel for hemp is better appreciated when it is known that a hemp cable ordinarily cannot be used to drill more than one or two wells, but the hemp cable possesses certain qualities which are not found in the steel cables and which must be considered in dealing with the problem. The careful driller never allows his tools to fall as a dead weight on the rock which he is drilling, but so adjusts the rope that the tools will stretch it in reaching the bottom of the hole. The nature of this action may be illustrated by suspending a weight by a piece of rubber elastic a little above a table or other surface. It will be found that by giving a slight reciprocal motion to the rubber the weight may be made to strike the surface with considerable force. Manifestly, the force of the blow is diminished by this arrangement, but in drilling this loss of force is more than compensated by the springing blow that is struck; and if the rock is easily cut by the drill this rebound is essential, as otherwise the drill will be imbedded so firmly as to make it difficult to remove except by jarring.

In drilling a deep well the stretch of the rope is often underestimated, and it may happen that the tools are falling when the walking beam is rising, thus bringing a great strain on the cable and making the blows of the drill very ineffective. The operation of the tools is rendered still more difficult when the hole contains several hundred feet of water, which interferes with the free upward and downward motion of the cable.

Steel cable, with its smaller diameter and greater weight, has the advantage of passing comparatively freely through water which may stand in the drill hole, the water friction being much less than on a hemp cable, and the water also reduces the shock of the steel cable by acting as a deterrent to the rapid drop of the tools. On drilling through thick oil as in Mexico, hemp cable would frequently be impossible. On the other hand, steel cable has very little elasticity, and drilling by the stretch of the rope is hardly possible. Every blow that is struck by the drill is a dead blow, as there is no compensating rebound and the upward stroke causes severe strain, both on the derrick and on the cable itself where it is attached to the tools at its lower end and to the temper screw at its upper end. The difference in stretch of the two kinds of cable is shown by the fact that with a 5-foot temper screw 7 or 8 feet may be drilled with hemp cable, while at best a distance of only $5\frac{1}{2}$ feet is possible with steel cable. Some drillers use 150 or 200 feet of hemp rope between the tools and the steel rope, and this gives some elasticity to the cable and rebound to the tools.

The use of the steel cable was considerably increased during the Spanish-American war by the fact that the price of hemp cable became so high that its use seriously increased the cost of a well.

In the last few years at least half of the oil wells put down in the California fields, where the wells are usually drilled "wet," have been drilled with steel cables. In other oil fields a very small proportion of the drilling is done with steel cables. For cleaning wells, however, it has largely supplanted hemp cable throughout the east, as in this work it is not necessary to use such a rapid stroke, and hence steel cable may be advantageously employed.

Experiments have been made by several supply companies looking toward the construction of some device that will give elasticity to a steel cable, but the thousands of dollars thus spent have had little practical result. Several experimenters, however, are continuing this investigation, working along the line of a spring fastened to the walking beam, the whole being adjusted in such a way that the spring, when given the proper tension, will take up the slack of the cable on the upward stroke and give it out again under the weight of the tools on the downward stroke. Experiments are also being made with a cushioned walking beam, looking toward the same result; and it is possible that a sufficient degree of efficiency may be reached in the construction of this device to permit the wider distribution of steel for hemp in future drilling operations.

The standard well-drilling outfit with steel wire drilling cable has been used to some extent in the Baku oil region of

Russia, where it was found that only a very limited amount of rotation could be imparted to a wire rope without damaging it, because of the untwisting and kinking of the strands. To overcome this disadvantage a special kind of wire rope was employed, consisting of left-hand and right-hand strands plaited together. It is said that this rope worked satisfactorily in the hands of a skilful attendant, but it had to be disconnected from the main drum at each change of operations.

As a general proposition it may be said that with wells which are drilled to any great depth a manila cable is used for the first 1,000 feet; after that it is the general practice to substitute a steel cable.

A complete outfit of cable drilling tools and machinery suitable to do testing or deep and difficult drilling consists of the following:—

1—25 h.p. boiler.

1—25 or 30 h.p. steam engine.

1—12″ 6-ply, 90 ft. rubber belt.

1—2¼″ Manila hemp drilling cable; length governed by the depth of hole to be drilled, or equivalent in steel cable.

1—Wire sand line, ½″ or 5-8″ in diameter, 2500 ft., in length.

2—Bull ropes, 2½″ in diameter, 85 ft. in length.

1—Temper screw.

1—Jack.

1—Blower for heating bits.

1—300 lb. anvil.

1—Full equipment of miscellaneous small tools, such as sledges, hammers, hatchets, wrenches, blacksmith's tongs, saw, square, etc.

1—16″	all crescent steel bit, weight	1500 lbs.
2—13″	" " " " "	1300 lbs. each.
2—10″	" " " " "	1100 lbs. "
2—8¼″	" " " " "	800 lbs. "

All of the above bits provided with taper pins 3¼ × 4½″: 7 flat threads per inch; outside diameter of collar 6¼″.

2—$6\frac{5}{8}''$ all crescent steel bits weight 500 lbs. each. Provided with taper pins $2\frac{3}{4} \times 3\frac{3}{4}''$; 7 flat threads per inch; outside diameter of collar $5\frac{1}{4}''$.

1—Crane and hoist for hanging or connecting bits to stem.

2—5″ cold rolled steel stems, 32 to 36 ft. in length; taper pins $2\frac{3}{4} \times 3\frac{3}{4}$; 7 flat threads per inch; outside diameter of collar $5\frac{1}{4}''$. Box $3\frac{1}{4} \times 4\frac{1}{4}''$; 7 flat threads per inch; outside diameter of box $6\frac{1}{2}''$.

2—4″ or $4\frac{1}{2}''$ cold rolled steel stems, 36 to 40 ft. in length; $2\frac{3}{4} \times 3\frac{3}{4}$ taper pins; 7 flat threads per inch; box of same size; outside diameter of box $5\frac{1}{2}''$.

2—Rope sockets; box $2\frac{3}{4} \times 3\frac{3}{4}''$; 7 flat threads to the inch.

2—Sets of drilling jars, with 6″ to 8″ stroke; box and pins $2\frac{3}{4} \times 3\frac{3}{4}''$; 7 flat threads per inch.

2—Sets of fishing jars, 18″ stroke; box and pins $2\frac{3}{4} \times 3\frac{3}{4}''$ 7 flat threads per inch.

1—Set tool wrenches.

1—Boiler tube, 11″ × 24 feet.

1—Boiler tube, 9″ × 24 feet.

1—Boiler tube, 7″ × 24 feet.

1—Boiler tube, $5\frac{1}{2} \times 30$ feet

Drilling Operations.

FISHING.

If a bit is lost from the bottom of the stem and the driller does not detect the break instantly he is likely to drive the top of the bit into the wall of the hole, in which event the box of the stem goes by the top of the bit and sticks. When the stem sticks in this way, if there is sufficient cable in the hole to permit the beam to continue its motion on the stretch of the cable, the engine will instantly increase its speed; the tension in the cable pulling the beam down quickly, only to be pulled up again by the engine. This notifies the driller that something has gone wrong and (if he is awake) he investigates.

If the tools are drilling in sand and the bit is even slightly worn, when it passes through the sand, it will have too much wearing surface to run in slate formation, in which event it will stick with the same results as noted above. In either case, the driller will loosen the tools by switching. This is done by increasing the speed of the engine, which gives the walking beam a quick motion which usually jerks the tools loose. When this is done, the tools are pulled out. If the bit is off, the stem is taken down and sent to the shops for a new box. A spud is attached to a light stem and lowered into the hole.

The cable is then connected to the beam. The wrist pin is changed in the crank to give the beam a short stroke. The tools are then operated much the same as if drilling, with the result that the spud usually brings the bit into an upright position again. After this is accomplished, a friction socket is lowered over the bit and it is recovered.

When tools lost in a hole are so large as not to allow a fishing tool of sufficient strength to withstand great weight or jerking, to go over them, it then becomes necessary to turn off the outside of the broken part in the hole, leaving a core to which the fishing tool can be attached. This is called milling a pin, and is accomplished by attaching a mill of the desired size to two-inch tubing. The tubing is lowered into the well until the top of the lost tools is found. The upper end of the tubing is connected to a wheel in the derrick which turns it. The weight of the tubing is lifted off the mill to allow it to turn freely. In this way the pin is milled. The tubing is removed and the necessary tool is lowered, and the lost tools are recovered.

The various fishing tools are referred to on a later page under difficulties in drilling.

SPUDDING.

The term spudding is applied to drilling without the aid of the walking beam—the method nearly always used in sinking the first 75 or 100 feet of a well, as the string of tools is too long to be operated from the walking beam in beginning work. It is possible to attach the tools to the drilling cable before the hole has been drilled to this depth, but owing to the short length of cable between the tools and the walking beam there is very little spring in the rope, and the hole must be spudded to a sufficient depth to allow a considerable length of cable to come between; otherwise the blow of the drill will be dead and the rope will be likely to break.

For spudding a short cable is run through the crown pulley at the top of the derrick, one end being attached to the bull wheel shaft and the other to the rope socket, to which are usually screwed only the auger stem and spudding drill. The drill may be given an up-and-down motion in two ways: In the first method the rope is carried around the bull wheel shaft in two or three turns, its end being left free. A man standing in front of the bull wheels grasps this free end of the rope and gives a slight pull, causing the coils to tighten and grip the revolving shaft, and by this means raising the tools; when the rope is slackened the tools fall. By alternately tightening and slacking the rope the operator may rise and drop the drill. The second method has come into use comparatively recently and is much more effective than the other. In this method, which is self-adjusting, the drill rope is wound about the bull wheel shaft and passed through the crown pulley, and from its end the tools are suspended in the drill hole. A rope called the jerk line is attached to the wrist of the band-wheel crank, brought inside the derrick, and attached to the part of the drilling cable which extends from the crown pulley to the bull wheel shaft by a curved metal slide called a spudding shoe. By carefully adjusting the length of this rope each revolution of the band wheel results in a pull on the line and its subsequent release, and a corresponding rise and fall of the tools. As the hole deepens the cable is let out by giving the bull wheel shaft a partial revolution, and the spudding shoe is slipped farther and farther down, for this downward sliding of the spudding shoe increases the length of the pull on the drilling cable and hence the distance through which the drill drops. The sliding motion is imparted by the driller's assistant, between the jerks of the line, by means of a crooked stick long enough to reach the spudding shoe from the floor of the derrick.

Spudding is much harder on the derrick than is ordinary drilling as the strain is brought on the top of the derrick where there is the greatest leverage. In drilling with the walking beam the weight comes on the samson post, which is not directly connected with the derrick, and the strain comes on the derrick only when raising or lowering tools or casing and when using the sand bucket or the bailer.

DRILLING WITH THE WALKING BEAM.

As the hole is deepened the tools are lowered by releasing the brake and allowing the cable to gradually unwind from the bull wheel shaft. After a certain depth is reached in this way, the bull ropes are thrown on the bull wheel and the tools are pulled up into the derrick, and the larger bailer, attached to the sand line and operated by the sand reel, is brought into use to remove from the hole the drillings which have been mixed by the bit. When this is done, the tools are lowered into the hole again and the spudding continued. The hole is usually spudded in this way to a depth of 150 feet, when the connexion is made to the walking beam by the use of the temper screw.

This is done by lowering the tools into the hole to the proper depth; the beam is elevated by putting the pitman on the wrist pin in the crank and a wrapper is securely wound around the cable at a point directly opposite the temper screw clamps.

This wrapper is tapered from the bottom upward, and when placed in the clamps, which form a kind of socket, the brake is released and the wrapper is allowed to settle into the clamps, which causes it to tighten on the cable. When this connexion is complete the bull wheels are released and some cable is taken from the shaft which will prevent the bull wheels from interfering with the motion of the beam. The beam is now put in operation by the driller standing near the hole in the derrick, who has control of his engine by means of a cord, called a telegraph line, which extends to and is wrapped around the engine throttle wheel. There is also a reverse pipe ½ inch in diameter connected to a reverse lever in the engine and of sufficient length to extend to the position in the derrick occupied by the driller. This connexion allows the driller to operate the engine at will.

In a shallow hole, the engine is usually run at a pretty rapid motion as the tools drop freely, but as the hole is deepened, the motion of the beam is slackened. The driller while drilling in a shallow hole, notes the working of the tools by a down jar as the tools strike the bottom. As the hole deepens this jar gradually works off and is changed to an up jar. While the tools are being operated, the driller usually stands near the hole with his hand on the cable, and by an unexplainable knowledge or intuition, gained only by experience, he is able to correctly note and determine the action of the tools. The labouring of the engine will also indicate to the driller whether or not the tools are working properly.

If the driller gets lost, or is not sure that his tools are a proper distance from the bottom of the hole to strike the most effective blow, by checking the motion of the engine, the tools, if working properly, will swing clear of the bottom and the jar is not noted on the cable. By increasing the motion of the beam again the tools will reach farther and again strike the bottom of the hole.

As the hole deepens the driller lets out the temper screw which lowers the tools, and this process is continued until the entire length of the screw is lowered, which deepens the hole approximately 6 feet.

The bull ropes are then thrown on the wheel, the tools are pulled out of the hole, the bailer is brought into action, by which the drillings are pumped out of the hole. Sufficient water is poured into the hole to mix another screw length; the tools are lowered again and the operation is repeated. As the hole is deepened and the soft cavey formation has been passed through, it is often necessary to keep the wall of the hole dry to prevent caving. This makes it necessary to lower the water in the bailer and dump it in the bottom of the hole.

Until within the last few years it was the custom to revolve the drill by inserting a stick in the rings below the temper screw and slowly turning the rope first in one direction and then in the other. This was thought to insure a round hole by causing the drill to strike each time in a different place. The drill, however, is jerked free from the rock unevenly, and the torsion of the drilling cable under the lifting strain has the effect of rotating the tools in one direction on the upstroke and in the other on the downstroke. This action, however, takes place to a notable degree only when there is a sufficient length of rope between the tools and the walking beam; until a considerable depth is reached it is often necessary to turn the cable by hand, otherwise the drill may strike successive blows in the same place, but it is now rightly considered that after the hole is 200 or 300 feet deep it is needless to turn the rope while drilling.

The skilled workman takes hold of the rope or swivel often, for by the feel of the rope he ascertains whether the string of tools is intact and the drill is cutting the rock. When the drilling bit strikes the bottom of the well, the cable is drawn taut and conveys the vibration to the driller's hand; by this means he soon learns when to adjust the temper screw. In the same way the operator learns whether or not the jars open and shut at each blow of the drill.

The proper tension of the cable can be determined only by practice. An old cable has more spring to it than a new one; and the weight of the drilling tools, the depth of the hole, and the speed at which the machine is running must also be taken into consideration. Ordinarily the engine should be speeded up until the cable tightens slightly in advance of the stroke of the drill, not so as to retard its fall, but so that when the drill touches bottom it will be instantly lifted, with no time either to settle or stick. This careful adjustment of the stroke is absolutely necessary for rapid and skilful work. If the drill touches bottom when at rest, there is too much rope out and it should be taken up with the temper screw, for the downward stroke of the drill will stretch the rope sufficiently to let the bit strike the bottom of the hole.

The motion of the drill will be greater than that described by the walking beam, unless too much cable is let out, in which event the stroke of the drill will be less than the stroke of the walking beam, the strain on the cable will be greatly increased, and little or no progress can be made. One of the hardest things for a beginner to learn is that he can not make the drill cut faster by letting out more cable. With a hemp cable, at a depth of about 50 feet, when the drilling tools are at the lowest point in the stroke, the point of the bit should hang 2 or 3 inches above the bottom of the hole. At 100 feet it should be 4 or 5 inches; at 200 feet it should be 6 to 12 inches; and at greater distances with greater depths. An unskilled driller will sometimes allow the full weight of the tools to fall on the drill rope, the drill actually being stopped in its descent a short distance above the rock in which it is supposed to be cutting. The likelihood of such an occurrence increases with the depth of the hole, for the increasing weight of the drill rope added to the weight of tools, often several tons in all, makes it difficult to detect by the feel of the rope whether or not the total weight is decreased at the end of the stroke by the weight of the tools below the jars.

As the drill cuts deeper it is necessary to let out the drill rope gradually, so that the drill will strike at each stroke. This is done by loosening the yoke clamp a little, and running out the temper screw a turn or two. At the end of from half an hour to several hours the temper screw has been run out its length of several feet and the drill has advanced an equal or greater distance. The tools are then withdrawn, the waste that has accumulated since the last bailing is removed with the sand bucket, and if necessary a sharpened bit is substituted.

The withdrawal of the tools is accomplished by first taking up the slack cable on the bull wheel shaft, thus transferring the weight of the tools to it through the crown pulley. The rope clamp is then loosened, the temper screw is disconnected, and the pitman is thrown off from the band-wheel crank pin, as in Plate V. By rotating the bull wheel brake shaft with the engine connexion, the tools may then be raised or lowered at will. This part of the work demands skill, for if the bull wheel brake should not be applied as the tools clear the hole and the tools are allowed to be raised to the crown pulley they would fall on the workmen beneath. After the tools are clear of the hole, they are swung to one side and caught in the loop of a $\frac{1}{4}''$ rope fastened to a leg of the derrick.

The operator is now ready to bucket the drillings from the well. The sand bucket, or bailer, consists of a section of tubing 15 to 60 feet long and somewhat smaller than the well. It has an iron valve at the bottom, either of the flat pattern, or the ball and tongue pattern. In some materials in which the drillings are thick and heavy and do not readily enter the bailer, a sand pump is used. In addition to the bottom valve this has a plunger which is worked like that of a water pump, and thus sucks the drillings into the tubing. The bucket or pump is suspended from a wire cable that is wound on the sand line reel and carried through the sand line pulley. The reel is operated from the derrick by a lever, which brings its friction pulley into contact with the band wheel. The sand bucket line is thus wound up and the sand bucket is swung over the hole. The friction bearing on the band wheel is then released and the bucket is lowered into the well at any desired speed. As the drillings form a thin mud, owing to the addition of water from time to time by the driller, they rise into the sand bucket, are retained by the valve in its bottom, and are then removed. The bucket is emptied by lowering it upon an upright stake or pin beside the well, thus opening the valve.

The liquid condition of the drillings often makes it possible to drill 5 or 6 feet without bucketing; otherwise the drill would become ineffective at the end of a very short time, by striking into its own cuttings, and the necessity for frequent bailings would greatly increase the work and cost of drilling. Water is usually added to the drillings by the bucketful at the well head. Sometimes it comes into the well from water-bearing strata that have been penetrated by the drill in a quantity sufficient to soften up the drillings, and yet not great enough to interfere with the work. It is then unnecessary to pour in water from the surface.

In many localities water is added to the drillings by means of a barrel set at one side of the derrick, from the lower end of which a pipe extends within 2 or 3 feet of the drill hole; to this pipe is fastened, by a loose joint, another piece of pipe as long, at least, as the height of the barrel and long enough also to reach from the end of the horizontal pipe to the mouth of the drill hole. When the short length is dropped to a horizontal position water flows from the barrel down into the hole; by raising the short pipe to a vertical position the flow is shut off.

TOOL DRESSING

While the tools are drilling in sand rock the bit wears out of gauge. It is usually taken off the stem after it has drilled five or six feet and another bit of the proper gauge, which is always in readiness, is put on the stem. While this bit is being run the tool dresser heats the bit taken off, which is done in a forge in the side of the derrick. When it is ready for dressing, the driller and tool dresser, each with a 15lb. sledge, upset and expand the face of the bit to a size larger than the hole being drilled. The bit is then turned on its edge and the corners are drawn forward and rounded to correspond to the circle of the hole, leaving the flutes or water course on the sides of the bit open. The bit is dressed with a double short bevel on its face and is otherwise shaped to do the most effective work in the formation it is required to drill.

To dress the bit the exact size of the hole, a steel gauge is used which is a complete circle the size of the hole.

When oil or gas is found the forge is removed from the derrick to a safe distance outside to guard against fire. The boiler is also moved for the same reason when necessary, and again connected to the engine by lengthening the steam lines.

HYDRAULIC ROTARY SYSTEM OF DRILLING.

This system is an improvement on the American Standard method, made to suit certain conditions, originally employed in Texas and Louisiana, but now extended to other parts of the world where very little, if any, solid rock formations are present; and, consequently, the ordinary churn drill or Standard method of percussion drilling will not apply.

This method of drilling was first successfully used in sinking oil wells in the Spindle Top field near Beaumont, Texas, where other methods of drilling had failed, and it has since been a great factor in the development of the Texas fields. Its successful use in that region and the consequent great improvement in the machinery employed has led to its increasing use where soft materials are encountered.

The Hydraulic Rotary system should be applicable to large areas in western Canada, where the formations are comparatively soft, but up to the present it has not been introduced.

Drilling with a rotary machine is not desirable where it can be avoided, inasmuch as the weight of water used to force the drillings out of the hole is greater than the rock pressure found in the producing sands. The sand formation is plastered with mud and often salivated to such an extent as to hide the value of the well.

Description.—A rotary drilling machine consists of heavy rollers placed in a revolving frame; the frame is supplied with cog gear, sprocket wheel and chain, which connect it to the engine which operates it. The drill stem, consisting of heavy four-inch pipe made especially for such work, passes through the rollers freely when being elevated or lowered. When the rotary is revolving, the rollers grip the drill stem and turn it; the bit made to resemble a fish-tail, is fastened to the bottom of the stem; a water pump is connected by a heavy two-inch rubber hose to the top of the stem with a swivel joint connexion; when in operation, the stem revolves quickly; the bit on the bottom of the stem cuts or loosens the formation, and at the same time the water is being forced down through the stem and escapes through holes in the bit, and coming up on the outside of the stem carries the drillings to the top of the hole.

With the hydraulic rotary outfit, a derrick similar to that of the standard rig is used, but the machinery and tools are unlike those of percussion outfits. The principal parts of the machinery are a revolving table or whirler, two hydraulic pumps, and boiler, engine, and line shaft to furnish power.

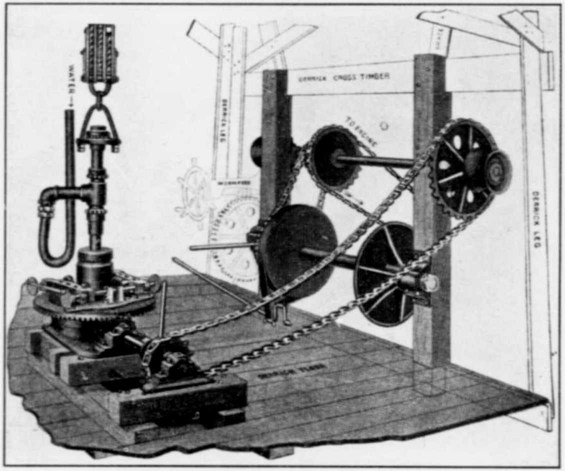
The revolving table is a heavy rotating device, set on heavy tool-steel rollers, that grips the casing firmly and permits it to be revolved and yet allows it to be gradually lowered as sinking progresses. The table is revolved by means of bevel gearing connected with the line shaft and controlled by a clutch and lever.

The hydraulic pumps, which supply water for drilling, are capable of developing pressure of from 125 to 175 pounds to the square inch. As the water used is very muddy, the pumps are made with but 6 to 10 valves, whereas if the water were clear

PLATE IV.

Rotary method of drilling, Caddo field, La., U.S.A.

Plate V.



Rotary hydraulic ready for use.

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20 to 24 valves would be used. The valves also fit more loosely than in ordinary pumps, so as to reduce the abrasion produced

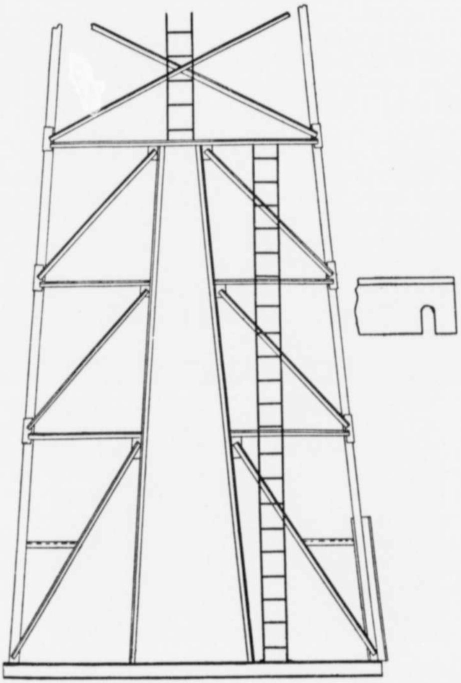


Fig. 14. Three sections of a rotary derrick; these derricks differ little from the ordinary standard derrick, only in the lower sections as shown here.

by the sediment. Only one pump at a time is in use, but to permit packing of the valves and to provide for accidents and emergencies two pumps are always installed. In many plants, two boilers are also installed for similar reasons. The pump that is in use is connected with the top of the casing through a hose line and water swivel similar to those in the self-cleaning outfit, but larger, so as to allow the continuous pumping of water into the casing while the latter is being rotated. A back-pressure valve is usually inserted in the gooseneck at the upper end of the swivel, to relieve pressure on the hose. Two swivels are needed, one being attached to the joint of casing, to be added next to the string, while the other is in use.

The drill stem is suspended from blocks through which lines pass up through and over pulleys on top of the derrick, returning to a wheel at the base of the derrick, where the reserve line is spooled and which is under the control of the driller, who can lower the drill stem at will by releasing a friction brake which holds the wheel.

The engine is connected by a link drive to the line shaft, which also furnishes power to the revolving table and to a hoisting drum and reel.

Thin mud or slush plays an important part in drilling, and a slush pit is an essential accessory to the outfit. This pit is usually dug near the derrick, on the same side as the pumps, and is about 40 feet long, 15 feet wide, and 3 or 4 feet deep, though the size varies with convenience and the preference of the driller. A ditch where sand may settle out of the mud is cut from the well circuitously to the slush pit, from which hose or pipes lead to the pumps.

The cost of a rotary outfit is somewhat variable, but may be placed in the neighbourhood of $3,000. The rig used is very similar to the American Standard rig.

Drilling Operations.

Drilling is accomplished by rotating the entire string of casing, on whose lower end is a fish-tailed bit. The rotation under heavy pressure breaks off and grinds up particles of the material that is being penetrated, and they are carried to the surface by water that is pumped down the casing under pressure and rises to the top on the outside between the casing and wall of the hole. Only one casing, that which is being revolved,

Raised derrick, showing "sludge pool," Oil City, Caddo field, La., U.S.A.

is used, for as the muddy water escapes upward it puddles the side of the well so that the material stands alone.

If a bed of clay is encountered, the water used in drilling is kept as clear as possible and is not drawn from the slush pit, for the clearer the water is when introduced the greater is its capacity to uphold and move particles of earth, and the clay is sufficiently compact to make a wall that will not cave. In penetrating sand and gravel layers, clay often has to be added to the slush pit, so as to make a thin mud that will plaster up these beds and prevent them from caving and also prevent the escape of drill water into them. In some oil fields, a trough with revolving paddles, called a mud mixer, is used to prepare the slush of proper consistency for plastering up sandy layers and also for closing gas pockets.

A pressure guage enables the driller to feed the casing into the hole with uniform pressure. The casing must be lowered with care, for if it is fed too fast the hole may become clogged by failure of the pumps to raise the outside column of water and carry up the drillings.

When the casing has been sunk so that its top is near the revolving table, another length of casing to whose upper end the second water swivel is attached, is elevated by means of the hoisting reel so that it can be screwed on to the last length used. The first water swivel is then unscrewed, the new length of pipe is coupled on, and the hose connected to the water swivel at its upper end. This operation requires only a few seconds of the skilful workmen's time, and drilling proceeds with scarcely any interruption. To prevent the drenching of the men during the attachment of the water swivel, the pipe couplings are sometimes fitted with back-pressure valves.

It is essential that the pump be kept going constantly otherwise the drillings will settle in the bottom of the hole and "freeze" the pipe fast. Should drilling cease at any time, the water circulation must be kept up if possible, as slight cavings of material will cause the pipe to become clogged.

Sharpe-Hughes Bit.—What is regarded as the greatest advance yet made toward the perfection of the rotary system of drilling oil, gas, and water wells has been accomplished by the invention of a practical and highly efficient mechanical bit, which successfully overcomes one of the weak spots in the rotary process—the difficulty of drilling through rock and other hard formations. Heretofore cable tools have had the best of the rotary in "making hole" in rock, but this new bit evens up the discrepancy in results in this respect as between the two methods, and removes the only valid objection to the rotary's claim of superiority over other systems of drilling in localities where soft formations predominate. It is the invention of Howard R. Hughes.

Briefly stated, it consists of two or more detachable, cone-shaped, hardened steel cutters, running on bronze bearings and lubricated with oil supplied by means of a small pipe carried inside the drill stem. The cutters, being detachable, may be removed and sharpened while duplicate sets are in use. The patent bit has sixty or seventy series of cutting edges as compared with the two cutting edges of the fish-tail bit.

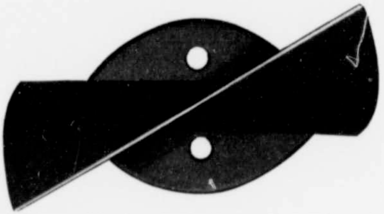
For fishing operations, which are sometimes rendered necessary by the twisting off of the casing, tools are used that do not differ greatly from those employed for similar purposes in percussion drilling. If the twisted-off portion is short, however, it may be possible to pass it by using a diamond-shaped bit and side-tracking or drilling past it.

As in the percussion methods of oil well drilling, the drive shoe is usually set in the formation that is known from other wells in the same locality to overlie the oil-bearing sands. Drilling is then continued inside the casing for the remaining few feet or yards to the oil sands, and a smaller string of casing with a strainer at the bottom is lowered to the oil.

Packing is accomplished, as in other methods of drilling, by seed bags, cement, or special packers. A packer called a boot leg is also frequently used. This is a slightly tapering leather sleeve somewhat larger than the casing. If it is slipped over the casing and its lower (smaller) end is tied fast to the casing a short distance above the strainer, the mud remaining about the casing settles into the open upper end of the boot leg and thus fills and packs the space between the casing and the side of the hole.

PLATE VII.

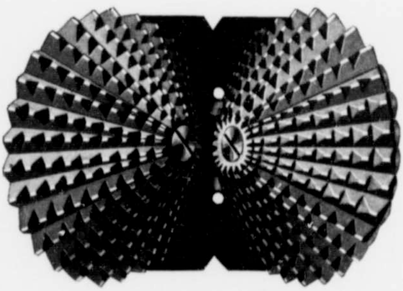
Sharp-Hughes patent cone-shaped cutter bit.



(a)

Standard Fish-Tail Bit

(Underside View)



(b)

Sharp-Hughes Patent Cone Bit

(Underside View)

Views showing the cutting edges of a Standard fish-tail bit, as compared with sixty or more rows of cutting teeth of the S-H cone bit.

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Many water wells sunk by the hydraulic rotary method are difficult to screen because of the depth at which the operation is conducted and the fineness of the material. A method in use is to puddle the wall of the well at the water bearing layer, set the screen, and draw the casing to the top of the screen. By pumping heavily for a few hours, the pores of the puddled water bearing sand are partly re-opened, but the method has the defect of leaving the water bearing layers more or less clogged by fine material. A more difficult but a better and more common way of screening is to sink the screen below the casing by forcing a hole down by a jet of water, the wash pipe being run ahead of it. A packer or lead seal is then inserted at the point where the top of the screen joins the well casing to prevent material from rising over the top of the screen and filling it.

Advantages and Disadvantages.

An objection to the hydraulic rotary method for drilling wells has been made by some engineers, who claim that the driller often seals oil off by puddling, and that the location of the oil bearing stratum must be known before drilling begins, otherwise it will be passed through without the driller being aware of its presence.

The hydraulic rotary is very rapid for drilling in loose material where the drill may descend continually. At Corsicana, Texas, 1,065 feet were drilled through clay and marl in thirty-two hours. Both method and machinery have been rapidly developed through extensive use in the Texas and California oil fields. The method will, however, never supplant the jetting and self-cleaning methods for shallow work where only a cheap, light rig is required, any more than the heavy standard oil well outfit will supplant portable rigs for drilling shallow wells.

THE COMBINATION METHOD OF DRILLING.

The combination method, used in localities where the formations are very soft and consequently suitable for the rotary; but where occasionally hard strata are encountered through which it is necessary to drill by the ordinary percussion method; in other words, the Combination rig is a combination of the American Standard rig and the Hydraulic Rotary rig. Such an outfit weighs about 47,000 pounds and costs approximately $5,000 in addition to the timber and lumber for the derrick. The combination method should be used in many parts of Alberta.

CALIFORNIA OR "STOVEPIPE" METHOD.

This form of well construction has been developed in California to meet local conditions, but it is equally well adaptable for use in many other parts of the country; particularly where a number of water-bearing beds are available in unconsolidated materials. This method has been described by Slichter.[1] The abundance of boulders and other heavy debris in the outwash in mountain valleys of southern California necessitated special devices. The sizes of these wells are 7 to 14 in. The well is started with a riveted steel starter, from 15 to 25 ft. long, made of two or three thicknesses of No. 10 sheet steel with a forged steel shoe at lower end. For ground containing large boulders still heavier starters are necessary. The rest of the casing consists of two thicknesses of No. 12 sheet steel in riveted length, each two feet long. One set of sections is made just enough smaller than the other to permit them to telescope together, and the outside section overlaps the inside section by about a foot; hence the name "stovepipe" method. The casing is sunk by ordinary heavy oil-well machinery, with a few modifications and the casing is forced down, length by length, by hydraulic jacks, which must be previously securely anchored. The material from inside the casing is loosened and removed with the sand pump, which must be large and heavy, generally weighing 1,100 to 1,400 pounds.

When the well has been drilled to the required depth a cutting knife is lowered into the well and vertical splits are cut in the casing opposite known water bearing beds, which have previously been determined by keeping an accurate log as the

[1] C. L. Slichter, Eng. News, Nov. 19, 1903, W. S. P., No. 110, U.S.G.S., pp. 32-36.

well progressed. Hence, by this method the screen may be made to occupy as much of the well as circumstances render desirable.

For splitting the stovepipe a special form of perforator is provided of which a number of forms are in use.

The advantages claimed by Slichter for the stovepipe method are as follows.[1]

1. The absence of screw joints liable to break and give out.

2. The flush outer surface of the casing, without couplings to catch on boulders or to hang in clay.

3. The elastic character of the casing, permitting it to adjust itself in direction and otherwise to dangerous stresses, to obstacles, etc.

4. The absence of screen or perforation in any part of the casing when first put down, permitting the easy use of sand pump and the penetration of quicksand, etc., without loss of well.

5. The cheapness of large size casings, because made of riveted sheet steel.

6. The advantage of short sections, permitting use of hydraulic jacks in forcing casing through the ground.

7. The ability to perforate the casing at any level at pleasure is a decided advantage over other construction. Deep wells with much screen may thus be heavily drawn upon with little loss of suction head.

8. The character of the perforations made by the cutting knife are the best possible for the delivery of water and avoidance of clogging. The large side of the perforation is inward, so that the casing is not likely to clog with silt and débris.

9. The large size of casing possible in thissystem permits a well to be put down in boulder wash where a common well could not possibly be driven.

10. The uniform pressure produced by the hydraulic jacks is a great advantage in safety and in convenience and speed over any system relying upon driving the casing by a weight or ram.

11. The cost of construction is kept at a minimum by the limited amount of labour required to man the rig, as well as by the good rate of progress possible in what would be considered in many places impossible material to drive in, and by the cheap form of casing.

The cost of constructing a 12 in. stovepipe well is given as generally 50c per foot for the first 100 ft. and 25c additional per foot for each succeeding 50 ft., casing to be furnished by owner. The cost of No. 12 gauge, double stovepipe casing averages $1.05 per foot, and a starter costs $40.

The style of rig varies with the driller, a common form being shown in Plate IX.

The stovepipe is devised to give the very maximum yield from every water-bearing formation penetrated by the well. Some of the best wells of this type in use are those of the Sea Side Water Co. at Long Beach, California.

[1] Ibid, pp. 34-35.

SINKING WELLS WITH PORTABLE DRILLING MACHINES.

This method is preferable in all cases where the wells are of shallow depth; and, consequently, that the great weight and strength of a Standard derrick are not required to carry the weight of the tools. For shallow wells, a rig which can be moved about has many advantages. Various portable drilling machines are in the market, among which may be mentioned the Star, Columbia, Keystone and others; and it would not be in the province of this Report to discriminate between them, as they are all good, and, moreover, they all have their special uses in various fields. The wells at Puce and Belle river in Essex county were drilled by such machines.

CANADIAN POLE TOOL SYSTEM.

The Canadian Pole Tool system of boring is perhaps the most useful all-round prospecting rig which can be purchased, and it is especially suitable for those regions where excessive caving makes it necessary to have some positive method of rotating the bit. The Russian and Galician systems are only modified pole tool processes in which the original ash drilling poles have been replaced by iron rods.

Rig.—The Canadian rig is a simple woodwork framing in which one shaft and two spools running in bearings transmit the various motions desired. The drive is taken by a pulley attached to the main shaft on which are also keyed two band pulleys which communicate by belting with two spools running immediately overhead in the upper part of the framework. The main shaft is also provided with a disc crank on one of its extremities which, through the medium of a pitman or connecting rod, transmits an oscillating movement to an overhead pivoted walking beam when the engine is run. The band and spool pulleys are flanged to prevent the driving belts which surround them from slipping off, as the belts are always left loosely in position, and the spools are put into action by jockey pulleys which are drawn firmly inwards by levers against the belts. One spool wheel operates the sand line when cleaning out the well, the other is used for raising and lowering the rods and tools as they are inserted or withdrawn from the well. To the walking beam is attached at the centre of oscillation a slipper out

PLATE IX.

Drilling in Delaware Extension pool, Oklahoma, U.S.A.

Cleaning well with Star No. 27 drilling machine,
Muskagee field, Okla., U.S.A.

Drilling rig, Petrolia, Ontario.

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which is used for giving the feed during drilling, and is merely a clutch gear attached to a spindle upon which is coiled a chain leading to the spring pole overhanging the well. At the end of the beam the chain several times encircles a fitting so that when the tools are released by the clutch gearing, the greater part of the weight is taken by the beam and not by the clutch.

Plate XI shows the general arrangement of a Canadian standard rig.

Drilling tools.—The tools consist of chisels or bits, sinker bar or stem, jars, substitute and wooden ash drill poles to the surface. Sometimes wing guides are coupled to the stem to keep the tools straight in inclined strata, and an under-reamer is occasionally connected also. The tools are very similar to those used for the cable rig, the only important difference being the ash drill poles which are used instead of a rope. The bits are sometimes fluted and sometimes flat, with or without side wings, and not infrequently eccentric bits are employed to enlarge the hole sufficiently to allow the casing to follow. The pole tool system permits under-reaming much better than cable systems, as the action is positive and definite, the rotation of the rods at the surface assuring the twisting of the bit in the hole. The sinkers have diameters between 2½ and 4 inches, and lengths from 10 to 30 feet, and the jars are similar to those already described under cable tools.

The poles are of 2 to 2½ inches hexagonal or round trimmed ash, in lengths of about 18 feet, to the extremities of which are riveted iron straps which partially encircle the rod and have a screwed pin or a box joint. Sometimes two such rods are coupled together by means of two iron straps encircling the pole, making 36-foot lengths. The joints are always screwed taper to take up wear, and there are six to eight threads to the inch. The figures below give the Canadian standard sized joints for poles and other attachments:—

No.	Diam. at point	Diam. at Shoulder	Length	Threads per inch	Size of Wrenches	Diam. of Collar
	Inches	Inches	Inches		Inches	Inches
1	1½	2¼	3	8	2¼	3¼
2	1¾	2¾	4	8	3	4⅛
3	2	3	4	8	3	4⅜
4	2½	3½	4	8	3½	4⅞

The rods are raised and lowered by a pole box and swivel on a $\frac{7}{8}$ inch steel wire rope worked by one of the spools, a suitable fork being pushed beneath the collar of each joint as it reaches the mouth of the well. The descent of the rope after a rod has been raised and placed aside in the derrick is brought about by a heavy weight coupled to the rope above the swivel-screwed joint by which they are lifted. When the tools and rods have been lowered to the bottom of the well, suitable short lengths of rods are attached to give the desired distance to couple up the feed chain on the walking beam by a drill swivel, the feed being adjusted by the slipper out clutch during work.

In addition to the ordinary sand pumps and bailers which can be operated by a steel wire line, augers can be lowered and rotated by the rods. The common fishing tools consist of horn sockets and slip sockets which can be guided over lost and broken rods by "bonnets," which are simply bell-mouthed guide pieces which can be attached to the tools.

SPECIFICATIONS OF CANADIAN RIG AND TOOL FOR DRILLING 2,000 FOOT WELL.

1 steam boiler capable of evaporating 1,000 lbs. of steam per hour at 100 lbs. pressure, with Colonial type fire-box, fusible plugs, feed pump, injector, and spares.

1 horizontal 12 by 14 inches single cylinder reversing stem engine, with pulley and flywheel, feed pump and feed-water heater, with means of operating steam admission and reversing gear from a distance.

1 derrick, 56 feet high, 18 feet square at base, $4\frac{1}{2}$ feet at top.

1 heavy drilling rig for 2,000 feet, including bolts, beams, husk-blocks, snatch post, spring pole, etc.

1	mud	pump,	12 in.	by	6 ft.	long,	with hinged	bail and	drill pin.
1	sand	"	$10\frac{1}{4}$	"	18	"	"	"	"
1	"	"	$7\frac{1}{4}$	"	36	"	"	"	"
1	"	"	$5\frac{1}{4}$	"	36	"	"	"	"
1	"	"	$4\frac{1}{4}$	"	36	"	"	"	"

Fishing Tools.

1 fishing jar, $1\frac{3}{4}$ by $2\frac{3}{4}$ inch box and pin.
1 pole hook for 10-inch hole.
1 9-inch horn socket, with 3 dogs.
1 $6\frac{3}{4}$-inch two-legged socket, with two dogs and springs.
1 $5\frac{3}{4}$-inch " " " "
9 $4\frac{1}{4}$-inch " " " "
6 bonnets for sockets for 5-inch, 6-inch, 7-inch, $8\frac{1}{2}$-inch, 10-inch and 12-inch casing.
1 wire rope knife.
1 " spear.

Casing, Elevators, etc.

2 casing swivels for 12-inch casing.
2 " 10 "
2 " $8\frac{1}{2}$ "
2 " 7 "
2 " 6 "
2 " 5 "
6 sets wooden clamps for above casing.
4 2-inch casing clamp bolts, with heavy nuts.
2 casing chains, $\frac{1}{2}$ and $\frac{5}{8}$ inch ring and hook.
3 clevices and pins for casing swivels.
1 extra heavy quadrangle block, with 15-inch sheaves and swivel head.
1 extra heavy treble block, with 15-inch sheaves and shackle.
1 steel shoe for each size of casing.

Cables, Wire Ropes and Belts.

200 feet $1\frac{1}{4}$-inch manilla rope.
200 feet $\frac{3}{8}$-inch "
200 feet $\frac{3}{8}$-inch "
1 $\frac{7}{8}$-inch by 120 feet draw line, with 2 eyes.
1 $\frac{5}{8}$-inch by 650 feet block line, with 2 eyes.
1 $\frac{5}{8}$-inch by 2,500 feet sand line, with 2 eyes.
2 12-inch by 65 feet double leather draw belts.

½ gross belt laces.
1 12-inch by 42 feet drive belt.
1 pair belt clamps.

Drilling Tools.

2 13¼-inch bits, 250 lb. steel, 3 by 4 inch pin-joint.
2 11¼ " 180 " " "
2 9½ " 150 " " "
2 8 " 110 " 2½ by 3½ "
2 6½ " 90 " " "
2 5½ " 75 " 1¾ by 2¾ "
2 4½ " 60 " " "
2 11¼-inch undercutting bits, 3 by 4 inch "
2 9½ " " " "
2 8 " " 2½ by 3½ "
2 6½ " " " "
2 5½ " " 1¾ by 2¾ "
2 4½ " " " "
1 7-inch by 15 feet long sinker, 3 by 4 inch joint.
2 5 " 15 " " 2½ by 3½ inch joint.
2 3½ " 12 " " 1¾ by 2¾ inch joint.
2 3 " 12 " " " "
1 6¼ " jar, 3 by 4 inch box, 2½ by 3½ inch pin.
1 5⅛ " " 2½ by 3½ inch box, 2½ by 3½ inch pin.
1 4⅛ " " 1¾ by 2¾ " 1¾ by 2½ "
1 substitute, 3 by 4 inch box, 2½ by 3½ inch pin.
1 " 3 by 4 inch pin, 2½ by 3½ inch box.
1 " 2½ by 3½ inch box, 1¾ by 2¾ inch pin.
1 " 2½ by 3½ " pin, 1¾ by 2½ inch box.
1 " 2½ by 3½ " box, pole pin.
1 " 1¾ by 2¾ " box, pole pin.
1 " 2½ by 3½-inch pin, pole box.
1 " 1¾ by 2¾ " "
2 heavy tool wrenches for 4½-inch square.
2 " " " 4 "
2 " " " 3 "
2 knock wrenches.
1 catch wrench.

1 key wrench for iron poles.
1 chain lever, heavy.
56 drill poles, 36 feet long.
4 tubular hand poles.
1 pole swivel, with chain.
1 drill swivel.
1 sand pump swivel.
1 sand pump hanger and chain.
1 pole hook.
1 3-inch clevice and pin for top of derrick.

HOLLOW-ROD METHOD.

Outfit.—The self-cleaning or hollow-rod method of wel sinking includes the essential features of the percussion methods, but differs in combining in one operation the breaking up and removal of the material.

The tools consist of a string of pipe with screwed couplings, usually of special manufacture to insure strength and durability, with a water swivel at the upper end and a drill bit at the lower end. Because of this use of joints of pipe instead of a drilling cable the machine is often called the hollow-rod outfit.

The water swivel is essentially a swiveled goose-neck that allows the water and drillings to be discharged from the pipe in a constant direction and still permits the drill pipe to be rotated. In the usual outfits of the class the pipe is 1½ or 2 inches in diameter and the drill is 2¾ to 4 inches across, though the hole may be enlarged by using an expansion bit.

The drill has one or more holes at its upper end and a flap valve that allows water and drillings to enter the pipe and be lifted automatically to the surface. Blind valves are also usually placed at intervals within the pipe to relieve the lower valve of the weight of the entire column of water and drillings.

In drilling by the self-cleaning method water must occasionally be poured into the well until it is encountered in sufficient quantity for the needs of drilling. The drilling operation is continuous, for as the drill is alternately raised and let fall the jumping or pumping action forces water and drillings into the drill rods and upward to the surface. This action resembles that of a hydraulic ram, but in the drill the sudden compression required to open the valve is obtained by the drop of the tools instead of by the fall of a water column, as in the ram.

A properly tempered bit will be sharper when it is taken out of the hole than when put in, for the wear comes mainly on its edge and tends to reduce its gauge. When the approximate depth of the hole to be drilled is known, bits may be run long distances. So long as they are larger than the joints on the rods they will not stick as will cable bits when worn, for the vibration of the rods keeps them free. Many holes 100 to 150 feet in depth have been drilled with one bit without removing it from the hole. When a bit is used too long, however, the hole must be reamed when a bit of standard gauge is substituted for it.

JETTING METHOD.

Outfit.—In the jetting method of well sinking the material is both loosened and carried to the surface by water under pressure.

The principal parts of the outfit are a force pump and water swivel, drill pipe, nozzle or drill bit casing, and drive weight.

Hand-power jetting outfits are made in several styles which differ chiefly in the arrangement for driving the casing. One outfit uses a block and tackle for raising and letting drop a weight of 200 pounds or more; another uses a lighter weight which is lifted directly by hand. Some outfits require a light derrick and working platform; others are operated from the ground.

In the jetting method water is led into the well through a pipe of relatively small diameter and forced downward through the drill bit against the bottom of the hole. The stream of water loosens the material and the finer portion is carried upward and out of the hole by ascending water current, as in the hydraulic rotary method.

Casing is usually sunk as fast as drilling proceeds. In the softer materials, by using a paddy or expansion drill a hole may be made somewhat larger than the casing, which may be lowered a considerable distance by its own weight. Ordinarily, however, a drive weight is necessary to force it down.

CORE-DRILLING.

General Features.—Core drills are little used for sinking wells, though they have been tried from time to time in developing new oil fields, and diamond drills have been employed to some extent in South Africa for deep-water wells. The core-drill principle is, however, occasionally employed in connexion with the more common well-drilling outfits.

The advantage of core drills over all other types of boring machines is that they enable an accurate sample of the material penetrated to be obtained. They are therefore widely used in prospecting for coal and other economic deposits, for making borings for foundations for dams and similar structures, in preliminary tunnel investigations, and in excavation work. The importance of obtaining a true sample of the material penetrated is illustrated by the experience of a firm of contractors, who became bankrupt because at a certain depth they encountered hard conglomerate instead of the gravel indicated by the drilling of a percussion outfit.

Rotary core drills of the several classes are alike in employing a hollow rotary drill that by abrasion wears an annular hole, leaving a core in the centre. The drillings are removed continuously by water under pressure, and the core is broken off and removed from time to time.

Core drills are intended primarily for drilling holes of relatively small diameter in hard material. They resemble hydraulic rotary outfits in method of operation, but the formation of a core and the necessity for its occasional removal makes the drilling process intermittent instead of continuous.

Core drills may be used in all kinds of rock, from the hardest trap to the softest shale, but where a core is not especially desired drilling in the softer formations can usually be done more rapidly by means of percussion, hydraulic rotary, jetting, or some other method, and as a rule saving can also be effected in the cost of outfit.

DIAMOND DRILLING.

Outfit.—Diamond-drill machines to be worked by hand are made, but the larger outfits require a derrick, hoisting sheave, and hoisting drum similar to those employed in other methods of drilling. The drilling apparatus includes a force pump and water swivel, drill rods and rotating device for turning them, feed mechanism, and a cutting bit.

The derrick in most common use is a tripod 20 to 80 feet high, the height varying with the work to be done. Where timber is easily available the derrick may be constructed of poles, but for drilling to depths of 1,000 feet or more a strongly braced 4-pole tower or a steel derrick is usually employed. The drill rods are smaller and lighter than those used with the hydraulic rotary outfit, and the hoisting drum, force pump, and water swivel though similar, are correspondingly lighter and are of somewhat different design. Only one force pump is installed. The drill rods are of heavy lap-welded iron tubing or of seamless steel tubing, with screw joints, and are 5 to 10 feet long. The sections are added as sinking progresses.

The bit is made of a ring or sleeve of tough but ductile steel, three-eighths to five-eighths inch thick, whose upper end is threaded to screw into the drill rods and whose lower end is turned true and bored with eight holes to contain the diamonds. The diamonds are carefully set in the holes so that their lowest points lie in a plane, and are arranged alternately on the inner and outer faces of the bit, so that the outer edges of four project a little beyond the outer face and give it a clearance, while the edges of the inner four project slightly beyond the inner face and clear the drill of the core. The diamonds are calked in place by carefully swaging the steel firmly against them with light blows.

Two kinds of diamonds, known as carbons and borts, are used in diamond-drill work. Carbons are found as opaque, irregularly shaped nodules, black on the outside and shades of grey on broken surfaces. They have no cleavage planes, and it is this quality, together with their hardness, which especially fits them for drilling in hard rock. Borts are semi-transparent diamonds similar in appearance to the rough brilliant but differing in crystallization. They are usually nearly spherical in shape, are as hard as carbons but not as tough, and have a cleavage plane, so that when used in hard rock they may break whereas carbons wear away but seldom break. Carbons come mainly from Brazil; borts from both Brazil and South Africa. Borts are much cheaper than carbons and may be used in boring in soft rock. In some holes a toothed cutter bit similar to that of the hydraulic rotary outfit is used in penetrating soft rock. In moderately hard material a drill armed half with carbons and half with borts may be used, but for drilling in very hard rock only carbons are suitable.

CALYX DRILL.

The calyx drill was invented in Australia. It is now in use in many parts of the world.

The hoisting and driving machinery of the calyx drill is similar to that of the diamond drill, and feed water is supplied through a swivel and hollow drill rods. The bit of the calyx drill is made of hardened tool steel and consists of a toothed collar, somewhat like the cutting shoe of the hydraulic outfit, but having longer barrel and teeth, the teeth being so set as to provide clearance to the core and to the bit and rods.

Above the core barrel a cylindrical chamber or calyx, open at the top, encircles the drill rods. Into it the coarser rock fragments torn off by the drill bit are caught as they are dropped by the upward water current when its velocity decreases. They are removed when the rods are hoisted to remove the core, and furnish a second record, in inverted order, of the materials penetrated. This record is of especial value in material too soft to yield a good core.

The action of the toothed bit in cutting the rock seems to depend largely on the torsional power of the drill rods, for the drill bites into the rock and resists turning until the twist of the rods forces it to loosen and partly turn around to a new grip. It thus has a "chatter" motion, which chips off fragments of the rock. Its action has been compared to that of the stone mason's chisel, which chips off rock fragments at each blow of the hammer.

The calyx drill is not restricted in size by such considerations of cost as is the diamond drill, and machines are built capable of taking cores 15 inches in diameter.

CHILLED SHOT METHOD.

Experiments in drilling by the use of loose abrasives poured down the drill hole led to the adoption for this purpose of chilled steel shot, such as is used in sawing marble and other stone. Other parts of the shot outfit are similar to those of the diamond drill, but cutting is accomplished by revolving an iron or steel tube on the shot. A slot a few inches long and half an inch wide cut into the lower end of the tube or bit allows the shot to reach the cutting surface more readily and be more evenly distributed. Distribution is also aided by slightly beveling the edges of the tube so that the shot may get under it. Under the weight of the drill rods the shot bites into the rock and chips out or wears off small pieces of it, which are brought to the surface by the water current.

That the supposedly round and smooth shot can thus wear away rock may seem at first almost impossible, but close examination of the tiny steel balls shows that they are slightly irregular in shape, and because of this unevenness of form they sink into the softer bit tube and are held firmly by it, abrading the rock surface as sand-paper abrades wood. The shot does not develop a tendency to polish the hard rock—a tendency sometimes shown by the diamonds used in the diamond drill.

COMPARISON OF CORE-DRILLING METHODS.

The diamond drill is especially adapted to penetrating hard rock to great depths, and will bore a hole at any angle; hence it is especially useful in mineral-prospecting work. It is somewhat restricted by the character of the rock formation, however; for example, no diamond-drilling firm will send a drill into the lead and zinc districts near Joplin, Mo., for the limestone there contains many chert nodules, loosely embedded, which tear the diamond bits. In highly inclined and flinty rocks there is thus the danger of loss of the stones. The high cost of the diamonds limits the use of this drill to boring holes of smaller diameter, and hence to the higher classes of work, such as prospecting for ore deposits.

The calyx drill is commonly used to bore much larger holes than the diamond drill, and in soft or moderately hard material it is cheaper. In very hard rock it works more slowly, however, and it is not adapted to boring holes at an angle greater than about 45° from the vertical. It is largely employed in coal prospecting and in boring holes for testing foundations.

The shot method may also be used in obtaining cores of large diameter. In very hard material it is more efficient than the calyx cutter, but it is not adapted to soft material. It may be used for boring holés at any angle, provided the drill is rotated rapidly and the shot kept properly distributed by centrifugal force.

All rotary core drills are portable and, as they can be taken apart for transportation on pack animals, can be used in regions where more cumbersome outfits are debarred. Nearly any power can be used—electricity, compressed air, steam, gasoline, horse, or hand—but where its use is possible steam is usually the best.

The three methods of rotary coring are sometimes used in boring the same hole, the style of cutting bit employed depending on the character of the material that is being penetrated. The shot and calyx bits are frequently interchanged, and on one of the leading makes of core drill the outfit is expressly designed to use a toothed cutter bit in soft and moderately hard rock and shot in penetrating the hardest materials. For this purpose a double water swivel is used, through one neck of which the shot is fed into the rods.

The percussion core drill should prove valuable in sampling coal beds and in other work in comparatively soft formations in localities where a cable rig can be advantageously set up.

DIFFICULTIES IN DRILLING.

The contractor usually holds the driller responsible for accidents caused by losing tools in the well, but not for those due to geologic conditions, unless the formation is well known from previous borings.

Causes of Loss of Tools.

These are usually due to one or more of the following conditions or causes:—

1. A worn cable. The stretching and bending of the part of the cable immediately above the socket cause it to become thin and frayed after a few weeks' wear.

2. The imperfect attachment of the cable to the socket. The joint should be tested by putting a strain on the rope while the drilling tools are anchored at the surface.

3. Neglect in setting up the tools after each run. If the parts are not securely fastened together, they become unscrewed and fall into the drill hole.

4. Paying out too much or too little cable. If too much cable is paid out, the jars will batter and break; if too little, the whole weight of the tools will fall on the cable and strain it excessively.

5. Crystallization of the iron of the tools through successive jarrings. The screw pin of the auger stem may break from this cause.

To ascertain the nature of an accident one-half mile below the surface in a hole perhaps only 6 inches in diameter, by means of a cable having a very appreciable stretch, is clearly an operation requiring great skill. As the string of tools is usually more than 50 feet long, weighs over a ton, nearly fills the hole, and is wedged in so tight that the strongest cable could not pull it loose in a straight pull, the conditions involved in some fishing jobs is obviously unusual. Occasionally, the driller is compelled to break up the broken tool in the well, crushing it with the driller by repeated blows.

Locating Lost Tools.

The first step in recovering a lost tool is to learn the shape of its upper end and the position in which it lies in the well. This knowledge may be obtained by lowering over the tool a sheet iron vessel containing soap or other soft material, in which an impression is easily made. An examination of the mould then enables one to determine the position of the tool and to devise means for its recovery.

If the fallen object has been caught in the well wall above the oil or water or lies in a dry hole, its position may be determined by reflecting light into the well from a mirror. It was perhaps this operation which suggested the invention of a photographic device for determinations of this character. The device was invented by Mr. Loran, a Baku engineer, and both the instrument and process of photographing have been described by A. Beebe Thompson.

The device consists of a stereoscopic photographic apparatus, which is lowered to a point near the lost tool, light for the negative being furnished by an electric current carried by wires arranged in the camera. Concerning its construction, Mr. Thompson says:[1]

An internally blackened, bell-mouthed vessel, at the small upper end of which is fixed the stereoscopic camera, and at the sides of which are fixed two small electric lamps with shades reflecting the light downward, is attached to a sinker rod with guides. Incased in an air-tight chamber above the photographic device is an electric accumulator, which supplies the light, and interposed in the circuit is a small clock that can be regulated to produce contact at any desired time, switching on the light and opening the camera shutter at the same moment. Above this is placed a cylinder in which compressed air is stored, leading by minute tubes to the bell-mouthed photographic vessel beneath. By a clever device, a quick upward or downward motion of a few inches causes a disk, nearly equal in size to the well, working freely on the central spindle, to rise or fall and transmit a motion to a lever which actuates an air valve leading from the air vessel. The pressure of air must exceed the pressure due to the submergence of the apparatus in the liquid, and on the air valve being opened the fluid is displaced in the bell-mouthed vessel and an undisturbed view of the lost article is secured. After an exposure of one or two hours, the air is shut off by a repetition of the before-mentioned jerk and the apparatus raised.

Recovering Lost Tools.

Most of the instruments made for recovering lost tools are expensive and so many of them have been devised that one contractor can not afford to own a complete set. Usually he purchases first the ones he is most likely to need and others as he may require them.

Slip socket.—If the drill is lost in the well, but is not jammed tight, it may be possible to lower a spudding spear into the well and prod the top of the drill loose from the wall. The drill may then be grasped and removed by a slip socket which consists of a pair of slips inserted in a tube-like instrument and

[1]Thompson, A. Beebe, The Oil Fields of Russia, 1904, 2d ed., 1908, p. 164.

suspended by a light string. The teeth of the slips are bevelled upward, so that when the socket is lowered the slips readily move downward over the upper part of the lost tool. By quickly jerking the socket upward the string supporting the slips is broken, the teeth bite into the tool, and as the socket is raised the bevelled groove in which the slips work narrows the space and causes the grip to become more firm. In this operation, it is essential that jars be used to cause the teeth of the slips to bite as deep as possible into the drill, and also to jar the drill from the rock in which it is held. If it is impossible to lift the tool, the socket may be driven down again. The slips are thus raised and are automatically caught on the side of the socket. If a harder pull on the object is required, the socket should be brought to the surface and reset. If the jars should be broken and the string of tools fall into the well, the tools may be withdrawn by lowering a slip socket of special pattern over the sides of the broken jar.

The slip socket was invented in this country and has been adapted to many uses and is more employed than any other instrument for lost tools. If it is properly arranged before being lowered into the well, it will not fail to seize the lost object and it grips it with greater and greater force as stronger pull is applied to the drill rope, and if the driller is unable to bring enough force to bear on the cable to withdraw the tools, it may be easily released and raised.

If tools have fallen far, and have become firmly embedded in the rock at the bottom of the well, the fishing jars must be very long and the longest possible stroke must be given to the walking beam. The tools may usually be loosened by repeated blows and then removed.

Horn sockets.—If the tools have fallen only a short distance, they may be removed by a horn socket, a tube with two slits, cut on opposite sides, which when jammed down over the fallen tools expands slightly and obtains a friction grip. It is cheap, easy to operate, and is almost as much used as the slip socket.

Electric-magnet.—Another device used in fishing is a powerful electro-magnet, by which a lost tool may be drawn out of a niche in the drill hole and recovered. The electro-magnet has been used successfully by Mr. Phillips, of the firm of Phillips and Worthington, New York city, in drilling a well in New Jersey, but the rigging up of the apparatus is expensive and difficult.

Rope spear.—If the cable has broken near its connexion with the temper screw and has fallen into the well, it may perhaps be withdrawn by catching it with a rope spear, a rod armed with upward pointing barbs, which is lowered into the well by a rope. If the drill is wedged in so tight that the cable can not be withdrawn by the spear, a rope knife is lowered by which the cable is cut off as near as possible to the drill. The drill may then be withdrawn by a slip socket and the cable speared and removed.

Defective casing.—Two instruments that are frequently used in dealing with defective casing are illustrated in Plate XII. If the casing has been dropped to the bottom of the well from a considerable height, it may be bent, or even twisted like a corkscrew, so that it can be withdrawn only in short sections. To do this the casing cutter is inserted, the knives of which expand as the pipe on which it is screwed is rotated, and the casing is cut at any desired point. If the casing is only slightly bent, it may be straightened by the use of a pipe swedge dropped into it repeatedly in the manner in which the drill is operated from the walking beam.

Redrilling and enlarging.—If the methods just described are ineffective in removing the broken parts, the driller may shift the drilling tools a few inches to one side and re-drill and enlarge the hole. By drilling some distance below the level of the top of the lost tools and spearing them into the new hole, part of them may usually be grasped by a slip socket and withdrawn. If the drilling is done in relatively soft material, the tools may be pushed to one side and passed by thus drilling a second hole. This at first seems to be an almost impossible operation, but it is easily done, and is effective in disposing of even large broken instruments.

GEOLOGIC DIFFICULTIES.

Spalls.—Spalls of rock or loose stones may fall from the wall of the hole on top of the drill and wedge it in so tightly it can not be withdrawn by cable pull alone. This is a common accident in wells in highly creviced or fissured rock or in glacial till, without casing or drive pipe. The spalls or loose stones may usually be broken up by a smaller drill, and the tools can then be withdrawn.

In brittle sandstone and in shale the top of the string of tools may become jammed in a cavity in the wall of the well, made by the detachment of rock fragments. It is then necessary to bring the string of tools into their normal position in the drill hole by means of the spudding spear. They can seldom be loosened simply by playing on the cable.

Boulders.—An accident that shows the close dependence of drilling on geologic conditions is the mistaking of a boulder for bed rock. Ordinarily the driller determines whether the hard rock which the drill has struck is or is not a boulder by noticing whether it seems loose and rebounds under the stroke of the drill. If it does not seem to be solid rock, he endeavours to break it to pieces and remove it.

The boulder may be so large that the driller mistakes it for bed rock, and after drilling into it for 3 or 4 feet sets the casing in the boulder, substitutes a smaller drill, and proceeds as if he were in bed rock, but after drilling a few feet farther he again encounters sand or clay of the same character as that above the boulder. He must then draw the casing set in the boulder and ream out the hole to a size which will enable him to sink the proper casing through it.

The error of mistaking a boulder for bed rock may be avoided by observing the drillings brought up to the surface and noting whether they are of material like the bed rock in the vicinity. In northern Indiana, for example, a driller may be pretty certain that if the drillings indicate granite, or schist, or trap, the drill is in a boulder and not in the bed rock, which in that region is for the most part limestone. If the rock appears to be a boulder, he will of course expect to find soft material below it and will proceed accordingly.

In the glacial regions of North America the bed rock is overlain by a bed of till that ranges in thickness from a few feet to several hundred feet and contains many large boulders. The bed rock in most places is shale, sandstone, or limestone, but the boulders, having chiefly come from the north where the rocks are of different character, are chiefly of granite, schist, and other crystalline rocks; some boulders, however, as those derived from the country rock, are of limestone and sandstone.

If a boulder is especially hard, it may be blown to pieces by dynamite or rock powder tamped with a bushel or two of dry sand or clay. This may split the boulder so that the casing will pass down between the broken parts, or it may break it into pieces so small that they can be further reduced by the drill and removed by the bailer. If a boulder is to be broken by explosion, the casing should be drawn 3 or 4 feet above the charge so that it will not be injured.

Running Muds and Clays.—Mud produced from some shales hardens quickly when exposed to the air. If such mud runs into a well and fills the space between the drill and the well, it may solidify and interfere with the withdrawal of the drilling tools. A hole drilled through a stratum of such shale must be cased down and drilling must be pushed forward so rapidly that the mud will not have time to solidify. The drill may be freed from obstruction by this mud and withdrawn by slowly working it up and down so as to gain on the up-strokes, and the mud may be removed by small buckets or augers. If this method fails, $1\frac{1}{2}$ or 2 inch pipes may be lowered into the well and the hardened mud and sand may be flushed out by a powerful water jet. Such a layer of mud and clay can sometimes be passed by casing it off with a short length of pipe and using a smaller drill, but the driller usually prefers to work patiently past it rather than to reduce the size of the hole by casing it off.

Even if only a small quantity of water is present, clay will "crawl" and relieve pressure by squeezing through very small openings in threads or sheets. The slow but forcible movement of plastic clay into a drill hole may fill the hole during a single night when drilling is suspended. When drilling is resumed, the next morning, the drill will strike this soft plug of clay and ram it down until the compression of the air below prevents its further movement. The drill may continue to pound this elastic cushion for days, or even weeks, without making further progress while the clay slowly accumulates in the hole. The difficulty may be overcome by casing off the clay before it forms a plug or by jetting through the plug. Plastic clays are encountered in South Dakota and in the Atlantic coastal plain, but most of the glacial clays are so sandy that they yield readily to the drill even if the well does become clogged.

Caving of the formations.—One of the most important difficulties which drillers have to contend with in oilfields is a frequent caving of the strata into the wells from the sides. In many fields there are special beds which cave particularly and these are often given names by the drillers in recording the depth in the wells at which they are found. For instance, a certain caving shale of peculiar character in the West Virginia oil fields is known by the drillers as the "pencil caving", being generally situated between two prominent beds of limestone in the Lower Carboniferous formation. In Oklahoma caving also takes place in formations similar to those of eastern Canada.

This is one of the great difficulties encountered in drilling in New Brunswick, and wells have frequently been delayed for many weeks owing to its occurrence.

Quicksand.

Character of the material.—In drilling water wells in the soft coastal plain formations that stretch from Cape Cod westward and southward along the border of the continent the most serious difficulty encountered is caused by beds of quicksand, which are as a rule interstratified with beds of coarser sand and of clay. The quicksand comes into the drill hole and must be bailed out in large quantities before the casing can be driven further and drilling continued. Under ordinary conditions, quicksand will not yield its contained water, and therefore, if it has a tendency to rise in the pipe the difficulty can seldom be obviated by pumping alone. The whole mass is saturated, its water can not be separately withdrawn, and it exerts practically hydrostatic pressure.

A driller in the Northern States may find pockets or lenses of clay or coarser sand in a quicksand layer, and these cause him to think he has passed through the quicksand. Coarse sand, such as "bar" sand, will not rise if the velocity of the water through it is less than about $2\frac{1}{2}$ feet per minute. The drive pipe shuts off the water and quicksand above such a pocket of coarse sand or clay, but as soon as the drill penetrates the pocket the quicksand again flows in and may rise to the height of the top of the deposit. If the bed is 20 feet or more thick, the pipe can not be driven through it on account of the resistance of the compact sand; and if the water in it is under great head, so as to force the sand up to or above the point at which the bed was struck, further progress may be almost impossible. In some wells, quicksand has risen in the pipe 100 feet above the depth at which it was struck.

Pressure of material.—If the drill hole is not kept full of water, the pressure exerted by quicksand on well casing may be very great. Experiments have shown that quicksand saturated with water exerts a lateral pressure equal to one-half its vertical pressure. Beyond the point of saturation, the pressure is hydrostatic, the vertical and horizontal pressures being equal. Quicksand can be confined only by using water-tight casing, for it is commonly so fine that it will pass a standard 100 mesh sieve. Saturated material of this fineness will flow wherever water flows. The lateral pressure of quicksand is exceeded only by that of clay, and the clay moves much more slowly.

Withdrawing tools.—When quicksand is encountered not only does the material require laborious excavation, but unless the drill is withdrawn rapidly it gets jammed in the hole and is buried by the sand. The driller is then under the necessity not only of cleaning out the hole, but also of recovering the drill before he can resume drilling. In this event it is usual to bail out the quicksand to the point at which the drill is stuck and then introduce into the well a wash pipe an inch or two in diameter. With this the quicksand is agitated (or jetted) and washed up to the surface. This operation continues until the drill is partly free, when a slip socket is inserted over its upper end and, with the assistance of the fishing jars, it is jerked free from the quicksand.

In connexion with the up-and-down motion given to the drill while it is being removed from the quicksand, it must be raised with each stroke, and in this way gradually freed. The same method of procedure is required where quicksand comes into a well suddenly, the drill being moved up and down as if it were cutting into rock, while at the same time it is lightly raised at each upstroke. This operation must be carried on rapidly, otherwise the sand will pack about the drill and prevent its removal.

If the driller is working in sand of rather fine texture, he draws the drill at night, as otherwise the sand may creep up around the drill and set almost as hard as rock. The drill is seldom left in the well over night on account of the danger from sand or of malicious cutting of the rope, or, in a rock well, or having a boulder fall and become jammed between the drill and the well wall.

Penetration of quicksand.—If the layer of quicksand is only a few feet thick it may be penetrated by bailing out and then driving the casing. The pipe is driven as far as possible into the bed without bailing, and the quicksand may occasionally be passed through at one drive.

A thin bed of quicksand that lies near the surface may be shut off by driving sheet piling around the mouth of the well.

Difficulty caused by quicksand may be partly overcome by filling the bottom of the well with mortar or Portland cement, which sinks through the quicksand and sets. The hole may then be drilled through the mortar or cement, which forms a wall that prevents further inflow of quicksand. Stones, clay, and asphalt have also been dropped or poured into the hole to restrain the quicksand, with some success.

Water pressure.—The head of water which produces the pressure in quicksand is nearly always less than that due to the elevation at which the mouth of the well is located. Some drillers maintain that quicksand can always be penetrated by keeping the drill hole filled with water. If the quicksand lies at a depth of several hundred feet and its pressure head is 100 or

150 feet below the surface, a column of water in the well will exert a back pressure on the quick sand of 43·4 pounds per square inch for every 100 feet of drill hole, which will prevent it from rising in the pipe. The sand bailer may then be inserted and the well may be bailed through the column of water.

It sometimes happens that after bailing out large quantities of quicksand the pipe becomes bent, a fact that is explained by assuming that the quicksand bailed out is removed from beneath a higher layer of firmer material, such as till or clay, on only one side of the pipe, and that the pressure of this material against one side of the lower end of the pipe causes it to be thrown out of alignment. The remedy consists in keeping the hole full of water. This prevents the formation of such an artificial cave; or if the pipe has already become crooked, corrects the trouble by causing the pressure on the pipe to be equal on all sides.

If such cave is formed beneath a layer of till, boulders may fall down from its walls and become jammed against the pipe and prevent it from being driven ahead. The side pressure caused in this way may likewise be at least partly overcome by keeping the hole full of water. If the trouble is not remedied by this means, the process may be supplemented by drawing the pipe until the drive shoe is above the boulder. The boulder may then be crushed with the drill and the pipe driven ahead.

Pumping.—By keeping the shaft full of water, J. E. Bacon, in sinking a large open well at Charlotte, Mich., in 1904, removed quicksand by a powerful sand centrifugal pump. This method was also successfully employed at Millville, N. J., in sinking a well 8 feet in diameter, to a depth of 36 feet, the lower 16 feet being through fine, saturated sand.

Freezing.—Quicksand has been penetrated by shafts by means of freezing. This method was first employed in 1883 by F. H. Poetsch, a German mining engineer, who by using it sunk a shaft in a mine near Schneidlingen, Prussia, through a bed of quicksand about 18 feet thick, lying about 100 feet below the surface. As other methods had proved unsuccessful, Poetsch drove pipes into the quicksand and circulated through them a refrigerating brine which froze a wall of quicksand 5 feet thick around the proposed shaft. Excavation was continued within this wall, and the shaft was carried downward through and below the quicksand. The same engineer later excavated through 107 feet of quicksand by the same means. The process has also been used in this country in sinking a number of shafts, one of which is described by D. E. Moran.[1] The machinery used in freezing the quicksand consisted of the following essential parts:

1. An ammonia compressor or pump with suitable motive power.

2. Pipe coils surrounded by constantly changing cooling water. In these coils the compressed and heated gas coming from the ammonia compressor is cooled to such a temperature that, at the pressure existing in the coils, it condenses to the liquid form.

3. A valve, regulating the flow of the liquid ammonia from the above described coils into—

4. A second set of pipe coils, surrounded by brine or other vehicle. The liquefied ammonia passes from the regulating valve into these coils and immediately expands, absorbing the necessary heat from the surrounding brine. From the coils the gas is led back to the compressor, completing the cycle.

The brine used was a 60 per cent solution of the impure calcium chloride of commerce. The cold brine was pumped from the refrigerating tank through a system of distributing pipes and regulating valves to the ground pipes, and after circulating through these it returned to the refrigerating tank, the velocity of the brine in the downward flow pipes being about 2 feet a second. No protection was given to the connecting pipes above ground, so that these were soon covered over with a snow-like ice, the result of condensation from the atmosphere, and this served as a cheap and effective lagging.

Soon after the brine was started in circulation the ground began to freeze around each pipe, forming frozen cylinders, which increased in diameter until at the end of six days adjacent

[1]Moran, D. E., The freezing process as applied at Iron Mountain, Mich., in sinking a shaft through quicksand: School of Mines Quart., vol. 2, 1890, pp. 237-254.

cylinders intersected and made a circular wall extending from the surface to the bottom of the drive pipe and thus formed a cofferdam inclosing the proposed shaft. Excavation was then begun inside this cofferdam, and no water came through the frozen wall at any time. The rate of freezing differed in different parts in the deposit, depending on the amount of water the parts contained. The smaller the amount of water the longer it required to effect freezing.

Some of the physical qualities of the frozen quicksand were noted.

Frozen quicksand may be regarded as a mortar in which the cementing material is ice, and, as in a cement mortar, the strength will probably be found to depend on the quality of the sand and the presence of sufficient cementing material, as well as on the strength of the cement.

Frozen quicksand looks like a fine-grained sandstone. It is perfectly homogeneous, breaks with a tendency to conchoidal fracture, and is hard to work as a stone of similar character. When mixed with gravel or boulders the mass resembles conglomerate or a concrete made with similar stone. The difficulty of working the material is more than doubled by the presence of gravel, which greatly increases its density and dulls the pick points or "moils" of the miners. The strength with which the quicksand adheres to the stone is shown by the line of fracture in such material. There seems to be no tendency for the rounded boulders to pull out of the quicksand, but rather for the break to follow the shortest line, whether through flint or quicksand.[1]

Quicksand beds that lie near the surface can be thus frozen without very great expense, but the expense of freezing beds that lie at depths of over 100 feet will probably be great and the process will be slow.

GENERAL DRILLING OPERATIONS.

Casing.

Primitive methods of casing.—As elsewhere stated, deep wells in the Orient are sometimes lined with bamboo or hollow tree trunks for casing.

[1]Op. cit., pp. 248-249.

Some bored water wells in Arkansas and Florida even, are lined with wood. This is ineffective as a means of preventing contamination; and besides has the disadvantage of decaying in time and adding organic matter to the water. A better casing for bored water wells is clay tiling, now frequently used.

Modern Methods—Conductor Box.—In many places the surface material consists of loose sandy clay, sand, and gravel, varying in thickness (in the Pennsylvania oil regions) from a few feet on the hills to several hundred feet in the valleys. To restrain this material, which would otherwise impede the work of drilling, a conductor box, made of plank, circular, square, or octagonal in shape, and 8 inches to 20 inches across, is sunk to the bed rock. If the rock lies only a few feet below the surface the necessary excavating is done by hand; if the soil is deep, a large drilling bit is used to spud down a hole, into which the conductor box or a section of large iron pipe may be sunk as fast as drilling proceeds.

Drive-pipe or conductor.—In starting a well it is the custom to extend what is known as a conductor or drive pipe from the surface to as great a depth as can be driven by ordinary driving methods, through the superficial formations to the solid rock. Years ago it was the custom to use a wooden conductor made of planks for this purpose; but at present the metal drive pipe is used almost exclusively. The ordinary sizes of the drive pipe are 10, 8, 6, and $4\frac{1}{4}$ inches in diameter. The length of the drive pipe varies very greatly; being in some parts of Ontario and elsewhere as much as 100 or 200 feet, while in other localities the solid rock comes to the surface and no pipe line is required.

The casing.—The casing of a well is not properly equipment used in its construction, but is rather part of the material which is used up in sinking the well; in other words, the rig machinery, rig and drilling tools can be used again in sinking some other well after the completion of the first, while a casing becomes a part of the well and is never used again, unless the well is a failure, in which instance it is pulled out and used in another well. The principal object of the casing is to shut off water which is encountered in the upper strata penetrated, but casing is also of service in preventing the caving of formations which are very soft. In most deep wells, casing of several different diameters is used; the larger sizes being put in the upper part of the well and smaller sizes used successively with depth.

The methods of casing vary somewhat according to the different methods of drilling; but the general principles are substantially the same, namely, that when a strong flow of water or dry caving formation is encountered, a casing should be inserted to line the well just as soon thereafter as a hard stratum can be reached in which the casing can be set. When once a casing has been set in a formation firmly to shut off the overlying water, it is then possible to drill deeper with a bit of smaller diameter until a deeper water vein be encountered, when a second string of casing is required, which will of necessity be of smaller diameter than the first.

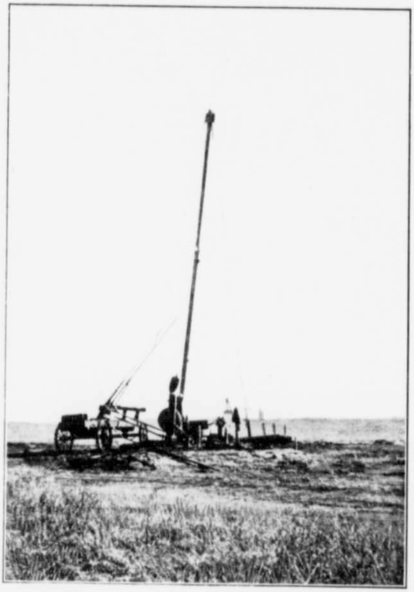
Casing is of various types and the type used in any particular field must correspond with the local conditions. The sizes of casing in common use in the oil fields are as follows:—

TABLE XIII.

Dimensions, etc., of Lapweld Casing.[1]

Diameter, Inches.			Nominal weight per foot.	Thickness, inches.	No. of threads per inch.	Outside diameter of couplings, inches.
Nominal.	Internal.	External.				
2	2·06	2¼	2·22	·095	14	2¾
2¼	2·282	2½	2·82	·109	14	3
2½	2·532	2¾	3·13	·109	14	3¼
2¾	2·782	3	3·45	·109	14	3½
3	3·01	3¼	4·10	·120	14	3 13/16
3¼	3·26	3½	4·45	·120	14	4
3½	3·51	3¾	4·78	·120	14	4¼
3¾	3·732	4	5·56	·134	14	4½
4	3·982	4¼	6·00	·134	14	4¾
4¼	4·218	4½	6·36	·141	14	5
4¼	4·094	4½	9·38	·203	14	5
4½	4·468	4¾	6·73	·141	14	5 7/32
4½	4·344	4¾	9·39	·203	14	5 7/32
4¾	4·704	5	7·80	·148	14	5⅝
5	4·954	5¼	8·20	·148	14	5 11/16
5	4·867	5¼	9·86	·191	14	5 11/16
5	4·753	5¼	12·80	·248	11½	5 13/16
5	4·65	5¼	15·88	·300	11½	5 11/16
5 3/16	5·187	5½	8·62	·156	14	6 3/16
5 3/16	5·042	5½	12·49	·229	11½	6 1/16
5⅝	5·688	6	10·46	·156	14	6⅝
5⅝	5·594	6	12·04	·203	11½	6⅝
5⅝	5·560	6	14·20	·220	11½	6⅝
5⅝	5·457	6	16·70	·271	11½	6⅝
6¼	6·280	6⅝	11·58	·172	14	7 9/32
6¼	6·219	6⅝	13·32	·203	14–11½	7 9/32
6¼	6·149	6⅝	17·02	·238	11½	7 9/32
6⅝	6·640	7	12·34	·180	14	7 11/16
6⅝	6·503	7	17·51	·248	11½–10	7 11/16
7¼	7·265	7⅝	13·55	·180	14	8 5/16
7⅝	7·617	8	15·41	·191	11½	8 21/32
7⅝	7·482	8	20·17	·259	11½	8 21/32
8¼	8·265	8⅝	16·07	·180	11½	9⅜
8¼	8·167	8⅝	20·10	·229	11½	9⅜
8¼	8·082	8⅝	24·38	·271	11½–8	9⅜
8⅝	8·640	9	17·60	·180	11½	9⅞
9⅝	9·577	10	21·90	·211	11½	10 29/32
10⅝	10·594	11	26·72	·203	11½	11⅞
11⅝	11·594	12	30·35	·203	11½	12⅜
12½	12·457	13	33·78	·271	11½	14
13½	13·432	14	42·02	·284	11½	15
14½	14·416	15	47·66	·292	11½	16⅛
15½	15·416	16	51·47	·292	11½	17⅛

[1]Catalogue of Oil Well Supply Co.



Machine set for pulling casing, Muskagee field, Okla., U.S.A.

Pulling Casing.

After casing has been in a well for a time the formation settles around it, sometimes making it difficult to remove it. If it cannot be pulled out in the ordinary way with blocks and lines, hydraulic jacks are used. If the bottom of the casing will not yield to the pressure of the jacks, it is usually parted. The upper part is pulled out. If a collar is left on the casing in the hole a steel die is attached to the collar and the casing is then pulled out. It is lowered again and the die firmly screwed into the casing below. If the collar is pulled off the casing left in the hole a steel collar with cutting dies is sent down and firmly screwed onto the casing. A casing cutter is then sent down on a string of tubing and the casing is cut off where it is thought the obstruction is holding it. If the first cut does not release it, it can be cut again and again each time higher up, until it is released.

Squibbing the casing with nitro-glycerine is the quicker and less expensive way to loosen it when there is no water in the casing to damage it by the explosion. This is done by filling a small tin tube with nitro-glycerine and attaching this tube to a wire line with a firing head attachment; on the bottom of the tube a piece of stiff V-shaped wire is attached, the points coming up on either side of the tube and extending to the casing. The points drag along the casing while the squib is being lowered. When the objective point is reached, the squib is pulled slowly until the points of the wire come to a collar, when they usually catch the bottom of the upper joint of casing and hold the squib; a piece of small pipe through which the wire has passed in lowering the squib is released; it drops upon the firing head. The explosion which follows separates the casing.

The size of the hole is always governed by the contemplated depth of the well, and the anticipated difficulties to be encountered.

In wild-cat wells, or wells drilled in undeveloped territory, sometimes an 18-inch hole is started which is drilled below the surface sands, which may contain water. Casing 16″ inside diameter is then placed in the hole and all water found to this level is shut off. The hole is then continued 16″ in diameter to other water sands and casing of $12\frac{1}{2}''$ inside diameter is inserted; the hole is again continued $12\frac{1}{2}''$ in diameter to another objective point, when casing 10″ inside diameter, 45 pounds to the foot, is inserted; the 10″ hole is then continued through the deeper water sands or cavey formation, when casing $8\frac{1}{4}''$ inside diameter, weighing 24 pounds to the foot, is inserted; the hole $8\frac{1}{4}''$ in diameter is then continued, usually to the top of the oil producing sand, when casing $6\frac{5}{8}''$ inside diameter 17 pounds per foot is put in, which shuts off all cave and water found above the oil-bearing sand. If, however, other difficulties arise and it is found necessary to use additional casing, casing $5\frac{3}{16}''$ inside diameter, weighing 13 pounds to the foot is put in.

In the event any of the strings of casing placed in the hole have not reached a sufficient depth to shut off water or caving as anticipated, the casing is pulled up eight or ten feet from the seat upon which it rests, and is suspended from clamps which securely hold it at the mouth of the hole; then a tool called an under-reamer is inserted and when it passes out of the lower end of the casing in the hole, it expands sufficiently to meet the wall of the larger hole and the shoulder or former seat of the casing is reamed so that the larger hole is carried to the point where it is desired the casing should be re-seated, in order to shut off water or cave which may have been encountered; the casing is then lowered on the shoulder or seat made by the under-reamer.

In proven territory, where conditions are well known and after a well has been fully completed and put in producing order, all of the larger sizes of casing are usually pulled out of the hole, leaving the inside string to shut off all water and cave from the oil-producing sand. The casing so removed can be used in additional wells, which greatly reduces the cost of operation.

Packing.—The importance of proper casing can not be over estimated. An important precaution with artesian wells is to make sure that no water escapes between the outside of the casing and the surrounding rock.

The usual method of preventing such an escape is to surround the casing just above the water-bearing stratum with a seed-bag, *i.e.*, a bag made of leather or rawhide and filled with dry flaxseed. The latter absorbs the water and by swelling it expands the bag so as to shut off all escape of water outside the pipe. The method of attaching the bag is shown in Plate XIII. Another method of shutting off the water is by means of rubber disks described later on.

In order to prevent water from entering an oil or gas well, the casing is set as tightly as possible on some tight rock below the point at which the water would enter. A small amount of water may enter at this point without doing serious damage, provided the pressure of the oil is strong and flushes invading water to the surface. Frequently, however, the amount of water which would thus enter is so great as to require special precautions known as packing. The water from casing wells should be packed in as completely as possible, otherwise it will accumulate in the well and frequently, by hydrostatic pressure, stop the flow of gas. In the early days of oil exploration, a bag of flax seed was sometimes inserted at the point where the casing was to be set. The seed swelled rapidly, closing the cracks between the end of the pipe and the rock. In other cases the bag of flax seed is placed around the casing where it is desired to fill the crack between the casing and the wall of the well.

Patent Packers.

While there are too many patent packers to be mentioned in detail, a device in most common use is made of two metal cylinders with rubber between, one or two inches thick and varying in length. Such a packer is lowered into the well by lengths of pipes to the position it is to occupy. A weight is then dropped into it which relieves a string, causing the two cylinders to approach and bulge the rubber out into the space to be filled. If the problem is to shut off water from the bottom of the hole, the packer consists of a rubber plug with a tapering hole. The top mandrel of wood or iron is driven into the block and expands the rubber to fit the wall of the well and shut off the water below.

Mr. Coste states that the wells at Bow Island are packed with a lead packer to keep out water from below. There are two of these wells which penetrated strata containing salt water and had to be packed.

The city of Iola, Kansas, is cleaning out the old gas wells by a simple method. The well is cased with 1½″ pipe. After it has been drained by the demands of the consumers and water has seeped into it until the gas no longer is forced upward, a smaller pipe is placed inside the first and connected at the top by a T shaped pipe, one side of which is connected with a drip reservoir and the other with the main gas line. From the drip-pan another pipe leads back into the well again.

When the smaller pipe is placed inside the large one, pressure is increased because of the smaller area of resistance. The water is forced up through the pipe even by the pressure of the old worn-out well and as the well cleans itself, the pressure grows stronger. The water is caught in the drip-pan, while the gas passes on through the pan, back into the pipe and is in turn forced back into the main, the T pipe being regulated by a valve which is operated to suit the conditions under which the well is being cleaned.

When medium size gas wells show water, it is best to use a ¾″ siphon or water line hanging from the top inside of the tubing and with a blow-off on the top end. The bottom of the siphon should be plugged and hung one foot from the bottom of the well. The joint of the pipe opposite the main gas sand is perforated with ¼ inch holes. Both sides of the pipe are drilled through and spaced one foot apart. If blown often, this method keeps the water out of the well. Where there is no floating sand in the well, the same method can be installed with a 1″ working barrel and anchorage on the bottom of the ¾″ pipe, using the ¾″ pipe as a sucker rod as well as a conductor for the water. The top of the ¾″ casing should work through a stuffing box on the top of the tubing with a small walking beam and gearing, using a horse for power, or a two to four h.p. gas engine.

In equipping gas wells with ¾″ water pumping outfits where the size of tubing is over 3″, a cast iron spider can be used on every second or third joint. The spider fits loosely in the tubing and is made to slip over the $\frac{3}{4}''$, but not large enough to slip by a $\frac{3}{4}''$ collar. This method prevents the $\frac{3}{4}''$ from weaving while pumping.

Screening.

Where wells are sunk in fine sand, etc., a screen must be used which will permit water or oil to enter, but not sand.

In Texas oil fields the screens or strainers are made of ordinary pipe, with perforations usually 2 to 6 inches apart. The pipe is then wrapped around with iron wire. If the sand is fine, the wire is wrapped close, if it is coarse, space is left between successive wrappings. This kind of strainer is supplied by machine shops throughout the oil fields, and can be made by any mechanic. Frequently the casing is perforated with slotted holes after being set.

Patented strainers are also used. Some makes, like the Layne strainer, differ from the shop-made ones in the shape of the wire used. In the Layne and similar streamers the wire has a triangular section and presents a narrow surface to the sand, and thus reduces the clogging of the screen and insures greater production and a longer life to the well.

Capping.

This operation merely consists of placing a gate on the tubing or casing and shutting in the well.

If in drilling a gas well a volume greater than 35,000,000 cubic feet daily capacity is anticipated, and the conditions of the well are favourable for casing to be used in place of tubing, a gate is screwed on the casing and the size of the drill or bit reduced just before drilling into the gas vein. If reducing the size of the bit is objectionable, a swedge nipple is used and a gate one size larger than the casing.

Torpedoing.

The torpedoing of oil wells with nitro-glycerine dates back almost to the very beginning of the oil industry, and there is no part of the construction and operation of oil wells which demands more careful attention. The very dangerous character of the high explosive is too well known to require comment here, but, regardless of danger, nitro-glycerine is freely used to stimulate the production of declining wells and is always used in torpedoing new wells when completed where the sand is found of a close hard texture.

Locating the glycerine in the pay sand is of the greatest importance. If the torpedo is allowed to extend above the pay sand, the barren formation shattered by the explosion will fall down and cover the pay sand, greatly interfering with the operation and production of the well.

A selfish competition among producers often prompts the use of large torpedoes, with the hope of shattering the pay sand to such an extent as to let the oil come more freely to the hole from a great surrounding area. Where large torpedoes are used in wells with limited pay sand, the barren formation is usually shattered to such an extent as to render the wells valueless.

The experienced and conservative producer will not ruin his property in this way. If he has a well with ten feet of pay sand, which he desires to torpedo, he will place 20 quarts or $66\frac{2}{3}$ lbs. of glycerine in a shell $5\frac{1}{2}''$ in diameter, and 4 feet, 4 inches in length. An anchor, consisting of a tin tube of sufficient strength to support the weight of the torpedo, and of sufficient length to elevate the top of the torpedo to within three and one-half or four feet of the top of the pay sand, is attached to the bottom of the shell. The shell is attached to a line with a hook which releases its hold of the shell when it reaches the bottom of the hole and after the torpedo is placed in this way, the careful operator, to guard against any possible error in calculation, or in danger of some obstruction preventing the torpedo from going to the objective point, will take a steel line measurement to determine the exact location of the torpedo before it is exploded. Should the torpedo be found misplaced, it is fished out of the hole; the obstruction is removed, or the anchor is shortened or lengthened, as the case may require, to bring the shell to the desired place in the pay sand.

When the explosion occurs, the fluid and much shattered sand is usually thrown out of the hole. Should the shattered sand settle into the hole made by the explosion, it is taken out by the use of tools made for this special purpose. When the hole is thoroughly cleaned, it is usually sufficiently large to admit several torpedoes of the size of the first one used, being placed in the same space in the pay sand.

When the shell of a subsequent torpedo is released from the line which carries it to the bottom of the hole, there being no wall to support it, it falls over in the hole; additional shells can be placed in the cavity, or shot hole, and in this way, the size of the torpedo greatly increased, and at the same time kept in the pay sand.

Shells used in subsequent torpedoes, or where the wall of the hole will not keep them in a perpendicular position, should be so constructed that the opening in the top of the shell through which it is filled, can be corked to prevent the glycerine from escaping from the shell.

The old style plan of exploding torpedoes in oil wells consisted of a small tin tube attached to the top of the torpedo shell and extending down on the inside into the glycerine. In this tube were several small steel pins fitted to percussion caps. A longer pin came up through the top of the tube and shell and connected to a flat cast iron disc, nearly the diameter of the top of the shell; this pin or rod made a connexion between the disc and the pins carrying the percussion caps.

When everything was in readiness to explode the torpedo, the "go-devil," a cone-shaped cast iron weight, was dropped from the top of the hole, which struck the disc on the top of the torpedo with the desired results.

Many premature explosions caused a change in this method of exploding torpedoes. The glycerine jack squib is now being generally used. This squib consists of a tin tube about ¾″ diameter, and two feet in length. A 3 minute fuse, with a fulminate cap attached to the lower end, is wound around the tube to the top and extends several inches above the tube. The tube and fuse are placed inside of a larger tin tube about 2″ diameter, and slightly longer than the inner tube. Dry sand tamping fills the space between the two tubes. The top of the larger or outside tube is turned in and pressed down on top of the sand, keeping it in place. When everything is in readiness to explode the torpedo, the inner tube is filled with glycerine and corked; the fuse is then lighted and the jack is dropped into the hole. The explosion usually follows.

It is desirable to have fluid tamping on top of the torpedo. Where this cannot be done on account of the proximity of the casing to the top of the sand, large torpedoes cannot be used with success.

Electric Torpedo.

When it is found necessary to case a well near to the top of the pay sand, it cannot be given a large torpedo safely in the pay sand without great danger of damaging the casing. In cases of this kind the well is given an electric torpedo, as follows:—

The torpedo is placed in the proper location in the hole; a squib containing two or three quarts of glycerine attached to an insulated wire is then lowered to the top of the torpedo. The casing is pulled out of the hole over the wire and the squib is exploded by a battery and it in turn explodes the torpedo. The casing is again put into the well, the hole cleaned out and the well put in producing order.

This style of shooting should only be resorted to in newly developed territory where there is a good rock pressure. In old territory where the rock pressure is low and where much oil has been taken out of the sand when the casing is removed, the water and cavings which have been shut off by the casing are allowed to flood the sand. When the torpedo is exploded the column of water offers more resistance than the rock pressure of the sand, with the result that the mud and water is blown into the pay sand and the well greatly damaged, and in many cases totally destroyed.

There are times when wells flowing large quantities of oil can be improved by torpedoing. This is a dangerous proceeding which is usually accomplished in this way. If the well is flowing by heads, careful gauges of its production are taken, noting the time between flows and the quantity of oil produced at each flow. When the maximum flow is ascertained in this way, it is known almost to a certainty how much time will elapse before the well will flow again. The torpedo is prepared, the well is watched closely; when it flows the gauge is taken and if it has produced the maximum flow there will then be sufficient time to lower the torpedo safely before the well will flow again. If the well did not make its maximum flow it will come in again in less than the usual time and if the well should flow while the torpedo is being lowered, it will be thrown out of the hole with disastrous results.

When a torpedo is safely landed in the pay sand, it will not be thrown out by the flow. The torpedo shooter is usually waiting for the well to flow and while the hole is empty or the oil which has been left in the hole is held in suspension by the gas, the torpedo is exploded safely without damage to the casing.

If a well flows continuously and the production is large, "well enough should be left alone." Such wells should not be torpedoed. If, however, the wells are gassy, and do not produce much oil, and the owner desires to torpedo with the hope of increasing the production of oil, and in the event the gas pressure offers too much resistance to permit the torpedo to be lowered into the hole, a weight sufficient to overcome the gas pressure is attached to the bottom of the torpedo which carries it to the bottom of the hole.

The Petrolia wells were shot with 8 to 10 quarts of nitroglycerine, the charge being much smaller than in the Pennsylvania fields, where 80 to 90 quarts are frequently used.

Shooting has been tried at Brantford, but as it does no good, the wells are not now shot.

FLOWING WELLS.

When wells are new, there is usually sufficient rock pressure to flow the production. Where the production is large and especially where there is much gas coming with the oil, the lead lines conducting the oil from the mouth of the hole to the receiving tank should be of sufficient capacity to relieve the well of all the back pressure. This, however, cannot be done in parts of Louisiana and Texas where some wells flow the sand out with the oil to such an extent as to wear out the heavy six-inch pipe used for lead lines within a short time. Such large wells in the districts referred to, when allowed to flow unrestrictedly, usually drill themselves into water; when the oil is greatly damaged by being cut or mixed with the water to such an extent as to make it difficult and expensive to refine it.

Where gas is found in large quantities above the oil producing sand and allowed to come in contact with it, it not only greatly interferes with the production of oil, but the oil which is produced is usually blown into the tank with much force and often much of it is lost, and the gas itself, a most valuable product, is lost entirely. This waste of oil and gas can be avoided in nearly every instance by the use of an extra string of casing. The bottom of the casing is supplied with a special gas packer to be lowered to a point below the gas, where the packer is set, which will prevent the gas going down by the bottom of the casing. An appliance called a stuffing box casing head is then attached to the top of the larger casing and the gas safely and securely confined between the two strings of casing. Suitable holes in the stuffing box head supplied with gate valves will control the gas and allow it to be utilized as needed. In this way, the production of oil and gas coming from the same well can be utilized.

The method by Pollard and Heggen for controlling great gas pressures so as to allow drilling to deeper oil sands, is referred to in the chapter on conservation.

PUMPING WELLS.

As the rock pressure of the oil sand or gas sand works off, the wells cease flowing and it becomes necessary to equip them for pumping. In good territory, where wells will pump a good production, each well is usually operated with an individual engine, which is used not only to pump it on the walking beam but also to pull the pumping equipment from the hole when necessary.

Pumping well, showing connexion with cam wheel.

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As the production declines, a central pumping power plant is installed. All wells are connected by iron rod lines to cam wheels in the power plant, which is driven by a gas engine. As the power plant is always centrally located, the rods in the wells on one side of the plant are dropping, while the rods in the wells on the other side are being pulled up. This forms a kind of teeter, it balances the strain on the cam wheel and relieves the power.

The oil when it comes from the well is conducted through a system of gathering lines to storage tanks, where it is measured and sold to the pipe line, or purchasing companies.

Where wells produce salt water from the same sand which produces oil, a separator for separating the water from the oil should be used and the salt water should not be allowed to go into the storage tanks.

Where a well produces water with oil, and in the event the valves are not kept in perfect condition, the leaking of the oil and water back through the valves will cut the oil to such an extent as to render it unmerchantable. In order to reclaim such oil, it must be heated by steam to a temperature of 80°F. and allowed to stand for several days during which time the water usually settles to the bottom of the tank and is drawn off, leaving the oil of a gravity to meet the pipe line requirements.

Wooden tankage is generally used on producing properties, ranging in capacity from 100 bbls. to 1600 bbls. To avoid evaporation, wooden tanks should be securely decked and housed. The lead line carrying the oil from the wells to the tanks should be buried before reaching the tanks to guard against lightning following the lines into the tanks.

COST OF DRILLING.

Only for well developed oil fields is it possible to give any general statement of the costs of drilling, and even then the prices per foot are subject to great variations under exceptional conditions. The following table shows in some cases the usual total cost in established fields and in others the price per foot, while in newer regions the cost of individual wells is mentioned.

As a rule in the Ontario fields the thrift of the oil and gas industry is much more advanced than it is in similar fields of the United States. While wells in some of the large fields of the United States have been abandoned sometimes in cases where they produced as high as 10 or 20 barrels per day, wells in the old Ontario fields, on the other hand, are seldom abandoned until the production falls to a few gallons.

TABLE XIV.

Cost of Drilling Wells.

Locality.	Standard Method.	Canadian Method.
Brant county		
Brantford fields		$ 800.00
Onondaga "		
Ontario.		
Petrolia		160.00
Bothwell		500.00
Haldimand county.		
Carlow..................	$ 700.00	
Simcoe.	1.35 per ft.	
Port Rowan	2,900.00	
Caddo, La.................	12,000.00	
Northern Alberta.		
Pelican		25,000.00
Central Alberta.		
No. 2 Tofield	9.50 per ft.	
No. 3 Tofield	7.50 per ft.	
Vegreville	9.00 per ft.	
Wetaskiwin	10.00 per ft.	
Southern Alberta.		
Medicine Hat............		7.25 per ft. for 10″ hole. 6.50 per ft. for 6″ hole.
Brooks station		40,000.00
Lethbridge		10,000.00
Gaines, Pa.	.65 per ft.	
Summerland, Cal...........	.85 per ft.	
Northern Mississippi valley..	.75 per ft.	
Eastern Washington	2.50 per ft.	
Texas.		
Beaumont field	4.00 per ft.	

In Ontario in the early days it naturally took a long time to put down a well, as the methods were not improved as they are at present. In 1868 it sometimes took six months to drill a well. In 1890, however, a hole could be drilled in four or five days at a cost of $160 per well, the owner of the well furnishing the casing. After the well is finished the pump is inserted by the driller and the well is tested for a day.

In the Petrolia fields a drilling gang consists of six men, three working in the day shift and three in the night shift. Pole tools are used, consisting of a bit and an iron bar about $3\frac{1}{2}''$ in diameter connected with the walking beam above by poles.

Owing to the decline in production and the abandonment of most of the oil wells in Ontario, it has been necessary for the men employed in the contracting and drilling business to seek employment elsewhere. The Canadian drillers, being very expert, have been in great demand, and have now moved to all parts of the world, including Germany, Austria, India, Burma, Mexico, Australia and some have even gone to Pennsylvania.

The cost of sinking an ordinary well in the Petrolia fields in the early days of development was about $1500. The cost in 1890 had dropped to $150 or $160, which is as cheap as wells can be drilled in almost any oil field in the world, with the exception of Oil Springs, where the depth is 100 feet less.

In the Petrolia field the plan was to drill one to ten oil wells to an acre, and it was supposed by the oil men that if less than four wells to the acre were drilled, the territory had not been thoroughly tested.

Wells in the Petrolia field are kept in good condition by occasionally cleaning them, which custom has been followed in recent years.

In the last few years wells have been rapidly abandoned in the old fields of Ontario.

In the Simcoe field, Ontario, American standard rigs are used in general, with 72 foot derricks, although there are several Canadian cable rigs in the field. Drilling as a rule, is done by contract at $1.35 per foot, the company furnishing water and charging 10 cents for gas, or a net price of $1.25 per foot for drilling alone. It costs from $2,900 to $3,200 to drill and equip a producing well in the Port Rowan district, the higher price being accounted for from the fact that American drillers use more iron in the well. Canadian rigs can drill better in a wet hole with a steel cable than the American; but the Americans can drill faster in a dry hole with a manilla cable. On this account the American drillers case off the water at from 600 to 700 feet, this accounting for the extra cost of such wells. Canadian rigs take from 24 to 28 days as a minimum, up to 60 days, to complete a well. The well on the Clemens farm was drilled in 24 days. But the average time to build the derrick, drill the well and tear down the derrick again is two months. The rock is sharp and hard on the bits. Pole tools could not be used with ash rods, although possibly solid iron rods could be used in this field. A new wire line is necessary for each well, on account of the hard drilling and the great amount of corrosive sulphur and mineral water. Farther east, in Selkirk, eight or nine 800-foot wells are drilled with one line.

The average cost of a 400-foot well in the Bothwell pool is about $500. Pole tools are used as a rule, and the derrick is removed upon completion of the well. A small three-pole or tripod derrick is then used for pulling the tubing and cleaning the wells. Most of the wells are pumped by iron or wooden shackle rods from a central steam plant, although several internal combustion oil engines are in use at present.

In the Petrolia field in Ontario wells were commonly $4\frac{5}{8}''$ in diameter, and where cased they are reamed to accommodate a casing of $5\frac{1}{8}''$ outside diameter. The wells were drilled in five or six days and the cost was $150 to $160. This was in 1890, but in the early days of the field the cost ranged from $1 to $3 per foot and the time occupied was from two to six months. Wooden rods were generally used instead of cables. The drilling was done in three shifts of three men each. The great majority of the drillers from the old Petrolia field have since gone to fields in Europe and Asia, being in great demand.

In the Vienna pool in Elgin county, both Canadian and American standard rigs are used, but the latter predominate.

In Ontario it is the custom to drill 10 feet through the White Medina, this giving a pocket in most wells below the pay stratum, of 113 to 125 feet. In one well the bottom of the Red

Medina was struck at 1,067 feet, and the well was drilled to 1,180 feet in depth.

In Haldimand county wells are largely drilled by contract. In the eastern part of the field they only cost from $1,000 to $1,200. In the Carlow field both cable rigs and drilling machines are used. One standard American rig with 64-foot derrick is in use and one steel derrick is giving good satisfaction. The average cost of drilling a gas well in the Carlow field is $700. Pockets of 50 to 100 ft. are drilled. In the Selkirk and South Cayuga fields gas wells are drilled with 50-foot pockets below the last producing stratum. By practice it has been found that this is necessary to keep the face of the sand clear, the pockets serving as a catchment for water and oil seepage, and also for the accumulation of sediments. One company, the Standard Natural Gas Company, has recently gone over all the wells and drilled all pockets deeper to 100 feet, claiming that they could be cleaned with greater facility.

The cost of drilling and equipping a producing well in the Onondaga pool of Brant county, including pump, tanks, etc., is about $900. Drillers contract for $800 to do the drilling alone, which is done with a standard Canadian rig, with a 55-foot derrick. Wells are cased to the top of the Clinton sand with 5⅝ inch or 6¼ inch casing.

The spacing of wells in this pool would be considered too close in many fields in the United States, especially in the paraffin oil fields. However, while at one place there are 22 wells in ten acres, and in another as many have been drilled in a five acre space, yet they are all small producers, and experience in the Petrolia and Bothwell pools has been of such a nature as to indicate that where like underground conditions govern, the most efficient recovery is obtained by a large number of wells. However, as the oil in the Onondaga field contains a greater proportion of the heavy paraffin, there being more gas associated with the oil and the productive formation being of a different nature, the rapid decline of wells in this field would seem to indicate that different handling was necessary from that of wells in the older oil fields of Ontario.

At Brantford they drilled a pocket for the oil, but not for the gas. It takes ten days or so to complete these wells. All the Brantford wells are small in volume. Most of the drillers in this field use standard rigs or petrolia rigs, but there are some Star drilling machines in the field; the Star drilling machine drills with a mast. Mr. Carmody has a 50-foot derrick, which he bolts together. It can be taken down in one day. He reports it good for drilling from 25 to 30 wells. He does not use a house over his engine in the summer time. The price paid for wells in the Brantford and Onondaga fields is $850. A contract is made at this price to drill 40 feet below the White Medina sand.

He states that all the wells have a pocket of 40 feet in the red shale below the sand, which gives room for the water to settle.

The machine wells at Brantford are drilled with masts. The Dominion Natural Gas Co. would drill one well to every 100 acres if they were let alone, but the other companies of course will not observe this rule.

The wells throughout the old Kent county field were drilled by the Canadian rig. When the wells were completed the rig was removed and a three pole rig erected for use during pumping of the wells. The power was transmitted by shackle rods operated by a gas engine at a central pumping station. In these fields the wells average 500 feet apart but are irregularly spaced.

The best time made in drilling a gas well in the Tilbury-Romney field is reported to be 17½ days for a 5⅝" hole, which was drilled to a depth of 1,362 feet by the Beaver Oil and Gas Company. American standard rigs with 72-foot derricks are used.

The principal objection to the American standard drilling rigs is that the driller is obliged to pay a duty on the United States materials. This is essential in the case of the deep sand pools, such as the Tilbury-Romney gas field, for the reason that the Canadian pole tools cannot be used in the deep wells.

In the Delhi field Canadian standard rigs are used for drilling, all drilling being done by the Company, which is cheaper than contract drilling. No tubing is used at Delhi, cheapening the cost of the wells.

THE CASING OF OIL WELLS.

By Ralph Arnold and V. R. Garfias.

GENERAL STATEMENT.

Oil wells generally are lined with wrought iron or steel casing, the depth to which any column or "string" is carried depending on the nature of the formation, the location, number, and importance of water and oil-bearing strata penetrated, drilling method employed and the ability of the driller.

As the nature of the formations penetrated by the well varies, not only in different fields but in distinct areas in any one territory, it is out of question that uniform methods of casing wells should prevail. For instance, the strata overlying the oil beds in some of the Russian fields are so incoherent that only comparatively shallow depths can be attained before the casing is frozen. For this reason it is customary to start a well of large diameter, a 40-inch hole not being uncommon. The opposite conditions are encountered in certain fields in the Eastern United States where it is possible to drill 2,000 feet or more without the necessity of lining the well, except to exclude the water before tapping the oil-bearing beds. Somewhat similar conditions prevail in parts of the Mexican oil fields where the wells pass through about 2,000 feet of practically impervious shales. Conditions in California, and in some of the Gulf Coast fields represent in a general way an average between those existing in Russia and the Eastern United States, it being necessary to line the hole as drilling progresses, but with less difficulty than in Russia. Thus it is common practice to carry a 10-inch hole for over 2,000 feet.

In drilling for oil it is the aim of the operator to tap the oil-bearing beds with a well not smaller than four inches in diameter.

Wells finished with six or eight-inch casing are usually operated more satisfactorily than with the four inch.

Oil-well casing is manufactured in two general ways: (1) from plates two or three feet in length, lap-riveted to diameters from twelve to twenty inches, and (2) in lap-welded sections twenty to forty feet in length and from four to sixteen inches in diameter. This represents the average American practice; the Russian wells are lined with casings of considerably greater diameter.

RIVETED CASING.

Riveted or stovepipe casing is manufactured from No. 8 to No. 12 steel plates in two to three-foot lengths, from twelve to twenty inches in diameter. To build a string of these short tubes two separate columns are necessary, one fitting tightly inside the other so that the joints between the tubes of one column come in the middle of the tubes forming the other. These two columns are riveted together in lengths from ten to twenty feet before insertion in the hole, and in order to obtain a better bond between the pipes they are indented by hammering with a pointed sledge.

Stovepipe is used for lining the first few hundred feet of hole in order to hold in place the loose surface material. This casing, owing to its smooth outer surface, penetrates more readily the gravel and coarse sediments generally encountered near the surface, and its freedom from screw joints makes it adaptable to heavy driving. The absence of screw joints, however, precludes the easy removal of a complete string of stovepipe, and it is usually left in the well or only partially taken out.

SCREW CASING.

After the stovepipe has been landed, the wells are lined with wrought iron or steel, lap-welded casing. This is made in twenty to forty foot lengths, four to sixteen inches in diameter, threaded at both ends and coupled by a threaded collar, the California standard thread for screw casing being ten to the inch and from three to three and one-half inches in length. The collars have at either end a smooth recess which fits tightly around the casing, thus affording greater rigidity to the string. During the last two years the manufacturers have put on the market casings provided with extra long collars with a deep recess at each end, and when one considers that the most frequent casing trouble in incoherent formations results from weakness of the joints, it is easy to realize the importance of a rigid and strong bond between casing and collar.

At times it is necessary to employ screw casing that will stand heavy driving, in which case the couplings are made so as to allow the joints to abut. The use of this drive pipe is only resorted to when it is thought that its withdrawal is non-essential.

Every string of casing generally is provided with a shoe at its lower end to facilitate its insertion and prevent damage. The shoe is riveted to the stovepipe and screwed to the lap-welded casing, the toothed shoe being a great improvement over the plain type.

As before noted, casings are made of iron or steel, and although each operator may claim all merit for the particular type he favours, it is safe to state that both are equally well adapted to the requirements, the deciding factor being the prevailing price, which now favours steel.

THE EXCLUSION OF WATER FROM OIL WELLS.

By Ralph Arnold and V. R. Garfias.

One of the most important problems encountered in well drilling is the permanent exclusion of water from oil wells. The details of the operation vary according to the location of the water-bearing beds in relation to the oil zone, it being comparatively easy to case off water occurring a considerable distance away from the oil zone, and proportionately harder to exclude water immediately over, between or below the oil-bearing beds and these difficulties are greatly magnified with the increased depth of the wells. The porosity of the formations penetrating the different gravities of the oil and the varying gas and hydrostatic pressure affecting the oil or water are also important factors having a direct bearing on the problem of shutting out the water.

The number of water-bearing beds encountered before the oil-producing zone is reached varies, usually being from one to five. In some fields there exist two or more distinct oil zones and water sometimes occurs between them, in which case the operation becomes doubly important as the greatest care must be exercised in order to effect the recovery of the oil from the different sources without admitting the intervening water.

At one time it was considered sufficient, in order to exclude water, to land a string of casing on any tough sticky shale or flat surface of hard shell encountered between the water and oil-bearing beds, it being considered that sticky shale gave, as a rule, better results. Later, this method was proven to afford in many instances only temporary relief, and at present it is thought that the only permanent means of excluding water is to place cement in the space between the casing and the wall of the hole.

Although there are in use many processes of cementing which differ in minor details, the operation generally is accomplished in one of two ways: (1) by filling with water the space between the inner casing and a column of tubing and pumping the cement mixture through the tubing, whence, unable to flow back between the tubing and the casing owing to the water pressure, it is forced outside the casing; or (2) by lowering the cement mixture in a dump bailer and forcing it to the outside, either by means of a plunger driven down with the aid of water under pressure, or with a plug fitted to the end of the casing. The first method is known commonly as the pump method while the devices used in the latter are variously designated, according to detail, by the name of the inventor.

For a detailed description of the operation one is referred to Technical Paper 32—"The Cementing Process of Excluding Water from Oil Wells as Practiced in California"—prepared by the writers for the United States Bureau of Mines.

Before cementing, it is essential to place the well in good condition, this being particularly true as regards lost or side-tracked casing and tools in the well. If gas appears through the water it should be excluded, as the agitation of the cement by gas often prevents it from setting. It is also advisable to under-ream the lower 100 feet of the well so as to obtain a cavity surrounding the casing, and in order that the latter may not touch the wall. Some operators prefer not to under-ream the lower few feet, so that the casing will be held fast at the bottom, presumably in the centre of the larger under-reamed hole above. In shallower wells a toothed shoe eliminates considerable under-reaming and casing troubles.

Cement, if properly placed, not only permanently excludes water but protects the casing from the action of mineralized waters and reduces the water pressure on the casing. In a number of cases it is found economical to cement all the strings before reaching the oil, and some operators believe that the larger-sized water strings should be cemented as nearly as possible over their entire length as these usually are left in the hole during the life of the territory.

When all the water encountered is excluded by cementing one casing alone, the failure of this one string jeopardizes the life of the well, but additional cemented strings add new barriers between the water and the oil sources, much as the different watertight compartments protect the eventual flooding of a ship. In order to avoid the possible cracking of the cement or the stratum on which the casing rests, it is considered best to support the weight of the string on clamps at the surface.

After the operation is accomplished, should it become necessary to drill through the cement core inside the casing, this is best done with a rotary, as the jarring of the standard tools is very apt to cause the cracking of the cement on the outside. When the well begins to produce, the oil should be tested for water at least once a week in order to ascertain whether the water is permanently excluded.

In certain cases the following procedure may be employed as a substitute for cementing. The hole is filled with muddy water containing about 40 per cent solids, this being forced between the casing and the wall of the hole. The casing is then landed and the well left to stand for a considerable time. In this way the clay held in suspension in the water settles and packs tightly around the outside of the casing, thus providing a natural and efficient water-tight bond between it and the wall.

A very necessary factor in the successful exclusion of water, and, in fact, in the intelligent operation of a well throughout its economic life, is a carefully compiled log, based on the most reliable and minute information. The log should record any water indications and the nature of the formation penetrated; all accidents encountered in drilling, either to tools or casing; and a description of whatever tools or fragments of casing may have been left in the hole together with the exact location of the same. A careful watch on neighbouring wells should also be maintained in order to counteract the bad effects of any carelessness of operation. For example, if the water has not been excluded in a neighbouring well and this is abandoned before reaching the oil beds, any barren sands penetrated by it would be eventually flooded, thus ruining adjacent wells in which the same beds were not cased off. If the defective well has been drilled into the oil, the water thus admitted will eventually force the oil in the reservoir away from the well. In this case some operators consider that the best policy is to shut off the water in nearby wells by landing the water string as near as possible to the oil beds, the presence of water in the wells thus finished indicating that practically all of the oil between these and the flooded well has been removed.

THE PREVENTION OF FLOODING OF OIL WELLS BY WATER.

The following statement of the injury to oil wells by flooding is taken from the report of Isaiah Bowman.[1]

Irremediable injury is constantly being wrought in both old and new oil fields by "flooding"—the invasion of the oil or gas bearing stratum by water from some higher source[2].

As water is heavier than either oil or gas, it displaces these substances or becomes mixed with them, and not only damages

[1] Isaiah Bowman, Well Drilling Methods, Water Supply Papers, U. S. Geol. Surv.

[2] The term "flooding" is also used locally in another sense with reference to cleaning wells.

the well into which the water first enters, but also floods the contiguous sands and may result in the destruction of an oil district.

In some wells flooding produces a mixture or emulsion of oil and water, which in the rock can only very slowly separate again under the influence of gravity.

Oil usually rests on salt water, and in order to keep the well in good condition as long as possible the oil should be pumped off the water slowly. In a state of rest the oil and the water are separated by gravity. The flow of oil from a well producing 500 barrels a day is so slow that it does not disturb the water, but if the amount is as great as 5,000 barrels a day the oil is drawn over the water so rapidly that the two are to some extent disturbed and the water is drawn into the porous beds containing the oil.

An emulsion is also formed if the well has been put down too far into the oil-bearing strata and the water level has risen by reason of continued and rapid outflow of oil. Forced production is often practised, however, because it enables the owner of one well to draw oil from under his neighbour's property before his neighbour has had time to sink a well. In small fields this forced production is important, because the oil is soon exhausted, and each well owner tries to get as large a share of the supply as possible.

Rapid pumping may exhaust a well and cause water to rise in the area around its lower end so as to flood adjacent wells and render them useless, as was shown in the fields at Chanute, Kansas, at Humble, Tex., and some fields in Illinois.

Rapid pumping may have the further disadvantage of making it necessary to store large quantities of oil at the surface, where 25 per cent of it may be lost during a single summer by evaporation. The sand or rock originally holding the oil is its best reservoir, because it does not permit evaporation, and it furnishes the maximum yield.

Well owners have apparently not realized the importance of considering the durability of well casing in connexion with flooding, yet the decay of the casing is probably the chief cause of the trouble. A well to which water has had no access for a score of years may be suddenly rendered useless by flooding caused by decay or break in the casing. It is more probable that by action of minerals in the water, chiefly iron sulphate, the pipe has been corroded and water allowed to come into the well.

Another source of flooding may be an abandoned or dry well—one that does not yield oil or gas, but contains water. The hole may have been drilled into sands that yield oil at some near-by point, and unless the hole is properly plugged before it is abandoned water from it may enter the oil sand, find its way into neighbouring wells, and cause great damage.

Where the rock throughout an oil field is widely flooded, as from abandoned wells whose locations even are no longer known, there seems to be no remedy for the flooding, either by pumping or by drilling deeper.

PERMANENT EFFECTS.

The permanence of the effects of flooding may be judged from the results of experiments made by a number of well owners. Mr. L. C. Sands, secretary of the Oil Well Supply Company, attempted over twenty years ago to restore a flooded area at Elizabeth, W. Va. The wells of the locality produced oil before the civil war at the rate of 200 to 300 barrels a day, but when the war began they were abandoned and water accumulated in them. Mr. Sands purchased about 1,000 acres of oil-producing land and attempted to pump the water off the oil sand. The pumping was continued for a long time, but the yield of oil was increased only about a barrel a day, and the experiment was therefore abandoned.

Flooding is a serious matter. Again and again it is caused by the ignorance or carelessness of the drillers that first enter a field, who practically destroy all chance that it will ever be successfully exploited. Wild-cat drillers in a new field, who work rapidly and move from one place to another, frequently cause flooding, for they drive many wells that do not yield oil or gas, and abandon them without casing off the water or properly plugging the wells. Even the casing may be withdrawn. Water and oil may be found near by and after the oil well is pumped for some time it begins to show water, which has entered from the hole first drilled and flooded the sands—that is, has partly displaced the gas and oil.

The term wild-cat driller is applied to one who drills in a locality where oil or gas has not previously been found—that is to say, to a driller engaged in exploration.

STATE LAWS FOR PREVENTION OF FLOODING.

PLUGGING.

To guard against flooding, several states in which oil and gas are found have passed laws making it an offense to abandon a drill hole without first plugging it with a wooden plug of a specified length, to be driven down by the drilling tools. The wood swells under the influence of the water and presses against the inner surface of the casing, firmly sealing it at the bottom. Most of the laws prescribe the distance above or below the oil sands at which the plug is to be driven.

If water fills the well to a considerable depth it is difficult to lower through it a plug of the required size, hence the plug is made in the form of a hollow cylinder, which is lowered to the well bottom, and a pin or plug is firmly driven into it by the string of tools. Several feet of earth are then thrown on top of the plug to complete the sealing process. If oil and gas are found at several horizons plugs must be inserted below the lowermost and above the uppermost horizon, and if a water-bearing stratum lies between oil and gas bearing strata this must be plugged satisfactorily both at its top and bottom. In addition the top of the well must be closed by a plug.

A few of the statutes relating to the plugging of abandoned wells are quoted here, as they show the seriousness with which flooding is viewed.

In Pennsylvania a law passed June 10, 1881 (sec. 1, P. L. 110), prescribes that—

> Whenever any well shall have been put down for the purpose of exploring for any producing oil, upon abandoning or ceasing to operate the same, the owner or operator shall, for the purpose of excluding all fresh water from the oil-bearing rock, and before drawing the casing, fill up the well with sand or rock sediment to the depth of at least 20 feet above the third sand or oil-bearing rock, and drive a round, seasoned, wooden plug at least 2 feet in length, equal in diameter to the diameter of the well below the casing, to a point at least 5 feet below the bottom of the casing, and immediately after the drawing

of the casing shall drive a round wooden plug into the well, at the point just below where the lower end of the casing shall have rested, which plug shall be at least three feet in length, tapering in form, ahd to be of the same diameter at the distance of 18 inches from the smaller end as the diameter of the well below the point at which it is to be driven (and) after it has been properly driven, shall fill in on top of same with sand or rock sediment, to the depth of at least 5 feet.

Ohio has statutes equally specific, as follows:—

Sec. 306-4. It shall be the duty of the owner of any well drilled for gas or oil and which in drilling shall have passed through any vein of mineral coal, before abandoning, or ceasing to operate such well, and before drawing the casing therefrom to seal the same in the manner following: There shall be driven in such well to a depth of at least 10 feet below the floor of the lowest coal measure a round seasoned wooden plug at least 3 feet in length and equal in diameter to the well at that point, on the top of which plug shall be filled at least 7 feet of sediment or drillings, or cement and sand. Where any gas or oil well passes through any gas or oil bearing rock lying above the coal measures, the owner of said well or his agent shall, upon abandoning or ceasing to operate such well, drive a dry wooden plug not less than 2 feet in length, equal in diameter to the diameter of the hole, to a point as near as possible to the top of the coal vein, on the top of which plug there shall be filled at least 5 feet of sediment or drillings, or cement and sand, as the mine inspector shall direct.

In case such well is not plugged as aforesaid within ten days from the abandonment thereof, the chief inspector of mines or a district inspector of mines may cause the well to be plugged, and the costs and expenses of such plugging may be recovered of the person, firm or corporation whose duty it is to plug the same, in the manner provided for the recovery of penalties by section 303-5 of the Revised Statutes of Ohio.

Indiana well owners are protected by the following statute:—

Sec. 651. *Plugging abandoned wells.* 2. Whenever any well shall have been sunk for the purpose of obtaining natural gas or oil or exploring for the same, and shall have been abandoned or cease to be operated for utilizing the flow of gas or oil therefrom it shall be the duty of any person, firm, or corporation having the custody or control of such well at the time of such abandonment or cessation of use, and also of the owner or owners of the land wherein such well is situated to properly and securely stop and plug the same as follows: If such well has not been "shot" there shall be placed in the bottom of the hole thereof a plug of well-seasoned wood, the diameter of which shall be within one-half inch as great as the hole of such well, extend at least 3 feet above the salt water level, where salt water has been struck; where no salt water has been struck such plug shall extend at least 3 feet from the bottom of the well. In both cases such wooden plugs shall be thoroughly rammed down and made tight by the use of drilling tools. After such ramming and tightening the hole of such well shall be filled on top of such plug with finely broken stone or sand, which shall be well rammed to a point at least 4 feet above the Trenton limestone, or any other gas or oil bearing rock; on top of this stone or sand there shall be placed another wooden plug at least 5 feet long with diameter as aforesaid, which shall be thoroughly rammed and tightened. In case such well shall have been "shot" the bottom of the hole thereof shall be filled with a proper and sufficient mixture of sand, stone, and dry cement so as to form a concrete up to a point at least 8 feet above the top of the gas or oil bearing rock or rocks, and on top of this filling shall be placed a wooden plug at least 6 feet long, with diameter as aforesaid, which shall be properly rammed as aforesaid. The casing from the well shall then be pulled or withdrawn therefrom, and immediately thereafter a cast-iron ball 8 inches in diameter shall be dropped into the well and securely rammed into the shale by the driller or owner of the well, after which not less than 1 cubic yard of sand pumping or drilling taken from the well shall be put on top of said iron ball. (R. S., 1897, sec. 7888; R. S., sec. 7511.)

The following law also makes it possible for others besides the well owner to remedy the defect and recover the cost of the labour and material:—

Sec. 653. *Liability.* Whenever any person or corporation in possession or control of any well in which natural gas or oil has been found shall fail to comply with the provisions of this act, any person or corporation lawfully in possession of lands situated adjacent to or in the vicinity or neighbourhood of such well may enter upon the lands upon which such well is situated and take possession of such well from which gas or oil is allowed to escape in violation of the provisions of section 1 of this act, and pack and tube such well and shut in and secure the flow of gas or oil, and maintain a civil action in any court of competent jurisdiction in this State against the owner, lessee, agent, or manager of said well, and each of them jointly and severally, to recover the cost and expense of such tubing and packing, together with attorney's fees and cost of suit. This shall be in addition to the penalties provided by section 3 of this act. (R. S., 1897, sec. 7890; R. S., 1901, sec. 7513.)

NECESSITY FOR RECORDING WELL RECORDS.

A complete and accurate record or log of the well while drilling should be kept by either the contractor or the field man. All formations and known sands should be shown with their proper names, depth of finding oil, gas, or water, and a statement of the thickness of the sands, with an opinion of the quality of the sand, should be included in the report.

In the United States in Pennsylvania, West Virginia, and Ohio, where natural gas and oil occur in the same regions in which large coal mining operations are conducted, accidents have sometimes occurred, owing to the fact that mines were extended into regions in which wells had been sunk and abandoned years ago; the gas escaping into the mines and becoming ignited. In order to prevent such disasters, it is quite important that records of all holes drilled in the west should be filed by the Government, as recommended by the Commission of Conservation.

DRILLING LINE AGREEMENTS IN CALIFORNIA.

In order to overcome the great disadvantage of forcing each company to drill on the property line to offset the wells on contiguous leases, much progress has been made in California in agreements to limit drilling to a given number of feet from the line.

Kern River Field.

The old practice in this field was usually to drill 100 feet from the property line. In later years this has largely been modified to 150 feet. The Associated now drills 150 feet from the lines but is not always able to get the neighbour to agree to this. In general the larger companies agree to this readily while the smaller companies, whose holdings are limited, drill closer, usually 100 to 125 feet. Probably none drill closer than 100 feet. These agreements are binding contracts and have been in vogue since the early years of the field. The oil sands are fairly uniform over considerable distances in this field and a uniform system is possible.

Coalinga Field.

Here the usual practice is to drill 150 feet from the line. On Section 36 the Associated drills 300 feet from its lines and where adjacent to the Kern Trading and Oil Company, the same is done by the K. T. and O. No other company in the field uses the 300 foot distance.

McKittrick Field.

Here the field is narrow and irregular. No uniform practice is used, where conditions permit the wells are not less than 100 feet from the lines. In one instance near the southwest limit of the field, there is an agreement between the Reward, C.J. and K. T. and O. companies in which the companies to the south drill 50 feet from the line and those north drill 150 feet making the distance between wells 200 feet. No uniform rule has been made to fit the McKittrick field on account of the complicated nature of the geology.

Midway Field.

The Associated has not operated in this field previous to 1910. Most of the wells in the "25 Hill" area were drilled 150 feet from the lines. Many of the older wells in other parts of the field were drilled very close to the lines but this may have been due to uncertainty as to the exact location of the lines. On its property in what is considered gusher territory, the Associated is endeavouring to get agreements with its neighbours to drill not closer than 300 feet from the property lines. It is presumed that with deep drilling and comparatively light free flowing oil, 600 feet between wells will be the most economical distance.

LINE DRILLING AGREEMENT.

....

And

ASSOCIATED OIL COMPANY.

Dated:

This Agreement, made and entered into this........................day of................ 19...., by and between.. the party of the first part, and ASSOCIATED OIL COMPANY, a corporation, the party of the second part.

WITNESSETH:

That Whereas, The party of the first part is the....................................... of the following described lands situate in the County of.................................. State of California, in what is known as the..Oil District, to wit:

and is engaged in the business of developing the same and producing crude petroleum therefrom: and

Whereas, Said party of the second part is the...................................... of the following described lands, situate in the County of.................................. State of California, in what is known as the..Oil District, to wit:

and is engaged in the business of developing the same and producing crude petroleum therefrom.

All of which lands are specifically delineated on blueprint hereto attached, referred to and made a part hereof, which blue print shows the dividing lines between the respective properties of the parties hereto; and

Whereas, It is important that wells should not at any time be drilled or sunk nearer to said dividing line between said properties than as indicated on said map or plate hereunto attached; and

Whereas, Said first party has already drilled wells along said dividing line as delineated on said map or blueprint, as follows:

And Whereas, Said second party has drilled wells on its property along said dividing line, as follows:

Now, Therefore, In consideration of the premises and the sum of Ten (10) Dollars by the parties hereto interchangeably in hand paid, the receipt whereof is by each hereby acknowledged, said parties hereto do hereby contract and agree as follows, to wit:

Said..party shall have the right to drill ....wells on its property along said dividing line and..feet therefrom as an offset to the wells drilled by..party along said dividing line, as indicated on said blue print.

It is further understood and agreed between the parties hereto that except as hereinabove stated, neither of the parties hereto will drill any well or wells closer to........................ line between the lands hereinabove described than.. feet from said dividing line; said dividing line forming the.. boundary line of said properties of first party and the.. boundary line of the properties of said second party hereto.

It is further understood and agreed by and between the parties hereto that upon any violation of any of the conditions hereinabove stated, either of the parties hereto shall have the right to apply for and obtain an injunction or injunctions, as the case may be, against the other for such violation and shall also have the right to use all other proper laws or remedies at law as the case may require.

This contract shall be binding upon and shall run with the land hereinabove described, and all right, title and interest of each of said parties therein shall be and the same is hereby made security for the faithful performance of this agreement.

This agreement shall be binding upon the successors and assigns of the respective parties hereto.

In Witness Whereof, the parties hereto have caused these presents to be signed by their officers thereunto duly authorized and their respective corporate seals to be hereunto affixed this the day and year first above written.

....

By..

By..

OIL COMPANY,

By..
President.

By..
Secretary.

DEEP WELLS.

The general policy of the larger oil companies in exploring any large oil field is, at sometime during the development, to make such deep drilling tests as will determine the greatest depth at which oil wells should be sought.

This subject is further discussed in connexion with the chapter on the efficiency of oil well drilling by Mr. R. H. Johnson.

This work, however, has produced certain wells which are phenomenal from the standpoint of well-drilling results, and are tabulated below.

Lately the United States Government and the Carnegie Institute are uniting in a systematic study of such deep wells with a view to determine rate of increase in temperature with depth, and with the view of determining whether any special terminal temperature can be connected with the occurrence of oil.

Of most prominent interest, in connexion with this deep drilling work, is the well still in progress at Derrick City, near Bradford, McKean county, Pa. This well is being drilled to test the Medina sands for oil and gas.

The drilling was started with a diameter of 12 inches and has proceeded with remarkably few accidents, and has now reached a depth of 5,673 feet. It is hoped that this well will be continued to the utmost depth possible.

DEEPEST WELLS IN AMERICA.

The deepest well ever drilled in America was sunk by the Forest Oil Company at West Elizabeth, Pennsylvania, 12 miles from Pittsburgh, to a total depth of 5,575 feet. It was started about 100 feet below the Pittsburgh coal vein. Only one string of casing was used, it being $6\frac{1}{4}$ inches in diameter and 900 feet deep. At 2,285 feet below the surface a quantity of gas was struck, which was sufficient to make steam to drill the rest of the hole. At 5,500 feet the temperature was 129°F. At that depth the crown pulley broke, cut the rope and dropped the tools 100 feet, causing a suspension of operations, and causing the well to be a failure.

To drill the well extra heavy machinery was necessary. The total weight of cable from top to bottom used in drilling was 14,000 pounds, representing a value of $2,250. The approximate cost of the well was $40,000.

The deepest well in the Eastern States that ever produced oil is supposed to be situated on the G. Robinson farm in Wetzel county, W. Va., and it reached a depth of 3,555 feet.

CONTRACT DRILLING.

Drilling by contract is advisable, provided the operator conscientiously looks out for the best interests of the proprietor in actually finding oil rather than drilling for a speed limit or to reach an exceptional depth in a given time. An important duty of the driller is the exclusion of water from the well during the process of drilling and though he usually receives only a small amount of pay during the suspension of drilling for this purpose, this course is necessary for complete success in bringing in a productive well.

The form of contract varies in different localities. Certain parts of the machinery as well as fuel and water must usually be found by the contractor, though he is sometimes furnished everything by the proprietor. The following is a typical form of agreement used by one of the largest oil companies of the United States:—

This Agreement, made this .... day of .... A.D., 19......, between .... of .... parties of the first part, and the .... Oil Company, party of the second part.

Witnesseth, That the said parties of the first part have covenanted and agreed with the said party of the second part, its successors and assigns, that said parties of the first part will drill for said party of the second part a certain well for the purpose of obtaining petroleum oil or natural gas, to be known as WELL No............................ on the farm of township .... county, ...

The material, machinery, and appliances necessary for drilling and completing said well shall be furnished, and the work of drilling the same shall be done in the manner hereinafter specified, viz.:—

A complete carpenter's rig of good quality (including wooden conductor) to be furnished by the party of the second part, and all repairs on same while well is being drilled shall be made by and at the expense of said parties of the first part.

All casing to be furnished by party of the second part.

Boiler, engine, belt, bullrope, steam and water pipe, and connections to be furnished at the well by party of second part.

The expense of fitting up and connecting same to be borne by parties of the first part.

Fuel to be furnished at expense of the parties of the first part.

Water to be furnished at the expense of the parties of the first part.

Oil saver and steel measuring line at expense of the party of the first part.

All machinery, material, and appliances furnished by said parties of the second part shall, at the completion or abandonment of said well, be returned to said party of the second part, in as good condition as when received by said parties of the first part, ordinary wear and the action of the elements alone excepted.

The said parties of the first part further agree to pay all expenses and furnish everything necessary to drill and complete said well, except the articles and appliances herein specifically mentioned to be furnished by the party of the second part.

The said well unless sooner abandoned by direction of the party of the second part, is to be drilled to 2,000 feet, the consideration for which shall be two dollars per foot.

All fresh water shall be cased off with a casing of a diameter of not less than .... inches, and all salt water cased off with casing of a diameter of not less than .... inches.

Data collected b

Location.
East of Rybnick, Up-Silesia, Ge many ....
McDonald, Washington co., Pa.
Schladeback, near Leipsic, Ge many..................
Derrick City, near Bradford, Pa
Springs, 25 miles east of Johanne burg, So. Africa..........
Dornkloof, 16 miles east of Ran fontein, So. Africa........
In Aleppo township, Gree county, Pa.................
2½ miles west of West Elizabet Pa......................
Bimerah Run, Queensland.....
Randfontein, South Africa.....
Slaughter creek, Kanawha c W. Va..................
Spur, Dickens co., Texas ......
Gaines, Pa..................
Bimerah, Queensland..........
Turfontein Estate...........
Johannesburg, So. Africa......
Near Boksberg on the Rand, Sou Africa..................
Pittsburgh, Pa..............
Elderslie No. 2, Queensland....
Clarksburg district, South Afric
In the Black Reed series 12 mil south of the main reef seri on the Rand..............
4 miles southeast of Wheeling, V Va......................
In the city of Erie, Pa..........
One well in State of South A tralia...................
Irwin, Westmoreland county, I
Buchanan well, 6½ miles sou of Burgettstown, Pa..........
Knurow, Upper Silesia.........
Glenariffe, Queensland ....
Warbreccan, Queensland ......
Dolgelly bore, New South Wales
Northampton, Mass...........
Winton, Queensland ....
In the Vlakfontein district, Sou Africa..................
New Haven, Conn............
Renova, Pa..................
Darr River Downs, No. 4, Quee land.....................
Norris well, Findlay, Ohio......
Grubb well..................

TABLE XV.

List of Deep-Well Borings.

Data collected by B. L. Johnson.

Location.	Depth Feet	Diameter Inches	Object	Remarks
East of Rybnick, Up-Silesia, Germany	6,572	3·6 to 2·7	Coal	Cost $18,241—completed Aug., 1893, after 1½ years' work—deepest bore in the world.
McDonald, Washington co., Pa.	6,487		Oil or gas	Still drilling.
Schladeback, near Leipsic, Germany	5,735	11 to 1·3	Coal	Cost $53,076—completed about 1893. Average daily rate of drilling 4½ feet.
Derrick City, near Bradford, Pa.	5,673	12 to 6	Oil	Boring being continued.
Springs, 25 miles east of Johannesburg, So. Africa	5,582	2 to 1⅝		Completed 1905, after 9 months' work. Diamond drill hole.
Dornkloof, 16 miles east of Randfontein, So. Africa	5,560	2 to 1⅝		Completed December, 1904, after 14 months' actual work—diamond drill hole.
In Aleppo township, Greene county, Pa.	5,322	13 to 6⅝	Gas	Abandoned July, 1905.
2½ miles west of West Elizabeth, Pa.	5,575	10 to 6¼	Oil	Cost $40,000—deepest well drilled with a cable—deepest well in the United States—third deepest well in the world.
Bimerah Run, Queensland	5,045		Water	Flow, 70,000 gallons a day.
Randfontein, South Africa	5,002			Diamond drill hole.
Slaughter creek, Kanawha co., W. Va.	5,000			
Spur, Dickens co., Texas	5,000			
Gaines, Pa.	5,000			
Bimerah, Queensland	4,860			
Turfontein Estate Johannesburg, So. Africa	4,845			Diamond drill hole.
Near Boksberg on the Rand, South Africa	4,800			
Pittsburgh, Pa.	4,618		Oil or gas	
Elderslie No. 2, Queensland	4,523		Water	Flow, 1,600,000 gallons a day, temperature 202° F.
Clarksburg district, South Africa.	4,500			
In the Black Reed series 12 miles south of the main reef series on the Rand	4,500			Diamond drill hole.
4 miles southeast of Wheeling, W. Va.	4,500	4⅞	Oil or gas	
In the city of Erie, Pa.	4,460		Oil or gas	Abandoned 1889.
One well in State of South Australia	4,420		Water	Flow 600,000 gallons a day.
Irwin, Westmoreland county, Pa.	4,380		Oil or gas	
Buchanan well, 6½ miles south of Burgettstown, Pa.	4,303		Oil or Gas	
Knurow, Upper Silesia	4,173	192 to 13		
Glenariffe, Queensland	4,140			
Warbreccan, Queensland	4,125			
Dolgelly bore, New South Wales	4,086		Water	Flow, 745,200 gallons a day.
Northampton, Mass.	4,022		Water	
Winton, Queensland	4,010			
In the Vlakfontein district, South Africa	4,003			
New Haven, Conn.	4,000	8	Water	
Renova, Pa.	4,000		Oil	
Darr River Downs, No. 4, Queensland	4,000			
Norris well, Findlay, Ohio	3,000			
Grubb well	2,470			

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The diameter of the well when completed shall not be less than..................inches.

The outside strings of casing, viz., the..................................inch and ....inch, shall be pulled at the expense of the party of the second part.

When said well reaches the oil or gas-bearing sand, the method of drilling through the same shall be under the direction of said party of the second part, or its agent in charge of the farm or lease, and if oil or gas is found in sufficient quantities to endanger the rig and material by fire from the boiler, then said parties of the first part shall, without delay, and at second party's own expense, move the boiler to a safe distance from the well. All pipe fittings made necessary by such removal to be furnished by the said party of the second part.

When completed, unless prevented by too great a volume of gas or oil, the well shall be thoroughly "bailed" and "sand pumped" by the said parties of the first part, until all drillings and sediment are removed therefrom and the well thoroughly cleaned.

The parties of the first part shall carefully examine all machinery, casing, and other appliances to be furnished for said well by the party of the second part, and if any defect be found therein sufficient to make the use of such machinery, casing, or other appliance unsafe, shall immediately notify the party of the second part of such defect or defects, and the party of the second part shall at once replace the article so found defective with a good and safe one; but if the parties of the first part shall not make such examination, or shall not report any defects in said machinery, casing, or other appliance, they shall be deemed to have assumed all risks and all responsibility for any mishap which may occur in the drilling of said well by reason of a failure in such machinery, casing, or other appliance.

No part of the contract price mentioned shall in any event be paid until said well be completed to the depth above required, and delivered to the party of the second part in thorough good order, free and clear of all obstructions.

The parties of the first part agree to begin the drilling of said well within thirty days from..and prosecute the work actively and continuously (Sundays excepted) to completion.

It is Further Agreed, That time shall be of the essence of this contract, and that in case the parties of the first part shall neglect or discontinue the work of drilling said well for the space of ten days, such neglect or discontinuance shall of itself be a forfeiture of all rights and claims of the parties of the first part under this agreement without any notice or demand by the party of the second part. The party of the second part shall have the right at any time after such forfeiture to take possession of said well, discontinue the drilling thereof, and at its pleasure dismantle or abandon the same without liability to the parties of the first part for any portion of the contract price above mentioned. The party of the second part shall also have the right at any time after such forfeiture as above mentioned, if it so elects, to take possession of said well and all the ropes, tools, and appliances thereat of the parties of the first part, and drill said well to completion. In case it shall succeed in completing said well, the cost of such completion without any allowance to said parties of the first part for the use of the said ropes, tools, and appliances, shall be deducted from the contract price above mentioned, and the balance, if any, paid to the parties of the first part; but if said party of the second part should not succeed in completing said well, it shall not be liable to the parties of the first part in any sum whatever, and shall return said tools, ropes, and appliances to the parties of the first part in as good order as when received, natural wear and tear and accidental loss or breakage excepted.

In Witness Whereof, the parties of the first part have hereunto set their hands and seals, and the party of the second part has caused these presents to be signed by its representative the date first above written.

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CHAPTER VII.

PUMPING, STORAGE, AND TRANSPORTATION OF OIL AND GAS.

PUMPING THE WELLS.

If wells are not "gushers," that is, if they do not flow of their own accord, they must be pumped. The preliminary pumping to determine the capacity and character of a new well is usually done directly from the walking beam of the drill rig. After more than one well has been brought in, however, the pumping is done from a central power plant by means of pull rods or pumping jacks, or in the Canadian fields by jerker rods, bell cranks and walking cranks. The pull rods are usually steel rods or wire cable mounted on supports at different heights, depending upon the topographic configuration of the land. An oscillating pull wheel or jerker in the central power house, by means of large double pull rods, which radiate from the power house, actuates a number of flat pumping discs, which rotate through about 50 or 60 degrees and from which further pull rods radiate to the pumping jacks over the individual wells. In this way a great number of wells may be pumped from a single power plant, and it becomes possible to profitably pump wells of small yield. The pumping jack consists of a right triangular framework suspended on a pivot at the right angle and connected up with the pump at the upper acute angle, and with the pull rod at the lower acute angle, so that when the pull rod brings the lower angle forward, the upper angle rises carrying up the pump rods. The weight of the sucker rods sinking back into the well takes the slack in the pull rods and brings them back into position for another pull. When the sucker rods are either too heavy or too light a weight on the appropriate arm of the triangle suffices to balance things.

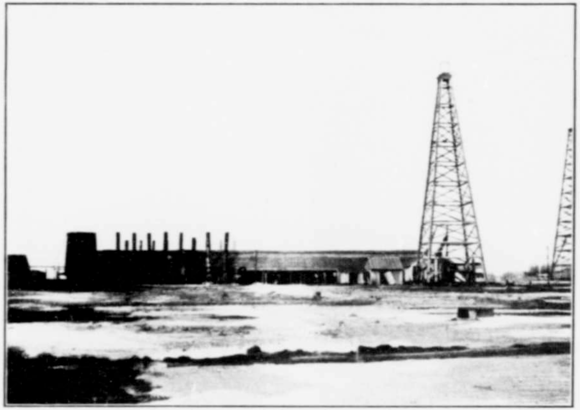
The pumping jacks are made of wood or steel. In the home-made form of pumping jack, the pivot angle is at the bottom, the pull angle at the top, and the pumping angle is connected with the pump by a rigid rod, by the thrust of which the pump is moved. In the Petrolia field wooden shackle rods, jerker lines, take the place of steel rods and cable, and are capable of transmitting the power many hundreds of feet, and in some cases as much as a mile. When the direction of the power must be changed horizontally, cranks are used, *e.g.*, where the pull is transmitted to the horizontal walking beam pump at the well. The jerker system of pumping was adopted in this field at an early date. Before that the wells had been worked by man power with spring poles.

The number of wells pumped from one power plant varies greatly. On the C. O. Fairbanks property at Oil Springs, 200 wells are pumped by one 40-horse power steam engine, and at one time there were 242 wells on this engine. The Canadian Oil Fields Co., Ltd., operates 240 wells from one power plant at Petrolia, and J. L. Englehart and Co. pull 226 pumps from one central power plant described in more detail below. In the Petrolia field a 12-horse power engine has driven as many as 90 pumps. A 50-horse power engine is generally regarded in the United States as capable of pumping 175 average wells. The cost of pumping in large series is so small that wells yielding but a few gallons daily are worked at a profit.

The following description of pumping arrangements on the J. L. Englehart and Co.'s land at Petrolia, is taken from the Canadian Department of Mines Report on the mining and metallurgical industries of Canada, 1907-8, page 435:—

"The pumping system which has been developed in the Petrolia oil fields is a somewhat interesting one, and differs in some particulars from that in vogue in Pennsylvania. A good example of this system is the plant operated by this Company. One central power plant pumps direct from 226 wells, scattered over an area of 400 acres. It is a balanced system, half of the dead load of rods and mechanism in the field being lifted, while the other half is descending, so that the power required is only that for overcoming inertia and friction, plus the weight of the oil lifted at each stroke. Counterweights are unnecessary, thus reducing the mass of material to be moved, and giving in consequence a higher efficiency. In the case of the Englehart plant, four engines, coupled in pairs, each of 40 indicated h.p., serve the entire group of 226 wells. These two pairs of engines are connected to two main, or master wheels, which, in addition to direct connexions to pumps, operate 22 secondary or local wheels, each controlling two jerker rods. These are large disks, set horizontally, cast with four lugs, at the ends of two diameters at right angles

PLATE XIV.



Compressed air-pumping plant of Crowley Oil and Mineral Co., Crowley, La.

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to each other. Each lug carries two wrist pins for connecting the jerker rods. The wheels have a reciprocating motion imparted to them, which causes them to swing through an arc sufficiently to give the jerker rods the necessary forward and backward motion to produce the proper length of stroke at the pumps, which is communicated to them in the ordinary way by walking-beam or triangle-arm connexions. The jerker rods are of wood, with spliced joints, suspended from posts by pin-connected hangers of iron, and serve, in conjunction with the pump rods, as the counterbalance in the system. The pump rods are of gas pipe, $\frac{3}{8}''$ pipe being used with a $1\frac{1}{4}''$ pump, and $\frac{1}{2}''$ pipe with a $1\frac{1}{2}''$ pump, the average length being 475 feet.

"The power plant consists of two tubular boilers of a total capacity of 200 h.p., heated partly by natural gas (derived from 7 wells), and partly by coal. There are 32 underground collecting tanks, each of 50 barrels capacity, distributed through the field, and two main collecting tanks, each of 700 barrels capacity, close to the power plant. A 2" pipe line connects the main tanks with the receiving station of the Imperial Oil Company, on the 12th line. There is also a complete drilling outfit always in use in putting down new wells."

The power for pumping is usually furnished by a gas engine or by a steam engine. A boiler is generally erected near the power house for emergency use, and for steaming the oil to precipitate suspended sulphur. In fields where gas is not available oil is burned beneath the boiler.

In some fields the oil is raised with an air lift by forcing compressed air deeply in the well through a central tube, the oil rising between this and the outer casing. The chief advantages of the air method are that it is automatic and that there are no wearing parts to get out of order and require care. However, this method has not been extensively adopted and has not been used at all in the Canadian fields.

In some fields where the wells do not flow and where there is so much sand that ordinary pumps cannot be employed, the oil is raised by a bailer holding commonly about 50 gallons. This is a long bucket which will move freely inside the well casing, and which has a valve at the bottom. The bailer is raised and lowered by means of a steam winch. This method is employed extensively in the Baku field.

STORAGE OF OIL.

The first oil from the new well is put into emergency tanks which are low cylinders of wood holding from 100 to 1,600 barrels of oil, but commonly of about 250 barrels capacity and costing about $100. When the permanent tanks are built the oil goes directly from the well to these tanks. In case there be more oil than can be taken care of in the tanks, temporary earthen reservoirs are built by throwing a dam across a hollow, or by building a square embankment on level ground. But permanence of production presupposes some system of storage. The tanks may be wooden, steel or earthen. A group of tanks is known as a tank farm. So far as the topography permits, the tanks are located so that the oil will flow into them by gravity from the contributory wells. When the oil will not flow by gravity, a donkey pump is used to force the oil from the well to the tanks.

The larger steel storage tanks, having a capacity of 35,000 barrels, are 90 feet in diameter and 30 feet in height, the steel varying from 13·64 lbs. per square foot in the lower ring of plates to 8·15 lbs. in the 7th or upper ring. Each tank has a conical roof of sheet steel and is equipped with a windlass to raise the swing pipe.

All sizes of steel and wooden tanks between the 250 barrel wooden tank and the large steel tank are found. When several smaller wooden tanks are situated in a row, they are covered with a low inclined shed to prevent evaporation of the oil and drying and warping of the tanks.

The oil in the Petrolia fields of Canada is frequently stored in large underground tanks which are excavated in an impervious clay and are boarded over and covered with earth. These tanks ordinarily are 60 feet deep and 30 feet in diameter, holding 8,000 barrels of oil. From these tanks the oil is pumped to the refineries. The underground system of tanking was devised in the early days on account of a fire which destroyed a large amount of property in 1867. The advantage of these earthen tanks is that the clay formation makes a perfect reservoir if the hole is kept filled with oil or water, and moreover the earth-covered tanks are practically fire and lightning proof. The following notes on the use of these earthen tanks are taken from an article by James Kerr in the Toronto Mail, December 1, 1888.

One of the necessities from the want of which the early oil operator suffered was tankage in which to store his oil pending the season of the year in which the bulk of it would be required, or to tide over a plethora of production till the requirements of the market could overtake it. Naturally the Canadians erected in the first place great wooden tanks, which increased in time to enormous proportions, some of them being as large as 24 feet in diameter and 29 feet deep, set on the ground and bound with iron hoops. Large iron tanks were introduced in 1865, two of which of 3,000 barrels capacity still remain a memento of that period. These, however, were found very expensive and subjected the oil stored in them to many sources of danger, and a vast improvement was found practicable, and of such a nature as no other part of the world has been known to supply.

The Erie clay, before referred to, would almost appear to have been supplied for the express purpose of oil storage. This clay is of a solid tenacious quality, free from seams or flaws, and easily removed. When properly constructed the tanks sunk therein prove to be cool, perfectly free from danger or loss from leakage or evaporation or destruction by fire, whether caused by lightning or otherwise. The tank is formed by excavating a circular hole about 30 feet in diameter to a depth of about 15 feet through the top soil, the Saugeen clay, which is somewhat porous; a wooden crib is placed therein formed of double inch rings, five inches wide, outside of which boards are nailed and clay from the strata below is solidly packed between the curbing and the wall, making a solid "pudding" about five inches thick. The sinking of the tank is then proceeded with to a depth of 50 or 60 feet; the entire wall is lined with segments made of inch pine about five inches wide, forming a perfectly tight tank holding from 8,000 to 10,000 barrels of oil, which saturating the wood renders it exceedingly durable. Timbers are projected across the top, supported by a bolt from the arch over it; joists are laid thereon, covered with plank and clay and the contents rest in perfect safety till required.

A large number of these tanks (of which about one million barrels capacity exist in this locality,) are owned by companies, who receive the oil from the producers at the wells and convey it through their pipe lines, some of which are nine miles in length, storing it and issuing certificates to the owners thereof.

In the Petrolia field tanking is undertaken by the Tanking Company which has many miles of pipe throughout the field, in order to gather the crude from the producers into the central underground tanks. The prices charged by the Tanking Company are necessarily variable, but range from 2 to 37 cents a barrel, according to the distance from Petrolia. The tanks are at Petrolia, and there are 50 or more of these reservoirs with a storage capacity of 8,000 barrels each, or a total capacity of 400,000 barrels. An 8,000-barrel tank of this description can be completed in six weeks at a cost of $1,760.

Storage capacity must not only be provided on the lease, at the loading rack, at the pipe line pumping station, and at the refinery, but also at the seaport, if the oil is to be transported over sea in tank steamers, and at the seaport where the oil is delivered by the tank steamers. A 37,000 barrel tank of the latter sort was recently completed near the wharves of the

Grand Trunk Pacific railway at Prince Rupert, British Columbia. An inner steel shell is surrounded and reinforced by a concrete wall 3 feet thick at the base, but somewhat thinner at the top. Pipes are laid under the wharves through which the oil is pumped into the tank from tank steamers which bring the oil from California. The oil is to be used as fuel for oil-burning locomotives on the Grand Trunk Pacific railway.

TRANSPORTATION OF OIL.

Where an oil field has a small yield, as when a small output of oil is incidental to natural gas production, and the market is purely local and the oil is used in a crude state, the means of transportation and distribution are apt to be correspondingly simple and primitive. For instance, in the gas fields of New Brunswick some of the wells yield a few gallons of oil per day. This is piped to a loading tank by the roadside, from which it is transferred to tank wagons which distribute it.

Some heavy lubricating, or otherwise peculiarly valuable oils which do not occur, or are not purchased in quantity sufficient to make a separate run in a pipe line or even to justify shipping in a tank car, or which are destined to points away from railway or pipe line facilities, are shipped in wooden barrels, or more generally in steel drums. In the early days of the industry, of course, this was the customary method of shipping crude oil, but now on land the great bulk of the petroleum product is transported in pipe lines, with smaller quantities in tank cars, and, on the ocean, in tank steamers.

Tank barges, 130 feet long by 22 feet wide and 16 feet deep, holding 2200 barrels of oil, were used in the early days of the Pennsylvania oil industry to transport crude oil from the wells on the lower Alleghany and the Little Kanawha to the refineries on the Ohio river.

In transporting oil by rail, the first form of tank cars in use about 1865 or 1866 consisted of flat cars on which two wooden tub-like tanks, holding about 2,000 gallons each, were fastened. These were succeeded in 1871 by cars with tanks of the present horizontal cylindrical type 24½ feet in length, 5½ feet in diameter, and holding about 5,000 gallons. The tank cars now used are 32 feet long, 6 feet in diameter, and hold 8,000 gallons. A train of tank cars is filled simultaneously from a loading rack which consists of a long platform beside the track and about on a level with the top of the tanks. The oil feed pipe runs along this platform, and at intervals equal to the distance between domes of the tank cars is fitted with valves and T branches through which, with suitable extensions, the oil is conveyed into the tanks. Such loading racks are provided with facilities for measuring the oil put into the tank cars.

In the Kansas and Oklahoma oil fields of the United States, in 1913, there were in September, 1382 tank cars still in use among refiners and small shippers. In addition to the cars owned by the railway companies, the Standard Oil Company and the Texas and Gulf companies, certain refining companies also had a large number of tank cars in these States and they were used also in connexion with eastern plants. In 1904 the Union Tank Line Company, a subsidiary of the Standard Oil Company, had about 9,000 tank cars, and the Waters Pierce Company had about 1000 tank cars. The capacity of the tank cars in the Kansas and Oklahoma fields ranges from 4,000 to 10,000 United States gallons.

The first successful pipe line was laid in Pennsylvania in 1865, was four miles in length, and was put two feet underground. The sections of pipe were joined by carefully fitted screw-sockets, whereas previous pipe lines had failed because of leaky joints. From that time until the present the use of pipe lines has rapidly grown. Most of the oil produced in the United States, except in Texas, Louisiana, and California, is transported to the refineries by means of pipe lines. A network of small pipes gathers the oil from the wells and trunk lines, often of great length, and conveys it to the refining point. The oil of Texas and Louisiana is used chiefly for fuel, largely within the States themselves. It is, therefore, transported chiefly in tank cars, though there are several short pipe lines to the Gulf ports. California oil is also used mostly for fuel but pipe lines reach from the oil fields to tidewater at Port Richmond and to the refinery at Port Costa and other points.

The rifled pipe line, introduced in 1907, greatly facilitates the transportation of the heavy viscous grades of oil. This pipe is provided with spiral grooves about an eighth of an inch in depth, and making a complete revolution of the pipe every ten linear feet. Through these grooves a lubricating current of water is pumped with the oil. In California the heavy oils are heated with steam and sometimes mixed with lighter oil or water, before being admitted to the pipe line. Insulating the pipe with some non-conductive covering is also found to help.

The construction and operation of pipe lines is discussed with some fullness in the chapter by Mr. Towl in the following pages.

The pipe lines of the United States, comprising those of seventeen subsidiary companies of the Standard Oil Company, and eight independent lines, owned and operated pipe lines, were estimated by the United States Bureau of Corporations in 1907 to total more than 45,000 miles of pipe ranging from 2 to 12 inches in diameter. The majority of the lines are 6 or 8 inches in diameter. The largest continuous line reaches from Oklahoma to New York city.

Two of the chief producing oil fields of Canada, the Petrolia and Oil Springs fields, are located within eight or ten miles of the refinery of the Imperial Oil Company, Ltd., at Sarnia, on the St. Clair river. From six receiving stations in these fields the oil is carried through pipe lines of the Imperial Oil Company to the refinery at Sarnia. From a receiving station in the centre of the East Tilbury field, oil is delivered through a 4-inch pipe line owned by the Imperial Oil Company to a large receiving tank of 700 barrels capacity at Merlin station on the Père Marquette railway. From Merlin the oil is shipped in tank cars to the refinery at Sarnia. These several short lines, together with the feeders from the producing properties to the receiving stations of the Imperial Oil Company, comprise all the oil pipe line service of the Dominion.

By sea, crude petroleum is transported in tank steamers or tank barges. Fuel oil from the Texas and California fields is piped to the seaports as noted above, and distributed to the various markets by tank steamers. Mexican oil likewise goes to European refineries and markets in tank steamers. From the eastern seaboard of the United States some crude oil is shipped to Europe in tank steamers and in tank sailing vessels, but the main employment of tank steamers is for shipping in bulk, refined oil or kerosene. On the Caspian sea, early in 1913, there were 168 vessels engaged in the transport of oil to and from different parts of the Russian empire. The vessels fitted with Diesel engines, owing to their low consumption of fuel, are rapidly replacing the other forms of power boats. As has just been said, the bulk of the oil transported in tank steamers is refined oil, including kerosene. Since 1905 the Standard Oil Company has also used tank barges. The tank steamer carrying 400 tons of oil tows a tank barge carrying 6,000 tons of oil, by means of a 600 fathom steel-wire hawser, fitted with winding drums which automatically take in or pay out the hawser depending on the strain upon it and thus act as shock absorbers. Both steamers and barges are entirely of steel, divided into compartments by bulkheads and provided with means of escape for the oil gases, and with supply tanks to make up any loss of oil in the tanks by leakage or evaporation. The Imperial Oil Company operates three tank steamers of 6,000 barrels capacity each, and with its shipping docks near Sarnia on the St. Clair river has all facilities for shipping its products by steamer as far west as Port Arthur and as far east as Montreal.

Refined oil products, lubricating oil, kerosene, gasoline and the like when shipped by rail are transported in tank cars, in wooden barrels, in steel drums, or in tin cans. Towns on a railway and large enough to support a distributing wagon service, have receiving storage tanks adjacent to the railway switch and the oil is pumped into these tanks from the tank cars. Smaller towns, especially those without railway communication, are supplied with oil in wooden barrels usually. In the western part of the country considerable oil is shipped in tin cans in wooden cases, each container holding two cans, each of 5 gallons capacity. Much kerosene is shipped to foreign countries in such cans.

MEASUREMENT AND TRANSPORTATION OF NATURAL GAS.

The volume of natural gas yielded by some wells is enormous. The Tippecanoe well in the Findlay field of Ohio yielded 32 million cubic feet the first day, falling to 19 million cubic feet the third day. The open pressure was 38 lbs. the first day and 11 lbs. the second day. The Mellott well six miles north of Findlay yielded 28 million cubic feet with an open pressure of 28 lbs., and a well near Bairdstown furnished 33 million cubic feet daily at an open pressure of 45 lbs. The Wallace well at Fostoria yielded 50 million cubic feet daily but lasted only three days. In the Sunset-Midway district of California there are very large gas wells. The largest one, which was a shallow 18-inch well lasting only a few weeks, was reported to yield 65 million cubic feet daily. Several others were estimated at 30, 35 and 40 million cubic feet daily. The gas wells so far struck in Canada have not such large yields as those just mentioned, though a well in Essex county, Ontario, yielded 10 million cubic feet per day and several wells in the East Tilbury field yielded 1½ million cubic feet daily. The Tuna well at Medicine Hat, Alberta, yielded 6 million cubic feet, and the first wells at Bow island 7 or 8 million cubic feet daily. Well No. 4 at Bow island is reported to have had an original flow of 29 million cubic feet, as measured by Eugene Coste.

When a gas well is struck, and capped, the pressure of the confined gas rises to a maximum point known as the rock pressure. The time required for the pressure to reach this point depends upon the porosity of the gas reservoir. In porous or fissured rock it reaches the maximum very soon. In tight reservoirs some time may elapse before the rock pressure is reached. The rock pressure varies greatly in different fields. In New York rock pressures as high as 1,500 lbs. per square inch are known. Rock pressures in Pennsylvania vary from 300 to 800 lbs. per square inch; and in West Virginia, 1,000 to 1,250 pounds to the inch; the rock pressure in Ohio and Indiana ranged between 50 and 800 lbs. per square inch. The original rock pressure in the gas field of Kansas was 325 lbs. to the inch; and in Oklahoma about the same. In California the rock pressure is very great in some districts. In the Sunset-Midway district one well has been measured at 2,000 lbs. to the square inch, and this was not the maximum pressure, but only the limit of the gauging appliances. Other wells in the same district have pressures ranging from 500 lbs. up to 1,200 lbs. per square inch. In Canada according to Coste[1] the rock pressure varies with the geologic horizon of the gas reservoir as follows: "In every field where gas is found in several strata, the highest pressure is always recorded in the lowest or deepest strata; for instance, in the Welland county field the rock pressure of the gas was 300 lbs. in the Guelph dolomite; 400 lbs. in the Clinton; 525 lbs. in the Medina white sand; and 1,000 lbs. in the Trenton limestone." The rock pressure at Medicine Hat, Alberta, is 550 lbs., and at Bow island 810 lbs. per square inch."

The cause of rock pressure has been variously ascribed to hydrostatic pressure of the ground water, to pressure due to accumulation of gas by distillation from organic remains, and to pressure of gaseous emanations from beneath the sedimentary rocks. Prof. Edward Orton of Ohio maintained the hydrostatic pressure theory and apparently demonstrated its truth for the Ohio fields deriving their supply from the Trenton limestone, since in nearly every case the observed rock pressure agreed with the required pressure assuming it to be of artesian origin, taking the level of Lake Erie as the elevation of the outcrop of the Trenton limestone. However, the occurrence in New York of rock pressures of 1,500 lbs. at many hundred feet less than the hydrostatic theory would require casts doubt on this theory as a general explanation. There remains for those who believe in the organic origin of gas and oil, the theory of pressure due to gases distilled from the organic remains of the sedimentary rocks, and for those who believe in its inorganic origin, the suggestion of gaseous emanation from below.

The minute pressure of a gas well is used in one method of obtaining the open flow of the well; *i.e.*, the volume of gas which will escape from the well into the open air in one day. It yields an approximate, but conservative result, and is much in use for rough measurements. The minute pressure is obtained by allowing the well to blow into the air until its head is blown off; *i.e.*, until the open pressure becomes constant. The well is then closed very quickly, and the accumulated pressure read one minute after the closing of the well.

[1] Coste, Eugene, Jour. Can. Min. Inst. vol. III, p. 83.

The formula for determining the open flow of a well by means of the minute pressure is given by Weymouth,[1] as follows:—

"Q, the open flow capacity of the well in cubic feet per day on an atmospheric pressure base of 14.4 lbs, per square inch absolute, becomes

$$Q = 1440V \left\{ \frac{pm + Po}{Po} - \frac{Po}{Po} \right\} = 1440 \frac{Vpm}{Po} = 100Vpm$$

in which V = volume of well tubing in cubic feet

pm = minute pressure in pounds per square inch gauge.

Po = atmospheric pressure in pounds per square inch absolute.

The Pitot tube is also used in the open flow measurements of gas wells. This method, which is generally employed in accurate measurements, was devised by Prof. S. W. Robinson,[2] and is bound upon this formula:—

$$Q = 1,462,250\ d^2 \left\{ \left(\frac{P_1}{Po} \right)^{0 \cdot 29} - 1 \right\}^{\frac{1}{2}}$$

in which

Po = absolute pressure of atmosphere, pounds per square inch.

P_1 = absolute pressure shown by Pitot tube, pounds per square inch.

d = internal diameter of well mouth in inches.

The Pitot tube consists of a short tube bent at a right angle and with one end drawn out into a nozzle. This tube is inserted into a horizontal pipe through which a liquid is flowing, with the nozzle pointing upstream. The height to which the liquid will rise in the vertical arm of the Pitot tube varies with the velocity of flow of the liquid and is a measure therefore of the volume of flow. The Pitot tube was adapted to the measurement of the flow of gases by bending twice the vertical arm of the tube to form an inverted U water manometer. An accurate

[1] Weymouth, Thos R., Measurement of Natural Gas, Trans. Am. Soc. Mech. Eng., vol. 34, 1912, pp. 1901-1104.

[2] Robinson, S. W., Van Nostrand's Eng. Mag. Aug. 1886; Ohio Geol. Surv., vol. 6, 1888.

Discharge of gas 0·6 specific gı

Pressure in inches	Cubic feet per hour	Pr in
0·10	495	(
·20	714	1
·30	857	1
·40	980	1
·50	1,106	1
·60	1,213	2
·70	1,310	2
·80	1,401	3

Discharge of gas of 0·6 speci

Mercury pressure in inches	Pounds gauge pressure per square inch	Cubic feet per hour
0·10	0·05	1,835
·20	·10	2,590
·30	·15	3,170
·40	·20	3,655
·50	·25	4,095
·60	·30	4,490
·70	·35	4,850
·80	·40	5,180
·90	·45	5,495
1·02	·50	5,790
1·52	·75	7,095
2·03	1·00	8,195
2·54	1·25	9,165
3·05	1·50	10,030
3·56	1·75	10,830
4·07	2·00	11,550
4·57	2·25	12,275
5·08	2·50	12,950

Multi

Size of opening diameter in inches	Multiplier	Size openi diame in incl
1/16	0·0038	1½
⅛	·0156	2
¼	·0625	2½
½	·2500	3
¾	·5625	4
1	1·00	4¼

TABLE XVI.

Discharge of gas 0·6 specific gravity from one inch opening corresponding to water pressure in inches.

Pressure in inches	Cubic feet per hour	Pressure in inches	Cubic feet per hour	Pressure in inches	Cubic feet per hour	Pressure in inches	Cubic feet per hour
0·10	495	0·90	1,485	3·50	2,928	10·00	4,950
·20	714	1·00	1,555	4·00	3,130	11·00	5,215
·30	857	1·25	1,738	4·50	3,321	12·00	5,422
·40	980	1·50	1,915	5·00	3,500	13·85	5,800
·50	1,106	1·75	2,070	6·00	3,834	20·77	7,110
·60	1,213	2·00	2,214	7·00	4,140	2·770	8,200
·70	1,310	2·50	2,475	8·00	4,428		
·80	1,401	3·00	2,712	9·00	4,694		

TABLE XVII.

Discharge of gas of 0·6 specific gravity from 1-inch opening corresponding to pressure of mercury column and of gauge pressure.

Mercury pressure in inches	Pounds gauge pressure per square inch	Cubic feet per hour	Mercury pressure in inches	Pounds gauge pressure per square inch	Cubic feet per hour	Mercury pressure in inches	Pounds gauge pressure per square inch	Cubic feet per hour
0·10	0·05	1,835	5·59	2·75	13,375	....	14·00	28,495
·20	·10	2,590	6·10	3·00	14,175	....	15·00	29,295
·30	·15	3,170	6·61	3·25	14,755	....	16·00	30,045
·40	·20	3,655	7·11	3·50	15,320	....	17·00	30,755
·50	·25	4,095	7·62	3·75	15,850	....	18·00	31,415
·60	·30	4,490	8·13	4·00	16,370	....	20·00	32,730
·70	·35	4,850	8·64	4·25	16,875	....	22·00	33,470
·80	·40	5,180	9·15	4·50	17,360	....	25·00	35,620
·90	·45	5,495	9·65	4·75	17,845	....	30·00	37,945
1·02	·50	5,790	10·16	5·00	18,330	....	35·00	40,040
1·52	·75	7,095	12·20	6·00	19,835	....	40·00	41,945
2·03	1·00	8,195	....	7·00	21,555	....	45·00	43,605
2·54	1·25	9,165	....	8·00	22,600	....	50·00	45,080
3·05	1·50	10,030	....	9·00	23,735	....	60·00	47,380
3·56	1·75	10,830	....	10·00	24,815	....	75·00	50,975
4·07	2·00	11,550	....	11·00	25,915	....	90·00	54,350
4·57	2·25	12,275	....	12·00	26,775	....	100·00	55,705
5·08	2·50	12,950	....	13·00	27,695	....	110·00	57,055

TABLE XVIII.

Multipliers for pipe of other diameters than 1 inch.

Size of opening diameter in inches	Multiplier	Size of opening diameter in inches	Multiplier	Size of opening diameter in inches	Multiplier	Size of opening diameter in inches	Multiplier
1/16	0·0038	1½	2·25	5	25·00	7	49·00
⅛	·0156	2	4·00	5 3/16	26·90	7¼	52·50
¼	·0625	2½	6·25	5⅝	31·60	8	64·00
½	·2500	3	9·00	6	36·00	8¼	68·00
¾	·5625	4	16·00	6¼	39·00	9	81·00
1	1·00	4¼	18·00	6⅝	43·90	10	100·00

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[1] Ohio G
[2] Oliphar
in 1902, p. 2(
[3] *Op. cit.*
[4] Gregor
184-207; wit

pressure gauge should be substituted for the water manometer when the Pitot tube registers more than 5 lbs. pressure. Tables for the calculation of volume of open flow of gas wells based upon Pitot tube readings have been prepared by Prof. Robinson,[1] and by F. H. Oliphant.[2] Of these the latter are here given as being more compact in form.

Correction for foregoing table: For any specific gravity other than 0·6, multiply by $\sqrt{\frac{\cdot 6}{\text{given sp. gr. gas}}}$. For temperatures of gas over 60° F. deduct 1 per cent for each 5°, and add 1 per cent for each 5° less than 60° F. In practice these corrections are usually neglected and the calculation made directly from the values in the table. Weymouth[3] has criticised the formula and the tables as giving quantities slightly in excess with high pressures, and somewhat too small with low pressures. A thorough discussion of the Pitot tube is given by W. B. Gregory.[4]

Natural gas is transported in pipe lines, except in rare instances when, greatly compressed, it is carried in cylinders as noted on a later page. The construction of pipe lines has been very fully discussed in the chapter by Forrest M. Towl, which follows on a later page. So too the compressor stations, at intervals along the long gas mains, in which the pressure of the gas is raised to a point sufficient to force it to its destination, have been described by Mr. Towl, and likewise the different forms of meters by which the volume of the gas transported or delivered is measured.

Pipe lines for the transportation of natural gas in the United States, while not of as great length as oil pipe lines, being rarely more than a hundred miles or so in length, are nevertheless very numerous. So too in Canada there are many gas mains for carrying natural gas. Of these the principal ones are as follows:—

In New Brunswick, gas is piped from the Stony Creek field 9 miles to Moncton through a 10-inch main, and 4 miles to Hillsborough through a 4-inch line.

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[1] Ohio Geol. Surv., vol. VI, 1888, pp. 572, 573.

[2] Oliphant, F. H., U. S. Geol. Surv., The production of Natural Gas in 1902, p. 26; reprinted in West Virginia Geol. Surv., vol. 1 (a), 1904, p. 39.

[3] *Op. cit.*, p. 1093.

[4] Gregory, W. B., Trans. Am. Soc. Mech. Eng., vol. 25, 1903-4, pp. 184-207; with supplemental note by Prof. S. W. Robinson, pp. 208-211.

In Quebec, the Three Rivers field furnished gas for Three Rivers, Yamachiche, St. Barnabé and Louiseville.

In Ontario the three gas fields have furnished much natural gas to the cities and towns of the province and much gas has been exported to the United States. The Essex county field furnished gas to Toledo, Ohio, by way of Detroit through an 8-inch main. Two mains laid across the bed of the river at Detroit furnish that city with gas from the same field, which also supplies Chatham, Leamington, Blenheim, and other towns. The Welland field gas is piped to St. Catharines, Niagara Falls, Bridgeburg and other places, and until 1898 was piped to Buffalo, N. Y. The Haldimand-Norfolk field furnishes gas to Hamilton, Dundas, Galt, Brantford, and elsewhere. These are by no means all of the towns supplied with natural gas in Ontario. Recently incorporated companies propose to pipe gas throughout western Ontario.

In Alberta the output of the Medicine Hat field is consumed in that city. The gas from the Bow Island field is piped in a 16-inch main 160 miles in length to Calgary, Lethbridge, and fourteen other towns. This is the only pipe line in that province at present, although others are planned.

DISPOSAL OF OIL PRODUCT.

In new fields where the yield of oil is small, with no gas, and there is much drilling, a considerable portion of the output of crude oil may be used as fuel in the drilling operations. So too when the field is close to an industrial market, the output of oil may be consumed as fuel. Large quantities of Beaumont, Texas, oil found a market in the field itself with the railway companies being used as fuel for oil-burning locomotives.

The great bulk of the oil, however, is sold to the pipe line companies, or to oil purchasing companies owning lines of tank cars. The methods pursued in the former case have been outlined in the chapter by Mr. Towl.

The refined kerosene, gasoline and lubricating oils are sold by the refinery company direct, or by subsidary wholesale dealers. As previously noted, these companies ship the kerosene and gasoline by tank cars to the local agents in the towns, where the oil is distributed from receiving storage tanks by means of tank wagons. Lubricating oils are sold in wooden barrels. Kerosene and gasoline are distributed to small country places without railway communication in barrels and tin cans, usually through wholesale grocery houses.

DISPOSAL OF NATURAL GAS PRODUCT.

More or less gas is produced in nearly every oil field. The local use of such gas as fuel in further drilling operations is comparable to the similar use of crude oil where gas is wanting. There is also more or less use of the gas in the field for domestic lighting and fuel purposes. When the field is near towns, the gas may be sold to local gas companies who distribute it, or if the supply be plentiful enough it may be piped to distant markets. Mention has been made of the pipe line from the Essex field of Ontario to Toledo, Ohio, and of the 160 mile main from Bow island to Calgary, Alberta.

While gas, struck without oil, will generally be closed off and utilized, it is nevertheless true that in new gas fields there is a great waste of gas in continuously burning flambeaux, and wild wells. On the other hand, it is the history of practically all oil fields, that in their earlier days the associated gas goes to waste. It has been true for Pennsylvania, Ohio and Indiana, Kansas and Oklahoma, and is now true for California in the United States, and was true of the oil fields of Ontario. There are, of course, reasons for this waste; among them, lack of markets, difficulty of controlling and closing off the flow; and the undesirability of stopping the flow of gas from an oil man's point of view because of his belief that if the gas be allowed to escape oil will usually follow it in the well; and finally, the lowering of the gas pressure to a point which makes it unprofitable to try to market it. Many states have enacted statutes compelling oil companies to close up and plug all gas wells, and to prevent the escape of gas from oil wells. A new provision that all reasonable precautions be taken to guard against the waste of natural gas was inserted in the Dominion petroleum and natural gas regulations, January 14, 1914. Such compulsory conservation is necessary and wise, though naturally repugnant to the oil prospector.

An economic use of natural gas which has been greatly developed within the last four or five years and which promises in time to do away with the waste of natural gas in most oil fields as well as gas fields, is the manufacture of gasoline from natural gas.

This subject is treated fully in Chapter IX.

CHAPTER VIII.

THE TRANSPORTATION OF OIL AND GAS.

By Forrest M. Towl.

When an oil well is completed, it either flows naturally or is pumped into a tank situated near the well. From this tank, the usual methods of transporting the oil to the refineries are by tank cars or through pipe lines. (Boat transportation is good and cheap if location of wells permits.) When tank cars are used, it is customary to gather the production from a number of wells through a system of pipe lines and to conduct it to some point located on a railroad. Before the production of a field reaches an amount sufficient to warrant the building of a pipe line, the oil is either collected in tanks and allowed to stand, or, if there is a railroad convenient, shipped by cars. After a field is developed enough to warrant a pipe line system for gathering the oil, there is run, from the producers' tanks at each individual well, a pipe line which connects with other similar lines leading to a point of concentration. The oil is either forced through these lines by a pump located at the well, run by gravity, or run into a system of lines having a suction pump at their terminus. The gravity system is to be preferred where it is possible to use it, even though it often requires larger lines. Where the oil is nearly as fluid as water, a pipe of about 2″ in diameter is used, but where the oil is viscous, larger pipes are necessary, the size, of course, depending on the amount of oil to be handled. With the same head, the more liquid oils flow about the same as water, but, when the oil becomes viscous and thick, the flow is very much reduced. The fluidity of the more viscous oils changes with the temperature. In general, the heavier oils are the most viscous, but there are many notable exceptions to this rule. The gravity of the oils is usually obtained by a Baumé hydrometer. The specific gravity of the oil can be obtained by substituting the Baumé gravity in the formula:—

$$\text{Sp. gr.} = \frac{144}{134 + \text{Baumé degrees}}$$

After the oil has been collected by the gathering system into the first concentration tank, it can be pumped through lines to some point of storage, or through a series of pump stations to the places where it is to be refined. There is a great difference in the crude oils, some of them being black, brown, or dark red; while others are amber or straw colored. As these lighter colored oils are often of more value than the darker, it is necessary to keep the different grades separate. This can only be done by pumping through separate lines, or handling the oil in large consignments. The history of the pipe lines dates back nearly to the discovery of oil in large quantities. The first successful pipe line in the United States was built in 1865 by Samuel Van Sickle. This line, between Pithole and Miller's Farm, was only four miles long, but they were able to pump 81 barrels of oil per day using three pumps. Since that time the pumping machinery has improved in line with other machinery being built. At first, high-pressure steam driven pumps were used, the steam being used but once. This was followed by the introduction of the compound pump, then the triple pump, which later gave place to the high-duty triple expansion condensing fly-wheel type of pumps. The first style of pumps required about 120 lbs. of water, converted into steam, per H.P. per hour. The last type of steam pumps require about 15 lbs. One pound of oil will evaporate about 15 lbs. of water, so that a pound of oil burned under a boiler with a good triple expansion pumping engine will furnish a H. P. for one hour. Recent developments in the oil engine have resulted in producing an oil engine driven pump which will furnish a H. P. per hour on less than 0·5 lb. of oil. In 1902 and 1903 the writer built a pipe line for handling the viscous California oil. The oil was heated by a surface heater using the exhaust steam from the pumping engines. This heating system is now in general use where viscous oils are to be handled

In the United States, the pipe lines take the oil from the producer's tank, gauging the tank before the oil is run into the pipe line system and after the run has been completed, care being taken to see that all of the water has been drawn from the tank before the run starts, and that the valves and connexions are all tight so that no water or oil can come into or leave the tank while the oil is being run into the pipe line. It is customary for the pipe lines to seal or lock their valves when oil is not being run from the producer's tanks. Where the oil is handled by a pipe line company not owning the production, the company furnishes the owner's representative at the well with a statement called a "Run Ticket", showing the level of the oil before starting to run, the level at the close of the run, and the number of barrels of oil taken from the tank as shown by the engineer's table. In the United States, the barrel contains 42 U.S. gallons of 231 cubic inches each. This is equivalent to 35 imperial gallons. There is generally some water and sediment in the oil coming from the wells and also considerable gas. For this reason, it is necessary for the oil to stand for some time before it is measured and run into the pipe lines. Even when this precaution is taken, it is found the lighter gravity oils, containing considerable gasoline, lose some in volume; for this reason, it has become a question to allow a certain percentage of difference between the gauge of the producer's tanks and the gauge in other tanks along the lines. With the light gravity oils, this loss amounts to about 2 per cent of the oil run which is the figure used in most of the fields producing light gravity oils. The heavier oils carry more water and sediment and hold them suspended for a long time. In handling the oils through pipe lines, it is necessary to be very careful around the pumping stations and keep fire or lights away from the oil or its fumes. Fires are often caused around the pumping stations and tankage fields by lightning. It has been found that a steel tank with a steel roof is not as liable to be struck by lightning as a steel tank with a wooden roof. Where there is a large tankage field, it is necessary to build banks around the tanks, or place them far enough apart so that when one is on fire it will not endanger others. Lightning rods have been used to prevent lightning striking the tanks, but it is generally considered that their value in preventing the loss by lightning does not warrant the additional expense. Where tanks are located near power plants having steam available, a steam pipe is connected into the top of the shell of the tank, so that, in case the tank is struck by lightning, steam can be turned in above the oil. If the roof of the tank is not blown off by the explosion, it is often possible to put out the fire in this manner. Care is to be taken to see that all of the openings in the tops of the tanks are closed to retain this steam. If water is available, it is the practice to play water on the adjacent tanks and sometimes on the tank which is on fire. This can be done with reasonable safety for a few hours after the tank has been struck. Oil is sometimes drawn off from the tanks by connecting pipe line systems and water forced in at the bottom to keep the burning oil as high as possible. By this means it is sometimes possible to save the bottom and lower ring of the tank, which is the most expensive part.

For the pipe lines, mild steel or wrought iron screw joint pipe is used. Bessemer steel also is used, but makes a cheaper and inferior grade of pipe.

In the collection of natural gas from the wells, there is often water or oil carried with the gas in such quantities that it will clog the lines. For this reason the wells are connected up with a trap to catch the liquid before it enters the lines. A number of wells are connected into a larger line and these larger lines converge to the trunk line which carries the gas to a point near to where it is to be consumed. At this point it is usual to reduce the pressure of the lines before distributing. The distribution is carried on in the same manner as when handling manufactured gas. When the pressure at the wells is not sufficient to deliver the gas to the market, compressor stations are put in and the pressure raised to a point sufficient to carry the gas through to the point of consumption. The following formula can be used in computing the amount of gas which will be delivered through a given line:

$$Q = C\sqrt{\frac{(P_1 + P_2)(P_1 - P_2)D^5}{L}}$$

No.	
1	Fuel boa
2	A pe ove
3	An o use
4	"Ligh
5	"Adn
6	"Resi
7	"Blac
8	A rel Die
9	A Ro
10	A Ro
11	Solar
12	Scotcl
13	Scotcl
14	Scotcl eng
15	A coa
16	A gas eng
17	A gas

TABLE XIX.

Chemical and Physical Properties of various forms of Fuel Oil.

No.	Description.	Specific gravity at 15° C.	Carbon.	Hydrogen.	Sulphur.	Oxygen and Nitrogen.	Net Calorific Value.	
			Per cent.	Per cent.	Per cent.	Per cent.	Calories.	British Thermal Units.
1	Fuel oil used on trial of a torpedo-boat destroyer	0.921	85.28	11.93	0.55	2.24	9,986	17,975
2	A petroleum product sold at a little over £2 per ton	0.888 (at 18° C.)	86.20	12.57	0.31	0.92	10,097	18,175
3	An ordinary crude petroleum often used for Diesel engines	0.923	–	–	0.45	–	9,956 (Hydrogen assumed as 12% for correction.)	17,921
4	"Light fuel oil"	0.900 (at 18° C.)	88.58	10,81	0.43	0.18	10,114	18,205
5	"Admiralty fuel oil"	0.928	86.40	11.55	0.34	1.71	9,961	17,930
6	"Residuum"	0.943 (at 18° C.)	86.44	11.23	0.30	2.03	10,065	18,117
7	"Black oil"	0.928	86.44	11.83	0.51	1.22	9,977	17,959
8	A refined oil specially adapted for Diesel engines	0.904 (at 18° C.)	85.05	12.15	0.37	2.43	9,998	17,996
9	A Roumanian crude oil	0.825	–	–	0.20	–	9,924 (Hydrogen assumed as 13.0%.)	17,863
10	A Roumanian crude oil	0.830	83.77	12,98	0.29	2.96	10,012	18,022
11	Solar oil (Texas)	0.862 (at 18° C.)	85.35	12.92	0.17	1.56	10,191	18,344
12	Scotch shale oil	0.855 (at 18° C.)	86.16	12.37	0.26	1.21	10,138	18,248
13	Scotch shale oil	0.8624	85.35	12.44	0.29	1.74	10,176	18,317
14	Scotch shale oil; works well on Diesel engines	0.867	–	–	0.33	–	9,961 (Hydrogen assumed as 12.5%.)	17,930
15	A coal-tar oil	0.958	86.16	9.05	0.80	3.99	9,422	16,960
16	A gas oil; gives trouble with Diesel engines	1.067	87.62	5.98	0.67	5.73	8,974	16,153
17	A gas oil; a composite coal-tar product	1.004	83.72	7.29	0.82	8.17	8,876	15,977

Q = cubic

P_1 = abso
inch.

P_2 = abso
square inch.

D = diam

L = lengt

C = a con

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Q = cubic feet per hour (15 lbs. absolute).

P_1 = absolute head or initial pressure in pounds per square inch.

P_2 = absolute delivery or terminal pressure in pounds per square inch.

D = diameter of the pipe in inches.

L = length of the pipe in miles.

C = a constant.

The onstant used for air computations is $C = 38 \cdot 28$.

The constant for any other gas is inversely in proportion to the square root of the specific gravity of the gas.

For a natural gas having a specific gravity of $0 \cdot 59$ the corresponding constant is $C = 50$.

These constants have been checked by many tests on pipe lines of various diameters and lengths.

With natural gas, it is seldom necessary to use gas holders to regulate the supply at the point of consumption as the line itself forms a reservoir and can be used to store a large amount of gas by what is known as "packing the line," which consists in permitting the pressure back of the regulator to increase until it approximates the pressure in the field. In Volume 34 of the Transactions of the American Society of Mechanical Engineers, page 185, is to be found a very interesting paper on problems in Natural Gas Engineering by Mr. Thomas R. Weymouth of Oil City, Pa. This includes a discussion of the properties and composition of natural gas, transmission of natural gas, pipe line storage capacity, the power required to compress natural gas, station designs, and general remarks on the subject. In the same volume on page 1091 is an article by the same author on the Measurement of Natural Gas. In the National Tube Company handbook of 1913, pages 320–325, there is an article on "Flow of Gas in Pipes—High Pressure," giving several coefficients and formulæ. The writer respectfully refers the student of these questions to the articles above cited.

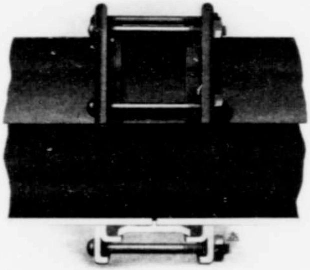
PIPE LINE REQUIREMENTS.

The transporting of gas requires a pipe line which shall be air tight. It is much more difficult to make a line to hold gas under pressure than it is to hold a liquid. Trouble has been experienced in almost all lines built for high pressures on account of the leaking of gas at the couplings. The first high pressure lines were laid with bell and spigot joints, caulked with lead. The lines might be tight when they were first laid, but the movement in expanding and contracting soon caused them to leak large amounts. The next lines used were of wrought iron or steel pipe, with screw joints. While these held much better than the bell and spigot pipe, there was still enough leakage to make it desirable to have a more perfect joint. The leakage on some of the earlier screw joint gas lines was such that by putting a rubber bag over the coupling, gas could often be collected at the rate of from 20 to 50 cubic feet per hour, or enough to run a good sized torch. This was true of lines up to 8 or 10 inches in diameter. When the lines became larger the leakage increased so much that it was practically impossible to use large size lines and get a large percentage of the product to the market. As the demand for natural gas increased it became necessary to use larger lines, and a rubber packed stuffing box was developed. The first successful joint of this kind in the market was the Dresser coupler, and it is due largely to this and other couplings that the natural gas industry has become so great.

The Dresser coupler consists of a sleeve into which the ends of the pipe are placed. There is a projection in the center of the sleeve so that the ends of the pipe will be each inserted into the sleeves the same distance. This sleeve acts as a follower to compress rubber in an annular space into the end rings which are drawn together by bolts. The rubber is surrounded on one side by the pipe, on another by the body of the coupling, and on the remaining sides by the end rings so that there is very little of the surface of the rubber exposed either to the gas on the inside or the air on the outside of the line. It is found that these joints will last for years. (Plate XV shows a cross section of the Dresser coupler).

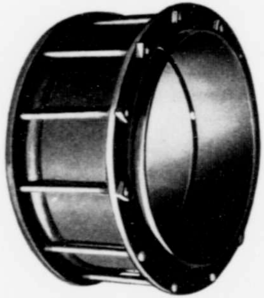
The Hammon coupler is a modification of the Dresser, one of the principal features of which is that the projection at the centre of the sleeve is made by lugs welded on to the sleeve. When it becomes necessary to take apart one of these couplers,

PLATE XV.



The Dresser coupler.

Plate XVI.



The Hammon coupler.

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the lugs can be broken off and the coupler slipped back so as to allow of the pipe being easily removed. (Plate XVI shows the Hammon coupler).

Lines of pipe can be built in almost any kind of country, but it is necessary in some places to arrange to keep the line from acting as a Bourdon tube and expanding in one direction until the ends of the pipe may be pulled out of the coupling. To avoid this trouble it is customary in such places as river crossings to use screw pipe, and to place over the collar a clamp which is constructed to make a rubber joint between the ends of the collar and the pipe.

For power transmission lines or for temporary gas lines where the distances are short or the service temporary and it is not considered necessary to bury the pipe, it will be found that the screw joint pipe is satisfactory, but for other natural gas or air service, the rubber coupling has many things to recommend it, and when the capacity requires large pipe it is almost absolutely necessary to use this type of coupling. These couplings have been used for manufactured gas, but it is found that the condensation from the gas collects in the coupling and soon causes a leak in the rubber joint. Work is now in progress to perfect a material which will not be acted upon by the condensation in the gas and which will make a gas tight joint.

METERS.

When gas having a commercial value is to be transported, it becomes necessary to measure it with a considerable degree of accuracy, and, as the problem of the flow of gas must be based on some measurement of volume or weight of the gas, the first thing required is the establishment of a basis for measurement and an apparatus for measuring. The basis usually employed is the cubic foot at atmospheric pressure and at a stated temperature, although many engineers use one pound of air as the unit. By Mariott's law, it is a simple problem to change from one basis to the other.

On account of the change of volume of the gas, for differences in temperature and pressure, the actual accurate measurement of the gas becomes a very difficult problem. It is usually considered that a gas meter is accurate if it registers within 2 per cent of the standard. The commercial gas meter has been perfected so that, when it is in good condition and working under normal speed, it can be relied on to give results within that amount, provided the temperature and pressure remain practically constant.

The measurement of gas at high pressures in particular presents many difficulties.

The following types of meters are at present in use:

The displacement or regular type of meter.

The orifice.

The proportional, which is a combination of the first and second.

The anemometer.

The dynamic, and

The electric.

Each of these forms of apparatus has its special advantages and limitations when employed in measuring gases at high pressure. For measuring large volumes at high pressure, the proportional meter, the orifice, the dynamic and the electric seem to be the only ones available.

THE ORIFICE METER.

A number of meters have been made using the orifice to measure the gas. The meter is usually calibrated by gas or air flowing through the orifice into a gasometer under a constant difference in head. After the orifice has been calibrated, one or more orifices are placed in line and the pressure is noted each side of the opening. This requires constant watching and readings in order to compute the amount of gas flowing. The St. Johns meter of this type uses a variable orifice and on a chart records the position of a plug in an opening. There is no attempt in this meter to make corrections for variations in pressure. The charts are averaged by a planimeter. This plan of measurement is used largely by the New York Steam Heating Company.

THE PROPORTIONAL METER.

In the proportional meter, it is necessary to make corrections on account of change of pressure. This requires either an observer to note the readings of the meter and the pressure or a recording apparatus to show the readings and pressures simultaneously. Such an apparatus is manufactured by several of the companies, but it is difficult to make the computations from the charts.

THE DYNAMIC METER.

The principal representative of the dynamic class is the Pitot tube. The General Electric Company makes a recording Pitot tube which is automatically corrected for variation in pressure. The general practice in measuring gases with the Pitot tube is to take readings at stated intervals and make computations from these readings.

THE ELECTRIC METER.

The electric meter is a recent development in gas engineering resulting from work done by Prof. Carl C. Thomas of Johns Hopkins University. It is based on the principle that to increase the temperature of a given weight of a gas a given amount requires the addition of a corresponding amount of heat. The heat is supplied electrically and the amount of energy required is measured.

In 1901 an 8″ pipe line supplying gas from northern Pennsylvania to the city of Buffalo, New York, was tested under various conditions to obtain the coefficient for the flow of natural gas. Pressure gauges were carefully calibrated and installed at each end of the line and at five intermediate points. Observations were taken every fifteen minutes night and day for a period of one week. The amount of gas delivered from the line at Buffalo by a Pitot tube showed the delivery to be at the rate of 221,000 cubic feet per hour. The temperature was 32 degrees F. and the weight of the gas per 1,000 ft. was 51·61 lbs. when measured at an absolute pressure of 14·65 lbs. From this test, the coefficient of C–50 for gas having a specific gravity of 0·64 was obtained which corresponds to a coefficient of 40 for air.

A number of formulas have been suggested, based on data which seems to show that the number of cubic feet per hour varies as the square root of the 5·33 power of the diameter. Other formulas suggested have slight variations in reference to the diameter but the author does not consider that the evidence is at all conclusive and prefers the formula using the square root of the 5th power of the diameter as it gives results which are in all probabilities as accurate as the gas measuring apparatus in use at the present time.

CHAPTER IX.

UTILIZATION OF PETROLEUM AND ITS PRODUCTS.

By T. T. Gray.

UTILIZATION OF CRUDE PETROLEUM.

Petroleum is sometimes used in the crude state for fuel, for surfacing roads, or for dust prevention on roads, but ordinarily the first stage in the utilization of crude petroleum for any purpose is to subject it to some form of distillation which will reduce it to the most desirable consistency for the purpose in question. Petroleums used in the crude state as fuel are the more viscous varieties occurring on the Pacific Coast and in Mexico. Perhaps 30 per cent of the fuel oil burned in Mexico in the year 1913 was burned as crude oil, without any form of previous treatment. These viscous oils contain, as a rule, considerable asphalt and sufficient water to make it difficult to distill them, and are therefore used in the crude state. Similarly the oils used on roads are the heavier grades containing asphalt which in California sometimes reaches 60 per cent.

PETROLEUM PRODUCTS.

The nomenclature of petroleum and its products has never been clearly defined, and is therefore often confusing. As stated in Chapter II of this report three general kinds of crude petroleum are spoken of, namely: paraffin-base, which carries solid paraffin hydrocarbons and practically no asphalt; the asphalt-base, which contains asphalt and no paraffin; and paraffin-asphalt, which is a combination of the two. Generally speaking, the paraffin-base petroleum is of lighter gravity, and yields a greater variety of lubricating oils.

In the early days of the petroleum industry, when petroleum was refined for illuminating products only, at which time gasoline was a drug on the market, the residue from the distillation known as tar which contained the lubricating oils, was run to waste. Later this tar was distilled separately for the manufacture of lubricating oils, being processed in stills and distilled to coke. The distillation of tar was particularly hard on the stills, due to the formation of a large bed of coke. Tower stills, or stills of the dephlegmation type were finally adopted, and the crude oil distilled to coke in one operation, which process is the one in general use to-day.

Asphaltic base oils are distilled to asphalt and the distillates are cut according to gravity. As asphalt base oil does not yield steam refined cylinder stock or paraffin wax, it does not answer well for an illustration of the different refining methods.

REFINING.

In general, whatever use petroleum is to be put to, it is normally pumped and shipped in tank cars to a refinery, and the lighter products are distilled off. The simplest methods are those applied to oils which are essentially fuel oils and from which a slight amount of naphtha and burning oil is distilled off in order to yield a fuel oil which can be stored with entire safety. The oil is pumped into a horizontal, cylindrical still and ordinarily heated by external fire made by burning crude oil or some form of residuum in a jet burner by which the oil is sprayed into the fire box and thus burned in a long flame under the boiler. These methods of burning oil will be described under fuel oils. The practice is becoming very general at the present time of introducing steam into the still for all kinds of distillation, this causing the distillation to take place at slightly lower temperatures than would be the case without the steam, and also preventing overheating the residum left in the still so that a sweeter product is left. In practice the distillation is carried on until the distillate which is passed through a condensor and appears in the so-called still house, shows by its specific gravity that the oil remaining in the still will have a flash above a degree designated as safe—usually 150° Fahr. The oil is then pumped, while still warm, into the proper tanks for distribution to the points of use.

In the manufacture of road oils, the process is the same although the practice is becoming more frequent of carrying the distillation until the residuum left in the still is largely asphaltic oil that is almost solid when cold. Steam is used very generally in the reduction of crude oils for road purposes because the resulting oil is more elastic than would have been the case if steam had not been used. Without steam, the oil is cracked into a product which is more brittle.

General Refineries.

A refinery which is intended to furnish the usual list of products is much more complicated than that required simply for the production of road and fuel oils. It was the former practice to pump the crude oil into stills of from 500 to 1000 barrels capacity and carry the distillation to the stage when first naphtha, and then the oil suitable for illuminating purposes had been distilled off and sent to the appropriate tanks for crude naphtha and crude burning oil distillate. The residium was then called tar, and was pumped while warm—but not hot—into tanks or direct into the so-called tar sills where the distillation was continued to coke with a fraction first of low grade naphtha, low grade illuminating oils, gas oils as the next succeeding product, then light lubricating oils containing paraffin wax, then successively heavier oils also containing paraffin wax, and finally paraffin butter as the last semi-solid product, leaving the last product of coke in the still. The still was then steamed free from explosive gases, allowed to cool down, and the coke dug out, and the still made ready for another distillation. The recent progress in distillation has avoided the use of two of these stages of distillation, in the two different kinds of stills described, and the crude oil is distilled clear to coke in the first stills, which are modified by the introduction of towers on top of the still through which the vapors pass and are more thoroughly fractioned, portions—when desirable—being returned to the still for the purpose of cracking them to afford a greater yield of light products. By this means, the present day stills can be made to yield very different proportions of products according to the market demand. As a rule, the greatest possible yield of naphtha and burning oil is desired, and the proportion now obtained is considerably greater than the same variety of oil would have yielded in the past under the former systems of distillation.

The crude products obtained from the primary distillation of crude oils are next redistilled. The crude naphtha is pumped into large stills, heated entire by injected steam, the outside of the still being well insulated to prevent loss of heat. A modern improvement in naphtha steam stills is to install over the still a higher tower through which the naphtha vapour from the still ascends and meets the cold, crude naphtha which flows down fron the top of this tower. The heat exchange thus effected has proved a great economy in naphtha distillation. By this distillation, the crude naphtha is fractioned into a great variety of products ranging from gasoline with specific gravities between 80 and 90 degrees Baume to ordinary stove gasoline with specific gravities between 70 and 80 degrees Baume. Motor naphthas with specific gravities of from 56 to 60 degrees Baume and certain special heavier products designed as solvents are prepared from a certain variety of crudes, especially in Texas and California. A considerable proportion of heavier material corresponding in gravity and flash point to illuminating oil is left in the still. This is added to the tank containing crude burning oil distillate. This distillate is similarly distilled, partly by fire underneath and partly by steam slightly super-heated. The first products from this steam still are again heavy napthas which are mixed with the corresponding product from the naphtha stills, and the burning oil is then taken off, distilled—being gauged both by its gravity and colour, and the distillation continued until one or the other is unsatisfactory when the residuum is either added to gas oil or returned to lower grade stock. The gas oil distilled is usually sold for enriching water gas, that is this gas oil is sprayed into the top of the white hot column of coke which is being decomposed into gas by the injection of steam below. The oil is principally broken into gases of high illuminating power. Within the last few months, this gas oil has been applied to the production of so-called motor spirits by distillation under pressure, according to Burton and other systems, in one of which the hydrogen or fixed gases obtained in various cracking processes with the refineries are passed, together with vapor of the gas oil, through porous, catalytic agents by which the permanent gases are so combined with the cracked gasoline as to afford material with satisfactory colour and odour.

In the case of oils from the Petrolia, Sarnia regions, etc., in Lambton county, Ontario, the crude burning oil distillate is agitated with copper oxide during the operation for the purpose of removing the sulphur, according to the process invented by Dr. Herman Frasch.

In distilling petroleum of the Pennsylvania type, three methods are used, namely: The dry or destructive distillation, the steam distillation, and the vacuum distillation.

The dry or destructive distillation, which causes cracking or decomposition, is conducted by means of fire heat only and is usually carried to coke. The process is better adapted to petroleum which is unfit for the manufacture of cylinder stocks.

The steam distillation makes it possible to distil oil at lower temperature than by the dry distillation, and is therefore used to prevent decomposition. The stills are of the same type as those used in the dry distillation, except that they are well insulated in order to prevent the vapors from condensing on the sides and falling back into the superheated oil. Steam is introduced into the body of the oil in the still, and the distillation controlled by fires underneath the stills.

Vacuum distillation is sometimes used in conjunction with the process of steam distillation. A partial vacuum is created by means of a pump, thereby causing the hydro-carbons to distil at low temperatures. This method requires heavier stills, and although the results are said to be superior, the difference is not usually considered great enough to warrant the increased cost of installation and operation.

Where Pennsylvania crude petroleum is subjected to distillation, gasoline is the first product to pass over. The stream starts flowing at about 75° Baume gravity, but as the distillation continues the gravity becomes heavier. Gasoline is separated by the gravity of the stream at some pre-determined point, which varies in different plants but which is in the neighbourhood of 57° Baume gravity. The stream of distillate starts practically water white in colour but darkens slowly until the cracking point is reached, or at about 43° Baume gravity, at which time the colour changes very rapidly.

The cracking which ensues after the normal illuminating oil distillate has been separated, gives rise to the production of a gasoline of unsaturated character. The different fractions separated, namely: gasoline, normal burning oil distillate, and low test or cracked burning oil distillate, are redistributed in specially constructed apparatus heated by steam. The heavy end of the gasoline fraction finds its way into the normal burning oil distillate, and the light end of the normal burning oil distillate goes into the normal gasoline fraction.

PRODUCTS OF THE DESTRUCTIVE DISTILLATION OF PARAFFIN BASE CRUDE OIL OF THE PENNSYLVANIA TYPE.

Gasoline.—This name has been applied broadly to the lighter products derived from petroleum, ranging in gravity from 58° Baume to the very high gravity products, 90° Baume and over, which are extracted from the still gases by the compression method.

There are two general grades of gasoline; the normal gasoline which exists naturally in petroleum, and the cracked gasoline formed by the decomposition of the heavier products. The normal gasoline has a low iodine absorption, whereas the gasoline produced by the cracking process has a high iodine absorption.

The examination of gasoline should include gravity test, temperature distillation, with determination of initial and boiling points, and the iodine absorption.

Normal gasoline should be water white in colour, of sweet odour, should evaporate without leaving any stain or appreciable odour, and the iodine absorption should be below five per cent. Normal gasoline is used, or rather should be, in all dry cleaning establishments.

Cracked gasoline, as the name implies, is likely to fluctuate in properties. Speaking generally, and of its application to use in gas engines, it should show a low initial boiling point, and should have a final boiling point of not higher than 350° F. As long as these conditions are fulfilled, the lowest gravity is the best product.

Illuminating oils.—These oils are the products heavier than gasoline, ranging from 100° to 250° F. flashing point. Like gasoline, they are divided into two general classes, depending whether they are normal or cracked products. The usual tests applied to burning oils are, gravity, flash point, fire test, distillation, sulphur determination, viscosity, colour and burning tests.

There are several grades of illuminating oils, which may be classified roughly as follows:—

1. 45° to 47° Baume gravity, usually called Water White burning oil (normal product), fire test 150° F. or better.

2. 43° to 45° Baume gravity, usually called Standard White burning oil (cracked product), fire test 100° F. or better.

3. Below 43° Baume gravity, a cheaper product which may be either normal or cracked, fire test 110° F. or better.

4. 300° F. fire test, known as 300° Oil, Mineral Sperm, Mineral Colza or Mineral Seal.

The first three grades are ordinary kerosene lamp oils. 300° oil is used as an illuminating oil in cases where lower fire test oils are objectionable.

The most practical test to apply to illuminating oils is to make an actual burning test, taking into consideration the incrustation of the wick and diminution of the flame. These tests are merely comparable and require some practice in order to judge the quality of the oil. Provided the flash is satisfactory, the best burning oil is that with the lowest viscosity, lowest iodine absorption, highest gravity, lowest sulphur, and best colour.

Fuel oils.—In judging the quality of fuel oils, consideration must be given to the following points: Safety, transportation, storage, and method of application. Naturally the best fuel oil is the one which will do the work most satisfactorily at the lowest cost. It would not be practical to design a set of fuel oil specifications for one case that would fit every other case.

Fuel oils, from a refining standpoint, are usually the distillates heavier than burning oil and lighter than the lubricating oils, ranging from 25 to 30° Baume gravity.

A discussion of the uses of fuel oils will be found on a later page.

Paraffin oils—The lubricating oils made by the dry distillation method are generally known as paraffin oils. They range in gravity from 30° to 20° Baume, in flash from 300° to 450° F. by the Cleveland open cup, in viscosity from 40 to 600 seconds on the Saybolt viscosimeter at 70° F., in cold test from 0° to 40° F., in colour from pale-yellow, through red, to dark green.

Paraffin oils are usually decolorized by the sulphuric acid treatment.

In judging the quality of paraffin lubricating oils we face the same condition as with fuel oils, in other words, the oil that does the work most satisfactorily at the lowest cost is the best product from the consumers' standpoint. The ordinary physical tests should be determined, such as gravity, flash-fire test, cold test, viscosity, and colour, and the oil should show no trace of acid.

Uses.—These oils are suitable for all kinds of lubrication, except perhaps for steam engine cylinders.

Paraffin wax.—Refined paraffin wax should be practically water white when in the molten state, should be odourless, and should not darken rapidly when exposed to the sunlight.

Paraffin wax is derived from the paraffin distillate, which it will be remembered, is the heavier distillate separated at the crude stills after the fuel oil has been cut and until just before the coking period, at which point a very heavy, sticky, green, asphaltic like substance known as wax tailings, distils over.

The paraffin wax is separated from the paraffin distillate by cooling and filter pressing. The pressed distillate is used for the manufacture of the paraffin oils, and is reduced by the steam distillation method.

Uses: Paraffin wax is used to a large extent in the manufacture of candles; it is used also in making so called wax paper, for water proofing, for laundering, protecting preserves from fermentation, in admixture with asphaltic products for making insulating pitches for wires, for floors and a variety of other purposes.

Wax tailings.—This product of decomposition contains chrysene, picene and other compounds formed by destructive distillation. It is of dark green colour but darkens on exposure to light. It is asphaltic in nature and varies in melting point according to the care with which it is separated and later refined.

Uses: Used for weather and waterproofing compounds, in some cases as a flux in street paving mixtures, and as a filler in very cheap axle greases.

Coke.—Petroleum coke usually shows the following composition: volatile and combustible matter, 5 to 10 per cent; fixed carbon, 90 to 95 per cent; ash, from a trace to 0·3 per cent; sulphur, from 0·5 per cent to 1·0 per cent. On account of the purity of petroleum coke it has found wide application in metallurgical processes, in making of battery carbons and carbon pencils.

PRODUCTS OF THE STEAM DISTILLATION OF PARAFFIN BASE CRUDE OIL OF THE PENNSYLVANIA TYPE.

Normal gasoline.—Same as with the dry distillation.

Illuminating oils.—The yield by the steam distillation is much lower than by the dry distillation.

Fuel oils.—Lower yield than by the dry distillation.

Spindle oils.—The lubricating oils range in gravity from 26° to 35° Be., in flash from 320° to 450°F. (Cleveland open cup), in viscosity from 400 to 40 seconds—Saybolt at 70°F., in cold test from 10° to 40°F., and in colour from almost colourless to dark red.

Spindle oils are usually decolourized by filtration through Fullers earth or bone-black, they differ from paraffin oils in that for a given viscosity they are of higher Baume gravity. For illustration, a spindle oil and a paraffin oil of the same gravity may have the following tests:

	Spindle Oil.	*Paraffin Oil.*
Baume gravity @ 60°F	30·0	30·0
Flash, Cleveland open cup........	420°F.	340°F.
Fire test, Cleveland open cup.....	475°F.	390°F.
Viscosity, Saybolt @ 70°F........	300 seconds.	60 seconds.

Spindle oils are used for all kinds of high grade lubrication except steam cylinders; as high grade engine oils; for spindles in textile mills from whence the name came, and on account of the fact that spindle oil does not make bad stains on fabrics whereas paraffin oils do. They find wide application as automobile oils, for which purpose they seem to be particularly well adapted. Specially purified oils of this class are being used in medicine with very successful results in treating cases of bowel auto-intoxication.

Steam cylinder stocks (oils).—These are the steam residues from high grade crude oil, they vary in gravity from 20° to 27° Baume, in flash from 650° to 475°F., in viscosity from 350 seconds to 100 seconds Saybolt universal viscosimeter at 210° F., in cold test from 30° to 60°F. They are dark green in colour and contain varying amounts of asphaltic matter, depending upon the quality of crude oil refined and the care exercised in refining. These oils are often further refined by filtration through Fullers earth or bone-black, which process raises the gravity and the cold test, but reduces the viscosity depending upon the degree of filtration. Filtered cylinder stocks may be recognized by their transparency.

Uses: The lubrication of steam cylinders, for which purpose they are often compounded with fatty oils.

Vaseline or Petroleum Jelly.—This is the steam residue from selected crude oil rich in amorphous paraffin wax, which has been refined and decolourized by filtration through Fullers earth or bone-black. The colour is dependent upon the extent of the filtration and varies from white to red.

Uses: Largely as a salve. It is also put on the market in medicated forms as an antiseptic salve.

Miscellaneous.

TURPENTINE SUBSTITUTES.

These products are usually intermediate between gasoline and illuminating oil. They vary in gravity from 40° to 58° Baume, and are more homogeneous than the burning oils. As they are designed for paint thinners and for admixture with turpentine, they should evaporate without leaving residues or stains. A representative sample found in the market gave the following tests:—

Baume gravity @ 60°F.	48·2
Refractive index @ 60° F.	1·4595
One drop evaporated from white paper	No stain.
15 drops in a watch glass evaporated in	2 hrs., 23 mins.
15 drops of turpentine in watch glass evaporated in	2 hrs., 15 mins.
Initial boiling point	282°F.
Final boiling point	426°F.

BLACK OILS.

These oils may be residues from crude oil or from distillates. They vary widely in tests and are cheap lubricants. They are used on car wheels and in other places where the higher refined oils are not necessary.

ASPHALTS.

The residues of asphalt-base oils are known as petroleum asphalt. They may be steam residues, dry or oxygenated residues. Asphalts are made also from the sludge acids resulting from the sulphuric acid treatment of paraffin oils, or they may be made by blowing distillates with air at high temperatures, which converts the low viscosity oils into asphalt by the abstraction of hydrogen and carbon and a reconstruction of the molecules.

Uses: Street paving, roofing pitches, water-proofing, and similar purposes.

Use for street oiling.—In the past few years various cities in Canada have taken up oil for oiling their streets instead of sprinkling with water, as heretofore. This has been done extensively in London, Ontario, and towns to follow suit are Windsor, St. Thomas, Aylmer, Tilsonburg, Parkhill, Otterville, Tilbury, Wheatley and Kincardine.

Conclusion.

In addition to the uses given above for petroleum products, they are used in the manufacture of harness oils, leather and belt dressing, greases, wool oils, soluble oils and in many other products and other ways too numerous to mention.

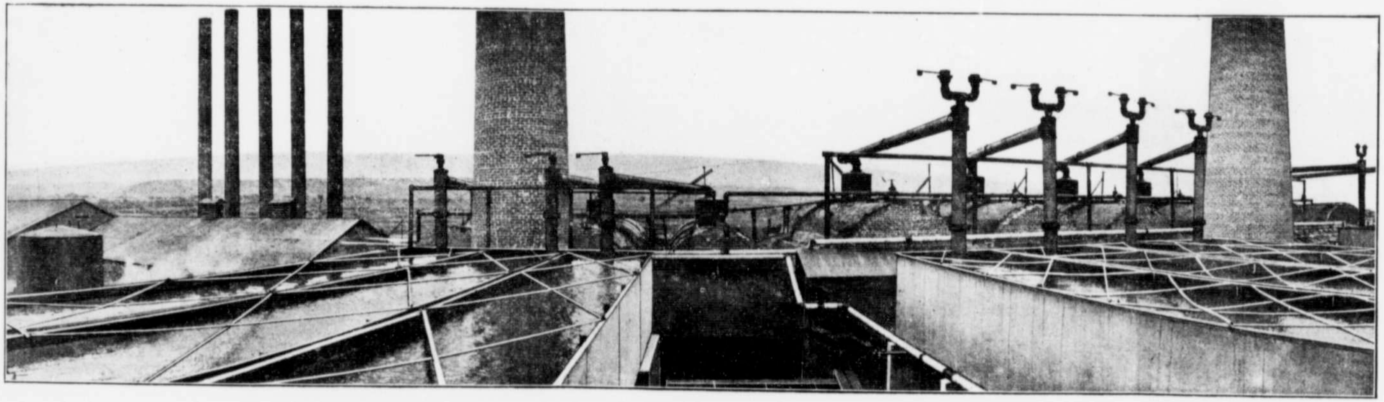
Pressure distillation, which for a long time was avoided on account of the hazard involved, has finally come into practical use in the manufacture of gasoline from heavy fuel oils. Under the patent of Dr. Burton, the Standard Oil Company is now making this cracked product under the name of Motor Spirits. Dr. David T. Day took out a patent previous to Burton's, which combines pressure distillation with hydrogenation. By this process hydrogen or a hydrogen carrying compound is introduced at the time of cracking of the fuel oil and, mixed with the light gasoline vapours formed, it then passes over a contact or catalytic agent. These processes will no doubt have much to do with the future development of the gasoline industry, and it is perfectly safe to say, that as long as we have oil, we will be able to manufacture gasoline in large quantities.

FUEL OILS.

GENERAL CONDITIONS.

There are certain oil products which must, in the future of the Canadian oil trade, require especial consideration. Chief among these is fuel oil. At present the situation is one of finding a supply, especially for railroad locomotive use, sufficient for a demand which is now not filled at all and yet is increasing rapidly. In spite of importation from the United States it is safe to say that the fuel oil will not be filled from the present sources of supply. Even a large development of the oil shale

PLATE XVII.



Stills at Casper, Wyoming, erected for the purpose of extracting gasoline from heavy oils by the cracking process.

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industry, which would be most fortunate for the eastern provinces, would find its product absorbed without affording any considerable low grade oil for fuel purposes. On the other hand it is quite likely that a large addition to the supply of Canadian oil may be furnished from Alberta or Saskatchewan at any time, when the conditions would be reversed and a larger market than now exists would be required to dispose of the supply.

DEVELOPMENT OF OIL AS FUEL.

In a previous paragraph fuel oils have been defined, as regards the product furnished by refineries. But in all oil countries so many products have been utilized for fuel that a brief review is desirable of the history of fuel oil.

The use of large quantities of any oil as fuel began in Russia when the one product in general demand from crude was kerosene and it was obligatory to find a use for the residue "astatka," which was sold for whatever it would bring for fuel in place of coal for the steamers on the river Volga. This was no definite product, but simply whatever was left behind when first gasoline and then kerosene had been distilled away from the crude oil. From that time to this the practice of the oil men has extended of getting rid of waste products by selling them as fuel oil. The points of advantage of oil over coal became so evident that the amount which could be sold as fuel was practically unlimited provided the price was not so high as to be entirely out of proportion to solid fuel. These advantages caused the adoption of oil in place of coal in certain places at prices far above the coal equivalent; thus, in the United States, glass makers adopted this easily regulated fuel, obtaining the supply from eastern refineries.

In 1901 the unearthing of a flood of oil at Spindletop, Texas, quickly brought about its adoption by the Southern Pacific railway, which was already using crude oil in the same way in California not only because there was little use for California oil for usual refining purposes but also because coal fuel was so very high priced. This crude oil became fuel oil, as well as the surplus refinery products. This has always been an expedient for marketing a surplus until the development of refining methods suitable for the new oil. Then the fuel oil trade again was filled by the less valuable residues.

Only a few years ago Dr. Rudolph Diesel found that many heavy oils could be efficiently burned in internal combustion engines, in place of gasoline, by so increasing the compression as to heat the oil to the point of ignition. Not all oil residues are acceptable for this Diesel engine, chiefly because it is difficult to feed certain thick oils to the combustion chamber in good admixture with air. But for this it is claimed that any oil would be satisfactory; in fact it is claimed that vegetable nut oils are thus used in Africa, and that coal dust could be burned if it could be properly supplied to the cylinder. As a matter of fact very clean oils free from sediment and not so thick as to clog the feed are desired for the Diesel engine, and distillates are preferred. With the progress in converting one kind of oil product in almost any desired condition it is probable that less attention will be paid to the improvement of Diesel engines for using heavier crudes and more will be given to the furnishing any desired grade of fuel oil.

CHARACTERISTICS.

A valuable description of the characteristics of fuel oils in common use was given in a lecture by Mr. W. Hamilton Patterson, M.Sc., in the University in Liverpool in 1912, from which the following is extracted from the Petroleum Review of January 15, 1913.

"Since the report of the Royal Commission on Coal Supplies in 1893 there has been vast development in the world's oil resources; new oil fields are being continually tapped. There has also been a great increase in the production of tar oil obtained from coal, and there will probably be a larger increase in the near future. In line with this the internal combustion engine has made rapid strides, being constructed of ever-increasing size and higher efficiency. An epoch in the history of internal combustion engines was inaugurated by the advent in 1897 of the Diesel engine, which is adapted to burn almost any variety of liquid fuel, at the same time creating a record in efficiency, being able to transform 37 per cent or more of the heat energy of the fuel into available work. Of no less importance are the engines of the semi-Diesel type.

The chemical side of the question has scarcely kept pace with the mechanical, and there is much room for scientific research and investigation in the preparation and utilisation of fuels. There is also much overlapping and ambiguity in the nomenclature of the various technical products which are put on the market as liquid fuels. To begin with, there ought to be some distinction between oil fuels and fuel oils. In this paper the term fuel oil will be reserved for oils burnt in external combustion, *e.g.*, under a boiler for the purpose of raising steam; oil fuels, on the other hand, will mean oils utilised for the production of power in internal combustion engines. The term liquid fuel may be applied in either case. Athough many fuel oils may often be equally well utilized as fuels, there is a difference in the requirements. In oil fuels, volatility is of greater importance, and the obtaining of oils which will neither corrode nor give trouble in the cylinders of internal combustion engines on explosion or burning. In fuel oils more vital factors are: cheapness, a fairly high flash point, and high calorific value. The various liquid fuels and their allied products, derived either from petroleum or coal tars, are not definite compounds; it is therefore impossible to assign to these varying mixtures scientific names. It is, however, greatly to be deplored that, in technical usage, the same name is not applied in different parts of the world to denote what is essentially one and the same product and vice versa. What confusion occurs, for example, in the designation of the words paraffin, benzine, solar oil, naphtha, etc. To add still further to the chaos which already exists, we find specially coined trade names. Of oil fuels, the only variety widely used for certain kinds of motor engines is petrol, but alcohol might be used instead, provided it could be obtained cheaply enough, and also benzol, or better still, a mixture of the two. When, however, liquid fuels have to compete with coal for the production of power, only crude products, by-products or residues can be considered . The available sources of such liquid fuels may be divided as follows:—

(1.) Crude petroleum, or residues and products from petroleum;
(2.) Tar oils from coal distillation, coking, or producer plants, especially from bituminous coal producers;
(3.) Liquids or oils from vegetable or animal sources, including alcohol and nut oils, at the present time of little importance;
(4.) Oils from lignite, peat, wood, or shale.

The last class is not very important as far as this country is concerned, except as regards the Scottish oil production from shale, which amounts to about 70,000,000 gallons per annum. This figure includes, however, a large percentage of constituents too valuable to be utilised as ordinary liquid fuel. The following results have been obtained in the examination of various liquid fuels, most of which are available in this country, and obtainable at the cheapest price; the highest price in any case in this country is a little over £1–3s. per ton, most of them, however, being cheaper. They have been examined more particularly with reference to their use as oil fuels. The calorific values were determined by the Mahler Bomb Calorimeter, a method which gives absolutely reliable results when worked under proper conditions. The sulphur was determined by titration of the bomb liquid, allowance being made for nitric acid produced in each case. Carbon and hydrogen were determined by the ordinary combustion method of elementary organic analysis. Open tests were made of flashing and burning points, while viscosity was determined in a special viscometer. The main figures are here tabulated:[1]—

Of these, Nos. 3, 11, and 14 have been found to work well on Diesel engines, and there is good reason to suppose that Nos. 1, 2, 7, 8, 13, and 14 would work equally well. Nos. 16 and 17 have been found to give trouble with Diesel engines.

As fuel oils, probably all the oils tabulated would give an efficiency proportional to their net calorific value. It will further be seen that the sulphur content is in no case excessive. The much lower calorific values of oils

[1]See Table XIX.

Nos. 16 and 17 may account in some measure for the trouble they give in Diesel engines, but there are other factors which are brought out in the tables above. In combustion of fuels in the bomb calorimeter, the products of combustion are cooled to the ordinary temperature of the calorimeter, the hydrogen of the fuel is oxidised to water, which gives up its latent heat on condensation. There is also a small amount of sulphuric and nitric acid produced which must be allowed for. The heat value actually obtained in the bomb calorimeter is the gross value, while that corrected for hydrogen and acid formation is the net value, and corresponds to the maximum energy of the fuel which is available for the production of work in ordinary practice. It is astonishing how, in ordinary commercial practice, the two values are confused. To apply the right correction for the water condensed, it is necessary to know the hydrogen in the oil (also the free water if there is any). To ascertain the correction due to the former cause, the only absolutely reliable means is to determine the hydrogen by making an elementary analysis of the oil. This is, however, a tedious process, and in most cases, as will be shown below, the hydrogen content may be assumed with an accuracy sufficient for the purpose of applying this correction in technical work. In the table given above the figures are given for the open flash points, burning points, hydrogen contents, gross calorific value given by the bomb calorimeter determination, the water correction for the hydrogen, the acid correction in the order, nitric acid, sulphuric acid, and the corrected or net calorific value.

In low boiling fractions of petroleum products, the hydrogen content may reach 16 per cent. or more."

Oil burning locomotives have been in use hardly a dozen years, but at the present time oil engines are rapidly being installed in ocean steamships and in the navy. The progress of fuel oil consumption has been largely increased through the invention of the crude oil consuming gas engine, which has rendered oil the world's best fuel. The British Admiralty has recently decided that the use of oil as fuel is of such great advantage over coal as to warrant its adoption in the navy. The American navy also is well advanced in oil burning. All battleships—the construction of which has been started within the past half dozen years—are equipped for oil burning, either as an auxiliary to coal or in place of coal. Oil is used as an auxiliary fuel in seven battleships and is used exclusively in four, while thirty torpedo boats have exclusively oil fuel. The superiority of the ocean steamers driven by internal combustion engines was largely a matter of theory up to the year 1912, but in that year the fuel question was revolutionized by a Danish Company operating a line from Copenhagen to Singapore, which completed a 7,000 ton steamer, equipped with oil engines, which was the first large steamer ever to use oil fuel. The latter has proved to be eminently successful. Since that time several other large oil burning steamers have been launched in various countries.

Advantages of oil over coal as ocean fuel.—The advantages of internal combustion engines over engines driven by burning coal are numerous. In the case of the navy the removal of funnels increases the firing arc for a number of guns. The proportionate energy of fuel oil over coal is considerable. The oil occupies much less space than would the coal; hence, there is an increase in horse power. The reduction in the number of stokers employed results in economy, both from the sleeping space and from the salary and food question. Perhaps one of the greatest advantages of oil is its cleanliness and the absence of smoke.

The United States has equipped its latest submarines with internal combustion engines. Since the discovery that oil possesses great advantages over coal as a fuel in warships, Great Britain has energetically prosecuted a search for a large fuel oil field throughout her colonies; nothwithstanding these efforts, no large supplies have been found in any of them. Some oil has been discovered in Trinidad, but this is far from sufficient for the purposes required. There have been encouraging prospects in Malaysia and the East Indies, but neither in India, Australia, Japan, or Canada have fuel oil fields been developed of large size, and it will be necessary for Great Britain to purchase her fuel outside the empire unless supplies can be discovered in some other places mentioned.

The largest supplies of fuel oil in the world have been discovered in Mexico and Russia. When stating that the British empire has not yielded important deposits of fuel oil, however, we must make an exception of the Yenangyaung in Burma, midway between Rangoon and Mandalay; but even this field, which produces approximately 7,000,000 barrels per year, is not comparable to the American, European or Dutch India fields. Consequently, it would be a great boon, not only in Canada, but to the British empire, if a large supply of oil could be developed in western Canada.

USE OF OIL AS RAILWAY FUEL.

On the Great Northern railway in British Columbia, oil has been used as fuel on the locomotives for several years, and since the installation of oil burners, no fires have been reported starting from locomotive sparks, whereas previously the fires were numerous. The use of oil in the same respect is also reported on the main line of the Canadian Pacific railway, between Kamloops and Field, British Columbia. Similar results are reported in the Adirondack mountains in New York state. Oil is also used as fuel on the Esquimalt and Nanaimo R. R. The total mileage on which oil is burned is 587 miles, exclusive of the Grand Trunk Pacific railway, which proposes to adopt oil burning locomotives on its Pacific division.

USE OF OIL FUEL FOR SMELTING.

The use of fuel oil for generating steam and in internal combustion has been discussed quite generally in the technical press, compared to the meagre accounts of the use of oil in smelting. This practice, however, has been remarkably successful in the United States and elsewhere and justifies the following description by E. H. Hamilton in the New York "Engineering and Mining Journal."[1]

"In Pueblo, in 1896, I roasted ores and mattes, using oil for fuel in Brown-O'Hara roasters and by proper adjustment obtained a perfectly nodulized product which was in ideal condition for smelting in a blast furnace. In another plant fuel oil was used with great satisfaction in the retorting of zinc crusts, but the economy depended upon the whim of the sellers of the oil. I also ran three muffle furnaces containing two muffles, each muffle $13 \times 21 \times 7\frac{1}{2}$ in., for assaying in a copper smeltery. We used 28 gallons of California crude oil per day of $6\frac{1}{2}$ hours per furnace, with good results.

The greatest advance in reverberatory smelting of recent times was the large reverberatory furnaces which were developed in Anaconda by Mr. Mathewson while I was his assistant. These furnaces were enlarged from a 50-ft. hearth up to 118 ft. The average tonnage was brought up to approximately 300 tons per day on a coal consumption of 1 to $4\frac{1}{2}$ of calcine.

In 1904 these furnaces were copied by Cyrus Robinson and built in Arizona with modifications to use California crude oil, and it became my lot to make them operate successfully. The ore was first roasted in Edwards roasters to which were attached oil jets. Whenever the heat began to get too low to do good work these jets were turned on for a few minutes. By this means the roasting was maintained in the furnace. At times when there was a shortage of sulphur the length of time for oil firing was increased considerably. Many difficulties were encountered, but the application of the oil as fuel was a great success.

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[1] Eng. Ming. Jour., Jan. 28, 1911.

It seems strange that the smelteries did not adopt that system in various parts of the country, where the conditions of the ore, etc., afforded ideal conditions for the working of oil-fired reverberatories. The conditions which were forced upon me were such that the silica in the slags ranged from 45 per cent downward and the lime from 2 per cent up to 23 per cent. The physical and chemical conditions of the constituents varied widely during the time these oil-fired furnaces were run and I know from three years' experience on the coal-fired furnaces of the Anaconda plant, that it would have been impossible to smelt charges in Anaconda with coal which I smelted successfully with crude oil for fuel. From tests made I came to the conclusion that, given the Anaconda conditions of charge (both chemical and physical) we would have been able to smelt over 300 tons per day in oil-fired reverboratories.

My experience showed that about 19 per cent to 20 per cent of the heat was absorbed by the charge and about 50 per cent was taken up by the boilers. However, anyone who has been a close student of the reverberatory smelting will know what a great range of possibilities there are which tend to vary these proportions and the firing of the furnaces by oil affords especially good opportunities to study these. In our case we had to produce power from the waste heat to run mines situated 20 miles away and to furnish power for a concentrator and to run the whole smelting plant and sampling mill.

With a furnace hearth of over 100 feet in length, all at a white heat, it was possible to regulate the flames so as to obtain complete combustion, if desired, before reaching the throat, where there was practically no CO. All the combustible constituents of the oil were completely burned before reaching the boilers, and in this way an efficiency was obtained which could not be obtained in ordinary oil-fired boiler practice.

One barrel of 42 gallons of the California oils was about equal to one ton of best bituminous coal. However, it must not be lost sight of that the heavy California oils have to be kept warm in passing through the pipes, and that a considerable amount of the steam generated in the boilers is used to atomize the oil. A small amount of steam is also used (either directly or indirectly) to run the oil pumps. Steam was also used to heat the oil in various tanks. These losses of course are variable, depending on many conditions, but in our case it averaged very closely to 7 per cent of the steam produced in the boilers. A great number of factors enter into the loss, many of which can be avoided by proper construction and by the arrangement and balance of the plant, but others cannot be avoided, such as weather conditions, etc. A great deal is being written about reverberatory smelting which is misleading. It is only under certain conditions that reverberatory practice is profitable.

Much has been written about burners. The point to be borne in mind is to "atomize" the oil and burn it in the right part of the furnace.

I also dried and heated up converters by means of a small oil jet. This for a time gave trouble as each new converter was cold and damp. Finally it was successful and the converters were dried and heated more economically than by any other fuel.

On one occasion during a scarcity of coke it became quite evident that we would not have sufficient coke to keep the blast furnace running and, as a shutdown was objectionable, I resolved to use oil as an auxiliary to replace some coke. So far as I was able to find out, the principal difficulty previously had been that the thick oil failed to reach the fire zone and the fire went out; so I rigged up a temporary "hot blast" consisting of one straight pipe around which I built a temporary brick furnace and put a small oil jet under it. This gave a warm blast for the tuyere in which the oil was injected. This gave an optical illustration of the action of the blast in the furnace, because we could see the flames from the oil in two or three tuyeres on each side of the one in which the oil was introduced. In this way we kept the blast furnace running several days longer than we would have been able to do otherwise, until a supply of coke arrived.

This was what I set out to do and it was certainly not done at any monetary loss as between a full coke supply and the cost of oil which replaced it. The question then arose as to how much of the saving of coke might be due to warm blast and how much to the oil fired in the furnace. So I proceeded to try the warm blast alone, but my "stove" burned out and as the manager did not see any immediate profit to the company the stove was not rebuilt. The only difficulty experienced was the slagging of the furnace tuyère."

UTILIZATION OF NATURAL GAS AND ITS PRODUCTS.

The most important use of natural gas and the use for which it is most beneficial is in domestic heating, lighting, and cooking. In all countries where gas is found, however, a certain proportion of the product is used for industrial and manufacturing purposes, particularly for burning brick and lime and in glass, iron and sugar works, in generation of steam, cement manufacturing, zinc smelters, etc., because it is very difficult and very costly to store natural gas from wells of high pressure, and the gas must either be used or wasted. In industrial works the price of gas is generally a little over half the price charged to domestic consumers; consequently, the depletion of the supply is generally very rapid in cases where industrial works exist within the range of the pipe lines.

ADVANTAGES OF NATURAL GAS.

People who live in portions of the country where natural gas has never been found do not appreciate the great boon enjoyed by the inhabitants of more favoured communities where gas can be found by drilling or within the range of pipe lines constructed from distant fields. The consumers of artificial gas do not appreciate natural gas after having once enjoyed it, since natural gas can generally be sold at a fraction of the price of artificial gas. One of the cheapest supplies of artificial gas in the country, or perhaps in the whole world is in the city of Toronto, where the price is only 75 cents net per thousand cubic feet; but even this price is three times as much as the price which the people of Wallaceburg, Chatham, and many other towns pay for natural gas.

GASOLINE FROM NATURAL GAS.

Natural gas is divided by chemists into two classes; first, a so-called "dry gas" known and used for years as the natural gas of commerce; and second, a gas which contains easily liquifiable vapours, which is known in the vicinity of the oil fields as a "wet gas".

For many years it has been known that gases could be liquified to a certain extent. As long ago as the 70's J. J. Coleman[1] succeeded in liquifying gases which were obtained from Scotch shale oils. Since that time gas has been made by cracking oils in hot retorts by the processes of Blau, Pintsch, Gray, Hastings, Brink, Swiss Liquid Gas Company, Schneider, Williams, Wolf, Wolski and others.[2] Gases thus made are commonly washed and compressed into steel cylinders capable of withstanding the pressures developed, and some of the companies have been commercially successful. Natural gas has rather recently been bottled in a similar way and sold commercially.

HISTORY OF NATURAL GAS GASOLINE.

The first gasoline in commercial quantities from natural gas was procured in 1904 near Titusville, Pa., by Pasenmeyer and others.[3]

In 1905 the yield of gasoline was further increased by chilling the pipes with cold water, and from 1905 to 1909 by the establishment of small low pressure single stage compressing plants. Since then the industry has made remarkable strides. Previous to the latest improvements the gas was compressed

[1]Chem. News, Vol. 39, 1879, p. 87.

[2]Allen, J. C. and Burrell, G. A. Liquified products from natural gas, Technical Paper No. 10, U. S. Bureau of Mines, 1912, p. 4.

[3]Taylor, Frank H. Early History of Utilization of Gasoline from Natural Gas. Oil City Derrick, May 6, 1911, p. 9.

Oil and Gas Journal, Vol. 9, May 11, 1911, p. 20. The gasoline from natural gas industry; Oil and Gas Journal, Vol. 9, March 2, 1911, pp. 2-6. Petroleum, March 17, 1911, Vol. 6, p. 896.

in single-stage compressors under a pressure of 150 to 300 pounds per square inch. Then the production was run into a tank and weathered, which process consisted in allowing the lighter portions to volatilize and escape into the air until the liquid had practically ceased to boil away. In this process there was a loss of 25 to 50 per cent of the natural gasoline, which was an absolute waste.

PRACTICAL METHODS IN NATURAL GAS MANUFACTURE.

A good summary of the methods of obtaining natural gas gasoline from the gas is given by Allen and Burrell.[1]

A very complete bibliography accompanies the paper which will give a reader access to all the literature on the subject published up to that time.

Natural gas occurs very frequently so associated with oil as to exist really in solution in the oil, in a manner similar to the way carbonic acid is found in many natural springs, dissolved in water. Just as carbonic acid, issuing from such a spring contains all the water vapour it can carry (that is, is saturated with water vapour) so natural gas—issuing from oil deposit, contains all of the lighter gasoline vapours of the oil that it can carry for that temperature. The warmer the gas when it issues from the well, the larger proportion of gasoline vapours it can contain. Therefore if such gases, in being piped to the place where they are to be utilized, become cooled, they will deposit some of the gasoline vapours as liquid, and in fact in many cases it is necessary to provide drip cups for collecting this liquid.

By slightly cooling such natural gas or compressing it, the heavier part of the gasoline will condense, and the stronger the pressure applied and the lower the temperature to which the gas is cooled, the greater the extent to which the gasoline vapours can be condensed to natural gasoline, until finally under a pressure of from 600 to 700 pounds at the ordinary atmospheric temperature everything can be condensed from the gas leaving only the gas itself, that is methane.

[1] Allen, J. C. and Burrell, G. A. Liquified products from natural gas, Technical Paper No. 10, U. S. Bureau of Mines, 1912, 23 pages.

Up to the last two years the general practice in the manufacture of liquid natural gas was to make the product by compression of the gas in single-stage compressors operated at a pressure of 150 to 300 pounds per square inch.[1] The one product thus obtained, so-called natural gasoline was run into a tank and weathered. The weathering consisted in allowing the lighter portions to volatilize spontaneously and escape into the open air until such time as the boiling away of the liquid had practically ceased. Thus the process involved a loss of 25 to 50 per cent or even more. This loss was absolute waste, not only of power and of cost of operating the engines and compressors but of the product itself.

The next step in the industry was to pass the waste gases (of which only the small quantity used for power had been utilized) from the single-stage compressor through a higher-stage compressor, thereby getting a second and more volatile product—a "wilder" liquid—which was run back to the first tank and mixed with the first or heavier condensate. This mixture was then again weathered to a safe degree, whereby it lost the greater part of the more volatile product that had been condensed in the second stage.

Recently the process has been improved another step, in that the first stage compressor product is run into one tank and handled as ordinary gasoline; the second stage compressor product is run into a second tank and handled as lighter gasoline,[2] with which the heavy refinery napthas can be enriched or enlivened.

The last mentioned method of using the second stage compressor product should receive wide recognition, and a market for the product should develop that would be no mean factor in the industry. Blending in the proportions of say 1 part of the product to 4 or 5 parts of the refinery napthas makes these heavy napthas more volatile and of greater value as fuel for automobiles; it also greatly increases their usefulness. The

[1]Liquefied Products from Natural Gas, Tech. Paper 10, Bureau of Mines, p. 7, Irving C. Allen.

[2]Fithian, Dr. Edwin J. The fractionation of natural gas gasoline: Natural Gas Association, sixth annual meeting, at Pittsburgh, Pa., May 16, 1911. Natural Gas Journal, August, 1911, pp. 16-17.

proportions to be used in blending, however, must be determined more definitely by test.

The natural gas of this country frequently contains light products that do not condense in the second-stage compressor, and for which it is practicable and necessary to install, three, four, and even higher stage compressors. These light products—true gases at ordinary temperatures and pressures—can be compressed and liquefied, but the liquid gases so obtained must be handled as gases and not as oils. The mistake, heretofore, has been made in the natural gas gasoline industry, as some have recognised, of attempting to handle the light gaseous products as oils and not as gases. Until the manufacturers of this lightest third and fourth stage compressor product recognize its gaseous nature, the absolute necessity for insuring the safety[1] of the public involves certain restrictions in its transportation, and not until the realization that this extremely volatile liquid should be handled only in strong steel containers capable of withstanding high pressures will it be transported with safety.

A great deal of complaint has been made regarding the light and volatile natural gas gasoline which has been sold in some places near the oil fields in the United States for automobile gasoline; but this is presumably due in large measure to an unwise proportion in the blending of the two grades. It is necessary to handle the liquid gases as gases and not as oils, and the lack of this proceeding was one of the mistakes made in the early days of the natural gas gasoline industry.

QUALITY OF GASOLINE NATURAL GASES.

Natural gases that issue from old wells in which the rock pressure has diminished to a marked degree, contain higher members of the paraffin series such as propane and butane in larger quantities; and when a pressure below the atmospheric pressure is applied to the wells, still larger quantities

[1]Dunn, B. W. Gas gasoline safety standards, Oil and Gas Jour., vol. 10, June 22, 1911, pp. 16-18; Standards for gasoline safety, Oil City Derrick, June 19, 1911, p. 8; Proposed regulations of Bureau of the Safe Transportation of Explosives and other Dangerous Substances for the shipment of liquids flashing below 20°F., Nat. Petroleum News, vol. 2, February, 1911, pp. 10-11.

of the higher paraffins are obtainable. Gases which contain methane only will not yield gasoline or liquid gas because methane liquifies at pressures so high and temperatures so low as to be impracticable, and the product if obtained, could not be stored even as well as liquid air. Gases which contain no paraffin hydrocarbons higher than ethane require a pressure of 600 to 700 pounds per square inch at 35° C. to liquefy the ethane, but at lower temperatures less pressures are required. Propane and butane are on the dividing lines between liquids and gases and must be handled as such.

GASOLINE FROM GAS IN CANADA.

Charles Bisnett of Blenheim, and certain parties from Brantford and Chatham, have erected a plant in the Onondaga field, for the recovery of gasoline from the gas associated with the oil. At the time the field was visited in 1912 the plant was reported complete, but no test of the plant had been made.

The gas from the New Brunswick field has been tested and found to be too dry for extracting natural oil and gasoline.

COMPRESSED NATURAL GAS ON RAILWAY TRAINS.

Throughout the entire line of the Intercolonial railway of Canada, running from the Atlantic seaboard to Montreal, the passenger cars are lighted with gas from the New Brunswick natural gas fields, the product having been successfully used in place of the Pintsch gas, with which the lights were formerly charged.

Gas is used exclusively as fuel and for power generation in the car shops at Moncton, over 30,000,000 cubic feet being consumed in September, while in winter months some 50,000,000 cubic feet are used. The steady and reliable heat makes it an ideal fuel for forges, furnaces and gas engines, no time is wasted in firing up and there is a considerable saving in expenditure.

The gas from the Canadian Pacific railway well at Medicine Hat is bottled in steel flasks 8 inches in diameter and 50 feet in length, and is shipped for use in lighting the cars. The pressure of the bottled gas is 1,700 pounds, according to Mr. Winter. All the cars are restocked with gas at Medicine Hat.

PRODUCTION IN THE UNITED STATES.

Although gasoline has been produced in a small way in the oil fields of Pennsylvania for as many as 12 years, it was not until within the last few years that steps were taken to produce it on a larger scale by making use of the enormous quantities of waste or casinghead gas from the oil wells of the country. The low price of gasoline in the year 1911 was a great hindrance to the progress of this industry, but during the year 1912 the price continued to advance. The natural gas gasoline industry is assuming large proportions and is likely to expand until it will become a very important adjunct of the natural gas business. The use of casinghead gas for the production of gasoline is one of the most important means of conserving the natural gas supplies.[1]

Not all natural gases are adapted to the manufacture of gasoline. As already stated, some gases are dry and contain very little if any gasoline; others or wet or casinghead gases may not contain sufficient gasoline to make it profitable to use them. A chemical analysis will show the expected yield of gasoline from a particular gas and will determine the probable quantity of gasoline to be obtained from any plant equipment, but the installation of a small experimental plant is a better test. This subject has been fully discussed in reports issued by the United States Bureau of Mines.

The following tables show that the total number of gasoline plants in operation in the United States increased from 176 in 1911 to 250 in 1912, and that the daily capacity almost doubled.

[1]Chapter on natural gas, Mineral Res. U. S., p. 48. (1912).

These figures include not only the regularly established compressor plants but also those which use the simple method called the gas-pump or vacuum process.

It will be seen that the natural gas gasoline industry was confined to eight states[1] in both 1911 and 1912. West Virginia takes first place in the quantity of gasoline produced in 1911 and 1912; Pennsylvania, which was third in 1911, takes second place in 1912; Ohio, although showing considerable gain in 1912 over 1911, drops to third place in 1912; Oklahoma and California are next in order in both years and are followed by Colorado and Illinois, which exchange places in 1912; New York is eighth on the list.

The total production of gasoline from gas in 1912 was 12,081,179 gallons, valued at $1,157,476 as compared with 7,425,839 gallons, valued at $531,704, in 1911. The average price increased from 7·16 cents per gallon in 1911 to 9·6 cents per gallon in 1912, a gain of 2·44 cents per gallon.

The estimated quantity of gas used in the extraction of 12,081,179 gallons of gasoline in 1912 was 4,687,796,329 cubic feet, an average yield of 2·6 gallons of gasoline per thousand cubic feet of gas used.

Various uses are made of the residue or exhaust gas, which is the gas left after the gasoline has been extracted. In some places it is sold to gas companies and run through their lines to consumers for domestic and industrial purposes; in other places it is used to drive gas engines and the gasoline plant of the operator; but it is most commonly returned to the original producer for field purposes. In some places it is entirely wasted.

In the following table are given statistics of the production of gasoline from natural gas in the United States in the years 1911 and 1912, by States:—

[1]The only gasoline produced in Kentucky came from natural condensation in the pipes.

TABLE XX.

Production of Gasoline from Natural Gas in the United States in 1911, by States.

STATE.	Number of operators.	Plants.		Gasoline produced.			Gas used.		Average yield in gasoline. Gallons.
		Number in operation.	Daily capacity. Gallons.	Quantity. Gallons.	Value.	Price per gallon. Cents.	Estimated quantity. Cubic feet.	Value.	
West Virginia	47	72	16,819	3,660,165	$262,661	7.18	1,252,900,600	$76,074	2.92
Ohio	26	39	6,454	1,678,985	118,161	7.04	469,672,000	37,574	3.57
Pennsylvania	43	50	5,669	1,467,043	109,649	7.47	526,152,663	52,615	2.79
Oklahoma	8	8	4,800	388,058	20,975	5.40	144,629,000	4,378	2.68
California, Colorado, Illinois, New York	7	7	3,358	231,588	20,258	8.75	82,343,000	6,320	2.81
	131	176	37,100	7,425,839	$531,704	7.16	2,475,697,263	$176,961	3.00

Production of Gasoline from Natural Gas in the United States in 1912, by States.

STATE.	Number of operators.	Plants.		Gasoline produced.			Gas used.		Average yield in gasoline. Gallons.
		Number in operation.	Daily capacity. Gallons.	Quantity. Gallons.	Value.	Price per gallon. Cents.	Estimated quantity. Cubic feet.	Value.	
West Virginia	66	97	22,366	5,318,136	$513,116	9.6	1,972,882,212	$163,749	2.8
Pennsylvania	69	83	10,524	2,041,109	217,016	10.6	722,730,117	62,010	2.8
Ohio	25	43	7,791	1,718,719	173,421	10.1	576,123,700	46,090	2.98
Oklahoma	11	13	11,910	1,575,644	99,626	6.3	701,044,300	24,901	2.25
California	7	7	6,669	1,040,695	112,502	10.8	600,743,000	25,573	1.7
Illinois	4	4							
Colorado	2	2	2,008	386,876	41,795	10.8	114,273,000	9,662	3.4
New York	1	1							
Kentucky	1	(a)							
	186	250	61,268	12,081,179	$1,157,476	9.6	4,687,796,329	$331,985	2.6

HEATING VALUE OF NATURAL GAS.

Natural gas with a heating value approximating 1000 heating units per cubic foot compared with a manufactured gas approximately 600 heating units, results in the conclusion that the relative value of the natural gas, for perhaps ninety per cent of all utility purposes, may be considered as being proportional to these heating units, or some 65 per cent greater in value than the manufactured gas. The fact that the use of natural gas, because of its lower candle power, compels the consumer to adopt the incandescent gas burner, ultimately tends to his benefit, because the efficiency of the light obtained from this burner is much higher than the efficiency obtained from the open flame of even a high candle power gas. Considering the sand pressure and supply this comparison of the two gases shows even greater contrast.

Manufactured gas at prices approximately 80 cents to $1 per thousand cubic feet to the general domestic consumer would compare with natural gas, supplied under the same conditions, at a value approximately $1.30 to $1.60 per thousand cubic feet. The ultimate saving to the consumer who could receive natural gas for 50 to 60 cents is apparent.

Concerning the heating value of gas, based upon natural gas practice, Mr. Thomas R. Weymouth[1] says:—

"When it is impossible to obtain a calorimetric determination of the heating value of a particular gas, the next best procedure is to compute it from the chemical analysis of the gas.

This, of course, is done by multiplying the percentage of each gas present by its corresponding heating value per cubic foot, and adding the products. The specific gravity is obtained by computation in precisely the same manner. Such computed results are necessarily subject to whatever errors there may be in the analysis of the gas, and unless this has been done with great care and precision, a wide discrepancy may exist between the calculated and actual values.

It is frequently desirable to get an approximate knowledge of the heating value of a gas when neither a calorimetric determination nor a chemical analysis is available.

In such cases, a fair "guess" may be made from a determination of the specific gravity of the gas, provided it is known to be a normal "dry" gas without freakish tendencies. The specific gravity is readily determined by the effusion method, in which the time required to pass a given quantity of the gas through a pin hole orifice in a thin plate under a given head, or pres-

[1] Journal of the American Society of Gas Engineers

sure, is divided by the time required to pass the same quantity of air through the same orifice and under the same pressure; the square of the quotient being the specific gravity of the gas, referred to air. For most reliable results, the air and gas should be run at the same temperature, to avoid the necessity of a correction for this factor.

Approximately a formula for determining the heating value from the specific gravity may be derived from the following considerations:

In the analysis for an average natural gas, the combustible gases, methane and ethane, comprise 93·5 per cent of the whole, and ethylene and carbon monoxide comprise 0·2 per cent each. No great error will be made, therefore, if these two latter gases are considered as being a part of the paraffin group, especially since ethylene and ethane do not differ greatly in either heating value or specific gravity. The inert gases may likewise be combined in one group, of which the resulting gravity may be considered equal to 1·0. Consequently for approximate results, the average natural gas may be regarded as made up of three distinct gases, methane, ethane, and "inerts."

Representing the relative volumetric proportions of these gases, expressed chemically, as m, e, and i, respectively, the following relations will obtain:—

$$m+e+i=1\cdot 0 \qquad (1)$$
$$H=897m+1594e \qquad (2)$$
$$G=0\cdot 552m+1\cdot 0368e+1\cdot 0i \qquad (3)$$

in which H = the lower heating value in B.Th.U. per cubic foot of natural gas at gas standard and G = the specific gravity of the gas. Eliminating m and e from equations (1) (2) and (3), the heating value of gas may be expressed in terms of i and G as follows:

$$H=1440G-v541i+100\cdot 6 \qquad (4)$$

The sum total of the percentages of the "inerts" is 0·061 = i. Substituting this in equation (4)

$$H=1440G+6\cdot 6 \qquad (5)$$

Applying equations (5) to an average gas of which the specific gravity is 0·6135 ,it would indicate the gas to have a fuel value of H = 890 B.Th.U. per cubic foot, as compared with a value of 887·3 as computed from analysis.

It was fair to conclude, therefore, that for purely approximate work, a reasonable notion of the heating value of natural gas may be obtained from the known specific gravity by using equation (5).

[1]RELATIVE HEATING VALUES OF NATURAL GAS AND PETROLEUM.

An interesting comparison can be made as to the relative heating values of natural gas and petroleum. The heating values of natural oils from Eastern America range from about 17,500 B. T. U., to 21,600 B. T. U. per pound—the average of 29 oils, listed by Poole,[2] in his work on the Calorific Values of Fuels, being about 19,600 B. T. U. In Poole's list only two Canadian oils—both of which are from Western Ontario, are mentioned—a Bothwell oil, specific gravity 0·857, B. T. U. 20,410; and a Petrolia oil, specific gravity 0·870, B. T. U. 20,530. These, unfortunately, appear to be the only two determinations avail-

[1]By A. W. G. Wilson.
[2]Second edition, p. 251.

able for Ontario oils. For purposes of comparison, the heating value of Ontario petroleums may be taken, in round numbers, as 20,400 B. T. U. per pound, or 176,700 B. T. U. per imperial gallon.

Direct determinations of the calorific values of Canadian natural gases are not available. The average calorific value of forty samples[1] of Ontario natural gas, as calculated from their chemical analyses, is 1,040 B. T. U. per cubic foot. Curiously enough this is also the average calorific value given by Poole for four samples of natural gas from Ohio, the nearest gas-field in the United States.[2]

Assuming the two measures given above as average values, we find that 1,000,000 cubic feet of Ontario natural gas possess the same heating value as 5,886 gallons of petroleum; or 1,000 cubic feet of gas have the same heating value as 5·89 gallons of oil. A barrel of oil (35 imperial gallons) would have the same heating value as 5,950 cubic feet of natural gas.

The present rates charged for the principal places where natural gas is used are shown in the following table:—

[1]Ontario Bureau of Mines, Vol. XXIII., page 254.
[2]See Poole, *op. cit.*, p. 254.

SELLING RATES OF NATURAL GAS.

Name of Company.	Town Supplied.	Rate per M Cu. Ft. Domestic.	Rate per M Cu. Ft. Industrial.
National Natural Gas Co.	Hamilton	$.35	
Union Natural Gas Co.	Alymer	.30	
Dunnville Gas Development Co.	Dunnville	.25	.20
Union Natural Gas Co.	Courtright	(First three years 30c.) .40	.25
Southern Ontario Gas Co.	St. Thomas	.30	
Hill and Melich (Minimum of $15 per year for each domestic consumer.) (Minimum 400,000 for industrial consumer.)	Canboro	.45	.35
Southern Ontario Gas Co. (During May and October, 45c.; rest of the year, 30c.; for domestic consumers.)	London (Commencing April 1, 1914.)	.45	.40
National Natural Gas Co.	Hamilton	.37½	
Canadian Western Natural Gas, Light, Heat and Power Co.	Calgary	.30	.15
Ingersoll Gas Light Co.	Ingersoll	.45 net	
Dominion Natural Gas Co.	Simcoe	.30	
Ontario Pipe Line Company	Hamilton	.40	
Beaver Oil and Gas Co.	Harrow	.25	
Central Pipe Line Co., Ltd.	Aylmer Malahide Bayham Vienna Port Burwell	.25	.12
Moncton Tramways Electricity and Gas Co., Ltd.	Moncton Hillsboro	.38	.15
Brantford Gas Co.	Brantford	.35 net .40 gross	.12
Chatham Gas Co., Ltd.	Chatham	.35 .25	
Dominion Gas Co.	Hamilton, Brantford, Galt, Paris, Dundas, St. George, Binbrook, Bartonville, Dunnville, Attercliffe, Cayuga, Selkirk, Jarvis, Hagersville, Vittoria, and Simcoe, Lyndoch, Vienna, Tilsonburg	.37	.20
Beaver Oil and Gas Co.	Kingsville Leamington Wheatley and Ruthven	.25	.15
Oxford Oil and Gas Co., Ltd.	Woodstock	.25	
Petrolia Utilities Co., Ltd.	Petrolia	.30	.12 to .14 .25 gas engine.
Sterling Gas Co., Ltd.	Port Colborne Humberstone	.32	.27
The Norfolk Gas Co., Ltd.	Port Dover	.25	.15 to .20
The United Gas Companies, Ltd.	St. Catharines Thorold Fenwick	.40 to .70	.35
Sarnia Gas and Electric Light Co.	Sarnia Point Edward	.35 gr. .30 net	.25 to .12½
Windsor Gas Co., Ltd.	Windsor Walkerville Sandwich	.30	.12 & .15
United Fuel Supply Co., Ltd.	Sarnia, Petrolia, Brigden, Dresden, Point Edward, Marthaville, Corunna, Paincourt	.25 & .30	.10 to .15
The Consumers' Gas Co., Ltd.	Wallaceburg	.40	.12
Canadian Western Nat. City of Medicine Hat Gas Dept.	Medicine Hat	.15	.05
Redcliff Realty Co., Ltd.	Redcliff	.12½ ($2 to $3½ per Mo.)	$10 to $100 per Month.
The Port Colborne-Welland Natural Gas and Oil Co., Ltd.	York and Caledonia	.25	.25

CHAPTER X.

CONSERVATION OF OIL AND GAS RESOURCES.

Marked and gratifying progress has been made during the last five or six years in the real conservation of the national petroleum and natural gas reserves in the United States. This has been along the practical lines of preventing large actual waste in production and in an approach toward securing the maximum efficiency from the marketed product. The general recognition of the fact that both oil and gas pools are exhaustible and that there has been in the past large waste in production has led many bright minds to the study of practical methods of overcoming this waste and of winning and turning into merchantable use every barrel of oil and every cubic foot of gas in the ground. Many wells, and, in fact, fields have been abandoned long before the available oil was exhausted, and the trend of experiments and effort has been toward reopening some of these old wells, and in new wells prolonging their lives.

In the early development of new fields in the hurry to tap the oil stratum in advance of rival operators the overlying oil sands are neglected and are usually cased off. In some instances these have since been developed and some of them have proved large producers.

On the other hand, improved methods of drilling, better geologic knowledge and greater oil demand have induced deep drilling in many of the older fields, some of which are now enjoying a new lease of life, notably parts of the Clinton fields of eastern Ohio, the St. Mary's pool in West Virginia, and some of the Pennsylvania fields. It is considered not improbable, according to L. C. Huntley of the Bureau of Mines, that the mid-continent fields have a deep-sand future.

Spacing of wells is an important factor in prolonging the life of a field, and while little in the way of regulating can be accomplished in territory where there are a number of small holders each working against the other, where large operators control sufficient acreage, more conservative practice is the rule.

The practice of using nitroglycerine for shattering the sand, as in the Glenn Pool, Oklahoma, has resulted in an increased productivity of many wells. Many older wells can also be made productive by cleaning. Roswell Johnson, Professor of Petroleum Engineering, University of Pittsburgh, makes the statement regarding the mid-continent fields that there are operators who never clean their wells, others who do it as a last resort, and others who do it periodically. The methods of cleaning are:—the removal of accumulated sand by tools and sand pump; the hot billet treatment which is probably most useful where the oil carries a large percentage of paraffin; the gasoline treatment which is very useful where the refiner owns the lease and can thus recover the gasoline; and freshening the hole with a small torpedo. Increased production may sometimes be obtained by using large casing. An interesting innovation last year in eastern Ohio gives promise of very beneficial conservation of old oil fields in the future. Compressed air was forced into the nearly exhausted oil bearing sands through a well situated centrally in a group of old wells and the increase of all the wells was marked.

Loss is often occasioned by the neglect and consequent corrosion of casing, causing the admission of water to the oil bearing stratum. This cause of decreasing production needs only the simple remedy of proper attention. In most fields where producing wells are closely grouped, as many as possible are pumped together from a common power plant. But in the high grade oil fields especially each well requires different handling. Pumping by heads is a step in the right direction, yet it is impossible to judge the best possible time to pump and the proper height of oil column to leave in the well at all times. At least one automatic control device, with valves set to start pumping upon the accumulation of a certain maximum pressure and to stop pumping upon the exhaustion of the oil to a certain set depth, has been tested with success, and there can be little question as to the advisability of the use of such devices at a great many wells. An automatic control for the pumping of oil wells, says Mr. Huntley, governed by natural underground conditions at each well would increase the production of districts now being abandoned with large quantities of oil still remaining in the ground. Such automatic devices are on the market, but owing to the inertia of the producer relative to trying out seemingly revolutionary methods they have not been given a fair trial.

The ideal regulation of private oil development would insure the same results as if, for instance, the Government should develop large tracts of its own oil lands. Under the guidance of its specialists it would thus doubtless so drill these lands as to avoid the waste that results from private ownership in small tracts with its accompanying competitive line drilling. Government wells would be so spaced as to eventually extract all of the extractable content from oil reservoirs but without unnecessary and undesirable duplication of wells. This would be conservation of capital without loss of the natural resources involved. Drilling under these conditions, and the consequent complete draining of the pools, would with little question occupy a much longer period than drilling and drainage under the competitive conditions of private ownership, and production from the field would thus be distributed over a much longer period. This should steady prices, since smaller quantities of oil would be thrown upon the market in the early history of the field, lessening the tendency to depress prices at this period, while on the other hand larger quantities would be thrown upon the market during the later history of the field, which would tend to prevent the inflation of prices at a time when the production of the field would be greatly decreased if developed privately in small tracts. The general effect would be conservation of capital because there would be fewer wells.

Concerning the prevention of the tremendous waste of oil and gas, known as gushers, particularly in the California field, Ralph Arnold and V. R. Garfias of the Bureau of Mines, say: "With the state of our knowledge regarding the situation of the 'gusher' and 'gasser' strata in the developed field, there is no excuse for the general lack of precautions taken before the depth is reached at which the flow is expected. The additional cost of safety devices is insignificant in comparison with the total cost of drilling, and with the amount that can usually be saved if the rate of production is regulated. Experience has shown that a gusher or a gasser will yield a greater total production if allowed to flow only to a fraction of its capacity. One of the most successful apparatus devised to control whatever flow of oil or gas is encountered is a blowout preventer, which has given general satisfaction."

There may be some excuses for a single blow out or "wild" well in a new field where conditions are unknown, but there is seldom any excuse for a repetition of such a disaster in the same field, for it can be prevented by proper precautions in drilling.

In California, as elsewhere, an important problem is that of the exclusion of the water before or after the oil sands are reached by the drill. The most successful method is probably the cementing process which is used throughout the eleven principal oil districts of the state. To prevent the flooding of the oil sands by the waters above or below, cement is forced into the space outside the casing in order to form a water tight bond between the casing and the walls of the hole.

Strange as it may seem, until a comparatively few years ago natural gas was believed by probably a majority of people to be inexhaustible, and consequently an enormous waste of this most perfect of fuels has resulted. This idea possibly resulted on account of the relatively slight use and exhaustion of the gas from some of the most ancient wells which, in fact, seemed inexhaustible. Gas has been used from many wells for many centuries in both China and Japan, while the region of eternal fires in the Apsheron Peninsula on the shores of the Caspian Sea where inflammable gases issue from the rock fissures, was known over a thousand years ago and the fires were worshipped by the Parsees.

Arnold and Garfias also describe a method of drilling through gas or oil strata to deep oil sands below which muddy water is forced to the bottom of the well as the drilling proceeds and this mud mixture further forced through the casing into the porous sand stratum penetrated by the drill, thus building a plaster wall of clay throughout the gas-bearing strata. The gas thus excluded can be recovered afterwards by drilling shallower wells to the upper sands.

This method of applying mud-laden fluid to well drilling is described in further detail by J. A. Pollard and A. G. Heggem in Technical Paper 66 of the United States Bureau of Mines. The statement is made that one of the greatest wastes of natural gas is that which often takes place in drilling oil wells and that if the well is being drilled by the usual methods the gas becomes a hindrance to drilling and the driller regards it as a nuisance; or the gas may be found in a field where it has little or no immediate commercial value, and hence is allowed to escape into the air without restraint. At other wells the gas is taken from the sands through hundreds of feet of open drill hole, the last or inner string of casing being stopped far above the gas sands, thus leaving the lower part of the hole uncased. When such a well is shut in, much of the gas escapes into the porous beds below the casing and above the gas sands, and is wasted. Not only so, but the gas may travel through the porous beds for miles and cause blow outs in other wells being drilled in the same vicinity. Some of these unexpected flows of gas have been ignited, causing injury to workmen, and burning of drilling rigs.

The mud casing is effected by drilling with the mud laden fluid in the hole; as the drilling progresses the particles of clay held in suspension in the fluid are forced into the porous rocks and sands forming the sides of the drill hole and thus constitute a gas tight natural casing. Methods are described by Messrs. Pollard and Heggem by which a gas well can be thus cased with mud fluid in the hole in a few hours without the slightest risk to the workmen. It is also entirely feasible to case wells already dry drilled that are blowing. The advantages of the method have been fully demonstrated, and, according to the Bureau of Mines, too much emphasis cannot be placed upon the importance of its use where gas and water are encountered; it not only greatly reduces the danger to the workmen but effects a large saving in the amount of casing needed and entirely eliminates the waste of gas while drilling is in progress. Additional to this, the methods offer a further advantage in that they absolutely prevent the contents of one bed mingling with those of another; thus water cannot enter the pay sands, neither can oil or salt water contaminate the fresh water of other beds.

For many years the oil driller had no use for the gas and got rid of it as a nuisance. This practice is largely being discontinued, and the gas is at once utilized, or is conserved in the ground for future use. In some cases in bringing in new wells the pressure is so great as to at first baffle attempts to cap the gas flow, but in no case is this believed to be impossible. A gratifying example of the subjugation of a supposedly uncontrollable well was that of the Gilbert well, Louisiana, which was successfully closed by the owners. This was one of the greatest "wild" wells ever known. Even with the conditions improved, McDowell estimates the value of the gas wasted in the Oklahoma fields during the past five years to be more than the value of all the oil produced in that time. In drilling for oil in the Buena Vista hills, California, one gas well was opened that wasted an estimated 55,000,000 cubic feet a day for three months. The final control of the well was a notable engineering feat.

A remedy for the gas waste during oil production is possible by proper cooperation between gas and oil companies. Such cooperation exists in West Virginia, Ohio, and Pennsylvania, where the gas companies and the oil companies are generally under the same management. Gas can be saved from oil wells by providing a prompt market for the gas. A partial solution is to compress natural gas in steel cylinders for transportation and for use on railways and in automobiles.

Since the discovery that some of the California gas is rich in gasoline, much gas formerly wasted has been conserved on this account. Plugging the dry and abandoned wells is required by several state laws and should be further extended and enforced.

The laws of Pennsylvania, Ohio, Indiana, and California provide for the efficient capping of every gas well when not in use. There should be similar laws in all states and provinces having gas fields. If the owners emphatically refuse to close their "wild" wells, the Louisiana remedy can be applied; that

Blown out gas well, Caddo field, Oil City, La., U.S.A. (The position occupied by the columns of water is the site of a well which was blown out.)

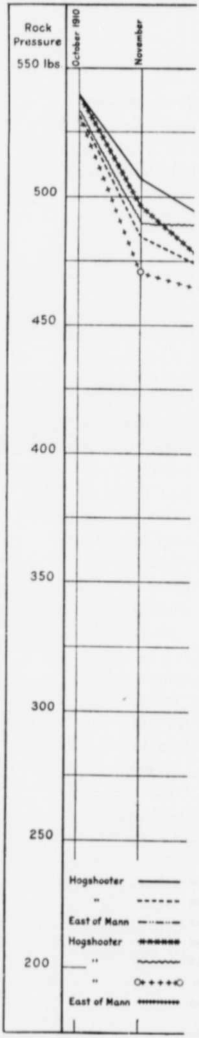

Fig. 15. Diagra

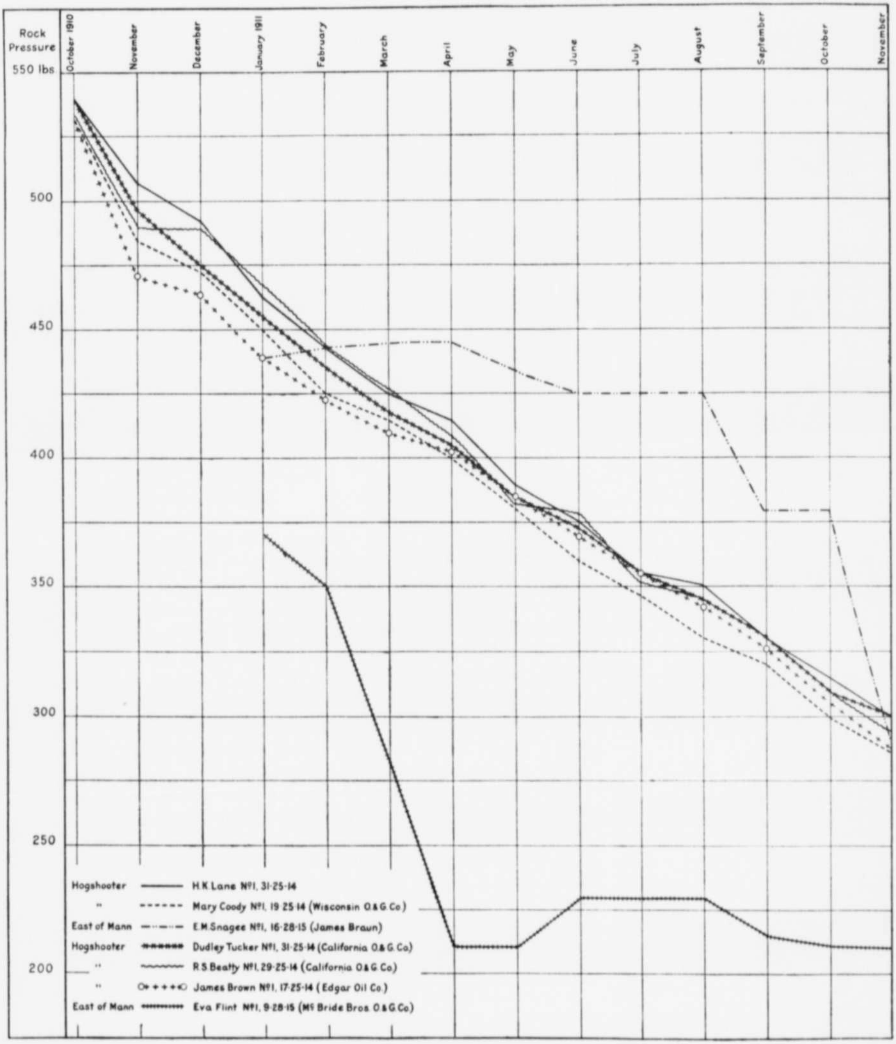

Fig. 15. Diagram showing the decline in rock pressure of natural gas in the Hogshooter district, Oklahoma.

Fig. 15. Diagram showing the decline in rock pressures of several gas wells

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is, empower a state commission to close the wells and levy the cost on the companies. In Louisiana the commission on the conservation of natural resources, after making an exhaustive examination of the situation in the Caddo field, recommended—

That the owners of the wild wells in the Caddo field be at once notified to take immediate steps to close the same;

That in the event of their failure or refusal to do so, the State, through its engineering department, forthwith take steps to bring about control of the wells and stop waste at the expense of the owners;

That if it be found that through failure of the law or otherwise the State can compel owners to bear the expense, then, and in that event, the State interest is sufficient to warrant the State in going to any reasonable expense to close the wells at the public cost.

The State of Louisiana has been called upon to close only one "wild" well, for the reason that all but one have been closed by the owners, and in this one the gas escaped from a shallow sand, 900 feet above the supply which is used commercially.

I. C. White, in speaking of the waste of gas of the West Virginia oil fields, suggests an effective method of conserving the gas by setting an extra string of casing in the 10 to 30 feet of gas sand lying over the oil sand.

Both gas and oil can be saved when they flow from the same well, as is verified by the fact that this is done by a few progressive operators, who use a gas trap, which separates the oil and the gas by the gravity method. The great difficulty seems to be to find a market for the gas in a new oil field which has no natural gas mains or other means of transportation at hand. It would seem that legislation might require the wells to be shut in until arrangements were made to bring gas lines to the oil wells, or until gasoline plants and other means of utilization were provided. If applied with discretion such legislation would work no injustice to the oil producer, as his ultimate profits would be larger through the sale of the gas. Some prominent gas producers have stated that every legal and legislative means should be used to force the oil companies to save their gas, even casing-head gas. They believe this can be accomplished without waste.

In the utilization of gas a real conservation is being effected by both the use of meters with consequent charge per cubic feet of gas used as against the flat rate, where the gas was allowed to burn at all times—from thousands of burners all night—and the increased use of gas as a household fuel rather than for manufacturing. Edward Orton wrote 14 years ago the natural gas ought to be confined exclusively to domestic use. A rolling mill will use from 1,000,000 to 5,000,000 feet a day. How far will 1,000,000 feet go in the support of household use? A house of 12 rooms, using gas in cooking range, laundry, and in six grates, uses on an average for the year about 400,000 cubic feet a month, or 1,333 feet a day. One million feet would supply 750 such establishments, or what the smallest rolling mill would use in a day would serve such a home for more than two years. But instead of using 1,333 feet a day, the average residence will find all its necessities met by less than one-half the amount named. Five hundred feet will make an ample daily supply for the majority of city or village homes—a supply for perhaps 1,800 homes.

The constructive efforts of oil and gas engineers have been so effective that many guides to better methods of developing fields have been devised which will be of the greatest value in the conservative development of new fields in Canada. The gratifying extent to which such methods have already been applied in the older oil fields of Canada is evinced by the long life of these fields which reached the maximum production so long ago.

In the following pages Prof. Roswell H. Johnson has formulated the methods of improving the efficiency of oil well drilling including the preparatory stages.

METHODS OF CONTROLLING GUSHERS.

The problems of shutting in wells, of which control is lost when they are drilled in, are usually to be solved only by the particular exigencies which arise when control of the well is lost.

Up to the spring of 1910, the Lakeview Oil Company's first well in the Sunset-Midway field of California proved to be not only the greatest oil well in the United States but control of it was lost. The daily flow soon reached 30,000 barrels. It destroyed the derrick, and for the better part of its life resisted all efforts towards its control. The flow increased to at least 40,000 barrels per day. The temporary storage made by damming a canyon, thus providing a lake, was soon filled, and much oil was lost. The flow was lessened, and finally controlled, by surrounding the well with a crater of bags of sand, and thus forming a pool of oil above the mouth of the well which to some extent choked the flow. Since that time, several other wells which will in all probability have as large a yield have been brought in, but by exercising great care have been largely kept under control, with the exception of one well brought in late in 1913 by the Standard Oil Company of California, which was carelessly set on fire, and extinguished only with great difficulty. The extinguishing of this well may be laid to the credit of chemicals—it was accomplished by the frothing process.

The greatest oil well in the world for daily output was undoubtedly the Potrero del Llano No. 4 of the Mexican Eagle Oil Company in the State of Vera Cruz, Mexico. This well produced as high as 160,000 barrels a day. By careful preparation for the contingency of striking a great gusher, the casing of this well was well anchored before the well was drilled in and a device for controlling it was planned by F. Laurie. This method will undoubtedly serve for other wells of great capacity where the casing is secured in the hole. The method is as follows:—

A heavy clamp is placed immediately under the collar of the 8-inch casing of which there are about 1,700 feet in this well. To this clamp, on opposite sides of the casing, are fastened 2-inch rods, hinged near the lower ends. The upper ends of these rods pass through a clamp above an 8-inch T joint having two gate valves. At the lower end of the T joint is a swedge bell nipple, 8-inch to 10-inch. By means of guys, the T joint on its hinged supporting rods was swung from a horizontal to a vertical position, bringing the bell nipple directly over the end of the 8-inch casing. The supporting rods are provided with threads and nuts at their upper ends and by means of these nuts the bell nipple was forced down over the end of the casing. An 8-inch pipe was connected to the T and the upper valve was gradually closed, the oil being thus forced through the pipe into the reservoir. The first controlling device had been tested to only 800 pounds, for it was not considered safe to close the well completely. A new T joint, bell nipple, and valves, tested to 2,000 pounds, were later substituted, and the well was completely closed. That is its present condition except for a small leakage about the valve gaskets. An earthern reservoir somewhat over 60 acres in extent was quickly and efficiently provided, but in 60 days this was filled with 3,000,000 barrels of oil, although the flow was checked as much as was deemed safe.

EXTINGUISHING BURNING OIL WELLS.

Much helpful experience in the managing of oil fires has been gained in the Caddo oil field of Louisiana. Well No. 6 in Section 33 near Jeems Bayou, Caddo district, Louisiana, belonging to the Producers Oil Company, yielded when drilling in 12,000 barrels per day. It was struck by lightning on the afternoon of June 19, 1910, but within 48 hours the well had been successfully extinguished. When it was set on fire, the well was flowing through a leaky pressure valve. Drillers were endeavoring to stop this leak with a housing when the storm came up necessitating their leaving the derrick on account of danger to the "greasy" men, including Mr. James Sharp, field manager of the Company, who were all thoroughly drenched with oil. They had barely gotten under the water of the bayou nearby when the well was struck. Twenty-five steam boilers were ordered from Shreveport, brought by rail to Mooringsport, thence by barges and towed through the shallow water of Ferry Lake and Jeems Bayou to the nearest spot to the well. A temporary bridge was built over the swamp, the boilers were hauled to position and filled with water, natural gas fuel was supplied, and the well was extinguished in just two days, by steam.

On May 12, 1911, a well known as No. 7 owned by the same company was set on fire by some unknown means—generally attributed to an onlooker who was watching the work of closing the well. It had come in late in the day before, flowing 20,000 barrels of oil and no water. It had been closed down to 8,000 barrels a day. Four men were burned, one fatally, three batteries of 16 boilers each were installed in 36 hours but were powerless. At the end of the week, Mr. Sharp decided to tunnel to the well pipe. A side pipe was tapped in through this tunnel and the oil diverted through the tunnel away from the well, and the fire was successfully extinguished.

During the summer of 1913, a large well burned for a week at Mooringsport, La. It was finally extinguished by the use of steam from a battery of 50 boilers in record breaking time, and, while the danger to the workmen was great, there were no casualties.

The first large gas well fire to be extinguished, and the well successfully closed in was the Maggie Vanderpool, a wild-cat well drilled for oil by the New York Oil and Gas Company in Indian Territory, about one mile south of the Kansas state line and about 4½ miles southeast of Caney, Montgomery county, Kansas. It was extinguished under the supervision of Mr. J. C. McDowell. The well showed dry gas and was, therefore, to be deepened in the hope of striking oil. When deepened only 2 or 3 feet into the sand, the flow of gas developed into 30,000,000 cubic feet per day with a rock pressure of over 600 pounds. The gas had been packed off but the packer failed to hold the same. A new packer was inserted and further drilling was about to be begun when the well was struck by lightning. An effort was made to extinguish the fire by swinging a large steel bell with a pressure valve over the mouth of the well, the bell having a side connexion below the valve which was connected with a side line of pipe and through which it was hoped to divert the gas, and thus extinguish the fire. This was finally accomplished, although the cutting action of the sand shot out by the gas cut the first bell to pieces.

The most successful work which has been done lately in stopping the waste of natural gas has been accomplished in the Caddo parish of Louisiana where two very large gas wells have been running wild for about five years. The first, known as the Gilbert well, formed a large fountain in the center of a lake some 600 feet in diameter. It was extinguished by drilling a well at an angle toward the wild well and as near as possible, and when the producing sand was reached mud was pumped in under as much pressure as possible until the wild well died down, and the accumulated water and oil above it choked the flow. The other wild well near the railway track at Oil City, Caddo parish, was closed late in the summer of 1913 through the intervention of the Louisiana Conservation Commission in the following manner: The Commission secured the co-operation of the oil and gas producers of Shreveport, La., who raised a fund for closing in the wild well. These producers formed a committee who drilled a relief well as near as practicable to the wild well with the idea of pumping water into the relief well and so flooding the gas sand and choking off the volume of gas, thus killing the wild well. A reservoir was constructed to hold water as a reserve supply when pumping should begin through the relief well. This well was drilled to a depth of 852 feet and cased to a depth of 792 feet, leaving an open hole of 40 feet for an outlet for the water pumped through this well into the gas stratum. Forty barrels of water an hour passed through the pump with 310 pounds pumping pressure. Later the volume of water was increased to 180 barrels an hour, and the pressure decreased to 50 pounds. Though there was no noticeable effect at first on the wild well, in a few days its action was considerably diminished and it soon appeared to be entirely dead. The water left in the crater of the wild well now settled entirely leaving the casing of the old well exposed. The hole of the old well was closed with sand, cement, and dirt, and no signs of a revival of its activity have been observed.

EFFICIENCY IN THE EXTRACTION OF OIL AND GAS.

By Roswell H. Johnson.

The wisest management of our oil and gas resources demands (1) the production of maximum amounts with a minimum sacrifice of human effort; and (2) the utilization of this product with the maximum satisfaction to ourselves. These topics have been discussed admirably in Dr. David T. Day's "Petroleum Resources of the United States," U.S.G.S. Bulletin 394, Arnold and Clapp's "Wastes in the Production and Utilization of Natural Gas," U.S. Bureau of Mines Technical Papers 38, and in Huntley's "Decline of Oil Wells," U.S. Bureau of Mines Technical Papers 51, and also in Technical Papers 38, 42, and 66. Fortunately these six papers are still in print and readily available. Though this chapter will touch upon nearly every important point in these valuable articles, it will deal chiefly with those phases of waste and conservation less fully treated by them if at all.

The discussion falls under two general heads, increased efficiency in production and in utilization.

EFFICIENT PRODUCTION.

The present methods of producing oil and gas leave very much to be desired. We may reasonably hope, if proper research is given to the subject, that in the next decade such advance will be made as to secure the product with a decided reduction in drilling expense, and what is more, to extract a far higher percentage from the sands that are reached. Unfortunately, current practice fails to make use of even those improved methods that have been already proposed or demonstrated.

LEASING.

The method of leasing to-day is peculiarly wasteful, for the reason that the royalty to be paid to the land owner is a fixed percentage. It is perfectly obvious that as the decline continues, the well must be abandoned when the producer's fraction of the production, say seven-eighths, no longer exceeds the maintenance charge, although the well could still yield more than the maintenance charge, if this one-eighth was not deducted. The obvious method, to correct this, is to exempt the production of a certain amount of the product from all royalty. This exemption should equal the maintenance cost of the well under less favorable circumstances, such as the necessity of operating one or two wells independently. This varies of course from field to field, but may be roughly estimated as $0.60 per day. In return for this concession on the part of the land owner, the producer in turn should also make a concession as to the percentage of the royalty. This can probably be accomplished most equitably by limiting the increase of royalty to the time during which the wells are larger than a standard size, as for instance, 25 bbl. per day.

With a decline of 15 per cent a year, which is not unusual, and with a royalty of one-eighth, the life of a well may be prolonged an additional year, as is shown in the accompanying diagram (Fig. 16).

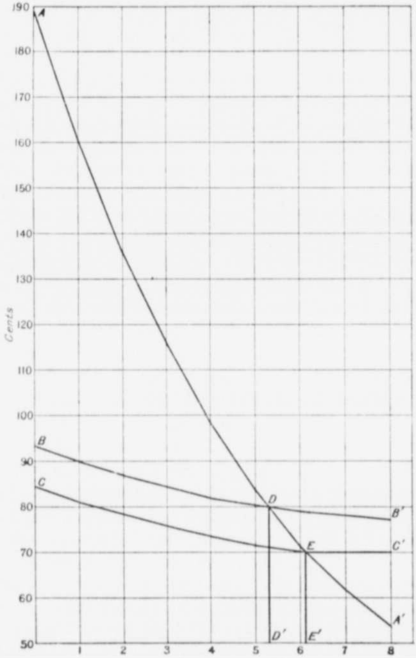


Fig. 16. To show that a fixed exemption from royalty prolongs the life of a well. Price of oil—\$1.89. Maintenance—\$0.70 per well per day. Exemption from royalty of \$0.70 worth of oil per day. A-A'—income from well. B-B'—maintenance and royalty without exemption. C-C'—maintenance and royalty with exemption. D-D'—time of abandonment without exemption. E-E'—time of abandonment with exemption. D'-E'—the prolongation of working life of well—9·6 months.

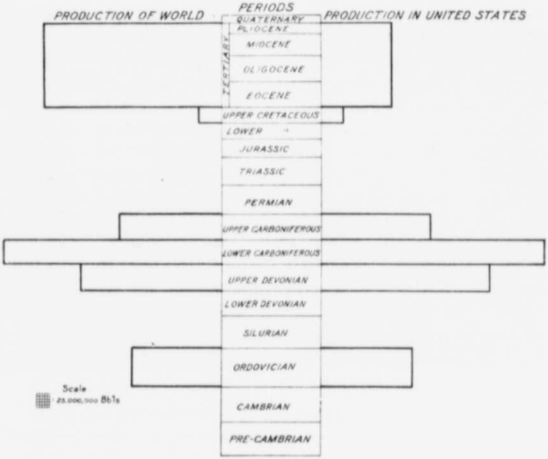


Fig. 17. Stratigraphical Distribution of Petroleum Production to 1913.

Tertiary	1,935,763,780	barrels.	California, Gulf Coast; Foreign except Canada.
Upper Cretaceous	42,548,025	"	Marion Co., Corsicana to Powell Texas; Wyoming; Colorado.
Pennsylvanian	343,843,256	"	Electra and Henrietta, Texas; Oklahoma; Kansas.
Mississipian	726,815,070	"	Illinois; one-half of the Appalachian field.
Upper Devonian	540,304,235	"	One-half of the Appalachian field.
Devonian	14,099,053	"	Canada
Ordovician	318,095,570	"	Luna-Indiana.

WELL RECORDS.

The necessity of more accurate logs of wells has been reiterated by every student of this subject. Indeed, inaccurate and inadequate logs, it must be said, are to be attributed much more to careless, indifferent and ignorant contractors and drillers than to any lack of appreciation on the part of superintendents and managers. However, the requisites of a good log include more than is usually appreciated, and as time goes on, more and more complete logs are sure to be demanded. A log should give an accurate steel tape line measurement to the top, at least, of the most widely used key horizon in the field, and on the top of each producing sand. In addition it should give the top of the water, if there is any, the bottom of the sand and the bottom of the well. Other desirable items are a shallow reference horizon, a reference horizon as near as possible to the sand, and every sand yielding oil, gas, or water, and other limestones or red beds unless very numerous, for the purpose of correlating the sands. These figures may be obtained by strings on the sand line, a method less accurate than the tape line but so much cheaper as to be permissible for the less vital parts of the log. An improvement, within feasible limits, in logs alone would probably save Canada 5 per cent of its dry holes.

METHODS OF LOCATING.

All too many oil producers have settled down into a fatalistic habit of thinking that the success of tests is so uncertain that no care or skill is required in their location. This is a very costly blunder. While all experienced persons know full well the uncertainties of drilling, the demonstrable success of improved methods in locating wells is so manifest that a neglect of geological considerations bespeaks incompetence. No extended description is here possible, but the following brief outline may arouse interest for further study of these methods.

In locating test wells the age of the rocks should be favourable. Commercial gas has been produced as low as the Potsdam formation in the Cambrian period, and oil as low as the Trenton formation in the Ordovician period. There are no good theoretical reasons why both should not be found in commercial quantities lower in the Cambrian. Prospecting in the Pre-Cambrian is not to be encouraged, though occasionally, when the Pre-Cambrian is in some particular relation with other formations, it has derived oil or gas from them. It must be said that in America, however, the producer finds much more encouragement in the formations from Ordovician to Upper Pennsylvanian, and again from Upper Cretaceous through the Tertiary. (Fig. 17).

The nature of the beds is of vastly more importance than their age. Ideal conditions are furnished by extensive dolomitization of limestone or beds of porous sandstone, 5 to 100 feet in thickness, lying within shales twice or more as thick again. The shales should be grey, black, brown or greenish in colour. White, yellow, red, and purple shales are unpromising. Outcrops bearing asphalt or ozokerite (mineral wax) are indicative of the presence of petroliferous beds, but by no means are infallibly

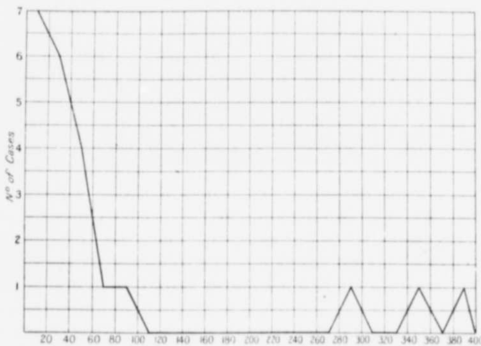


Fig. 18. Graph of frequency of various dips in feet per mile. The pools were those in a district of southeast Ohio and northwest Virginia.

safe indications Nor on the other hand, does the lack of such evidence condemn a region. When drilling is not upon the crest of an anticline, dips of less than 5 per cent are to be preferred, but are not necessary (Fig. 18).

The expected sandstones should be at a suitable depth at the selected point. An adequate cover without too much faulting is to be desired. This requires a greater thickness in the case of gas where high pressures are desirable, than with oil. Yet it is rarely wise to go to the very considerable expense of deep drilling when the expected sand lies below 3,000 feet.

However, other exceptionably favourable circumstances might make it worth while, such as very promising geological conditions, high price of oil, or very large amounts of land owned or leased by the company.

Tests in new territory are best located at the highest points of well-marked domes. In the event of the dome being unsymmetrical in its dips, the well should be drilled toward the lesser dips from the centre, since the dome in the sand will not lie directly under the dome on the surface. And next, where domes are not available, anticlines with level axes are to be preferred. Anticlines that plunge become proportionately less valuable.

When oil or gas has been discovered in one well, skill is necessary to locate adjacent wells, and also to choose and secure leases wisely, in order that there may be a minimum of dry holes and worthless leases. The producer may proceed according to several methods.

(1) The first of these is the method of *strike*. By this new locations are made away from the discovery well in the two directions of the strike, that is, in such a direction that the sand is found at the corresponding level. This can be ascertained by learning the lay of the beds at the surface. From this data a map of some upper formation is prepared and when enough holes have been drilled the convergence or lack of parallelness between this upper bed and this sand can be mapped and allowed for. Then a map of the particular oil sand can be made.

(2) *Method of dip.*—In the event that a well has oil only in the lower part of the sand and gas in the top, when oil is sought for, the next well should be drilled down the dip, in order to reach the sand where the oil occupies a greater relative thickness of the sand. Conversely, where the oil is within a few feet of the top of the sand and is underlaid by water, the next well should be up the dip.

(3) *Method of streak.*—The oil reservoirs have neither uniform thickness nor great extent from side to side. More frequently than not, the oil sand extends farther in one direction than in the opposite, making what is known to the producer as

a streak. In any one particular horizon, these streaks, though variable, generally have a prevailing direction. A comparison of near-by streaks in the same sand, or if these are lacking, of other sands in the same field, offers some guidance. The producer should be alert to detect the thinning or reduced porosity in the several directions in order that the streak direction may be inferred as early as possible. The method of streak is also valuable in connecting up two groups of wells, each centered around a successful test in one streak. This possibility should always be kept in mind when the two groups are not separated by a distance exceeding the reasonable and common area of the reservoirs in that sand. And again this is possible when the producing sand is at a corresponding depth below a reference horizon and when the gas, oil, or water of the two groups are of similar quality.

(4) *Method of inferred shore line.* In fields where development has not gone far enough to determine the prevailing direction of the streak directly, an inference of some value may be based upon the probable shore line at the time of deposition. This requires the broad knowledge and experience of a geologist, who, in brief, would base his conclusions on the following principles. In general, the shore line will lie at right angles to the direction of deepest water on the one hand, and of the dry land on the other. The direction of deepest water is indicated by increased thickness and purity of the limestones and the increased fineness of the material. The direction toward the continent is shown by increased coarseness of the material and the greater time interval represented by the unconformities. The present distribution of outcrops of different ages can also be used but with great care, since subsequent movement and erosion of the beds introduce many complications.

The prevailing direction of the long axis of these sand bodies (or of the sand axis, if the data is not adequate for recognizing the former) is most easily expressed by means of polar coordinate paper as in Fig. 19. The relative importance of streak and strike in determining the long axis of any field is well represented, after the strike has been determined, by plotting the angle, which the long axis of the pool makes with the strike, as in Fig. 20.

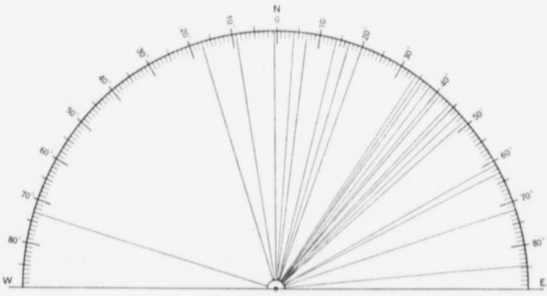


Fig. 19

The direction of the long axis in the same pools, showing the origin of the common belief of N. 45° E. as the prevailing direction in this region and yet how variable it is.

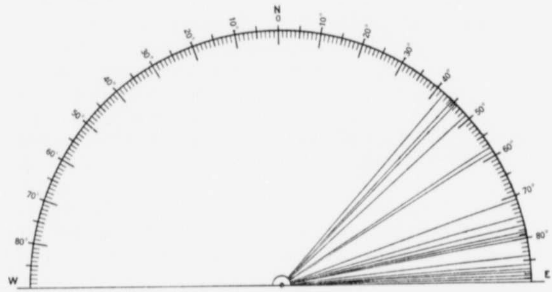


Fig. 20

The deviation of the long axis from the strike in the same pools: figures = degrees of angle.

(5) *Method of proximity.*—The rule of drilling next to good wells doubtless seems too axiomatic to be dignified as a method. Yet one of the most important decisions a producer must make

is that of leasing nearer to or farther from a discovery well of established production at correspondingly graded prices. It is therefore imperative that he estimate the relative values of

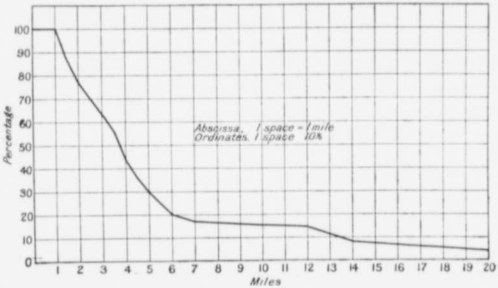


Fig. 21. The percentage of the number of the same pools as long or longer than the distances indicated.

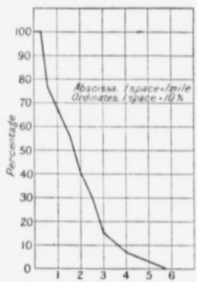


Fig. 22. The percentage of the number of the same pools as broad or broader than the distance indicated.

different degrees of proximity. To do this we take statistics of the dimensions of the known pools in that sand or in sands that seem most comparable. These should be plotted in a cumulative curve of frequency, separately as to the long axis (Fig. 21), short axis (Fig. 22), and for both axes of the pools, Fig. 23. From such curves the relative chance of a pool being of any particular size may be calculated, and from this, after making some allowance for the insurance of risk, a proper price for leases at given distances from the discovery well can be decided upon. Further allowance should be made, however, for any unusual porosity or thickness of the sand in this discovery well.

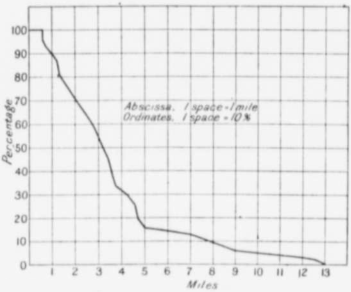


Fig. 23. The percentage of the number of the same pools having an average diameter as great or greater than the distances indicated.

(6) *Method of pressure decline.*—An unusual persistence of pressure after prolonged flow is of the highest value as indicating contiguous, undrilled areas.

(7) *Method of chemical analysis.*—When the gas from a gas pool is dry and light, we may infer that that reservoir contains no oil, and save ourselves the expense of drilling further down the dip, so far as that sand is concerned. If on the contrary, the gas is heavy and oily in odour, we have strong indications, unless the sand is of extremely fine porosity, that prospecting down the dip does offer encouragement. But when the gas is intermediate in quality, rather than markedly light or heavy, then a chemical analysis or compression test should be had.

The results would guide the producer's further operations and also determine whether a gasoline recovery plant is advisable.

The analysis of oil may be of use in making locations in the following circumstances: (1) To find if two pools some distance apart may be in the same sand, as in that event, there would be a stronger chance of production in that sand in the intermediate territory. (2) To determine whether a given sand is the same as an outcropping sand showing asphalt or ozokerite. (3) A very heavy oil at a considerable depth causes the suspicion as to a nearby fault or outcrop, whereas one of extraordinary lightness has probably moved a long distance and has been subject to considerable fractional filtration. It is, therefore, less likely to be a successful commercial proposition, as the recent strike at Calgary, Alberta. On the other hand, it is an indication of the general petroliferous character of the strata.

In the case of salt water, an analysis is also of value. The nature of the salts it contains will assist in the correlation or non-correlation of the two sands in question. It will also help determine whether the water pumped with the oil comes from the producing or some upper sand. But most important of all is the fact that methane and the next four members of the paraffin series are soluble in water to an extent of about 3 per cent, which varies of course with temperature and pressure. We may then analyse the water for a particular sand and deduce from the content of methane and ethane the presence or absence of natural gas in the same sand farther up the dip. And if the analysis shows the higher paraffins such as propane and butane, we should expect oil also in the same reservoir farther up the dip. If a test hole on the side of an untested anticline encounters water, we may by this method determine whether another test up the dip will be worth while.

Producers might wisely urge the Canadian Government to make a large number of comparative analyses to be used as standards of comparison, and further, that the various, possible analytic methods be compared with respect to their economy and efficiency for this class of work. In the meantime, however, we may employ current methods. The Pittsburgh Testing Laboratory is prepared to test for dissolved gases in salt water.

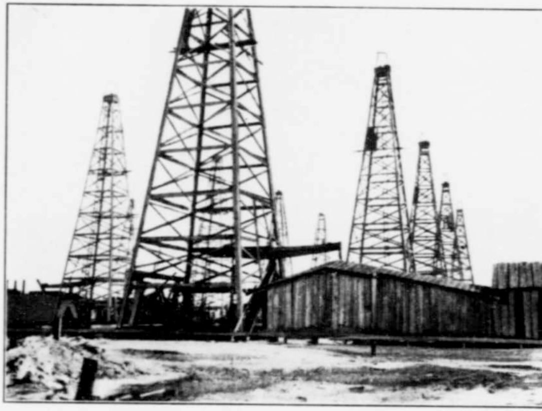
The Bessemer Gas Engine Co., is constantly making gas analyses, for the purpose of ascertaining whether the quality of the gas warrants the installation of a gasoline recovery plant. The method of sampling is of superior importance in either case and should be done according to explicit directions.

(8) *Geothermic method.*—Hoefer believes, and presents some evidence to substantiate his theory, that the increase of heat with depth is greater over oil deposits. The Carnegie Geophysical Laboratory is investigating along this line. But it must be said that the outlook for a successful use of this method is not very promising. It is difficult to see any connexion between the isogeotherms and oil. It would appear theoretically more reasonable to look for the association of gas with isogeotherms. But nothing can be done in a practical way until the whole subject has been very much more thoroughly reported upon.

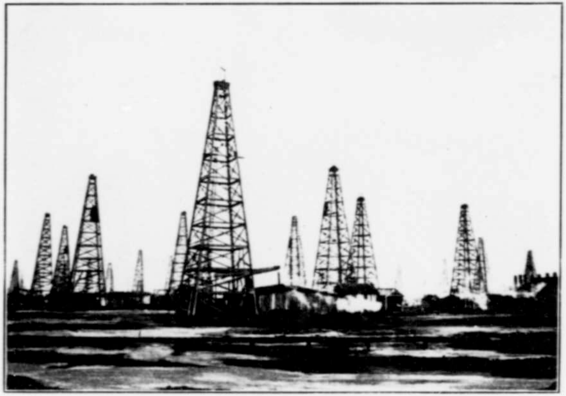
SPACING OF WELLS.

In the Oklahoma field half a million dollars has been spent on unnecessary wells in two square miles. Nearly any field shows most extraordinary waste from too close spacing. A marked contrast in the closeness of wells may be observed in almost any field where one company owns a very large tract and a group of small, competing leasers hold adjoining properties. No general rule can be made as to the proper distance between oil and gas wells. For each sand, the producers must watch closely the results of wells drilled later among the older wells. Since it is the common practice to lease in blocks or multiples of blocks of ten acres which equal 660 feet square, it is wise to put oil wells at this distance of 660 feet from each other, if this is approximately the distance that would have been selected for other reasons. There is a strong tendency to observe this distance among mid-continent and Illinois producers at the present time. In California, they still drill closer than that ordinarily, because of the large size of the wells. And in the Appalachian field the leases are so irregular in shape that there is less incentive to conform to this particular distance.

Plate XIX.



Wells in Jennings field, Jennings, La., U.S.A.



Wells in Spindle Top field, Texas, U.S.A.

Gas wells may be spaced at much greater distance, 1,320 feet being sufficiently close.

When wells for either oil or gas are drilled on a very large tract of land and so the off-setting of neighbour's wells is not a consideration, there is a more economical arrangement than the the old one of locating the wells in straight lines crossing each other at right angles. By a staggered, or quincunx arrangement, all of the given area may be brought within closer range of some one well, as is shown by Fig. 24. Unfortunately the staggered arrangement is seldom feasible on smaller leases held by competing producers.

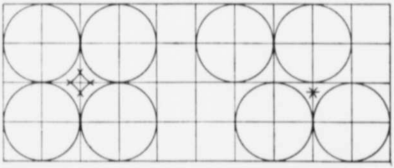


Fig. 24. To show rectangular versus staggered arrangements of wells. The area in the small square is farther from the wells than any point in the staggered arrangement.

On these small leases there is generally a well located in each corner. Between these corner wells, other wells are distributed at a distance from the property line equal to the distance at which the neighbour's wells stand back from the line. However, it is by no means advisable to put in as many wells between the corners as the neighbour does. Very frequently a conference between two neighbouring producers will lead to an agreement not to drill an additional well between the two that may be already producing along a 1,320 foot side. (See pp. 240-242). Whereas, without such an agreement, one of the producers might drill in between, which would nearly always lead his neighbor to meet him with an offset, though it would be to the ultimate interest of both not to drill these accessory wells. The same situation arises inevitably on all sides of a lease. A producer should always seek to enter into an agreement with each one of his neighbours, to the end that their wells may be as near 330 feet back from the line and as near 660 feet apart along their lines as each will consent to. This is, of course, if 660 feet has been decided upon as the best distance for that particular sand and depth.

Table XXI gives the territory lost if one does not offset in the most familiar situations that arise:—

TABLE XXI.

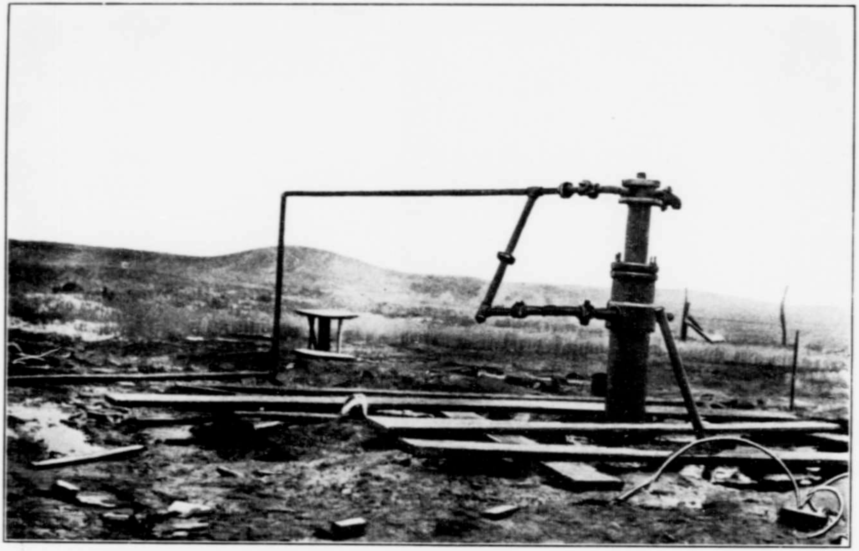
Offsetting.

	200 ft. from line	150 ft. from line
Along the long side of an eighty:—	Acres	Acres
Case 1, 5 wells meeting 8 on the side of 4 tens loses......	1·05	1·69
Case 2, 5 wells meeting 6 on the side of 2 forties loses....	·55	·90
Case 3, 4 wells meeting 5 on the side of an eighty loses...	1·01	1·88
Along the side of a forty:—		
Case 4, 3 wells meeting 4 on the side of a forty loses......	·24	·42
Case 5, 3 wells meeting 4 on the side of 2 tens loses......	·13	·41
Case 6, 2 wells meeting 3 on the side of a forty loses......	1·39	2·45

The method of ascertaining the lost area is to draw lines on the map midway between each line well and its two opposing line wells, if one is not exactly opposite. This is done by drawing circles with each well in question as a center and joining the points of intersection with a line. These lines then make triangulars with the lease boundary showing areas lost or gained.

The area of the lost territory thus outlined must now be computed as well as any territory which may be gained from the neighbour. This may be done by making this construction on cross section paper, counting the number of squares or fractions of squares included in the area. A more exact method is to compute the area of the triangle by the well known formula of the base times one half the altitude. In the event that the area is polygonal instead of triangular, it is divided into triangles and the area of each computed and added together.

In unusually shaped leases, it is well to plan several methods of placing wells. If the cost of wells, the price of oil, and



Well producing oil from two horizons; one through inner casing and one from space between casing.

the royalty are fairly constant, it is quite possible to construct tables showing how much production to the acre the lease must have to warrant the drilling of a particular extra well. The tremendous loss occasioned by the cutting up of an oil or gas pool into many small holdings will be discussed later under the head of large versus small companies.

In fields where the dip is high, such as is likely to be the case in some of the new fields to be developed in Alberta, it is better to have wells drilled closer along a lease boundary, paralleling the strike and less close to one paralleling the dip, as the interference of well with well is much less in the former case.

DEPTH TO WHICH WELLS SHOULD BE DRILLED.

This is an extremely important consideration, second only in importance to the selection of the location. And as regards depth, as in the case of locations, geological knowledge and skill are necessary. Quite commonly the tradition is established in a field that it does not pay to drill below a certain "farewell sand." In some instances this decision has been a wise one, but all too frequently it has been the result of ignorance of the formations below, and has resulted in the premature abandoning of thousands of wells. Before any test is drilled, the producer should investigate the formations he is likely to meet, so as to have some idea of the depth. This advance knowledge is also useful to him in drawing up the drilling contract, and in deciding on the method of drilling and the size of the hole. A good illustration of the losses occasioned by loose work in this matter is that of the Cherokee Nation, where most of the early wells were stopped at the Bartlesville sand. Whereas, only 150 feet deeper, more or less, depending upon the location, there is another sand distinctly worth while, and to which new tests now extend, and to which old wells, about to be abandoned, are being deepened. Another illustration, also in Oklahoma, is offered by the region from Owasso, to the Arkansas river, where it is quite probable that some producers have stopped wells at the Pitkin limestone, mistaking it for the Boone limestone or the Mississippi lime, which is not very much deeper, and is yet distinctly worth drilling to. The Bridgeport, Illinois, pool is another instance where the early unsuccessful tests were almost all discontinued at too shallow a depth, many of them causing the surrender of leases that have since become productive. The most frequent cause of too shallow drilling is the indifference paid to the dip by drillers or producers who have come from older fields, where the dip is so slight as to be ignored by them. A well was unwittingly started at Boulder, Colorado, that could not have reached the producing sand till a depth had been reached more than twice that of the producing wells of the North Boulder pool. In most fields the geologist can predict the age and general nature of the strata to depths exceeding that feasible for drilling.

One should take care to drill through the whole of the oil sand, for occasionally the shale which seems to underlie the sand may in reality be merely a break of a few feet of shale with additional pay beneath. Even though a lower pay is not obtained, this pocket is sometimes valuable to receive sand and mud which otherwise would accumulate in the hole and reach up to the level of the perforations and greatly interfere with the pumping later.

However, in the event that the oil is found under very high pressure, the driller needs to be particularly careful in penetrating the sand, inasmuch as any underlying water will rush in the hole more readily than the oil and in some instances drown it out. In these cases of high pressure, it is best to let the well flow until the pressure is reduced, when deepening can more safely be continued.

But where the contents of the pool are not under high pressure, because relieved by neighbouring wells, there need be no such fear of water. Fig. 10 shows how desirable it is to drill through into the water sand, since such a well, while pumping some water, also pumps an increased amount of oil. This happens because the removal of this water leaves a funnel shaped depression in the top of the water sand and in the bottom of the oil sand which invites, as it were, a more ready flow of oil into the hole, both by means of the gradient established and by contact of the oil with the less viscous and more easily flowing water. This method of purposeful deepening of oil wells into the water sands is patented in the United States, but not in Canada.

NEGLECT OF SHALLOW SANDS.

We have in the history of many fields a later development of a shallow sand that was passed through by early operators, being considered too insignificant for production, or because gas only was sought at the time. There have been many instances in Oklahoma where oil has oozed slowly from some shallow sand around the casing to the surface. Such a sand has in nearly every instance, later proved worth while when properly shot. It is remakable how shooting has made sands productive which at first seemed disappointing.

Unless absolutely necessary, the operator should avoid drilling test holes by the rotary method, as in that case he gets poorer logs, and may pass through a very fair oil sand without detecting it, because of the weight of the considerable quantity of mud and water which hold back the oil and gas.

PUMPING.

The best results in pumping, after the pressure has declined, is obtained by frequent, intermittent pumping rather than by prolonged, occasional pumping. In wells of reduced pressure, one of the principal factors to bring the oil to the hole is gravitational seepage, and of course this cannot be effective when the oil stands high in the hole unless the main mass of oil pay extends higher up the dip. Devices for automatic pumping, controlled by the accumulation of the fluid, have not as yet been successful. A mechanical turning on and shutting off of power would be quite feasible, if the pumping were by electricity or compressed air, but is next to impossible with the common steam or gas engine powers of to-day. Producers should appreciate the great economy of pumping several wells by one power. All too frequently the installation of multiple powers is too long delayed. We can anticipate with the improvements time will bring, improved powers that will not only pump a larger number of wells, but will also pump from greater depths.

MORE EFFICIENT EXTRACTION.

It is customary at the present time to continue pumping in the usual way till the receipts have fallen below the maintenance charges. Then the well is abandoned without any additional efforts to get the last of the oil. If we calculate the amount of oil per acre from the porosity of the sand, we find that the amount actually extracted is considerably less than 50 per cent in the case of firm sandstones, and even in the loosest sands is seldom more than this. In the aggregate this loss is staggering. The time has come when we should make a determined effort to obtain the unreached oil.

The first step in this direction is doubtless a more careful conservation of well pressure, as it is this which is especially effective in driving the oil to the hole. To this end, it is advisable to equip all drilling holes where high pressure is expected with proper casing gates or well cappers. By this means a sudden strike of oil or a prolonged flow after a shot may be piped into the tank without that occasional long and useless gushing over the derrick.

The discharge from the flow line should be into a gas trap, because it is unwise to let the well pressure decrease rapidly, and because this gas is unusually rich in recoverable gasoline.

It is desirable to tube the well early with the perforation set low in the sand, for this does not seriously reduce the production, and it has the merit of keeping the pressure of the gas in the upper part of the sand in place, where it is valuable for its power of expulsion. From the gas trap the line should go to a covered tank. This, if other circumstances, such as aridity, favour its use, should be of iron instead of wood, for the greater tightness. The vapour also from the top of such tanks should be piped to a gasoline recovery plant.

When flowing has nearly ceased, equipment for pumping is put in. It is desirable to have the pump high, so that the oil enters the perforations in the gas anchor a little above the top of the sand while the pressure is such that the oil is forced into the hole far above the level of the sand. The casing head should be kept closed at this stage, so as to save pressure. Care should be taken not to pump after the oil has been pumped down to the perforations. When production has dwindled, after applying this method, and the pressure is found to be low, the perforations should be lowered below the bottom of the sand, if there is no water. Or if there is water, then they should be placed partly below the level of the water. From this time on, pumping should be at frequent intervals, so as to keep the level of the fluid low. It is quite true that this increases the paraffining of the sand, but it is necessary to get the full effect of gravitational seepage, and the paraffining of the sand face will be very much less than it would have been earlier, when the pressure was high. The casing head can now be connected with the gasoline recovery plant. But the gas should be pulled upon only slightly at first, then gradually more and more till as high a vacuum is attained as is feasible. Then in turn this method will also be abandoned as too unproductive.

There will ordinarily be little trouble from paraffining until the perforations have been set low. After this when the production is considerably reduced, it is desirable, after as much cleaning as is necessary, to treat the sand face with an electric well heater for 100 hours. In case the producing company consumes its own product, it would be advisable to follow the heating with a naphtha bath.

When production has reached an unprofitable point, the well should not be abandoned, but held in reserve until the whole pool can be brought under the management of one great company or of several co-operating companies. Only by concerted action can the next effort by the water flush method be used to extract the remaining oil. Water should be turned down the well situated at the lowest point of the sand. It can be gotten either from one of the shallow sands or else introduced from the surface. This should be run in fast enough to keep the hole filled up, in order to have a good head and correspondingly rapid penetration. Then an adjacent well should be given test pumpings, if not regularly pumped, until the on-flow of this water increases the oil output. After a period of much improved oil production, it will yield more and more water in ever increasing proportions. Then when the amount of oil is no longer in paying quantities, this well in turn should serve as a point of entrance for water. In this way, the oil is gradually flushed up the pool to the highest wells. When only these highest are producing, discontinue introducing water at the lowest wells, so as to prevent the oil being washed by the water up

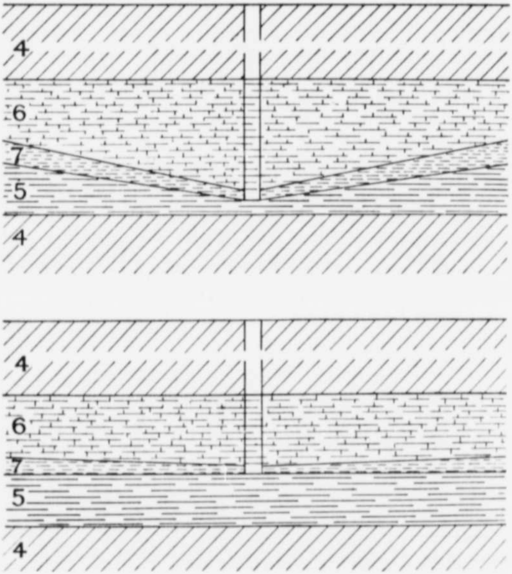


Fig. 25. Upper. Showing the accumulation of the oil in the lower part of the sand as it becomes drained. The oil becomes dependent upon gravitation for movement to the well. As it flattens out, the gradient becomes less and the movement declines. 4, shale; 5, water; 6, drained sand; 7, oil.

Lower. Showing the effect of deepening the well into the water sand and so causing a flow of water to the well and a funnel shaped depression in the water surface, which increases the flow of oil to the hole.

the dip past these wells. Theoretically, it would seem wise to keep the wells farther down the dip open, so that compressed air could be forced in. This air, bubbling through the water-filled sand ought to disengage some oil that the moving water alone could not dislodge. The accumulation of the air in little domes and pockets in the top of the sand would dislodge oil that had been retained there, so that it would move on up the dip to the pumping wells. Whether this compressed air system will warrant the expense, only actual trial can prove. But judging from the outcome of laboratory experiments, the prospect is promising.

CONCENTRATION.

The relative economy and efficiency of large and small producing companies is a matter of great interest and importance. The following theoretical considerations, as well as actual practice, all point to the overwhelming *advantage* of large units of capital and management. The advantages are:—

(1) Access to a much larger percentage of well records in the vicinity.

(2) Ability to employ more efficient and more highly specialized men.

(3) The considerable reduction in the number of offsets to be drilled.

(4) Ability to connect up the largest number of wells that each power is capable of pumping.

(5) Economy in labour, by having one pumper tend several neighbouring powers.

(6) The more continuous utilization of the plant and equipment, such as pulling machines, for instance.

(7) Saving in time and teaming by maintaining carefully distributed and well stocked store houses.

(8) The ability to install a gasoline recovery plant, because of the company's control of the necessary number of neighbouring wells.

(9) The conservation of pressure and the use of water flushing can be more frequently employed when the whole

pool is owned by one company, or at most, by but a few companies whose managers could easily reach an agreement, which would be difficult were there, instead, many small lease holders.

(9) Important experiments can be tried, such as testing the relative merits of competing methods and materials.

(10) Economy of surveying.

(11) By holding several contiguous leases, instead of a few scattered ones, a large company may "feel out," from established production, location by location, relatively unhampered by property lines.

(12) By holding several contiguous leases, the large company will far less frequently be forced to drill according to the terms of the lease, before the needed information is in hand.

(13) The logs in a large company are nearly always more carefully recorded and are always available. Whereas, among many small companies, there are invariably some who keep very poor logs or hold them secret, and in some cases there are some who even falsify their records. By means of this fuller information, casing requirements and the proper depths of tests can be anticipated, sometimes saving an unnecessary hole, or preventing the premature discontinuance of one.

(14) Lower prices and better quality in supplies are possible when purchased in large lots.

(15) The economy of a large company drilling its own wells without letting them out to contractors. Or, if because of the difficulty of getting a competent superintendent of drilling, the company decides to contract after all, this can be done at far cheaper rates than ordinarily, from the circumstance of there being many wells close together in one contract.

(16) A lessened danger from premature flooding by water from improper casing or plugging. Also less gas waste by small, irresponsible or incompetent neighbors.

INTEGRATION.

These foregoing reasons apply to the greater efficiency of concentrated or large producing companies. The following considerations indicate the higher efficiency which results from the integration of the industry, that is, the bringing under one management of the various successive steps in the oil and gas industry, such as production, transportation, refining, and distribution.

(1) With intergration, it would be possible to store oil in relatively few central, large, steel tanks, when otherwise, the oil would deteriorate more rapidly in numerous small, and more leaky tanks.

(2) Gasoline recovery plants, installed for handling gas from wells, might also recover gasoline from the pipe line company's storage tank vapours.

(3) By controlling, to a certain degree the rate at which wells are drilled, the danger of overproduction may be reduced, and at the same time, the production may be better adjusted to the needs of the refinery.

(4) The oil and gas business should be in the hands of the same company, as otherwise the one sided eagerness of the oil producer may not only lead him to waste vast quantities of gas, but also renders the search for gas more difficult and expensive on the part of the gas company.

(5) Pipelines and laterals can be planned in a more systematic and foresighted way. Competing lines to a small pool, which in a year or so would barely supply even one of the lines, could thus be avoided.

(6) Water and fuel for pumping and drilling can be cheaply supplied from the nearest available source.

(7) The guarantee of a regular production for the refinery makes for greater economy and efficiency there as well as in the marketing of the oil.

As a partial off-set to these advantages of both concentration and integration, there are the following five foes to efficiency in all large scale business.

(1) Unwarranted favoritism in employment and promotion.

(2) Slacking up, because the personal interest is less keen and vital.

(3) The temptation to sacrifice the interests of the company to those of officers, superintendents and foremen.

(4) Jealousy among departments or divisions of the company.

(5) A clique spirit that tends to advance the men already with the company, when sometimes new and valuable men from the outside are needed.

These difficulties are not necessary, and can be overcome in a large measure by a high degree of executive ability on the part of the management. In practice, the losses from these five causes are evidently less than the gains, because, as a matter of fact, the large, integrated companies are constantly buying more properties, so that the percentage of leases held by great companies is steadily increasing.

WISER UTILIZATION OF OIL.

Once the petroleum is pumped to the surface there is very little preventible loss, other than that in casing head gas and by evaporation, both of which have been already discussed. Yet there is one very serious loss of a different and wilful type—the burning of good oil for inferior uses. For instance, it is common to burn a grade of oil under the boilers that is capable of being refined into lubricating oil, and which may even carry a fair percentage of gasoline, kerosene, and paraffin. Doubtless in California, where coal is scarce and oil inferior and plentiful, this is justifiable. But to burn the residuum of most Canadian oils except for specific purposes, would be a lamentable use to make of a product that would be worth so much more in the future for higher purposes. When an oil is to be used for the production of power, far greater efficiency can be had by the internal combustion engine, of either the carboretor or Diesel type. The following table from Oliphant, as quoted in Westcott's "Handbook of Natural Gas" is conclusive:—

Average amount of natural gas required to operate gas engines or for steam engines where natural gas is used as fuel under boilers, in cubic feet per indicated H.P. per hour.

Type of Engine.	*Gas, Cu. Ft.*
Large natural gas engine, highest type..................	9
Ordinary natural gas engine............................	13
Triple expansion condensing steam engine...............	16
Double expansion condensing steam engine...............	20
Single cylinder and cut-off steam engine..................	40
Ordinary high pressure, without cut-off, steam engine.....	80
Ordinary oil well pumping steam engine..................	130

CONSERVATION OF GAS.

The most serious cause of the waste of gas is that by the oil producer who is not himself a distributer of gas and who, in his eagerness for oil, is ruthless in its waste. Only four years ago in Oklahoma gas wells sent into the air more than 10,000,000 cubic feet a day, just because operators wanted to get rid of it, so they could get their oil out. This should be illegal. No operator should be allowed to enter a gas sand unless without casing it off promptly, or having legitimate means of using it himself. If the gas of a shallow sand is of too low pressure to sell to the gas company, he should nevertheless be forced, with rare exceptions, to save it by installing pumps to lift it to the necessary pressure to put it in the line.

The escape of casing head gas should also be prohibited with a few exceptions.

Another cause of considerable waste is the current habit of blowing the water off gas wells. This sacrifices too much gas, and if the gas is being sold so cheaply that the operator cannot afford to pump off the water or blow it out through a small inner tubing, then the price of gas must be lifted to a point where he can.

Still another disastrous procedure is to call upon the wells for a very high percentage of their capacity, owing to the danger of flooding with water. In my opinion this is quite safe with certain wells that are well up the dip, but for other wells, already threatened with water, it is distinctly unwise.

It is of course imperative that the government should insist upon all abandoned gas wells being plugged so as to protect the gas sand from water from other sands, and also to protect coal mines from gas from abandoned wells. All too often gas sands have been abandoned because their pressure was no longer adequate to put gas into high pressure mains. These wells, still containing much valuable gas, will produce under a vacuum, after their own pressure is entirely gone. The very slow decline of wells being treated in this way, near Pittsburgh, is remarkable. Gas is thus brought into the gas sand proper from the surrounding sand of low porosity that would otherwise be unproductive.

WISER UTILIZATION OF GAS.

Gas is so wonderfully well adapted to the household needs of cooking, lighting, heating, and for small gas engine power units, that its use for inferior purposes is to be deplored. Yet in many oil fields we find flambeaux one or more feet high burning night and day. And staggering quantities of gas are being burned in smelters and mills at prices ranging from one-fifth to one-tenth of what it commands for household purposes. Even in the home it is sometimes used in the very wasteful and inadequate fan-tail burner. The following data quoted from Oliphant in Westcott's "Handbook of Natural Gas" shows how vastly superior is the mantel light.

"Where natural gas can be had at 25 cents per 1,000 cubic feet and 50 candle power can be obtained from the consumption of 2½ cubic feet per hour with a mantel, the cost per candle power per hour is but ·00125 of 1 cent.

"In an ordinary Argand burner with chimney it will give about 12 candle power in consuming 5 to 6 cubic feet per hour. If consumed in an ordinary tip, 7 to 8 cubic feet per hour will yield 6 candle power. All natural gas has not the same illuminating value. In some districts it carries a small percentage of heavier hydrocarbons, which add much to its illuminating properties."

It would therefore seem reasonable to prohibit by law the selling of natural gas to one consumer at less than one-half the price paid by another consumer, also to prohibit more than a certain fraction of capacity of the well to be taken, during the early life of the well. But to prevent undue hardship, such a law would have to go into operation very gradually.

The notoriously unscrupulous waste of gas when burned on flat rates indicates the need of selling all gas by the meter. In fact, gas is generally sold so much too cheaply as to offer no incentive for economy on the part of the consumer. Bearing in mind the relatively small quantities of gas in the ground, and the comparatively short time it will last, it would seem best for the state to fix a minimum price. In any event, gas companies should never enter into a contract with a consuming city to furnish gas for all time at the same rate. In later years it will be only just to pay a higher price for the gas, as it will have to be piped farther and as the supply begins to dwindle the percentage of successful wells will be smaller and the wells themselves will be smaller.

CHAPTER XI.

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APPENDIX.

TESTS FOR PETROLEUM, AS SUGGESTED BY THE INTERNATIONAL PETROLEUM CONGRESS.[1]

SYSTEMATIC METHODS OF TESTING PETROLEUM PRODUCTS.

At the International Petroleum Congress held in Bucharest, in 1907, a preliminary scheme of testing was offered for use, until a commission appointed at that Congress could establish more satisfactory international methods.

This Commission reported a number of tests at a meeting in Vienna in 1912, which were adopted by some of the countries present and not by others.

The following scheme of examination of petroleum products is a translation of the tests adopted by the International Petroleum Commission, to which have been added some additions and criticisms of the methods proposed, in the form of footnotes supplied by Dr. Day. It simply represents progress in the direction of uniform testing methods.

I. The ODOUR of an illuminating oil is not characteristic as to its illuminating value. If a test (should) be considered necessary, it should be made by shaking (about) 100 cubic centimeters of oil in a bottle of 200 cubic centimeters capacity, with a clear width of neck of 18 mm., at a temperature of about 20°C. for a minute, (and then noting the odour).

II. The test for COLOUR and FLUORESCENCE of an illuminating oil is matter for future agreement. The test for colour is to be made with a colorimeter, using standard glasses whose colour value is to be determined by comparison with normal liquids yet to be agreed upon. Before testing the colour, the petroleum must be filtered through paper.

III. SPECIFIC GRAVITY is to be determined by the usual methods (officially standardized thermo-areometers, pycnometers, Mohr scales, areometers for small quantities, alcohol floatation process) according to the nature and quantity of the material and the accuracy desired. The standard temperature is fixed at 15°C., the unit of weight to be water at +4°C., and the specific gravity to be reduced to vacuum. The determination of specific gravity may be made at higher or lower temperature and reduced to the normal temperature at 15°C. by means of coefficients of expansion to be determined by each country for its own petroleum, provided only that the specific gravity does not lie so near a limit that errors could thereby occur. In this case the determination must be carried out at 15°C. or at a temperature very near to this.

IV. In case the determination of SPECIFIC VISCOSITY is desired, it is recommended to use the Engler viscosimeter modified by Ubbelohde for illuminating oils (described in Post, Chemisch-technische Analyse, Vol. 1, part 2, p. 312, and in the periodical "Petroleum"—(Berlin)—1909, IV, No. 15, also "Moniteur du Pétrole," 1909).

[1]Translated from the German by Dr. David T. Day and Dr. Frederick E. Carter. Some comments by Dr. Day are also added as footnotes.

V. The determination of the FLASH POINT of illuminating oils is to be made in the Abel-Pensky apparatus.

Exportation and transport regulations in the different countries are postponed for further deliberation.

The rules for the determination of the flash point of illuminating oils, whose flash point is higher than 50°C., will be based on experiments still to be carried out.

VI. COLD TEST. Fresh samples must always be used, and not such as have been previously cooled off to a lower temperature for any considerable time. Testing is necessary only when precipitation might be harmful in the use of an illuminating oil. If on cooling a sample in the test glass precipitation or solidification is observed, then the determination of the cold test must be carried out according to the method recommended for lubricating oils. The freezing point of the distillatioa residue left from illuminating oils at 275°C. may also be determined. Due regard is also to be given to changes noted during the cooling.

VII. The FRACTIONAL DISTILLATION is effected in the Engler bulb according to the continuous method. (Compare L. Ubbelohde, "Mitteilung aus dem Königlichen Material-prüfungsamt" 1909, p. 261 and "Moniteur du Pétrole" 1908, pp. 280, and 282). The height of the barometer is to be given and, by making a test with a thermometer of equal dimensions, a correction for the emergent mercury filament to be made. The condenser tube must be entirely dry. The boiling point is that point at which the first drop falls off from the exit tube of the Engler bulb.[1]

The limits of temperature within which the distillates are taken off must be divisible without remainder by 25.

Ordinarily the fractions are measured volumetrically, the residue, boiling above 300°C. and remaining in the retort, being weighed. For more exact investigations, the weight of the distillates and of the quantity used is determined.

VIII. ILLUMINATING POWER. As the unit of measurement of illuminating power the Hefner amyl acetate lamp is used. For changing from this unit into other units, the tables published by the "Verein der Gas und Wasserfachmänner" are used. For exact photometric determinations the grease

Unit	*H.*	*V.*	*E.*	*P.*	*C.*
Hefner	1	·833	·877	·091	·092
Vereins	1·2	1	1·05	·109	·111
English	1·14	·95	1	·104	·105
10 c.p. Pentane lamp	11·0	9·16	9·6	1	1·01
Carcel	10·80	9·0	9·5	·98	1

spot is not appropriate. It is necessary to use the photometer of Brodhun, or Lummer, or other modern apparatus.

The illuminating power of an illuminating oil does not depend solely on its composition, but most particularly upon the construction of the lamp

[1]It is better to take the temperature when the first drop falls from the condenser because frequently this occurs before a drop falls from the exit tube of the distilling bulb.

and (the) chimney used to determine the illuminating power. For these tests (of illuminating power), the following points must be observed:—

The size of the burner, of the chimney, and the distance from the edge of the burner to the level of the oil before and after the experiment must be given.

Before the experiment dry the wick (for two hours) at 100°C. (212°F.), then plunge it at once, warm, into the lamp oil, and let it soak there for an hour. The top of the wick should be trimmed with care by means of scissors until an even flame is obtained.

The duration of the combustion should be in general six hours. In particular cases an appreciable longer duration of combustion may be used.

During the first quarter of an hour turn up the flame to the highest point possible. Later, a quarter of an hour before the first photometric measurement, turn it up again, then leave it to itself (without touching it).

The photometric measurements should be done after the first, second, third, fourth, fifth, and sixth hours.

In determining the total consumption of oil, weigh the lamp before and after the test.

In order to obtain more exact determinations, the lamp should be weighed at each photometric determination. Differences in the temperature of the oil are without sensible effect upon the weight. In addition to the mean illuminating power and the total quantity of oil burned, the consumption per candle-power per hour is to be given. The kind of wick used must be given. The International Commission has left this subject to the study of a special commission.

IX. Behaviour of Burning. This subject also has been left to subsequent study by the Commission.

X. Degree of Refining:

Acid Content. 1. Shake 100 cubic centimeters of illuminating oil with 10 cubic centimeters of distilled water with addition of a few drops of an aqueous solution of methyl orange, 1:1000. The water must not become pink.

2. Dissolve 100 cubic centimeters of the illuminating oil in 100 cubic centimeters of a freshly neutralized mixture of 4 parts of ether, 1 part of 95 per cent alcohol, and 1 drop of phenolphthalein solution. Add a drop of one-tenth normal sodium hydrate solution, and shake in a cylinder with a stopper. If the illuminating oil is neutral, the pink colouring does not disappear during the shaking.

If an acid reaction has been detected by either of the two qualitative tests, then the quantitative determination of the acid content is to be undertaken by the known analytical methods. Meanwhile it may be of value to test the behaviour towards sodium hydrate by using the so-called "soda test" (Muspratt, "Technische Chemie" 1898, p. 234, or Post Chem. Tech. Analysen Ed. 3, vol. 1, p. 320) in which sodium hydrate solution (1·02 Sp. Gravity) diluted with water in ratio 6:100 is used. However, the result of the soda test alone is not decisive, but when it discloses nothing, a possible acid centent or "acid figure" is to be determined by 1. or 2., or if no free acid is present, the ash content. (See XII).

Xa. *Hydrocarbon Characteristics*: The determination of hydrocarbon content is referred to a committee for further study.[1] The problem of this committee is to be the preparation of methods for determining the various hydro-carbons groups that go to make up petroleum and its products.[2]

XI. Storage Stability. For studying the liability to alteration of petroleum in storage, a Special Committee is named to collect and work up material relating to this question for presentation to the next meeting of the International Commission.[3]

XII. Ash Content. For determining the ash content, about 1 litre of filtered oil will be used, taking into consideration the filter residue qualitatively and, if necessary, quantitatively. The ash must be indicated in percentage by weight. The ash is determined by distilling off the sample to about 30 cubic centimeters. This residue is poured off along with the last portions of the distillate into a platinum dish, evaporated to dryness with removal of the vapours, and incinerated.

XIII. Sulphur Determination. The determination of the sulphur is effected quantitatively either according to the method of Engler-Heussler ("Zeitschr. f. angew. Chemie" 1895, p. 225, Engler, "Chemikerzeitung" 1896, p. 1897, Post. Chemisch-Techn. Analysen, Vol. 1, part 2, p. 321), making if necessary at the same time a blank test to eliminate errors arising from the SO_2 content of the air of the laboratory, or else by the method of combustion in the bomb.

XIV. Water Determination. Water determination for illuminating oil is dispensed with. In case of the occurrence of clouding, it must be determined if this results from the water content.

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[1] Nominated as members of SPECIAL COMMITTEE are Engler, Holde, Zaloziecki, Edeleanu, Gurwitsch, Nicolardot, Allen, and Sluyterman van loo.

[2] In this regard Dr. Engler has already communicated the following partial method worked out in his laboratory by Dr. Tausz and Dr. Pfeiffer: For qualitative detection of the unsaturated hydrocarbons a small quantity of benzine is shaken and boiled with concentrated aqueous mercuric acetate solution. Olefins and cyclic unsaturated hydrocarbons dissolve cold and are oxidized in boiling. In this process they reduce the mercuric acetate, which precipitates on cooling. Moreover butylene colours red, amylene yellow, and hexylene pink. For their quantitative determination the unsaturated compounds are for the most part thoroughly shaken with mercuric acetate at ordinary temperature and distilled out of the solution after adding hydrochloric acid. These regenerated unsaturated hydrocarbons are identified as formolite in the usual way in which the cyclic ones are identified. The remainder of the unsaturated hydrocarbons of the benzine, not dissolved by mercuric acetate is destroyed (decomposed) with fresh mercuric acetate by boiling with a return condenser whereupon the remaining more stable hydrocarbons are distilled off, separated by a special method, and determined quantitatively. The difference between the volume of the benzine used and that of the last named distillate gives the content in unsaturated hydrocarbons. The correction for unavoidable losses is found by a blank experiment.

The subsequent analysis is qualitative. The aromatic hydrocarbons are detected as formolite. In their presence the formolite reaction with the total distillate is repeated, until the hydrocarbons distilled off no longer give formolite. For detecting the cyclo-hexanes in this remainder a sample is passed at about 300°C. in a hydrogen atmosphere over finely divided nickel. If the condensate now shows the formolite reaction, then there were cyclo-hexanes present. Zelinski thinks they can be determined quantitatively by dehydrating with palladium black. Naphthenes and paraffines are recognized as usual from the physical constants of the carefully fractionized remainder.

[3] Dr. Singer is named as chairman, and the following are members: Allen, Guiselin, Gane, Sohn, and Berguer.

BENZINE (Gasoline, Naphtha, etc.)

I. SPECIFIC GRAVITY. Same as for illuminating oils.

II. DISTILLATION. The tests are the same as for illuminating oils. Fractionating is to be effected while making the limits of temperature divisible by 10. Final point of the distillation to be regarded as that temperature at which the bottom of the retort appears (to be) dry, or when white vapours make their appearance.

III. DEGREE OF REFINING. Tests to be omitted until a uniform method is fixed.

IV. FLASH POINT. In case such test is to be made, (German Abel-Pensky apparatus) is to be used.

V. ACID CONTENT. The rules given for illuminating oils are to be used, mutatis mutandis.

VI. HEAVY HYDROCARBONS. Referred to the Committee on point Xa for illuminating oils.

VII. WATER DETERMINATION. The same rules as for illuminating oils.

VIII. CALORIFIC VALUE. To be determined by bomb or other suitable apparatus. Indication must be given as to which apparatus was used.

IX, X and XI. (High boiling contituents, odour and colour, and illuminating power). These were referred to a Special Committee to investigate and report as in the case of illuminating oils.

LUBRICATING OILS.

I. COLOUR. Transparency of the oils in a thin layer is to be determined by letting them run over a glass surface. Colour is to be determined, as a rule, by simple ocular inspection in a test tube. In special cases, examination is made in rectangular vessels 10 centimeters in height, 10 centimeters in length, and 15 millimeters in width (inside measurement), made of pure white glass of 5 millimeters thickness of wall, and by both transmitted and reflected light. The colour is of no influence on the lubricating value, and as a rule is regarded only as an assistance for identification.

II. SPECIFIC GRAVITY. (a) Limitation of the specific gravity with reference to the proposed use is not necessary, and must not be subjected to too narrow limits. Only when oils of a determined origin are demanded, certain limits of gravity may be set for classification purposes, and these must not be drawn too narrowly. (b) Specific gravity serves only as a means of classifying mineral oils of known origin, and for tests of identity and comparison. (c) The determination of the specific gravity is effected according to the nature and quantity of the material and the degree of accuracy desired, according to the usual processes (officially standardized areometers, pycnometers, Mohr scales, areometers for small quantities of oil, alcohol floatation process). For thick oils, the method of mixing with kerosene is to be carried out. The standard temperature of 15°C. is fixed; as unit of weight, water at +4°C.; also specific gravity is always to be reduced to vacuum. The determination of specific gravity may also be effected at higher or lower temperatures than 15°C., and be corrected by the coefficients of expansion to the normal temperature of 15°C. Each country must determine for its own mineral oils the coefficients of expansion (correction figures). In case the specific gravity so calculated lies so near to a limit that errors might arise, the determination must be carried out at 15°C., or the coefficient of expansion (correction) exactly determined.

III. FLASH POINT. (a) In all cases where it is a question of obtaining the greatest possible exactness, the Pensky flash point apparatus must be used. in other cases also the open cup preferably with a mechanical device for bringing up the test flame and with an adjustable burner. (b) In case of absence of other prescribed methods a porcelain cup 4 cm. in width and 4 cm. in height is to be used for the determination of the flash point in the open cup, This is to be set in a sand bath up to the level of the oil. (For mode of experiment see Holde, Untersuchung der Mineralöle und Fette Ed. 3, p. 13). In determining the flash point in the open cup a thermometer with a short bulb is to be used, similar to that used with the Pensky apparatus; the centre of the bulb must be in the centre of the oil. Indication must always be given whether the work was prosecuted with or without consideration of the correction for the emergent stem of the thermometer. The officially standarized thermometers for the Pensky apparatus are so graduated that the indication of error includes the last mentioned correction (at the same time).

IIIa. EVAPORATION. Referred to a special committee.

IIIb. DISTILLATION TEST. Distillation test in general to be effected in the Engler bulb, using 100 cubic centimeters. Distillation to be carried on to 270°C., the temperature being taken in the vapour.

IV. BURNING POINT. This determination is carried out in the open cup, as in the case of the flash point. The heating must be continual, at the rate of about 4°C. a minute—at the outside 6°C. a minute.

V. SPECIFIC VISCOSITY. The Commission has referred this subject to a special committee.

VI. CAPILLARITY. Also referred to a special committee.

VII and VIII. COLD TEST. (a) For the simple determination the test tube method is sufficient, to be carried out in the following way: Into two test tubes of 18mm. diameter, the oil is to be poured to the height of 3 cm. In one of these test tubes a thermometer is dipped into the liquid. Both samples are kept for an hour in a freezing mixture at the desired temperature. The sample without the thermometer is then tilted, and the consistency, that is, the flowing capacity of the oil, determined. (b) In case of numerical comparison of the flowing test by the U-tube process, the sample in the test tube is to be cooled off for an hour to the experiment temperature, while maintaining 50mm. water pressure in the tube with width of 6 mm. (limit of error of plus or minus 0·3), pressure action lasting for a minute with a stipulated minimum rise.

(c) Preliminary treatment of the samples: For the consideration of the changes in the cold point conditioned by the influence of temperature changes, the samples are to be tested in two separate experiments, in the condition when delivered and after heating for ten minutes to 50°C. In the case of the oil tested in the heated condition, the determination is to be repeated for safety if the oil (left over) from the first test is sufficient. (d) For removing chance impurities, the oil before heating is to be poured through a sieve with a one-third mm. mesh. For this purpose very thick oils must be heated slightly. (e) Oil containing water must be decanted, and afterwards filtered through cotton wool dried at 100°C.

IX. Asphalt-Like Bodies. Referred to special committee.

X. Water and Mechanical Admixtures.

(a) *Water.*—The water content of oils is to be determined quantitatively, only in case the qualitative test has shown a notable water content. In case of pure mineral oils, which at 50°C., have an Engler degree of less than 8, the determination is made in the following way: About equal weights (each about 100g.) of the original and of the dehydrated oil are heated in glass dishes on a boiling water bath until the formation of foam (scum) has ceased, and the loss in weight determined. From the difference in loss of weight of the two samples the water content in the original oil is to be calculated. The dehydration of the oil, before heating, is effected by shaking the slightly heated oil in an Erlenmeyer flask with calcium chloride, and afterwards filtering on a dry filter. In case of oils of more than 8 Engler degrees, it is sufficient to establish the loss of weight by heating, and a parallel experiment with dehydrated oil is superfluous. In other cases, for instance with oil of high water content (solid fats), the determination according to Marcusson is to be employed, depending on the distillation of a considerable quantity of oil with xylol and the measurement of the water distilled over. All the other usual methods of testing (usual) for this purpose can be used, but the process must always be specified.

(b) *Mechanical Impurities.*—5 to 10 grams of well shaken oil are dissolved in a glass cylinder in 100 cubic centimeters of benzine (in case of light coloured oil from which no asphalt will separate, benzine may be used also). After standing all night, the solution is poured through a weighed filter. The cylinder is well rinsed out and the filter washed with the solvent until the wash liquid after evaporating on the water bath no longer gives a residue. The filter is dried at 105°C. to a constant weight and then weighed.

XI.—Ash and XII and XIII—Stability to Heat and Air in Storage and XIV, XV and XVI—Stability Towards Water Vapour, Superheated Steam and High Pressure—deferred for further investigation.

XVII. Degree of Refining.—*Free Acids*:

(a) Existing processes for determining free acids in lubricating oils are retained. Mineral acids are to be determined in the aqueous extract of about 100 grams of oil, with the use of methyl orange as indicator as in the case of illuminating oil. Organic acids are to be determined by titration with alcoholic 1/10 normal caustic alkali; an alcohol-ether mixture is used to dissolve 10 cc. of a light oil, and in the case of a dark oil absolute alcohol is the solvent. (b) The quantity of mineral acid is to be calculated in percentage of SO_3, the organic acids expressed as "acid figure." (The acid figure indicates the number of milligrams of KOH necessary to saturate the free acids contained in 1 g. of oil.)

Free Alkali.—Determine the presence of alkali in the aqueous extract of at least 100 grams of oil.

Salts (Ash Content).—Inorganic salts are determined in an aqueous extract of 100 cubic centimeters of oil. The presence of alkali soaps in case of pure mineral oils generally makes itself manifest by permanent emulsion and slightly alkaline reaction of the aqueous extract, in which case the qualitative detection of the alkali soap is effected by the following method: In a test tube of 15 mm. diameter 5 cubic centimeters of 0·5 Baumé caustic alkali solution is heated to boiling over the Bunsen burner. An equal quantity of oil is added and it is heated again for a minute to boiling, in such a way that the two liquids mix as intimately as possible during the boiling. This sample is then set for two or three hours in a boiling water bath. Then the sample, on inspection, must show the following results: The oil, in case it is pure, must be clear, and the alkali extract must appear transparent in so far that small print can be read through it. Clouding indicates napthenic acid salts, and in that case the ash determination must be carried out.

XIX. Admixtures. (a) *Fatty Oil*: Fatty oil is detected qualitatively by the heating for a quarter of an hour of 3 or 4 cubic centimeters of the oil to be tested in a paraffin bath (oil bath) at about 340°C. with a small piece of sodium hydrate or, in doubtful cases, with metallic sodium. After cooling off to ordinary temperature, the oils show some lather in case of presence of fatty oils, or else they gelatinize. The soap lather is in the case of cylinder oils the deciding sign of the presence of fatty oils. Napthenic acid may produce similar phenomena. Quantitatively fatty oil is determined according to the approximate quantity and the degree of exactness desired, by determining the saponification figure or gravimetrically according to Spitz and Hönig.

XX. Paraffin. The determination of the paraffin content can generally be dispensed with in testing lubricating oils because any high percentage of paraffin would become apparent during the cold testing. In special cases, for instance in litigation tests, etc., the alcohol-ether process of Engler and Holde for paraffin determination can be used.

XXI. Lubricating Capacity. This point, as well as the study of transformer oils, sampling and measuring mineral oils kept on supply in tanks, ships, and so forth, is deferred.

INDEX.

A

B

C

F

G

H

I

J

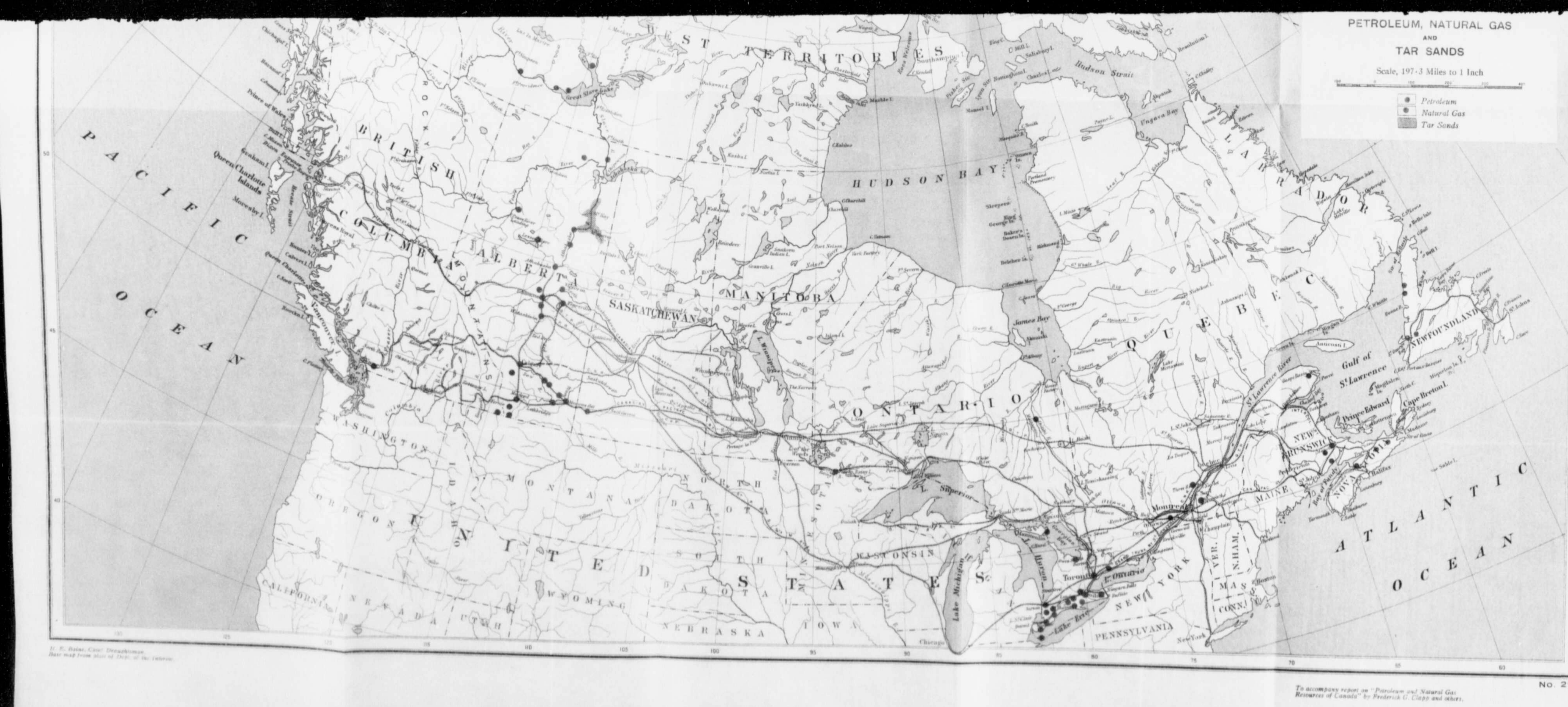
K

L

M

Q

Canada
DEPARTMENT OF MINES
Hon. Louis Coderre, Minister, R.W. Brock, Deputy Minister.
MINES BRANCH
Eugene Haanel, Ph.D., Director
1914



H. E. Baine, Chief Draughtsman.
Base map from plan of Dept. of the Interior.

To accompany report on "Petroleum and Natural Gas Resources of Canada" by Frederick G. Clapp and others.

No. 293

CANADA

DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; R. G. MCCONNELL, DEPUTY MINISTER.

MINES BRANCH

EUGENE HAANEL, PH.D., DIRECTOR.

REPORTS AND MAPS

PUBLISHED BY THE

MINES BRANCH

REPORTS.

1. Mining conditions in the Klondike, Yukon. Report on—by Eugene Haanel, Ph.D., 1902.

†2. Great landslide at Frank, Alta. Report on—by R. G. McConnell, B.A., and R. W. Brock, M.A., 1903.

†3. Investigation of the different electro-thermic processes for the smelting of iron ores and the making of steel, in operation in Europe. Report of Special Commission—by Eugene Haanel, Ph.D., 1904.

5. On the location and examination of magnetic ore deposits by magnetometric measurements—by Eugene Haanel, Ph.D., 1904.

†7. Limestones, and the lime industry of Manitoba. Preliminary report on—by J. W. Wells, M.A., 1905.

†8. Clays and shales of Manitoba: their industrial value. Preliminary report on—by J. W. Wells, M.A., 1905.

†9. Hydraulic cements (raw materials) in Manitoba: manufacture and uses of. Preliminary report on—by J. W. Wells, M.A., 1905.

†10. Mica: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 118.)

†11. Asbestos: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 69.)

†12. Zinc resources of British Columbia and the conditions affecting their exploitation. Report of the Commission appointed to investigate—by W. R. Ingalls, M.E., 1905.

†16. *Experiments made at Sault Ste. Marie, under Government auspices, in the smelting of Canadian iron ores by the electro-thermic process. Final report on—by Eugene Haanel, Ph.D., 1907.

†17. Mines of the silver-cobalt ores of the Cobalt district: their present and prospective output. Report on—by Eugene Haanel, Ph.D., 1907.

*A few copies of the Preliminary Report, 1906, are still available.
†Publications marked thus † are out of print.

†18. Graphite: its properties, occurrence, refining, and uses—by Fritz Cirkel, M.E., 1907.

†19. Peat and lignite: their manufacture and uses in Europe—by Erik Nystrom, M.E., 1908.

†20. Iron ore deposit of Nova Scotia. Report on (Part I)—by J. E. Woodman, D.Sc.

21. Summary report of Mines Branch, 1907–8.

22. Iron ore deposits of Thunder Bay and Rainy River districts. Report on—by F. Hille, M.E.

†23. Iron ore deposits along the Ottawa (Quebec side) and Gatineau rivers. Report on—by Fritz Cirkel, M.E.

24. General report on the mining and metallurgical industries of Canada, 1907–8.

25. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D.

26. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†27. The mineral production of Canada, 1907. Preliminary report on—by John McLeish, B.A.

†27a. The mineral production of Canada, 1908. Preliminary report on—by John McLeish, B.A.

†28. Summary report of Mines Branch, 1908.

29. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel. (Supplementary section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.)

30. Investigation of the peat bogs and peat fuel industry of Canada, 1908. Bulletin No. 1—by Erik Nystrom, M.E., and A. Anrep, Peat Expert.

32. Investigation of electric shaft furnace, Sweden. Report on—by Eugene Haanel, Ph.D.

47. Iron ore deposits of Vancouver and Texada islands. Report on—by Einar Lindeman, M.E.

†55. The bituminous, or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, LL.D.

58. The mineral production of Canada, 1907 and 1908. Annual report on—by John McLeish, B.A.

†Publications marked thus † are out of print.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1907-8.*

†31. Production of cement in Canada, 1908.

42. Production of iron and steel in Canada during the calendar years 1907 and 1908.

43. Production of chromite in Canada during the calendar years 1907 and 1908.

44. Production of asbestos in Canada during the calendar years 1907 and 1908.

†45. Production of coal, coke, and peat in Canada during the calendar years 1907 and 1908.

46. Production of natural gas and petroleum in Canada during the calendar years 1907 and 1908.

59. Chemical analyses of special economic importance made in the laboratories of the Department of Mines, 1906-7-8. Report on—by F. G. Wait, M.A., F.C.S. (With Appendix on the commercial methods and apparatus for the analysis of oil-shales—by H. A. Leverin, Ch. E.)

Schedule of charges for chemical analyses and assays.

†62. Mineral production of Canada, 1909. Preliminary report on—by John McLeish, B.A.

63. Summary report of Mines Branch, 1909.

67. Iron ore deposits of the Bristol mine, Pontiac county, Quebec. Bulletin No. 2— by Einar Lindeman, M.E., and Geo. C. Mackenzie, B.Sc.

†68. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

69. Chrysotile-asbestos: its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E. (Second edition, enlarged.)

†71. Investigation of the peat bogs, and peat industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenberg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep, Jr.; also a translation of Lieut. Ekelund's pamphlet entitled 'A solution of the peat problem,' 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second edition, enlarged.)

82. Magnetic concentration experiments. Bulletin No. 5—by Geo. C. Mackenzie, B.Sc.

† Publications marked thus † are out of print.

83. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others.
   - Vol. I—Coal washing and coking tests.
   - Vol. II—Boiler and gas producer tests.
   - Vol. III—
     - Appendix I
       - Coal washing tests and diagrams.
   - Vol. IV—
     - Appendix II
       - Boiler tests and diagrams.
   - Vol. V—
     - Appendix III
       - Producer tests and diagrams.
   - Vol. VI—
     - Appendix IV
       - Coking tests.
     - Appendix V
       - Chemical tests.

†84. Gypsum deposits of the Maritime provinces of Canada—including the Magalen islands. Report on—by W. F. Jennison, M.E. (See No. 245.)

88. The mineral production of Canada, 1909. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1909.*

†79. Production of iron and steel in Canada during the calendar year 1909.

†80. Production of coal and coke in Canada during the calendar year 1909.

85. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1909.

89. Reprint of presidential address delivered before the American Peat Society at Ottawa, July 25, 1910. By Eugene Haanel, Ph.D.

90. Proceedings of conference on explosives.

92. Investigation of the explosives industry in the Dominion of Canada, 1910. Report on—by Capt. Arthur Desborough. (Second edition.)

93. Molybdenum ores of Canada. Report on—by Professor T. L. Walker, Ph.D.

100. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by Professor W. A. Parks, Ph.D.

102. Mineral production of Canada, 1910. Preliminary report on—by John McLeish, B.A.

†Publications marked thus † are out of print.

†103. Summary report of Mines Branch, 1910.

104. Catalogue of publications of Mines Branch, from 1902 to 1911; containing tables of contents and lists of maps, etc.

105. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

110. Western portion of Torbrook iron ore deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Fréchette, M.Sc.

111. Diamond drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D., with introductory by A. W. G. Wilson, Ph.D.

118. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

142. Summary report of Mines Branch, 1911.

143. The mineral production of Canada, 1910. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1910.*

†114. Production of cement, lime, clay products, stone, and other materials in Canada, 1910.
†115. Production of iron and steel in Canada during the calendar year 1910.
†116. Production of coal and coke in Canada during the calendar year 1910.
†117. General summary of the mineral production of Canada during the calendar year 1910.

145. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.

†150. The mineral production of Canada, 1911. Preliminary report on—by John McLeish, B.A.

151. Investigation of the peat bogs and peat industry of Canada, 1910-11. Bulletin No. 8—by A. v. Anrep.

154. The utilization of peat fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.

167. Pyrites in Canada: its occurrence, exploitation, dressing and uses. Report on—by A. W. G. Wilson, Ph.D.

170. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

184. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.

201. The mineral production of Canada during the calendar year 1911.—Annual report on—by John McLeish, B.A.

†Publications marked thus † are out of print.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1911.*

181. Production of cement, lime, clay products, stone, and other structural materials in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

†182. Production of iron and steel in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

183. General summary of the mineral production in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

†199. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1911. Bulletin on—by C. T. Cartwright, B.Sc.

†200. The production of coal and coke in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

203. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.

209. The copper smelting industry of Canada. Report on—by A. W. G. Wilson, Ph.D.

216. Mineral production of Canada, 1912. Preliminary report on—by John McLeish, B.A.

222. Lode mining in Yukon: an investigation of the quartz deposits of the Klondike division. Report on—by T. A. MacLean, B.Sc.

224. Summary report of the Mines Branch, 1912.

227. Sections of the Sydney coal fields—by J. G. S. Hudson, M.E.

†229. Summary report of the petroleum and natural gas resources of Canada, 1912—by F. G. Clapp, A.M. (See No. 224.)

230. Economic minerals and mining industries of Canada.

245. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

254. Calabogie iron-bearing district. Report on—by E. Lindeman, M.E.

259. Preparation of metallic cobalt by reduction of the oxide. Report on—by H. T. Kalmus, B.Sc., Ph.D.

262. The mineral production of Canada during the calendar year 1912. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1912.*

238. General summary of the mineral production of Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

†Publications marked thus † are out of print.

†247. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.

†256. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1912—by C. T. Cartwright, B.Sc.

257. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Report on—by John McLeish, B.A.

†258. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

266. Investigation of the peat bogs and peat industry of Canada, 1911 and 1912. Bulletin No. 9—by A. v. Anrep.

279. Building and ornamental stones of Canada—Vol. III: Building and ornamental stones of Quebec. Report on—by W. A. Parks, Ph.D.

281. The bituminous sands of Northern Alberta. Report on—by S. C. Ells, M.E.

283. Mineral production of Canada, 1913. Preliminary report on—by John McLeish, B.A.

285. Summary report of the Mines Branch, 1913.

291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:—

Vol. I.—Technology and Exploitation.

299. Peat, lignite, and coal: their value as fuels for the production of gas and power in the by-product recovery producer. Report on—by B. F. Haanel, B.Sc.

303. Moose Mountain iron-bearing district. Report on—by E. Lindeman, M.E.

305. The non-metallic minerals used in the Canadian manufacturing industries. Report on—by Howells Fréchette, M.Sc.

309. The physical properties of cobalt, Part II. Report on—by H. T. Kalmus, B.Sc., Ph.D.

320. The mineral production of Canada during the calendar year 1913. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1913.*

315. The production of iron and steel during the calendar year year 1913. Bulletin on—by John McLeish, B.A.

316. The production of coal and coke during the calendar year 1913. Bulletin on—by John McLeish, B.A.

317. The production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year 1913. Bulletin on—by C. T. Cartwright, B.Sc.

†Publications marked thus † are out of print.

318. The production of cement, lime, clay products, and other structural materials, during the calendar year 1913. Bulletin on—by John McLeish, B.A.

319. General summary of the mineral production of Canada during the calendar year 1913. Bulletin on—by John McLeish, B.A.

322. Economic minerals and mining industries of Canada. (Revsied Edition).

336. Notes on clay deposits near McMurray, Alberta. Bulletin No. 10—by S. C. Ells, B.A., B.Sc.

The Division of Mineral Resources and Statistics has prepared the following lists of mine, smelter, and quarry operators: Metal mines and smelters, Coal mines, Stone quarry operators, Manufacturers of clay products, and Manufacturers of lime; copies of the lists may be obtained on application.

IN THE PRESS.

291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:—

Vol. II.—Occurrence of petroleum and natural gas in Canada.
Also separates of Vol. II, as follows:—
Part I, Eastern Canada.
Part II, Western Canada.

323. The Products and by-products of coal. Report on—by Edgar Stansfield, M.Sc., and F. E. Carter, B.Sc., Dr. Ing.

325. The salt industry of Canada. Report on—by L. H. Cole, B.Sc.

331. The investigation of six samples of Alberta lignites. Report on—by B. F. Haanel, B.Sc., and John Blizard, B.Sc.

334. Electro-plating with cobalt and its alloys. Report on—by H. T. Kalmus, B.Sc., Ph.D.

FRENCH TRANSLATIONS.

†4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques pour la réduction des minerais de fer et la fabrication de l'acier employés en Europe—by Eugene Haanel, Ph.D. (French Edition), 1905.

26a. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†28a. Summary report of Mines Branch, 1908.

56. Bituminous or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, LL.D.

81. Chrysotile-asbestos, its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E.

100a. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by W. A. Parks, Ph.D.

149. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.

155. The utilization of peat fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.

156. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D.

169. Pyrites in Canada: its occurrence, exploitation, dressing, and uses. Report on—by A. W. G. Wilson, Ph.D.

180. Investigation of the peat bogs, and peat industry of Canada, 1910-11. Bulletin No. 8—by A. v. Anrep.

195. Magnetite occurrences along the Central Ontario railway. Report on —by E. Lindeman, M.E.

196. Investigation of the peat bogs and peat industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenburg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep; also a translation of Lieut. Ekelund's pamphlet entitled "A solution of the peat problem," 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second Edition, enlarged.)

197. Molybdenum ores of Canada. Report on—by T. L. Walker, Ph.D.

198. Peat and lignite: their manufacture and uses in Europe. Report on—by Erik Nystrom, M.E., 1908.

202. Graphite: its properties, occurrences, refining, and uses. Report on—by Fritz Cirkel, M.E., 1907.

†Publications marked thus † are out of print.

219. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

226. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel, M.E. (Supplementary section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.)

231. Economic minerals and mining industries of Canada.

233. Gypsum deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E.

263. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

264. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

265. Annual mineral production of Canada, 1911. Report on—by John McLeish, B.A.

287. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.

288. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

289. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Bulletin on—by John McLeish, B.A.

290. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada during the calendar year 1912. Bulletin on—by C. T. Cartwright, B.Sc.

308. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma. E., and others—
Vol. I—Coal washing and coking tests.

IN THE PRESS.

179. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

204. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.

223. Lode Mining in the Yukon: an investigation of quartz deposits in the Klondike division. Report on—by T. A. MacLean, B.Sc.

246. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

308. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others—
Vol. II—Boiler and gas producer tests.
Vol. III—
Appendix I
Coal washing tests and diagrams.
Vol. IV—
Appendix II
Boiler tests and diagrams.

314. Iron ore deposits, Bristol mine, Pontiac county, Quebec, Report on—by E. Lindeman, M.E.

MAPS.

†6. Magnetometric survey, vertical intensity: Calabogie mine, Bagot township, Renfrew county, Ontario—by E. Nystrom, 1904. Scale 60 feet to 1 inch. Summary report 1905. (See Map No. 249.)

†13. Magnetometric survey of the Belmont iron mines, Belmont township, Peterborough county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1905. (See Map No. 186.)

†14. Magnetometric survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1905.

†33. Magnetometric survey, vertical intensity: lot 1, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†34. Magnetometric survey, vertical intensity: lots 2 and 3, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†35. Magnetometric survey, vertical intensity: lots 10, 11, and 12, concession IX, and lots 11 and 12, concession VIII, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

*36. Survey of Mer Bleue peat bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nystrom, and A. v. Anrep. (Accompanying report No. 30.)

*37. Survey of Alfred peat bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*38. Survey of Welland peat bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*39. Survey of Newington peat bog, Osnabruck, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*40. Survey of Perth peat bog, Drummond township, Lanark county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*41. Survey of Victoria Road peat bog, Bexley and Carden townships, Victoria county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*48. Magnetometric survey of Iron Crown claim at Nimpkish (Klaanch) river, Vancouver island, B.C.—by E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

*49. Magnetometric survey of Western Steel Iron claim, at Sechart, Vancouver island, B.C.—by E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)

*53. Iron ore occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White and Fritz Cirkel. (Accompanying report No. 23.)

*54. Iron ore occurrences, Argenteuil county, Quebec, 1908—by Fritz Cirkel. (Accompanying report No. 23.) (Out of print.)

*57. The productive chrome iron ore district of Quebec—by Fritz Cirkel. (Accompanying report No. 29.)

†60. Magnetometric survey of the Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†61. Topographical map of Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†64. Index map of Nova Scotia: Gypsum—by W. F. Jennison.

†65. Index map of New Brunswick: Gypsum—by W. F. Jennison.

†66. Map of Magdalen islands: Gypsum—by W. F. Jennison.

(Accompanying report No. 84.)

†70. Magnetometric survey of Northeast Arm iron range, Lake Timagami, Nipissing district, Ontario—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 63.)

†72. Brunner peat bog, Ontario—by A. v. Anrep.

†73. Komoka peat bog, Ontario—by A. v. Anrep.

†74. Brockville peat bog, Ontario—by A. v. Anrep. . . . .

(Accompanying report No. 71.)

†75. Rondeau peat bog, Ontario—by A. v. Anrep.

†76. Alfred peat bog, Ontario—by A. v. Anrep.

†77. Alfred peat bog, Ontario: main ditch profile—by A. v. Anrep.

(Out of print)

†78. Map of asbestos region, Province of Quebec, 1910—by Fritz Cirkel. Scale 1 mile to 1 inch. (Accompanying report No. 69.)

†94. Map showing Cobalt, Gowganda, Shiningtree, and Porcupine districts—by L. H. Cole. (Accompanying Summary report, 1910.)

†95. General map of Canada, showing coal fields. (Accompanying report No. 83—by Dr. J. B. Porter.)

†96. General map of coal fields of Nova Scotia and New Brunswick. (Accompanying report No. 83—by Dr. J. B. Porter.)

†97. General map showing coal fields in Alberta, Saskatchewan, and Manitoba. (Accompanying report No. 83—by Dr. J. B. Porter).

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†98. General map of coal fields in British Columbia. Accompanying report No. 83—by Dr. J. B. Porter.)

†99. General map of coal field in Yukon Territory. (Accompanying report No. 83—by Dr. J. B. Porter.)

†106. Geological map of Austin Brook iron bearing district, Bathurst township, Gloucester county, N.B.—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†107. Magnetometric survey, vertical intensity: Austin Brook iron bearing district—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†108. Index map showing iron bearing area at Austin Brook—by E. Lindeman. (Accompanying report No. 105.)

*112. Sketch plan showing geology of Point Mamainse, Ont.—by Professor A. C. Lane. Scale 4,000 feet to 1 inch. (Accompanying report No. 111.)

†113. Holland peat bog, Ontario—by A. v. Anrep. (Accompanying report No. 151.)

*119-137. Mica: township maps, Ontario and Quebec—by Hugh S. de Schmid. (Accompanying report No. 118.)

†138. Mica: showing location of principal mines and occurrences in the Quebec mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†139. Mica: showing location of principal mines and occurrences in the Ontario mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†140. Mica: showing distribution of the principal mica occurrences in the Dominion of Canada—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†141. Torbrook iron bearing district, Annapolis county, N.S.—by Howells Fréchette. Scale 400 feet to 1 inch. (Accompanying report No. 110.)

†146. Distribution of iron ore sands of the iron ore deposits on the north shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie. Scale 100 miles to 1 inch. (Accompanying report No. 145.)

†147. Magnetic iron sand deposits in relation to Natashkwan harbour and Great Natashkwan river, Que. (Index Map)—by Geo. C. Mackenzie. Scale 40 chains to 1 inch. (Accompanying report No. 145.)

†148. Natashkwan magnetic iron sand deposits, Saguenay county, Que.—by Geo. C. Mackenzie. Scale 1,000 feet to 1 inch. (Accompanying report No. 145.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†152. Map showing the location of peat bogs investigated in Ontario—by A. v. Anrep.

†153. Map showing the location of peat bog as investigated in Manitoba—by A. v Anrep.

†157. Lac du Bonnet peat bog, Manitoba—by A. v. Anrep.

†158. Transmission peat bog, Manitoba—by A. v. Anrep.

†159. Corduroy peat bog, Manitoba—by A. v. Anrep.

†160. Boggy Creek peat bog, Manitoba—by A. v. Anrep.

†161. Rice Lake peat bog, Manitoba—by A. v. Anrep.

†162. Mud Lake peat bog, Manitoba—by A. v. Anrep.

†163. Litter peat bog, Manitoba—by A. v. Anrep.

†164. Julius peat litter bog, Manitoba—by A. v. Anrep.

*165. Fort Francis peat bog, Ontario—by A. v. Anrep.

(Accompanying report No. 151.)

†166. Magnetometric map of No. 3 mine, lot 7, concessions V and VI, McKim township, Sudbury district, Ont.—by E. Lindeman. (Accompanying Summary report, 1911.)

†168. Map showing pyrites mines and prospects in Eastern Canada, and their relation to the United States market—by A. W. G. Wilson. Scale 125 miles to 1 inch. (Accompanying report No. 167.)

†171. Geological map of Sudbury nickel region, Ont.—by Prof. A. P. Coleman. Scale 1 mile to 1 inch. (Accompanying report No. 170.)

†172. Geological map of Victoria mine—by Prof. A. P. Coleman.

†173 " Crean Hill mine—by Prof. A. P. Coleman

†174. " Creighton mine—by Prof. A. P. Coleman.

(Accompanying report No. 170.)

†175. " showing contact of norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†176. " Copper Cliff offset—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†177. " No. 3 mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†178. " showing vicinity of Stobie and No. 3 mines—by Prof. A. P. Coleman. (Accompanying report No. 170.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†185. Magnetometric survey, vertical intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†185a. Geological map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186. Magnetometric survey, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186a. Geological map, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187. Magnetometric survey, vertical intensity: St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187a. Geological map, St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188. Magnetometric survey, vertical intensity: Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188a. Geological map, Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†189. Magnetometric survey, vertical intensity: Ridge iron ore deposits, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†190. Magnetometric survey, vertical intensity: Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Acccompanying report No. 184.)

†190a. Geological map, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191. Magnetometric survey, vertical intensity: Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191a. Geological map, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†192. Magnetometric survey, vertical intensity: Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†192a. Geological map, Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193. Magnetometric survey, vertical intensity: Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193a. Geological map, Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†194. Magnetometric survey, vertical intensity: Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†204. Index map, magnetite occurrences along the Central Ontario railway—by E. Lindeman, 1911. (Accompanying report No. 184.)

†205. Magnetometric map, Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman, 1911. (Accompanying report No. 303.)

†205a. Geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario, Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman. (Accompanying report No. 303.)

†206. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: northern part of deposit No. 2—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†207. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 8, 9, and 9A—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposit No. 10—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208a. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: eastern portion of Deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208b. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: western portion of deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208c. General geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario—by E. Lindeman, 1912. Scale 800 feet to 1 inch. (Accompanying report No. 303.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†210. Location of copper smelters in Canada—by A. W. G. Wilson. Scale 197·3 miles to 1 inch. (Accompanying report No. 209.)

†215. Province of Alberta: showing properties from which samples of coal were taken for gas producer tests, Fuel Testing Division, Ottawa. (Accompanying Summary report, 1912.)

†220. Mining districts, Yukon. Scale 35 miles to 1 inch—by T. A. MacLean (Accompanying report No. 222.)

†221. Dawson mining district, Yukon. Scale 2 miles to 1 inch—by T. A. MacLean. (Accompanying report No. 222.)

*228. Index map of the Sydney coal fields, Cape Breton, N.S. (Accompanying report No. 227.)

†232. Mineral map of Canada. Scale 100 miles to 1 inch. (Accompanying report No. 230.)

239. Index map of Canada showing gypsum occurrences. (Accompanying report No. 245.)

240. Map showing Lower Carboniferous formation in which gypsum occurs in the Maritime provinces. Scale 100 miles to 1 inch. (Accompanying report No. 245.)

241. Map showing relation of gypsum deposits in Northern Ontario to railway lines. Scale 100 miles to 1 inch. (Accompanying report No. 245.)

242. Map, Grand River gypsum deposits, Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 245.)

243. Plan of Manitoba Gypsum Co.'s properties. (Accompanying report No. 245.)

244. Map showing relation of gypsum deposits in British Columbia to railway lines and market. Scale 35 miles to 1 inch. (Accompanying report No. 245.)

†249. Magnetometric survey, Caldwell and Campbell mines, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†250. Magnetometric survey, Black Bay or Williams mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†251. Magnetometric survey, Bluff Point iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†252. Magnetometric survey, Culhane mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†253. Magnetometric survey, Martel or Wilson iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†261. Magnetometric survey, Northeast Arm iron range, lot 339 E.T.W. Lake Timagami, Nipissing district, Ontario—by E. Nystrom. 1903. Scale 200 feet to 1 inch.

†268. Map of peat bogs investigated in Quebec—by A. v. Anrep, 1912.

†269. Large Tea Field peat bog, Quebec " "

†270. Small Tea Field peat bog, Quebec " "

†271. Lanoraie peat bog, Quebec " "

†272. St. Hyacinthe peat bog, Quebec " "

†273. Rivère du Loup peat bog " "

†274. Cacouna peat bog " "

†275. Le Parc peat bog, Quebec " "

†276. St Denis peat bog, Quebec " "

†277. Rivière Ouelle peat bog, Quebec " "

†278. Moose Mountain peat bog, Quebec " "

†284. Map of northern portion of Alberta, showing position of outcrops of bituminous sand. Scale 12½ miles to 1 inch. (Accompanying report No. 281.)

†293. Map of Dominion of Canada, showing the occurrences of oil, gas, and tar sands. Scale 197 miles to 1 inch. (Accompanying report No. 291.)

†294. Reconnaissance map of part of Albert and Westmorland counties, New Brunswick. Scale 1 mile to 1 inch. (Accompanying report No. 291.)

†295. Sketch plan of Gaspé oil fields, Quebec, showing location of wells. Scale 2 miles to 1 inch. (Accompanying report No. 291.)

†296. Map showing gas and oil fields and pipe-lines in southwestern Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 291.)

†297. Geological map of Alberta, Saskatchewan, and Manitoba. Scale 35 miles to 1 inch. (Accompanying report No. 291.)

†298. Map, geology of the forty-ninth parallel, 0·9864 miles to 1 inch. (Accompanying report No. 291.)

†302. Map showing location of main gas line, Bow Island, Calgary. Scale 12½ miles to 1 inch. (Accompanying report No. 291.)

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2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

†311. Magnetometric map, McPherson mine, Barachois, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

†312. Magnetometric map, iron ore deposits at Upper Glencoe, Inverness county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

†313. Magnetometric map, iron ore deposits at Grand Mira, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

Address all communications to—

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