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SECONDARY RECOVERY OF OIL IN ILLINOIS †

BY

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ABSTRACT

Secondary-recovery methods which have been used in the older Illinois oil fields for some years include vacuum, gas repressuring, and water flooding, and all of these have been tried to some extent in the newer fields discovered since 1936.

Repressuring of Illinois oil sands began in 1922, 17 years after the discovery of the Southeastern Illinois Field. According to an investigation made in 1932, an estimated 3,488 acres or 3.6 per cent of the total area of this field had been affected by repressuring. Since that time, a few new repressuring operations have been begun in Illinois. These include the Colmar-Plymouth pool in McDonough County and the Carlyle pool in Clinton County, of the old fields; and the Louden pool in Fayette County and the Salem Pool in Marion County, of the new fields. Few intentional water-flooding operations have been tried in Illinois; but a number of accidental water floods, particularly in the Robinson sand in Crawford County, seem to indicate that the method has favorable possibilities in some areas. The paper includes a preliminary discussion of the results obtained by repressuring and water flooding up to date, and an appraisal of their prospects for further extension in Illinois.

INTRODUCTION

Illinois operators have made use of vacuum, water flooding, and gas repressuring in the old fields for some years, and each of these methods of secondary recovery is being tried to some extent in the new fields that have been discovered since 1936.

Vacuum was introduced in Clark County in 1910, repressuring with gas and air in Crawford County in 1922, and water flooding in Crawford County in 1924. The use of vacuum has been commercially unsuccessful, but flooding and repressuring have been and should continue to be profitable. The results have not been spectacular, but have been long-lived.

As yet, repressuring has been applied in only a small part of the total productive area. The success of the process in a given pool indicates favorable prospects for its usefulness in other pools that have similar sand conditions. Fig. 1 shows pools in which repressuring has been used. The area affected, and the number of input wells for each pool, are given in Table 1.

The largest area of production in the State for any one "sand" is the 46,000 acres of McClosky which, because of its oolitic composition and great permeability, gives promise of successful operation by gas repressuring. This has been advocated by the Illinois Geological Survey since 1937.

The sequence of rock strata and the relative position of the oil-producing zones in the Illinois Basin are shown in Fig 2.

† Prior to revisions as given herein, this paper, as prepared by Alfred H. Bell and Frederick Squires, was presented at the spring meeting of the American Petroleum Institute, Eastern District, Division of Production, Pittsburgh, Pa., April, 1941.
Reprinted from, "Secondary Recovery of Oil in the United States," Am. Petroleum Inst., New York, pp. 150-160, 1942.

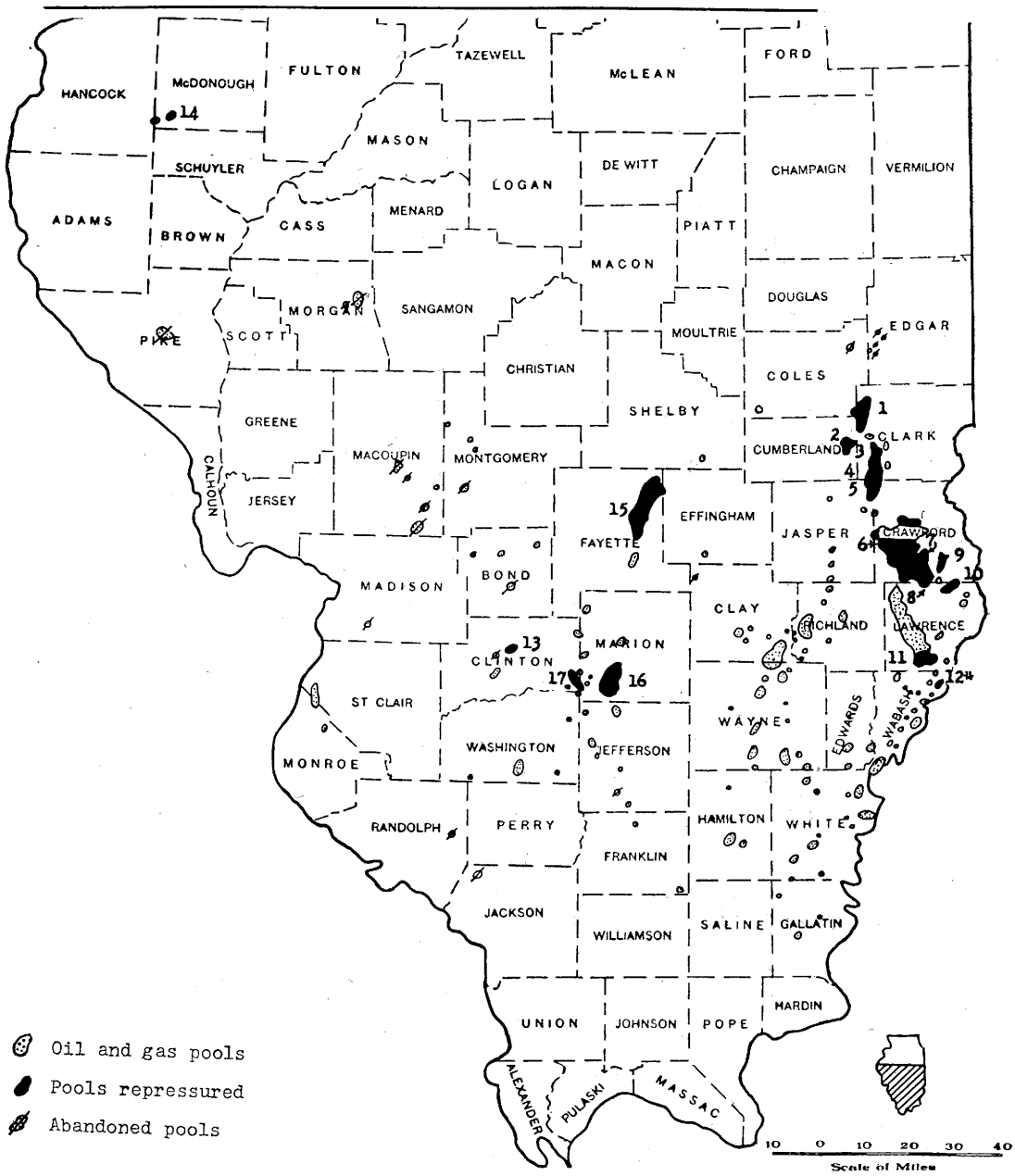

FIG. 1.—Repressuring and artificial water flooding of oil sands in Illinois.

Note: Index map of Illinois oil pools, showing in solid black those pools in which one or more repressuring or water-flooding plants are or have been operated. As explained in the text, the total repressured area is only a small fraction of the total producing area.

	Pool	County
1.	Westfield	Clark
2.	Siggins	Cumberland
3.	Casey	Clark
4.	North Johnson	Clark
5.	Bellair	Crawford, Jasper
6.	*Main	Crawford
7.	New Hebron	Crawford
8.	Chapman	Crawford
9.	Flat Rock	Crawford
10.	Birds	Crawford
11.	Lawrence	Lawrence
12.	*Allendale	Wabash
13.	Carlyle	Clinton
14.	Colmar-Plymouth	McDonough, Hancock
15.	Louden	Fayette
16.	Salem	Marion
17.	Centralia	Clinton, Marion

* Artificial water flooding in addition to repressuring.

January 1, 1941

Illinois State Geological Survey

TABLE 1.—REPRESSURING AND WATER-FLOODING OPERATIONS IN ILLINOIS, BY POOLS.

Map No.[4]	Pool	Operating Company	Number of Input Wells	Acreage Affected[1]
1	Westfield[2]	Dinsmoor Oil Co.	3	70
		Tide Water Associated Oil Co.		
		The Ohio Oil Co.		
2	Siggins	Bell Brothers Oil Co.	5	140
		Dinsmoor Oil Co.		
		The Ohio Oil Co.		
3	Casey	Kewanee Oil and Gas Co.	20	500
		W. C. McBride, Inc.		
		Dinsmoor Oil Co.		
		Ohio Remlik		
4	North Johnson[2]	Remlik Oil Co.	2	35
5	Bellair	The Ohio Oil Co.	3	70
		Remlik Oil Co.		
		Dinsmoor Oil Co.		
6	Main[3]	Dinsmoor Oil Co.	120	3,030
		Tide Water Associated Oil Co.		
		Bell Brothers Oil Co.		
		Brenneman and McDonnell		
		Kewanee Oil and Gas Co.		
		The Ohio Oil Co.		
		Remlik Oil Co.		
		Charles Grace		
		Arkansas Fuel Oil Co.		
		Stranahan and Cheuvront		
		Niagara Oil Co.		
		Mallory and Crawford		
7	New Hebron	Toomey and Bryan	2	50
8	Chapman	Bell Brothers Oil Co.	1	35
9	Flat Rock[3]	Selby Sisler Producing Co.	2	50
10	Birds	Dinsmoor Oil Co.	6	105
		Remlik Oil Co.		
		The Ohio Oil Co.		
11	Lawrence	Bruner	1	20
12	Allendale[3]	Toomey Estate	3	90
		Adams Corners	4	40
13	Carlyle[3, 2]	The Ohio Oil Co.	20	680
			20[7]	100[7]
14	Colmar-Plymouth	The Ohio Oil Co.	9	275
15	Louden	The Carter Oil Co.	63[5]	5,000
16	Centralia	Adams Oil and Gas Co.	4	150
		Gulf Refining Co.		
17	Salem	The Texas Co.	32[6]	1,200
		Total	300	11,540

[1] Estimated.
[2] Abandoned.
[3] Water-flooding operations.
[4] Refers to numbered locations of pools in Fig. 1.
[5] As these input wells inject the gas into more than one sand, they are affecting the producing sands in the pool at points totaling at least twice the number of input wells.
[6] As most of these input wells inject the gas into more than one sand, they are affecting the sands in the pool at a total of 49 points.
[7] Input wells formerly used for water flooding, now used for repressuring, and acreage affected as of Jan. 1, 1941 (not included in totals).

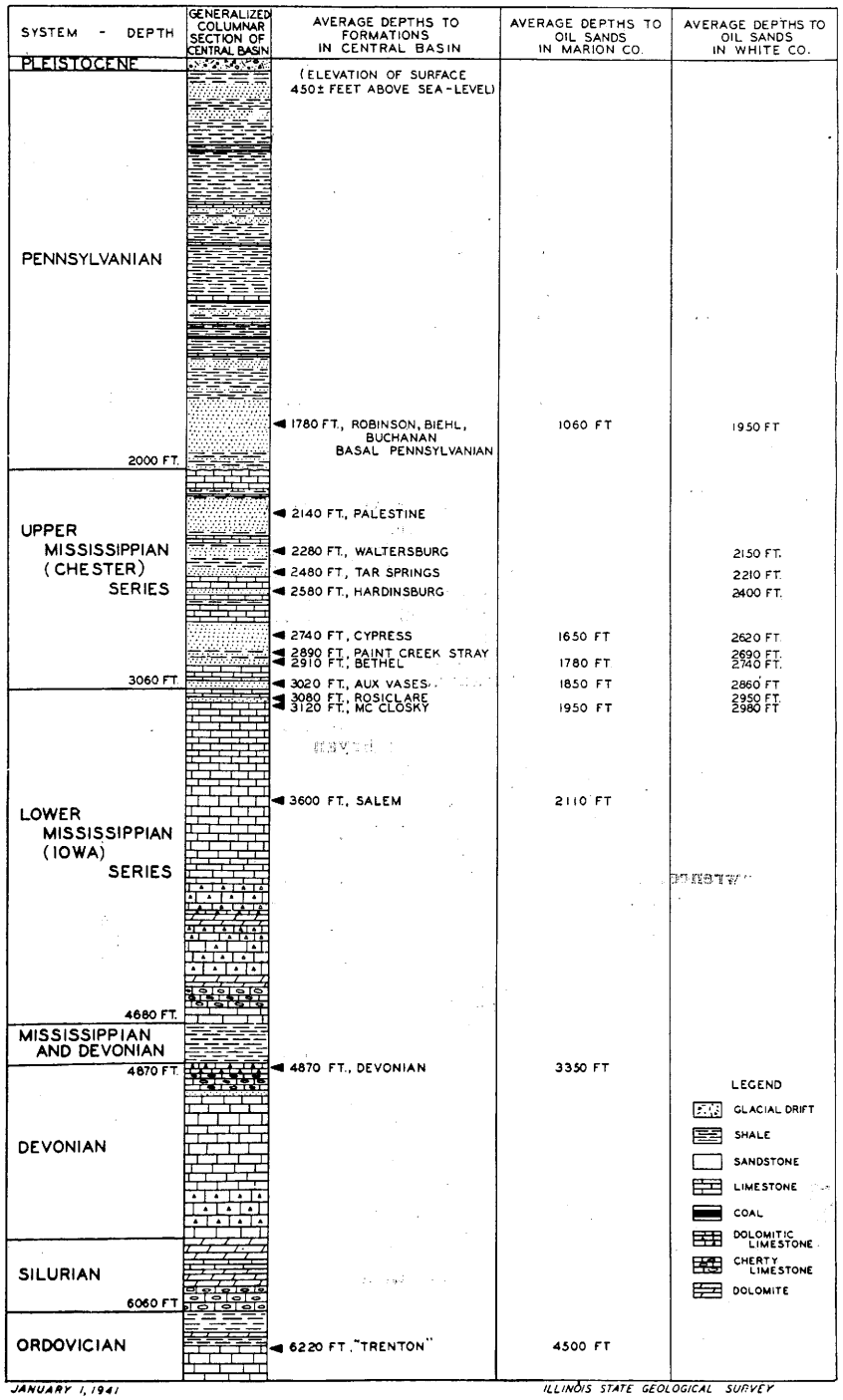

FIG. 2.—Geologic column for Illinois basin, showing the position of oil-producing strata.

Regional Structure‡

All of the oil fields discussed in this article are located in the Eastern Interior Basin, a major area of downwarping which occupies about four-fifths of Illinois and includes adjoining parts of southwestern Indiana and western Kentucky. A majority of the new fields discovered in this region in the past five years are located on structural highs within the Illinois Basin—which is defined as the central deepest part of the Eastern Interior Basin, lying between the DuQuoin-Centralia monocline on the west and the LaSalle anticline on the east, and extending approximately from the latitude of Mattoon on the north to that of Shawneetown on the south.

Description of Producing Sands in Illinois§

PENNSYLVANIAN SYSTEM

Sandstones of Pennsylvanian age have produced more than half the oil in the old Illinois Southeastern Field, which includes parts of Edgar, Coles, Clark, Cumberland, Jasper, Crawford, Lawrence, and Wabash Counties. The area of Pennsylvanian production in the Southeastern Field is approximately 65,000 acres.

Production from Pennsylvanian sandstones was obtained in the Wamac and Junction City Pools, Marion County, and in Macoupin, Morgan, and Montgomery Counties. Oil production was not large, and gas without oil was produced in several areas in Macoupin County.

In the development of the new pools in Illinois since January 1, 1937, production was obtained from small areas in the Mt. Carmel and Griffin Pools in Wabash County, and the Herald Pool in White County. Also, two additional small pools were discovered in Montgomery County.

Pennsylvanian sandstones producing oil in Illinois are composed of angular quartz grains, fine to medium size, cemented with silica. The sandstones are micaceous, carbonaceous, and pyritic in varying amounts. In the cores examined by the survey, the physical character of the sands appears suitable for repressuring purposes; and the mineral content and cementing material, in addition to the quartz grains, are not great enough to be much hindrance in this operation. The lenticular character of the sandstones, however, is one difficulty encountered in repressuring programs. In some operations this condition was so pronounced that little or no results were obtained by repressuring.

In general, the sands will average from 18 to 20 per cent pore space, with permeability varying from 0.0 to 2,430 millidarcys. The average total thickness of the producing sands ranges from 25 ft. to 33 ft., and the depth below the surface in the producing areas varies from 160 ft. in Edgar County to 2,000 ft. in Wabash County. In Crawford County, the largest area of Pennsylvanian production, the average depth of the producing formation is from 900 ft. to 1,000 ft.

CHESTER SERIES

Sandstone formations of the lower Chester series were productive in the Lawrence County Pool and the Bellair Pool in the old Southeastern Field, and in small pools in Bond, Clinton, Marion, Randolph, and Jackson Counties of southwestern Illinois. Natural gas, without oil, was produced in the Ayers and the Greenville Pools in Bond County. The greatest area of Chester sand production in the old pools was in Lawrence County, where the Cypress (Kirkwood) sandstone was productive in an area of 16,000 acres, and where the Bethel (Tracey) sandstone was productive in 4,000 acres. The total area of Chester production in the old fields (prior to January 1, 1937) was approximately 21,000 acres. Production was principally from the Cypress, Bethel, and Aux Vases sandstones.

‡ For further information on this subject consult the following:
Alfred H. Bell, "Natural Gas in the Eastern Interior Coal Basin." *Geology of Natural Gas—A Symposium*, 813-42, Am. Assoc. Petroleum Geol., Tulsa, Okla. (1935).
Alfred H. Bell, "Development in Eastern Interior Basin in 1940." *Bull Am. Assoc. Petroleum Geol.* 25 [6] 1114-24 (1941).

§ For detailed information regarding producing sands in Illinois, see *Trans. Am. Inst. Mining Met. Engrs.* 274-98 (1941).

Chester sandstones have been productive in the new pools in the Illinois Basin —particularly on the west side of the deep basin area in Fayette, Marion, and Jefferson Counties, and on the east side of the deep basin area in Wabash, White, and Gallatin Counties. Production on the west side includes the Cypress, Paint Creek "stray," and Bethel sandstones, whereas on the east side of the deep basin area all of the Chester sandstones are productive in one pool or another. Of the foregoing formations, the Cypress, the Waltersburg, and the Tar Springs sandstones are the most important producing formations. The total area of Chester production in the new pools is approximately 48,000 acres.

Chester sandstones are composed of very fine to fine angular quartz grains, commonly cemented with silica or calcite, or both. The sandstones may be micaceous and occasionally pyritic, and may have numerous shale partings in the upper and lower parts of the formations. The formations are fairly uniform in texture, and for this reason appear suitable for repressuring.

The porosity or pore space of the sandstones is usually 19 or 20 per cent, and the permeability varies from 1 to 1,120 millidarcys. The average thickness of the sands is from 20 ft. to 25 ft.; however, in some areas the thickness may be as much as 30 ft. or 40 ft. The depth to producing Chester sands in the pools varies from 800 ft. in the Ava-Campbell Hill gas pool to 3,300 ft. in the Mill Shoals Pool near the deepest part of the Illinois Basin.

LOWER MISSISSIPPIAN

Oil production from lower Mississippian strata in Illinois has been principally from the "McClosky lime" in the Fredonia member of the Ste. Genevieve limestone. In the old pools, the McClosky lime is productive in an area of 7,000 acres in Lawrence County and in a small area north of Oblong in Crawford County. In the new pools, the McClosky lime is the principal producing formation in the central-basin fields in Jasper, Clay, Richland, Wayne, Edwards, and northwestern White Counties. It is also productive in the Salem and Tonti Pools in Marion County, and in certain pools in Jefferson, Franklin, and Hamilton Counties. The total area of McClosky production in the new pools is approximately 40,000 acres.

The "McClosky lime" refers to any porous zone in the Fredonia limestone which contains either oil or water, or both. The porous zone usually consists of spherical grains of calcium carbonate, called oolites, which are cemented together with calcite. Porous zones in dolomite and dolomitic limestones are also present in the Fredonia limestone, but production is principally from the oolitic zone.

The pore space in the McClosky lime varies from 5 to 26 per cent, and the permeability ranges from 0.0 to 3,630 millidarcys. Although porosity and permeability of the McClosky are more variable than in some of the upper producing formations, the McClosky lime is sufficiently uniform in certain areas to warrant repressuring. The producing zone usually averages 10 ft. in thickness. The depth to the McClosky lime ranges from 1,340 ft. in Crawford and 1,700 ft. in Lawrence County to 3,420 ft. in the deep basin area.

ST. LOUIS-SALEM LIMESTONES

Production from the St. Louis and Salem formations has been obtained in Westfield and Martinsville Pools, Clark County; Salem Pool, Marion County; Ina Pool, Jefferson County; Whittington Pool, Franklin County; and Jacksonville gas pool, Morgan County. The largest area of production from these formations is in the Westfield Pool, where 9,000 acres were productive during early development of the pool. The other pools had small areas of production, and the Jacksonville gas pool is now abandoned.

Production from these formations is from porous zones in the crystalline dolomitized limestone and dolomitized oolitic zones. Porosity and permeability determinations of these formations are not available, and it is difficult to predict what results would be obtained in repressuring the producing zones. Only a very small portion of the oil produced in Illi-

nois to date has been from these formations, and the wells have small initial productions except when crevice conditions are encountered. Small oil production tends to make these formations less attractive for repressuring purposes. The thickness of the producing zone varies from 5 ft. to 20 ft. The depth to the top of the producing zone in St. Louis-Salem limestone in the Westfield Pool is 330 ft., and in the Whittington Pool, which is the deepest St. Louis limestone production to date in Illinois, the depth to the top of the producing zone is 3,060 ft.

DEVONIAN LIMESTONE

The Devonian limestone now is producing in 8 pools in Illinois with a total area of 8,500 acres. The Salem Pool, with 5,000 acres of Devonian production, and the Centralia Pool with 2,000 acres are by far the most productive areas of Devonian production in the State. During 1940 the estimated crude-oil production from this formation in these two pools was 36,000,000 bbl. Devonian production is obtained also from the Sandoval and Tonti Pools, Marion County; Bartelso Pool, Clinton County; Irvington Pool, Washington County; Sorento Pool, Bond County; and the Martinsville Pool, Clark County. The Martinsville Pool is the only one which had Devonian limestone production prior to the recent development in Illinois, which began in January, 1937.

The producing zone consists of fine-grained porous dolomite, which contains solution cavities and becomes sandy near the base. The pore space in a Devonian limestone core that was analyzed by the Survey varied from 14 to 22 per cent, and permeability ranged from 2 to 66 millidarcys. The average thickness of the pay is 9 ft., but in the Salem Pool it is 30 ft. The average depth to the top of the Devonian limestone in the Salem Pool is 3,340 ft., and in the Centralia Pool it is 2,860 ft.

From the available data regarding the physical character of the producing formation, the advisability of repressuring this formation is doubtful.

HOING SAND

A sandstone of Devonian age at the base of upper Devonian strata and overlying Maquoketa shale is productive in the Colmar-Plymouth Pool in McDonough and Hancock Counties. To the end of 1940 the pool had produced a total of 2,673,000 bbl. of oil. The sandstone averages 21 ft. in thickness, and is productive over an area of 2,450 acres. The sandstone is composed of fine rounded to angular quartz grains cemented with dolomite and silica. The pore space in the sandstone averages from 19 to 20 per cent, and the permeability ranges from 1 to 2,530 millidarcys. Repressuring in this pool has been carried on for several years, and favorable results have been obtained.

TRENTON LIMESTONE

The Trenton limestone is productive in the Westfield Pool, Clark County; Salem Pool, Marion County; Centralia Pool, Clinton County; Dupo Pool, St. Clair County; and Waterloo Pool, Monroe County. The total area of Trenton limestone production in Illinois is 2,000 acres. The Salem Pool to date has an area of 900 acres of Trenton production, which is the largest area of production from this formation in the State. The total oil produced from the Trenton is a very small amount of the State's total production. The Dupo Pool, having an area of 670 acres and producing solely from the Trenton, had produced a total of 1,275,000 bbl. of oil to January 1, 1941. Initial production of Trenton wells is small as compared to that from other formations producing in Illinois, but the decline in production from Trenton wells is not nearly so rapid as it is in the Devonian limestone.

Production in the Trenton is from porous zones in the crystalline Kimmswick limestones. Core studies of the producing zone show the porosity to vary from 2.6 to 19.0 per cent, with an average of 14 per cent; and permeability ranges from 0 to 61 millidarcys, with an average of 7.7 millidarcys. The producing zone is from 50 ft. to 75 ft. thick. The depth to the top of the Trenton in the Dupo Pool in St. Clair County is 500 ft.;

and in the Salem Pool, which is the deepest Trenton production in the State, it is 4,500 ft. In consideration of the variable and low permeability and porosity of the formation, it is doubtful if satisfactory results could be obtained by repressuring the Trenton.

OCCURRENCE OF OIL, GAS, AND WATER IN THE SANDS

A considerable amount of gas is produced with the oil from the Chester sands, McClosky lime, and Devonian limestone in the new pools of Illinois. Wells producing only gas were drilled in the Storms Pool in White County; some of these wells later produced oil. The producing formation in this pool is the Waltersburg sandstone of the Chester series. A gas cap occurs in those Chester sands which are producing in the Louden Pool. Natural gas without oil is produced from one well in a lower Pennsylvanian sandstone in the field, and gas has been noted in the Palestine sandstone. Available data on hand indicate an absence of gas caps in most of the new pools, and that the gas is in solution with the oil. In the old Southeastern Field, and in other old pools in the State also, records indicate that the gas was in solution in the oil. Many sands of Pennsylvanian and Chester age in the old pools produced considerable amounts of gas and little or no oil.

Water is produced with the oil in most of the old pools, and its presence is noted in wells near the limits of production in many of the new pools. Typical water encroachment has been noted in the Devonian limestone in the Centralia and Sandoval Pools. In the old Southeastern Field, water encroachment has occurred in the South Johnson Pool, Clark County; Bellair Pool, Flat Rock, Birds, and Parker Pools, Crawford County; and in several areas in the Lawrence County Pool. Other outstanding examples of water encroachment are in the Bethel (Benoist) sandstone in the Sandoval Pool, which has produced oil for 32 years, and in the Trenton limestone in the Dupo Pool. The Dupo Pool was discovered in 1928, and the encroachment of water caused the early abandonment of many wells. Centrifugal pumps were installed recently on some wells and, by handling large quantities of water, the amount of oil production was increased greatly. One well equipped with a centrifugal pump had an initial production of 25 bbl. of oil and 6,000 bbl. of water.

ANALYSES OF CRUDE OIL

Most of the crude oil now produced in Illinois has an API gravity between 35 and 40 deg., and averages about 38 deg. Oil in the old fields of Illinois had an average gravity of approximately 33 deg. API. The viscosity of most crude oils in the new fields falls in the range from 40 sec. to 45 sec. (Saybolt Universal at 100 deg. F), and averages approximately 42 sec. No data are available to indicate what difference, if any, exists in the character of crude oil produced from the same wells before and after repressuring operations. However, some oxidation takes place when the repressuring medium is air; this is indicated by the presence of substantial quantities of carbon dioxide in the recovered gases for numerous properties in Crawford County, Illinois.

For information on the chemical character of Illinois crude oils, the reader is referred to *Illinois Geological Survey Bull. 54*, Table 3, opposite p. 22; and *Bur. Mines Rept. Investigation No. 3532: "Analyses of Some Illinois Crude Oils."*

VACUUM

The first use of vacuum in oil wells in the State was made by Harry Werts on the J. H. English farm, Sect. 2, Johnson Township, Clark County, in 1910. This application not only was the first, but probably one of the most successful; and it resulted in a widespread use that on the whole has been a detriment rather than an advantage to its users.

When the owner of one producing farm in a pool applies vacuum, everyone else follows suit because of the fear of loss of gas and oil from his property to the vacuum user unless he protects himself by a similar use. The result is the spread of the process over a few farms

to which it is suitable and many to which it is not. Furthermore, vacuum must be operated continuously during the whole life of the lease, a very expensive process and one, in Illinois at least, which is seldom justified by returns.

When the gas from the vacuum process is compressed in a gasoline plant, the gasoline yield is greater because the lowering of pressure on the crude enriches the gas, and in this way alone does the use of the gas pump justify itself commercially.

At present a majority of farms in the old fields are under vacuum and will probably remain so to the end. The use of vacuum in the new fields is practically negligible.

In the authors' opinion, the use of vacuum in the new fields would not be advisable.

Source of Gas Supply

In the old fields the gas supply comes from oil wells and is hardly more than enough to provide fuel for the pumping engines. One by one the gasoline plants which operated on the excess casinghead gas have been abandoned, until very few remain. For repressuring purposes in such areas, gas must be supplemented by air, or air must be used exclusively. In this connection safety devices should be provided to eliminate the risk of explosions from compressing and igniting explosive mixtures.

It is interesting to note that the Tide Water No. 3 plant has been injecting air into the Robinson sand for 15 years, and is still able to rely for fuel on the air-gas mixture emerging from the pumping wells.

The heavier hydrocarbons, butane and pentane, have not been used as a repressuring medium, and their high market value eliminates them from consideration. In the new fields of Louden and Salem, repressuring is tied up with absorption gasoline extraction, part of the tail gases from the plants being returned to the sands. It is unfortunately true that only a small proportion of the total throughput of gas is so used, the greater volume being used for power on the producing properties or burned outside the plants in flares.

The most urgent need of the new fields is a more complete use of the gas produced with the oil as a repressuring medium. It is true that great investments in compressing machinery would be required to return all the available gas to the less permeable oil sands, but large volumes that are now destroyed could be stored in any one of the more permeable sands, and this could be done at less expense.

Air and Gas Repressuring

The first successful repressuring operation in Illinois was carried out on the Mumford farm, Sect. 26, T.10N, R.14W, Clark County, in 1921. Between 1921 and 1932 the practice was considerably extended, especially in Clark and Crawford Counties.

A systematic investigation of repressuring Illinois oil sands was undertaken in 1932, and the results were published in *Illinois Petroleum No. 23.** Since that time, additional acreage has been repressured with results which are in line with the average results found by the Survey.

In 1932 repressuring had been tried in the Southeastern oil field on 107 leases, 77 of which yielded increased recovery for 1 year or more. The repressured leases had a total area of 11,049 acres by complete farms, of which 3,488 acres had been affected by repressuring.

Out of the 3,488 acres, increases in production for 1 year or more were obtained on 2,548 acres or 73 per cent. The total number of input wells was 126, of which 93 were on leases which showed increased production. Out of 613 pumping wells, 458 or 75 per cent showed increased production.

The daily average production of the 458 wells, which was 0.73 bbl. before repressuring, was increased to 1.21 bbl. for an average period of 5½ years, or an increase of 66 per cent. These wells have produced 1,111,392 bbl. of oil as

* Alfred H. Bell, and Frederick Squires, Preliminary summary of results obtained from a survey of repressuring operations in the southeastern Illinois oil field, *Illinois Geol. Survey, Illinois Petroleum No. 23* (1932).

against a production of 668,440 bbl., which would have been the total production for a similar period of time at the rate before repressuring was applied, so that the difference of 442,952 bbl. may be credited to the process.

The greatest percentage of increase in oil production due to repressuring was obtained in the Robinson sand in Crawford County. Numerous leases have been repressured for periods as long as 8 to 10 years, and the average rate of production during this long period has been held above the rate previous to repressuring. The average volume of air or gas used per barrel of increased production from this sand was 8,000 cu. ft.

Success in the Robinson sand augurs well for extension of repressuring to the very similar Bridgeport sand in Lawrence County, which covers 6,000 acres and has not been tested as yet.

One repressured lease producing from the Biehl sand in the Allendale Field, Wabash County, gave 57 per cent increased recovery for a 3-year period. Other plants installed on this sand since also have been successful. The average volume of air or gas required per barrel of increased oil production has been low, as have been the pressures required.

For the Casey sand in Clark County the oil recoveries have been less, and the volumes of air or gas required have been nearly double the Robinson sand figures.

McClosky Possibilities

Most attempts to repressure limestone oil pays have been unsuccessful. However, it is believed that the McClosky is an exception and would show favorable results. It produces from oolitic zones which, although composed almost entirely of calcium carbonate, are very like sandstones in texture, as shown by the microphotograph (Fig. 3). Investigations of McClosky water floods demonstrate that, unlike many limestones, the McClosky is continuously permeable over long distances, e.g., for more than two miles in Dennison Township in Lawrence County. Production covers 9,000 acres in the old fields. The 37,000 acres of McClosky production in the new fields are drilled, in general, with the wide spacing of 1 well to 20 acres. The reservoir pressure has diminished greatly and, accordingly, if the remaining oil is to be recovered, secondary-recovery methods must be used.

The McClosky is the most permeable of any Illinois oil reservoir rock for which core analyses have been made, running on an average of over 500 millidarcys; and this is favorable for repressuring. The McClosky is being repressured successfully on one lease in the old field, and the process is being applied to one pool in the new fields.

Repressuring of Sandstone Pays

Tests on the Kirkwood sand in Lawrence County and the Carlyle sand at Carlyle in Clinton County have not been encouraging, probably because the equipment was not adequate in either case. The Kirkwood has been, relative to other sands in the old fields, extensive, uniform, and rich, and deserves thorough tests—especially because in Lawrence County it covers 11,000 acres.

A well-conducted repressuring operation covering 750 acres was begun in October, 1926 by the Tide Water Oil Company on a solid block of leases in Sect. 9, 10, 11, and 16, Robinson Township, and Sect. 2 and 3, Hutsonville Township, Crawford County.

The producing sand is the Robinson, to which 162 wells were drilled, of which 18 were converted into input wells. The compressing plant consists of 2 two-stage compressors, each direct-driven by a 190-h.p. engine. Cooling water is raised by automatic air pumps to an elevated storage tank, from which it passes through the cooling jackets by gravity. Air only is compressed, being air-cooled at both stages by passing it through headers of 1-in. pipe. Gas is collected at all pumping wells and returned to the plant and pumping powers for fuel.

The plant has been in continuous operation for 15 years and is still run at a profit. For the first 5 years volumes varied from the high point of about 1,000,000 cu. ft. per day to an average of 475,000. Oil production increased

from 400 bbl. per week before repressuring to a high of nearly 1,000, and an average of more than 800 bbl. per week for the 5 years. The production after 15 years is still above the figure before the plant was installed.

The operation has developed some emulsification of oil—a condition requiring treatment—and a considerable formation of carbon dioxide, which has diluted the gas to such an extent that a few of the offending wells have had to be taken off the gas line.

Studies of the volumes of air forced into each input well and the amount emerging from pumping wells demonstrated that the sand, although continuous, is sharply divided into three permeable areas separated by almost impermeable bands.

An interesting production method employed on this tract consisted in recompleting abandoned wells by drilling with compressed-air jets.

The territory was originally of light production, and the history of the operation shows that proper engineering has had much to do with the success of the repressuring project.

New Fields

In the new fields, repressuring is operating at Louden, Centralia, and Salem.

The Carter Oil Company is operating a carefully engineered plant in the

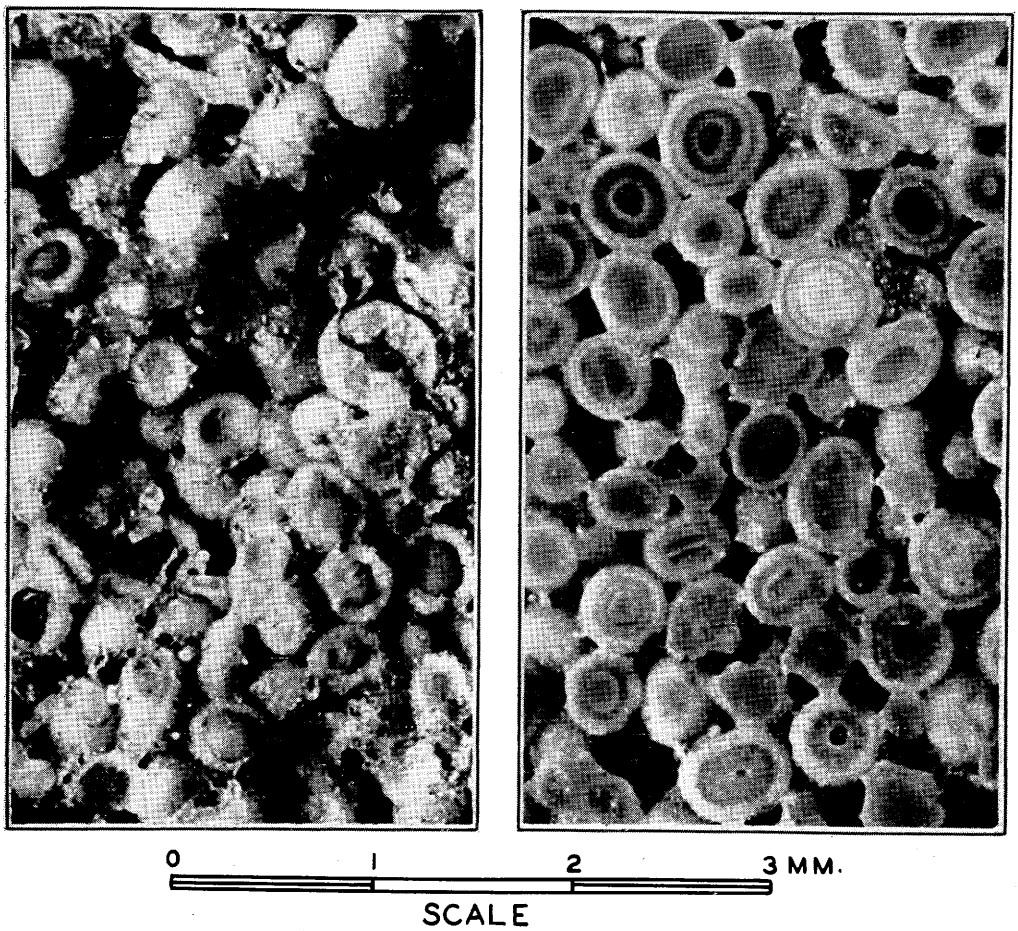

Fig. 3.—Ste. Genevieve limestone (McClosky "Sand"), W. SW., NE., sec. 8, T.3N. R.9E, Noble Field, Richland County, Illinois (Left, Broken Surface; Right, Smooth Surface, Acid-rinsed).

Louden Pool. The pattern is the sunflower, with the input well in the center of an octagon repeating unit with 1 pumping well for each 20 acres.

At present there are 63 input wells dividing 2,250,000 cu. ft. of input gas at an average of about 35,000 cu. ft. per day, each under a line pressure of 700 psi and a sand pressure varying to best develop each sand. The plant consists of four 300-h.p. Cooper Bessemer engines directly connected to four 3-stage compressors. The moving parts are protected by ingenious automatic safety devices. The amount of input gas is but a small fraction of the total amount currently produced with the oil and, accordingly, supplies are adequate for considerable expansion of repressuring operations.

Gasoline is made from the gas by pressure and absorption, and the tail gases are dried at the plant before being returned to the field. The cooling water is automatically pumped from the river and purified before use.

Electric power is generated at the plant and used for pumping all wells. The operation more properly may be referred to as pressure maintenance, rather than repressuring, and the results in production are satisfactory to the owners.

All sands—the Cypress, Paint Creek, and Bethel—are affected by the 63 input wells. Only a small part of the total area of production is at present covered by the operation which, no doubt, will be extended in the future.

At Centralia, the Gulf Refining Company is introducing gas from Devonian wells into the Benoist sand through three input wells on its Buehler lease. About 25,000 cu. ft. per day per well is entering the Benoist at an average pressure of 75 psi. The owners report an increase in gas from the Benoist wells and some increase in oil production. The operation started in July, 1940, the last input well having been put in operation during October of the same year.

The Adams Oil and Gas Company is introducing gas through one well on its Copple lease, with a volume of 60,000 cu. ft. entering under 280 psi pressure.

At Salem, The Texas Company is returning 2,500,000 cu. ft. of gas per day to the Benoist, Aux Vases, and McClosky, at varying pressures on the sands, through the 32 wells contacting the Benoist sand at 26 points, the Aux Vases at 15 points, and the McClosky at 4 points. The average input of gas is something more than 50,000 cu. ft. per well per day.

It is interesting that here, for the first time in the new fields, gas is being circulated through the McClosky. This limestone, because of its oolitic character and high permeability, seems to present great opportunities for increased recovery.

The following Illinois oil-producing sands have been repressured:

System or Formation	Producing Strata	Pool	County
McLeansboro group	Upper Siggins gas	Siggins	Cumberland, Clark
Carbondale group	Bellair 500	Bellair	Crawford, Jasper
	Casey	Casey	Clark
	Claypool	North Johnson	Clark
	Lower Siggins	Siggins	Cumberland, Clark
	Upper Partlow	South Johnson	Clark
Tradewater-Caseyville group	Biehl and Jordan	Allendale	Wabash
	Robinson	Main and others	Crawford
	Petro	Wamac	Marion
Cypress sandstone	Carlyle	Carlyle	Clinton
	Kirkwood	Lawrence	Lawrence
	Cypress	Louden	Fayette
Paint Creek sandstone	"Stray"	Louden	Fayete, Effingham
Bethel sandstone	Benoist	Centralia	Clinton, Marion
	Benoist	Louden	Fayette
	Benoist	Salem	Marion
Aux Vases sandstone	Aux Vases	Salem	Marion
Fredonia limestone	McClosky "lime"	Lawrence	Lawrence
	McClosky "lime"	Salem	Marion
St. Louis-Salem limestone	Westfield limestone.	Westfield	Clark
Devonian sandstone	Hoing	Colmar-Plymouth	Hancock, McDonough

Water Supplies for Flooding

A large portion of the Illinois fields is situated favorably with respect to an adequate supply of fresh water for flooding. The Wabash River parallels the old fields and part of the new fields, and the areas in these fields containing the oil-bearing sands that offer the best opportunity for success are near the stream. Many of the pools are in a territory of extensive gravel deposits which offer an almost unlimited water supply already partly filtered by the gravel itself.

Water, for use in gasoline plants and for other operating purposes, has been piped to Louden and Salem from the Kaskaskia River, distances of 5 and 14 miles, respectively. This pipe-line capacity could readily be enlarged to handle flooding requirements. The same river could supply the Patoka Field, six miles away. Carlyle readily found in Beaver Creek a supply adequate for flooding. Little Wabash River and its tributary creeks probably would be adequate for the Cisne, Clay City, Noble, and the nearby group of pools.

Water-bearing sands above the producing sands are found in almost all fields. In the old wells, these sands have accounted for a great many accidental floods through holes in casing. The success of such floods would argue that salt water is a possible flooding medium wherever there is enough of it.

In the new fields, the practice of returning salt water from the Devonian and other water-bearing oil sands to some upper permeable sand will probably present for solution the problem as to what kind of water treatment will be necessary to avoid plugging intake wells. Any successful practice for this purpose, it is believed, would apply to the use of this salt water for flooding oil-bearing sands.

The kind of treatment that would be required for water from the fresh-water sources mentioned above is not known. At Louden and Salem the river water is filtered and softened to avoid deposits in the cooling apparatus. Filtering and chemical treatment may be needed for flood water, although at Carlyle the flood water was filtered only and no chemical treatment was used, yet no sand-plugging difficulties were encountered.

Water Flooding

Interest in water flooding of Illinois sands was aroused by observation of the results of natural and accidental floods at many places and in many different sands, and by the unusually large returns from those pools which produced oil accompanied by large volumes of water.

It has been found that accidental floods produced more than 400,000 bbl. of oil up to 1936, and edgewater encroachment in such formations as the McClosky has produced very much larger amounts.

A practical application of the lesson has been made on the Biehl sand at Allendale, where intentional flooding has been practiced on five properties with considerable success. One firm is still producing many times its previous amount of oil after six years of flooding.

The Allendale Field was discovered in 1912, and now has about 200 wells producing from the Biehl sand. The wells came in with an average initial production of 70 bbl., and now are producing approximately 2 bbl. daily. The sand averages 29 ft. in thickness.

In several instances water has broken through the pipe which shuts off the upper water-bearing sand, permitting a column 1,200 ft. high to stand on and feed through the oil sand. Such accidents have resulted in flood production of 58,000 bbl. of oil from 9 flooded wells. Operators have taken advantage of these results to institute purposeful floods in this pool, which have been very successful.

Conclusion

From the facts presented herein it appears that secondary recovery of oil in Illinois has not yet been applied on an extensive scale in comparison with the total oil-producing area.

Because of the preoccupation of most operators in the area with the discovery and development of new fields during

the past five years, the adoption of secondary-recovery methods has been retarded, except in the case of the pressure-maintenance projects described above. The outlook for the future is for a considerable extension of secondary-recovery methods in the oil fields of Illinois.

ILLINOIS STATE GEOLOGICAL SURVEY

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