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UNITED STATES
DEPARTMENT OF THE INTERIOR
Harold L. Ickes, Secretary

BUREAU OF MINES
R. R. Sayers, Director

REPORT OF INVESTIGATIONS

AIR AND GAS INJECTION IN THE OIL FIELDS OF ILLINOIS

BY

C. M. Keithly and Thomas Jennings

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By C. M. Keithly[2] and Thomas Jennings[3]

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1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Rept. of Investigations 3783."

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INTRODUCTION

This report is one of a series[4,5,6] concerned with presenting historical, development, and operating data on secondary-recovery projects in various States to stimulate interest in sound secondary-recovery programs. Preceding reports in this series have dealt exclusively with descriptions of and results obtained by water flooding in three States, but no recent publication of comparable purpose describes gas-injection[7] practices. The authors intend to present material relevant to the development and operation of gas-injection projects in Illinois, with particular emphasis on those producing from oil-bearing horizons that had been depleted to a point near the economic limit of operation by past oil-recovery methods.

Most operators realize that the energy expended on the movement of fluids through gas-expansion- or gas-cap-type oil reservoirs to producing wells must be supplemented to attain maximum recovery of the oil present. Under favorable conditions, many operators choose to maintain oil-propulsive forces at or near their original magnitude by injecting extraneous fluids into a reservoir or recycling produced fluids early in the life of a field. More common, and less desirable, is the practice of replenishing these forces after primary producing methods become unprofitable. The latter practice has been adopted in many stripper fields in Illinois and most of the oil-producing States during the last 40 years, but other old oil fields, and oil properties within those fields which were partly exploited by secondary-recovery methods, also may offer favorable opportunity for further development. To encourage and aid operators in the development of gas-injection projects in the old oil fields of the United States, four projects have been described in detail in this report.

ACKNOWLEDGMENTS

This report was prepared under the general supervision of R. A. Cattell, chief engineer, Petroleum and Natural Gas Division, Bureau of Mines, Washington, D. C., and N. A. C. Smith, supervising engineer, Petroleum Experiment Station, Bureau of Mines, Bartlesville, Okla., and under the direct supervision of Ludwig Schmidt, senior petroleum engineer, Bureau of Mines, Bartlesville, Okla., and C. J. Wilhelm, supervising engineer, Bureau of Mines, Franklin, Pa.

4/ Taliaferro, D. B., and Logan, David, History of Water Flooding of Oil Sands in Oklahoma: Bureau of Mines Rept. of Investigations 3728, 1943, 182 pp.

5/ Grandone, Peter, History of Water Flooding of Oil Sands in Kansas: Bureau of Mines Rept. of Investigations 3761, 1944, 146 pp.

6/ Taliaferro, D. B., Keithly, C. M., and Jennings, Thos., Water Flooding of Oil Sands in Illinois: Bureau of Mines Rept. of Investigations 3778, 1944, 23 pp.

7/ The term "gas injection" is used connotatively throughout this report unless emphasis is to be placed on the type of medium injected.

The authors are greatly indebted to the companies and individuals conducting gas-injection operations in the State of Illinois for their active cooperation in supplying information on which this report is based. Special recognition for helpful information and assistance is due to Ivan G. Burrell and Millard H. Flood, The Ohio Oil Co., Marshall, Ill., and to R. A. Wilson, Tide Water Associated Oil Co., Mount Carmel, Ill.

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J. R. Eaves and W. O. Smith of the Bureau of Mines, Bartlesville, Okla., assisted materially in compiling and preparing most of the data presented.

HISTORY OF GAS INJECTION

Records indicate that the injection of a gaseous medium into an oil reservoir to stimulate the oil-recovery rate first occurred in 1903 in the Macksburg field near Marietta, Ohio. I. L. Dunn introduced gas through a well completed in the Macksburg 500-foot sand for a 10-day period at a pressure of 45 pounds per square inch. When the gas was released from the sand the well pumped much oil. The method was demonstrated commercially by Dunn in 1911 on the Wood farm near Chesterhill, Ohio, where air was injected trhough a well (completed in the First Cow-Run sand) at a rate of 150,000 cubic feet per day and at a pressure of 40 pounds per square inch. Within a week the oil-producing rate of surrounding wells had increased. The use of compressed air as an injection medium was extended to other parts of the property, almost doubling the oil-producing rate 2-1/2 years after the air drive was begun. The air- and gas-drive method developed by I. L. Dunn and two associates, O. C. Dunn and H. E. Smith, sometimes is referred to as the "Smith-Dunn" or "Marietta" process.

The initial success of the gas-injection process on the Wood farm led to its use in other oil fields in Ohio and West Virginia. Lewis[8] reported that by 1917 approximately 4,000 oil wells had been affected by the injection of air and gas. The method was extended to Pennsylvania, Illinois, and the Mid-Continent area during the years immediately following the First World War.

8/ Lewis, J. O., Methods for Measuring the Recovery from Oil Sands: Bureau of Mines Bull. 148, 1917, 128 pp.

Gas injection originated in Illinois in 1921, when the Dinsmoor Oil Co. introduced gas through a well on the Mumford farm in the Casey field, Clark County. The project, still in operation, produces from the Casey sand, which occurs at an average depth of 450 feet. On August 1, 1943, the project included 2 injection and 13 oil wells located on 40 acres and produced oil at a greater rate than in 1920, the year preceding initial injection of gas.

Most properties in the old oil fields of southeastern Illinois produced from sands that were subjected to vacuum when the gas-injection process was first introduced in the State, and operators were reluctant to use a method that might drive oil from their properties to adjacent, vacuum-operated properties. Therefore the gas-injection process was exploited cautiously, usually by combining it with vacuum operations. The Illinois State Geological Survey reported[9] that by 1932 gas-injection operations in the State had affected 613 wells, of which 458 produced oil at an increased rate. Since that date secondary-recovery methods involving the injection of gas into oil reservoirs have been adopted in some of the newer, as well as older, oil fields.

AIR-AND GAS-INJECTION PROJECTS IN ILLINOIS

Location of Gas-Injection Projects

Few systematic gas-injection projects have been developed in Illinois other than those in fields discovered within the last 10 years. A majority of these projects are in fields discovered near the turn of the century in the south-eastern part of the State, and only four have been operated long enough to prove their effectiveness in recovering additional oil. The Robinson field, Crawford County, offers the most favorable opportunities for profitable development of gas injection of any of the old oil fields, and several well-organized projects have been started in this field within the last 2 years. A map of Crawford County showing the productive area of the Robinson sand and the location of all gas-injection projects in the Robinson field on July 31, 1943 is shown in figure 1.

Shallower oil sands north of the Robinson field, in the Johnson, Casey, and Siggins fields of Clark and Cumberland Counties, also have been subjected to gas injection; but results are not encouraging because of their low oil saturation and variable permeability. In deeper oil sands south of the Robinson field, in Lawrence, Wabash, and White Counties, gas injection has been successful. Except for the Bridgeport field, however, the old oil fields in this area are small and offer limited opportunity for development. Two of the largest gas-injection projects in operation in the old oil fields are in the Colmar and Plymouth fields, Hancock and McDonough Counties, in the west-central part of the State.

9/ Bell, A. H., and Squires, Frederick, Preliminary Summary of Results Obtained from a Survey of Repressuring Operations in the Southeastern Illinois Oil Field: Illinois Petroleum No. 23, Press Bulletin Series, Illinois State Geol. Survey, Sept. 24, 1932, 22 pp.

In addition to gas injection in the stripper oil fields of Illinois, extensively developed projects are located in some of the oil fields discovered since 1937. The largest project is that of the Carter Oil Co. in the Louden field, Fayette County; two others of comparable size are the Salem project of The Texas Co. in Marion County and the New Harmony project jointly operated by Superior Oil Co., Tide Water Associated Oil Co., and Sun Oil Co. The joint project included most of the New Harmony oil field, in White County, Ill., and Posey County, Ind. A smaller project includes parts of the Hoodville and Walpole oil fields in Hamilton County, where residue gas and some of the liquid products from a gasoline-extraction plant are injected into two sandstones.

Features of Reservoirs Being Exploited

Gas is being injected into oil sands occurring at depths ranging from 400 feet in the Siggins field to 3,075 feet in the Walpole field. The sands are of Pennsylvanian, Mississippian, and Devonian age; most old oil fields in southeastern Illinois produce from Pennyslvanian and Upper Mississippian formations. The important newer fields in which gas-injection operations are active produce oil from sands of Mississippian age. Gas is injected into three oil sands in the Louden field, two sands in the Salem field, and seven sands in the New Harmony field.

The porosity of most oil-producing sandstones in Illinois ranges from 17 to 20 percent and averages 18 percent.[10] Measurements of the permeability of the sandstones range from 0 to 2,530 millidarcys, averaging over 100 millidarcys. The high average permeability characteristic of many of the oil sands permits the use of low injection pressures.

The oil-producing formation of greatest areal extent in the older oil fields of the State is the Robinson sand of Pennsylvanian age. Most wells in the Robinson field were drilled before the value of information concerning the characteristics of an oil sand was appreciated, and few core analyses of the sand are available. Results of a few analyses indicate that the porosity of the Robinson sand ranges from 17 to 19 percent and its permeability is as high as 2 darcys, averaging about 125 millidarcys. Oil- and-water-saturation values fluctuate so widely that no general statement regarding them can be made. Blatchley[11] has described the Robinson sand as follows:

> The Crawford County pools are distinctive for possessing one general oil-producing zone known as the Robinson sand. This sand is so broken and lenticular that it offers little opportunity for structural study. In fact the sand shows innumerable streaks, tongues and detached portions and so prohibits correlation and contouring. In some portions of the field, however, the sand is regular in its distribution.

10/ Bell, Alfred H., Squires, Frederick, and Cohee, George V., Secondary Recovery of Oil in Illinois: Illinois Petroleum No. 43, Press Bulletin Series, Illinois State Geol. Survey, Jan. 20, 1943, 14 pp.

11/ Blatchley, Raymond S., Oil in Crawford and Lawrence Counties; Illinois State Geol. Survey Bull. 22, 1913, pp. 97, 98, and 99.

AIR-GAS-INJECTION OPERATIONS, CRAWFORD COUNTY, ILL.

Shown in Figure 1

REFERENCE MAP NO.	COMPANY	LEASE OR PROJECT	REFERENCE MAP NO.	COMPANY	LEASE OR PROJECT
1	Brenneman & McDonnel	Dee - Kirtland	39	Tide Water Associated Oil Co.	Due No. 1
2	Mahutska Oil Co.	Bond	40	do.	Due No. 2
3	The Ohio Oil Co.	Henry	41	do.	Mann No. 1
4	Niagara Oil Corporation	Stifle	42	Bell Bros.	Maxwell
5	Tide Water Associated Oil Co.	J. Randolph	43	do.	Daron Heirs
6	Kewanee Oil Co.	Headley - Chalon	44	Cheuvront & Brown Oil Co.	Robinson
7	Brenneman & McDonnel	Wekenman	45	Kewanee Oil Co.	Headley
8	Tide Water Associated Oil Co.	Stifle No. 1	46	Dinsmoor Oil Co.	Grogan-Henry-Randolph
9	The Ohio Oil Co.	Edwards	47	The Ohio Oil Co.	Drake
10	Mahutska	Clark	48	Tide Water Associated Oil Co.	Wattleworth - T. Randolph
11	Dinsmoor Oil Co.	Wilson	49	Dinsmoor Oil Co.	S. Wilkin
12	The Ohio Oil Co.	Hulse	50	Tide Water Associated Oil Co.	Ikemire
13	Tide Water Associated Oil Co.	Rutherman	51	do.	E. Stifle
14	do.	Drake No. 2	52	Arkansas Fuel Oil Co.	Ikemire
15	do.	Clark	53	Mahutska Oil Co.	Shire
16	The Ohio Oil Co.	Wilkin	54	Tide Water Associated Oil Co.	P. Drake
17	do.	Arnold	55	do.	Henry
18	Mahutska Oil Co.	Price	56	Arkansas Fuel Oil Co.	Drake
19	Tide Water Associated Oil Co.	Dees - Mason	57	The Ohio Oil Co.	Hill - Stentz
20	Kewanee Oil Co.	Best	58	Arkansas Fuel Oil Co.	McClain
21	The Ohio Oil Co.	Warnock	59	Tide Water Associated Oil Co.	Culver
22	Mahutska Oil Co.	Reedy	60	Bell Bros.	Hill
23	American Oil Development Co.	Wall - Short	61	Kewanee Oil Co.	Curtis
24	The Ohio Oil Co.	Woodworth	62	Bell Bros.	Johnson
25	do.	Wood	63	Tide Water Associated Oil Co.	Howard
26	Kewanee Oil Co.	Shilts	64	American Oil Development Co.	Wood
27	Tide Water Associated Oil Co.	Birch	65	do.	Athey
28	do.	Murphy	66	The Ohio Oil Co.	Lewis - Fawley
29	do.	Good	67	Tide Water Associated Oil Co.	Tracey
30	The Ohio Oil Co.	Siler	68	do.	Barrick No. 3
31	do.	Prior	69	The Ohio Oil Co.	Wilson
32	do.	Shire	70	Tide Water Associated Oil Co.	Horning McCane
33	Kewanee Oil Co.	Hooker	71	do.	Meserve
34	do.	Martin	72	do.	Conrad
35	J. D. Toomey Estate	Highsmith - Mills	73	do.	Newlin
36	Mahutska Oil Co.	Carlton	74	do.	Austin
37	Kewanee Oil Co.	Wright	75	do.	Sankey
38	Tide Water Associated Oil Co.	Dennis	76	do.	Correll

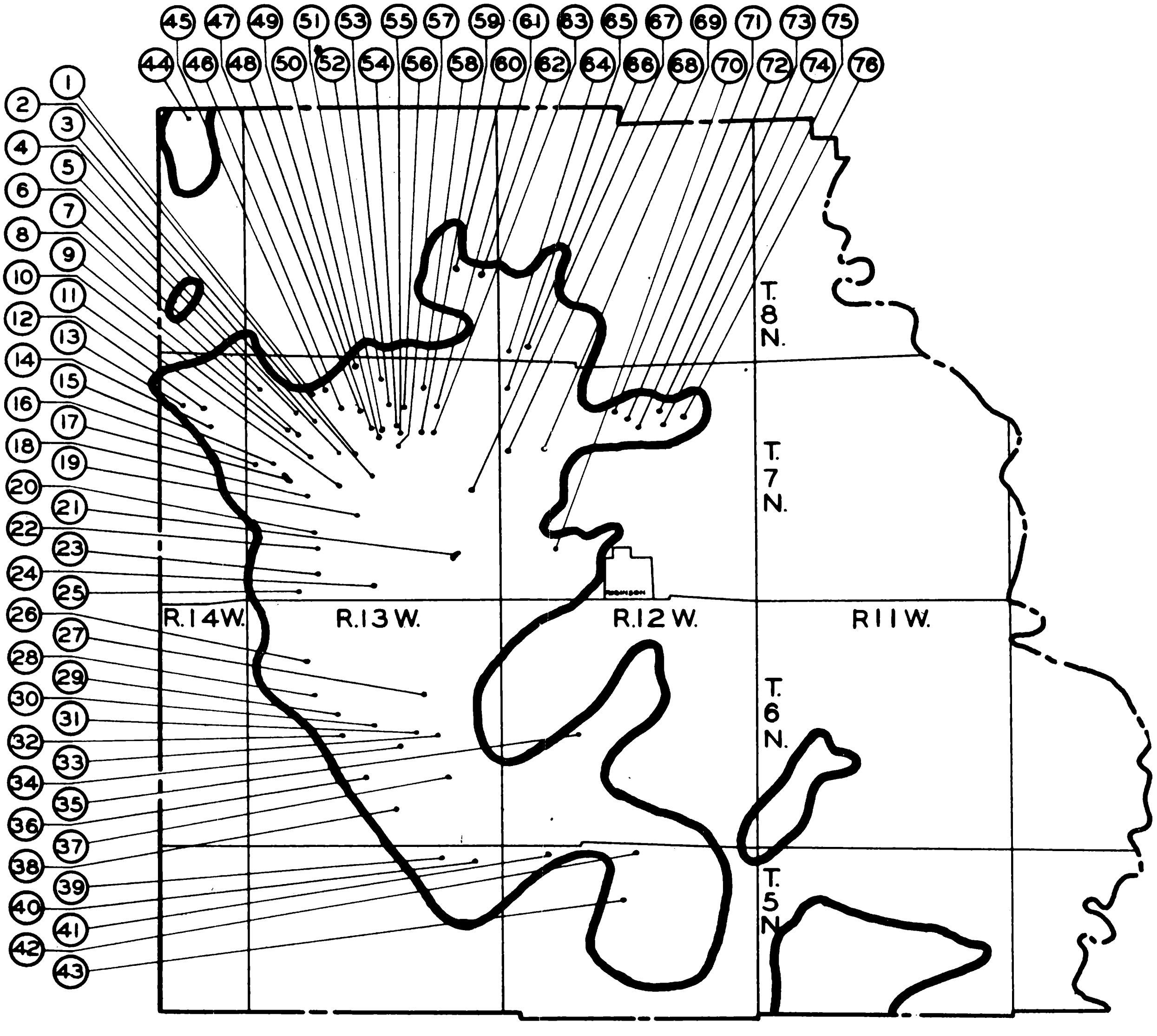

FIGURE 1.- Map of Crawford County, Ill., showing location of gas-injection projects in the Robinson field, July 31, 1943.

It is split into two or three persistent lenses that show average depths of about 850, 900 and 940 feet with an average interval between the tops of the sands of about 50 feet. The thickness of the sand lenses varies between 2 and 50 feet with an average of about 25 feet. The wells in which one or two lenses are absent are too numerous to mention. There are additional lenses of sand both above and below the zone which includes the three persistent lenses. One above is known as the "gas" or "stray" sand. It is usually from 6 to 20 feet thick and about 20 to 50 feet above the top-most lens of the Robinson sand. The sand lens lower than the oil zone may belong to the Robinson sand as a fourth lens, so closely is it related to the upper lenses. There are other minor streaks of sand even in the producing zone that add further confusion to the correlation.

Source of Gas for Injection

The supply of natural gas in the old oil fields of Illinois usually has been inadequate for gas injection. In the Colmar and Plymouth oil fields of western Illinois, where the volume of natural gas produced is inadequate to supply fuel for central-power engines, air is injected into the oil sand. Operators in the Robinson oil field in the southeastern part of the State have been more fortunate. After air has been injected into the reservoir for several months, enough gas is produced to provide fuel for engines on most of the projects, and part of the produced air-gas mixture is reinjected. Within the last 5 years, however, only air has been used as an injection medium on several projects because the air-gas mixtures produced by the oil wells have become deficient in gas.

Natural gas is produced in some of the newer oil fields in quantities exceeding their requirements for gas injection and fuel. It is unfortunate that gas from these fields (all of which are less than 70 miles from the Robinson oil field) has not been used to replenish the diminishing supply of gas in the older oil fields in that part of the State.

Development Practices

Ordinarily most operators of gas-injection projects in the stripper fields of Illinois have converted old oil wells to injection wells and have drilled no new wells. On a few, large, well-organized projects one or more wells have been drilled to obtain information on the reservoir. Absence of extensive drilling programs has resulted in a material saving in the cost of developing many projects, but the scarcity of core samples from the oil-producing sands has made it difficult to design systematic gas-injection projects. Thus, projects have been developed slowly, usually by experimental injection, and it is common practice for an oil well to be converted to an injection well and reconverted to a producing well within 1 year.

With few exceptions, the 12 oil-producing companies operating gas-injection projects in the old oil fields have utilized second-hand equipment in the development of their projects. In the southeastern oil fields gas pumps and compressors, utilized in vacuum operations and the extraction of gasoline from the natural gas produced with the oil, have been included in compressor plants to supply either air or gas under pressure for injection into the oil sands.

Air- and gas-distribution systems usually include pipe and fittings salvaged from the normal accumulation of used equipment in old oil fields. Low injection pressures, ranging from 20 to 190 pounds per square inch, make this practice possible. A few operators have reduced development costs by changing gathering-line systems, used in vacuum operations, to distribution lines for the injection medium. The saving realized is not large, but steel is conserved. Most air- and gas-distribution lines consist of 2-inch pipe and fittings, but larger projects, such as those in the Colmar and Plymouth oil fields, are equipped with trunk lines of 3-inch pipe laid through the center of the project, and air or gas is delivered to injection wells through 2-inch lateral lines connected to the trunk lines.

Compressed air or air-gas mixtures are used as the injection medium on most projects in the old oil fields, and some provision is made to reduce the moisture content of the gas after compression. The presence of moisture in the injection medium not only stimulates the rate of corrosion of pipe and fittings but forms an emulsion with oil that has leaked by compressor rings and may plug the sand face in injection wells over a long operating period. In the winter, when atmospheric temperatures below freezing are common, the accumulation of water in distribution lines may cause much difficulty; therefore a nipple and valve usually are installed at low points in the lines, and the water is blown periodically to the atmosphere. On most projects the provision made for condensing and removing moisture immediately after compression of the gas consists of a 2-inch riser pipe 10 or 15 feet long on the discharge lines of the compressor. Moisture condensed by a reduction in temperature between the compressor cylinder and the vertical pipe is trapped and discharged from the line. Radiation of heat alone seldom reduces the temperature enough to cause appreciable condensation at the compressor plant, and additional traps at points more distant from the plant frequently are necessary. The temperature of the compressed gas can be reduced more satisfactorily by passing the gas through water-cooled coils. This method of cooling is being employed with good results by The Ohio Oil Co. on the Warnock project in the north central part of the Robinson field.

The calculated maximum percentages of water vapor that can exist in gas at various temperatures and pressures are shown in table 1. The calculations were based on the following formula:

$$S = 100 \frac{P_w}{P_m},$$

where S = water vapor existing in the gas, percent;

P_w = vapor pressure of water at the temperature of the compressed gas, pounds per square inch;

P_m = pressure of the gas and water-vapor mixture, pounds per square inch absolute.

TABLE 1. - Maximum percentage of water vapor in gas
(Pressure base, 14.4 lb. per sq.in.abs.)

Gage pressure,	Temperature, °F.										
lb. per sq. in.	32	50	60	70	80	90	100	120	140	160	180
0	0.61	1.24	1.78	2.52	3.53	4.86	6.60	11.8	20.1	33.0	52.2
10	.36	.73	1.05	1.49	2.08	2.87	3.90	6.95	11.9	19.4	30.8
20	.26	.52	.75	1.06	1.48	2.03	2.76	4.93	8.41	13.8	21.8
30	.20	.40	.58	.82	1.14	1.57	2.14	3.82	6.51	10.7	16.9
40	.16	.33	.47	.67	.93	1.29	1.75	3.12	5.32	8.72	13.8
50	.14	.28	.40	.56	.79	1.09	1.48	2.63	4.49	7.37	11.7
60	.12	.24	.34	.49	.68	.94	1.28	2.28	3.89	6.38	10.1
70	.11	.21	.30	.43	.60	.83	1.13	2.01	3.43	5.62	8.90
80	.09	.19	.27	.39	.54	.74	1.00	1.80	3.07	5.03	7.86
90	.09	.17	.25	.35	.49	.67	.91	1.62	2.77	4.55	7.20
100	.08	.16	.22	.32	.44	.61	.83	1.48	2.53	4.15	6.56
150	.05	.11	.16	.22	.31	.43	.58	1.03	1.76	2.89	4.57
200	.04	.08	.12	.17	.24	.33	.44	.79	1.35	2.22	3.50

Well Spacing

No spacing relationship exists for oil and injection wells in the old oil fields. Densities of injection wells on systematic projects range from 20 to 35 acres per well. In the Robinson field old oil wells usually are spaced 440 feet apart along the boundaries of leases, the interior of which is undeveloped by drilling. These undrilled areas and the arrangement of oil wells in irregular lines preclude the development of repeating well patterns.

Well-Completion Methods

The conversion of an oil well to an injection well includes the replacement of corroded casing with good pipe, cleaning out the shot hole, and either cementing 2-inch tubing above the oil sand or setting it with a tubing packer in the lower part of the casing. The tubing, extending to the bottom of the well, contains a perforated section 4 to 20 feet in length and opposite the sand face. The oil sand in injection wells is not shot. A few operators have converted old oil wells to injection wells by cleaning out the shot hole, running a burlap packer on 2-inch tubing into the well, and setting the packer in the open hole below the casing. This practice usually is not satisfactory in Illinois because well bores in the old oil wells have caved, making it difficult to isolate the oil-producing zone with a packer in the open hole.

Use of Air-Gas Mixtures

Vacuum has been maintained on most of the oil sands in southeastern Illinois for over 30 years, and large quantities of natural gas obtained by its use were sold or wasted before operators considered installation of gas-injection projects advisable. In general, air injection was adopted in conjunction with vacuum operations, and although only small volumes of gas were being produced when air first was injected, the air introduced into oil sands forced large volumes of natural gas to producing wells. During the first year or two of operation many projects produced enough gas to establish a cycle, and air was introduced (or injected) thereafter only once or twice yearly for 30- to 60-day periods to replace the liquids removed from the reservoir and the gas used as fuel. The air-injection periods increased in succeeding years, and as the percentage of natural gas in the produced air-gas mixtures decreased the extraction of gasoline from the gas became unprofitable and entire air-wet-gas mixtures were recycled. In 1943, recycled air-gas mixtures were being supplemented with air continuously on nearly half of the gas-injection projects. On the remainder of the projects only air was being injected; and the produced air-gas mixtures, because of low fuel value, were being discharged into the atmosphere.

Explosion Hazards

When air or air-gas mixtures are compressed an explosion hazard is present; however if the fundamental laws governing combustion are recognized and precautionary measures are taken explosions on air-gas injection projects can be avoided. A complete discussion of explosive limits of air-gas mixtures is not within the scope of this report, but the subject has been evaluated comprehensively by Jones and associates.12/, 13/, 14/ Experience has shown that ordinarily months or years elapse after initiation of air-injection projects before the produced air-gas mixture comes within the explosive range (unless excessive bypassing or channeling is occurring in the reservoir).

Air-gas mixtures containing 10 percent oxygen or less will not burn or explode, therefore compression is relatively safe if the oxygen content of the produced air-gas mixture is kept below 10 percent. Some operators in Illinois have successfully compressed and injected into oil sands air-gas mixtures containing as much as 16 percent oxygen (approximately 76 percent air). Mixtures containing 16 percent oxygen or less can be explosive, however, depending mainly upon the kind and proportion of inert gases present (nitrogen in excess of that in air and carbon dioxide) and to some extent upon the composition of the natural gas portion of the air-gas mixture. Explosive limits of air-gas mixtures are not altered much by temperatures or pressures encountered in compressors ordinarily used on air-gas injection projects in the older oil fields of Illinois.

Tests should be made periodically to determine the explosibility of air-gas mixtures produced on air-injection projects. Some operators make oxygen and carbon dioxide tests on composite samples of the air-gas mixtures semi-monthly or monthly with an Orsat analyzer. Ordinarily when the composite samples contain 10 percent or more oxygen the gas produced by each

12/ Coward, H. F., and Jones, G. W., Limits of Inflammability of Gases and Vapors: Bureau of Mines Bull. 279, 1939, 146 pp.

13/ Jones, G. W., and Kennedy, R. E., Limits of Inflammability of Natural Gases Containing High Percentages of Carbon Dioxide and Nitrogen: Bureau of Mines Rept. of Investigations 3216, 1933, 23 pp.

14/ Jones, G. W., Inflammability of Mixed Gases: Bureau of Mines Tech. Paper 450, 1929, 38 pp.

oil well is analyzed, and wells producing mixtures having the highest oxygen content are withdrawn from the gathering system. Either back pressure is applied to the sand in oil wells with high air:gas ratios or the gas-injection rate of the nearest injection well is reduced. Oil wells with persistently high ratios are removed permanently from the gathering system.

The results of periodic tests that indicate the injection medium is not explosive are reliable only at the time of the test. In southeastern Illinois Orsat analyses of air-gas mixtures once or twice each month have proved adequate; but, in addition, operators observe closely those operating conditions that are apt to alter the composition of the mixtures. Three operations having important bearing on the alteration of air-gas mixture compositions are the unexpected channeling of the injection medium through the reservoir from injection to producing wells, the withdrawal of producing wells from the gathering system for reconditioning, and the rise and fall of fluid levels in oil wells. These conditions can be controlled, resulting in an air-gas mixture of more uniform composition.

Oxidation of Crude Oil

The use of air, or air and gas, as the injection medium in air-injection projects probably has resulted in some oxidation of the oil in the reservoirs. The time allotted for this investigation did not permit a study to determine the degree of oxidation, but analyses of air-gas mixtures from 62 oil wells show that the percentage of carbon dioxide in the mixture produced by many of these wells was higher than would be expected ordinarily, which indicates that oxidation of the oil may have occurred. The results of these analyses are given in tables 5, 11, 17, and 23. High concentrations of carbon dioxide in some of the mixtures produced on the Henry and Warnock projects probably were due to the cumulative effects of recycling air and gas mixtures containing the inert gas.

Taylor and Smith reported[15/] that the resistance to oxidation of crude oils studied by them decreased in the following order: Paraffin base, intermediate base, and naphthene base. In the laboratory they also found that when the crude oils were oxidized severely asphaltic materials and gums insoluble in the oil were formed; and in the presence of water, the oil emulsified more readily because of a decrease in interfacial tension between the oil and water. Field studies,[16/] however, indicate that oxidation of oil under field conditions is not severe.

Physical properties of the intermediate-base oils produced in the old oil fields of Illinois may be altered over a long period of air injection, but no evidence was obtained during this study which indicated that oxidation of the oil has affected the oil-recovery rate.

15/ Taylor, Sam S., and Smith, H. M., Summary of Experimental Data on Laboratory Oxidation of Crude Oils, With Particular Reference to Air-Repressuring: Bureau of Mines Rept. of Investigations 3238, 1934, 11 pp.

16/ Johnson, T. W., and Taylor, S. S., A Study of Oxidation of the Oil in Two Air and Air-gas Repressuring Projects: Bureau of Mines Rept. of Investigations 3325, 1937, 24 pp.

Summary

Information regarding all gas-injection projects active in Illinois on July 31, 1943, is summarized in table 2, which includes information on the Dinsmoor Oil Co. Mumford project, which was developed in 1921 and was the first successful gas-injection operation in the State. Complete data were not available for the two largest projects, in the Louden and Salem oil fields.

Gas-injection projects in the old oil fields comprise 13,788 acres; 42 percent (5,832 acres) have been affected by air and air-gas mixtures introduced into the oil sands through 279 injection wells. By July 1943 these projects had been in operation for an average of approximately 9 years and were producing oil at an average rate of 1.3 times the average rate for the period immediately preceding gas-injection operations. A maximum rate usually was obtained 1 to 18 months after initial gas injection on a fully developed project; depending on the injection rate and the degree of control over excessive channeling through the oil sands of the medium injected. The maximum oil-producing rate after air and gas injection was begun averaged 1.8 times the average rate for the period immediately preceding gas injection. Approximately 2,400 cubic feet of air and gas were injected into oil sands for each barrel of oil produced in the old fields; and about 8,000 cubic feet of air and gas were injected for each barrel of oil estimated to have been gained by August 1, 1943.

More systematic gas-injection projects in the stripper fields have been developed in the Robinson, Bridgeport, Colmar, and Plymouth oil fields. The quantity of oil gained in these fields by projects that have been operating 9 or 10 years is not spectacular when compared to results obtained by successful water-flooding operations. Development costs for gas-injection projects in the old oil fields of Illinois have been so low, however, that profitable operation has been assured over a longer period than the life expectancy of an average water-flooding project. Development expenditures for well-organized projects in the old oil fields of Illinois did not exceed $50.00 per acre before the present World War, but in 1943 material and labor costs would increase the investment for the development of similar projects. The low development costs are attributed chiefly to the absence of extensive drilling programs which ordinarily are necessary for the proper development of water-flooding projects.

Oil-producing companies usually agree that because of lack of uniform permeability and the irregular distribution of oil sands, and the unusual local variations in the oil saturation of the sands, the general application of secondary-recovery methods in the old southeastern Illinois oil fields would not result in a profitable recovery of more oil. A complete study rarely can be made of the applicability of gas injection to an oil property in an old oil field. A proper evaluation would include consideration of the analyses of core samples of the oil sand, and these seldom are available. Wehn the results of core analyses of the sand are not available assumptions may be made regarding the probable success or failure of secondary-recovery operations by comparing the oil productivity of the property in the past with

TABLE 2. - Active gas-injection operations in Illinois

July 31, 1943

Sand: Name	Sand: Average depth, feet	Sand: Average thickness, feet	Location: County	Location: Legal description: Section	Location: Legal description: Township	Location: Legal description: Range	Company	Lease or project: Name	Lease or project: Total area, acres	Lease or project: Estimated affected area, acres	Number of injection wells	Oil wells: Total number	Oil wells: Number affected	Injection medium: Type	Injection medium: Average injection pressure lb. per sq. in.	Injection medium: Average volume injected daily, M cu. ft.	Average daily oil production, bbl.: Before air-gas injection	Average daily oil production, bbl.: Maximum after air-gas injection	Average daily oil production, bbl.: July, 1943	Initial air-gas injection
								Allendale field												
Biehl	1,450	28	Wabash	5	1 N.	12 W.	J. D. Toomey Estate	Litherland	89	55	2	2	2	Air	75	40[1/]	8	25	12	1939
								Totals:	89	55	2	2	2			40[1/]	8	25	12	
								Bridgeport field												
Bridgeport	925	40	Lawrence	32	4 N.	12 W.	The Ohio Oil Co.	Johnson	460	250	10	58	40	do.	75	250	171	No increase	137	1943
								Totals:	460	250	10	58	40			250	171		137	
								Calvin field												
Aux Vases	2,800	25	White	8	4 S.	14 W.	Herndon Drilling Co.	Bond	155	60	1	11	6	Gas	380	240	125[2/]	do.	90[2/]	1942
Bethel	2,690	22	do.	17	4 S.	14 W.	Trans-Tex. Production Co.	Bramlett	80	40	1	12	6	do.	380	50	220	do.	165	1942
Paint Creek Bethel Aux Vases	2,655 2,670 2,810	14) 12) 16)	do.	8 and 17	4 S.	14 W.	do.	Coulter	40	40	1[3/]	4	4	do.	380	27	37	do.	26	1943
Paint Creek Bethel	2,670 2,695	12) 16)	do.	17	4 S.	14 W.	do.	Glaze "D"	200	40	1[4/]	22	4	do.	380	70	505	do.	155	1943
								Totals:	475	180	4	49	20			387	887		436	
								Casey field												
Casey	450	25	Clark	26	10 N.	14 W.	Dinsmoor Oil Co.	Mumford	40	35	2	13	10	Air	100	20[1/]	10[1/]	23	13	1921
								Totals:	40	35	2	13	10			20[1/]	10[1/]	23	13	
								Colmar field												
Hoing	465	12	Hancock	9,10,14,15,16	4 N.	4 W.	The Ohio Oil Co.	Colmar	1,800	1,100	44	177	157	do	45	704	149	378	226	1935
								Totals	1,800	1,100	44	177	157			704	149	378	226	
								Hoodville field												
Bethel Aux Vases	2,950 3,050	20 20	Hamilton	3	6 S.	6 E.	The Texas Co., The Ohio Oil Co., and Tide Water Associated Oil Co.	Hoodville	419	88	3[4/]	34	8	Gas	80 260	46 22	1,250[1/]	No increase	1,193	1943
								Totals:	419	88	3	34	8			68	1,250[1/]		1,193	

TABLE 2. - Active gas-injection operations in Illinois (cont'd.)

July 31, 1943

Sand: Name	Sand: Average depth, feet	Sand: Average thickness, feet	Location: County	Location: Legal description: Section	Location: Township	Location: Range	Company	Lease or project: Name	Lease or project: Total area, acres	Lease or project: Estimated affected area, acres	Number of injection wells	Oil wells: Total number	Oil wells: Number affected	Injection medium: Type	Injection medium: Average injection pressure lb. per sq. in.	Injection medium: Average volume injected daily, M. cu. ft.	Average daily oil production, bbl.: Before air-gas injection	Average daily oil production, bbl.: Maximum after air-gas injection	Average daily oil production, bbl.: July, 1943	Initial air-gas injection
								Robinson field												
Robinson	900	25	Crawford	20	6 N.	12 W.	J. D. Toomey Estate	Highsmith	40	40	1	7	7	Air and gas	125	25	3	10	3	1923
Do.	900	25	do.	20	6 N.	12 W.	do.	Mills	80	15	1	1	1	do.	125	15	1	4	2	1923
Do.	1,000	30	do.	2	8 N.	14 W.	Cheuvront & Brown Oil Co.	Robinson	40	40	1	6	6	Gas	100	20	2	4	4	1938
Do.	950	30	do.	4	7 N.	13 W.	Dinsmoor Oil Co.	S. Wilkin	40	40	2	3	3	Air	100	50[1]/	1	4	2	1924
Do.	930	30	do.	5	7 N.	13 W.	Kewanee Oil Co.	Headley	160	27	1	17	4	Air and gas	50	9	8	No increase	7	1937
Do.	925	30	do.	21	6 N.	13 W.	The Ohio Oil Co.	Shire	200	100	3	19	8	Air	30	20	30	59	59	1941
Do.	925	35	do.	22 and 23	6 N.	13 W.	do.	Prier	240	150	10	71	10	do.	40	90	30	33	33	1943
Do.	900	35	do.	26	6 N.	13 W.	Kewanee Oil Co.	Wright	80	13	2	19	3	Air and gas	80	25	19	24	21	1937
Do.	875	20	do.	22	6 N.	13 W.	do.	Martin	40	16	1	7	3	do.	100	10	5	7	7	1941
Do.	900	50	do.	23	6 N.	13 W.	do.	Hooker	60	16	1	11	3	do.	175	23	5	6	6	1941
Do.	900	35	do.	28	6 N.	13 W.	Mahutska Oil Co.	Carlton	80	37	1	14	5	Air	30	23	9	17	10	1937
Do.	925	30	do.	27 & 34	6 N.	13 W.	Tide Water Associated Oil Co.	Dennis	80	40	2	16	6	Air and gas	30	30	34	36	25	1932
Do.	900	20	do.	1	5 N.	13 W.	do.	Due No. 2	60	20	1	6	2	Air	100	10	2	3	2	1941
Do.	900	25	do.	2	5 N.	13 W.	do.	Due No. 1	40	20	1	8	4	Gas	45	12	5	9	5	1932
Do.	950	30	do.	15, 16, 21 and 22	6 N.	13 W.	The Ohio Oil Co.	Siler	540	150	12	82	5	Air	125	100	43	No increase	39	1943
Do.	875	25	do.	32	7 N.	13 W.	American Oil Development Co.	Wall-Short	145	85	3	17	10	Air and gas	45	37	16	65	47	1936
Do.	900	30	do.	10	7 N.	13 W.	Arkansas Fuel Oil Co.	Drake	98	68	2	13	7	Gas	20	33	19	45	22	1936
Do.	950	30	do.	5	7 N.	13 W.	Brenneman & McDonnel	Dee	40	15	1	10	3	Air	30	25[1]/	17	25	20	1941
Do.	950	30	do.	5	7 N.	13 W.	do.	Kirtland	40	10	1	25	3	do.	30	25[1]/	40	45	40	1937
Do.	950	30	do.	6	7 N.	13 W.	do.	Wekenman	40	20	1	8	3	do.	30	25[1]/	7	13	8	1936
Do.	900	35	do.	21	7 N.	13 W.	Dinsmoor Oil Co.	Wilson	40	30	2	4	3	do.	100	50[1]/	1	8	4	1922
Do.	900	30	do.	9	7 N.	13 W.	do.	Grogan	40	40	2	4	4	do.	100	50[1]/	1	21	2	1922
Do.	850	30	do.	9	7 N.	13 W.	do.	Henry	40	25	1	3	1	do.	100	25[1]/	1	4	4	1923
Do.	950	30	do.	9	7 N.	13 W.	do.	Randolph	10	10	1	1	1	do.	100	25[1]/	0	2	2	1924
Do.	875	40	do.	29	7 N.	13 W.	Kewanee Oil Co.	Best	40	20	1	9	2	Air and gas	20	12	5	7	7	1940
Do.	950	45	do.	8	7 N.	13 W.	do.	Headley-Chalon	80	25	2	9	4	do.	50	6	13	23	13	1937
Do.	975	20	do.	11	7 N.	13 W.	do.	Curtis	54	20	1	4	3	do.	45	4	2	13	2	1936
Do.	950	15	do.	8	6 N.	13 W.	do.	Shilts	85	10	1	10	2	do.	40	25	15	18	14	1934
Do.	900	20	do.	10	7 N.	13 W.	Mahutska Oil Co.	Shire	100	25	1	18	4	Air	30	23	15	23	18	1937
Do.	900	25	do.	16	7 N.	13 W.	do.	Bond	120	20	1	22	4	do.	30	23	20	31	28	1937
Do.	900	25	do.	17	7 N.	13 W.	do.	Clark	80	25	1	11	32	do.	30	23	10	20	14	1937
Do.	900	25	do.	20	7 N.	13 W.	do.	Price	40	20	1	6	3	do.	30	23	5	17	10	1937
Do.	900	25	do.	29	7 N.	13 W.	do.	Reedy	40	20	1	6	3	do.	30	23	5	14	13	1937
Do.	950	40	do.	8	7 N.	13 W.	Niagara Oil Corporation	Stifle	57	29	1	6	2	Gas	50	20	4	8	4	1939

TABLE 2. - Active gas-injection operations in Illinois (cont'd.)

July 31, 1943

Sand: Name	Sand: Average depth, feet	Sand: Average thickness, feet	Location: County	Legal description: Section	Legal description: Township	Legal description: Range	Company	Lease or project: Name	Lease or project: Total area, acres	Lease or project: Estimated affected area, acres	Number of injection wells	Oil wells: Total number	Oil wells: Number affected	Injection medium: Type	Injection medium: Average injection pressure, lb. per sq. in.	Injection medium: Average volume injected daily, M cu. ft.	Average daily oil production, bbl.: Before air-gas injection	Average daily oil production, bbl.: Maximum after air-gas injection	Average daily oil production, bbl.: July, 1943	Initial air-gas injection
								Johnson field												
Casey	480	25	Clark	27	9 N.	14 W.	Kewanee Oil Co.	Larrison	40	15	1	9	3	Air and gas	40	21	11	16	13	1937
Do.	450	25	do.	2 and 3	9 N.	14 W.	Tide Water Associated Oil Co.	Brimmer	40	16	1	5	2	Air	30	27	7	8	7	1942
Do.	450	25	do.	3 and 11	9 N.	14 W.	do.	Howe	120	15	1	15	2	do.	110	16	12	14	13	1941
								Totals:	200	46	3	29	7			64	30	38	33	
								Loudon field												
Weiler Paint Creek Bethel	1,477 1,537 1,562	24 14 14	Fayette	1,2,3,9,10,11,12, 13,14,15,16,20,21, 22,23,24,26,27,28, 32 and 33 34,35,36	8 N. 9 N.	3 E. 3 E.	The Carter Oil Co.	Loudon	8,840	8,840[5]/	94[6]/	464[7]/	464	Gas	393 433 414	2,676	[8]/	[8]/	10,655	1939
								Totals:	8,840	8,840	94	464	464			2,676			10,655	
								New Harmony field												
Waltersburg Cypress Weiler Bethel Aux Vases O'Hara McClosky	2,200 2,600 2,650 2,730 2,850 2,860 2,870	23 23 15 27 18 5 7	White	27,28,29,32,33 and 34 4,5,9,10	4 S. 5 S.	14 W. 14 W.	Superior Oil Co. Tide Water Associated Oil Co. and Sun Oil Co.	New Harmony	2,000[1]/	1,700[9]/	40[10]/	317	201	do.	295 510 470 450 480 570 295	710 618 237 1,365 820 10 862	14,700	No increase	11,300	1942
								Totals:	2,000[1]/	1,700	40	317	201			4,622	14,700		11,300	
								Plymouth field												
Hoing	430	11	Hancock and McDonough	19 and 20 24	4 N. 4 N.	4 W. 5 W.	The Ohio Oil Co.	Plymouth	450	350	19	42	36	Air	45	225	75	111	65	1934
								Totals:	450	350	19	42	36			225	75	111	65	
								Robinson field												
Robinson	900	25	Crawford	3	5 N.	12 W.	Bell Bros.	Maxwell	40	10	1	2	1	do.	[8]/	25[1]/	[8]/	[8]/	1	1930
Do.	900	25	do.	9	5 N.	12 W.	do.	Daron Heirs	146	20	1	4	2	do.	[8]/	25[1]/	[8]/	[8]/	1	1930
Do.	900	25	do.	5 and 6	5 N.	12 W.	Tide Water Associated Oil Co.	Mann No. 1	140	100	3	16	13	Gas	25	50	22	80	70	1935

TABLE 2. - Active gas-injection operations in Illinois (cont'd)

July 31, 1943

Sand: Name	Sand: Average depth, feet	Sand: Average thickness, feet	Location: County	Location: Legal description: Section	Location: Legal description: Township	Location: Legal description: Range	Company	Lease or project: Name	Lease or project: Total area, acres	Lease or project: Estimated affected area, acres	Number of injection wells	Oil wells: Total number	Oil wells: Number affected	Injection medium: Type	Injection medium: Average injection pressure, lb. per sq. in.	Injection medium: Average volume injected daily, M cu. ft.	Average daily oil production, bbl.: Before air-gas injection	Average daily oil production, bbl.: Maximum after air-gas injection	Average daily oil production, bbl.: July, 1943	Initial air-gas injection
								Robinson field												
Robinson	925	30	Crawford	18,19,30	7 N.	13 W.	The Ohio Oil Co.	Arnold	520	165	11	57	16	Gas	160	40	59	86	68	1942
do.	925	30	do.	15,16,21 and 22	7 N.	13 W.	do.	Henry	380	175	7	57	14	Air	60	85	29	85	85	1941
do.	925	30	do.	18	7 N.	13 W.	do.	Wilkin	330	75	5	77	8	do.	40	60	89	113	113	1943
do.	925	30	do.	7 and 8	7 N.	13 W.	do.	Edwards	325	100	7	38	8	do.	150	60	19	37	34	1938
do.	925	30	do.	32	7 N.	13 W.	do.	Wood	321	40	2	43	4	do.	60	10	30	40	38	1941
do.	925	40	do.	11 and 12	7 N.	14 W.	do.	Hulse	80	25	1	12	2	do.	50	15	13	22	16	1938
do.	875	25	do.	25,26, and 35	7 N.	13 W.	do.	Warnock	660	300	8	81	20	do.	125	85	31	46	38	1936
do.	950	25	do.	9	7 N.	13 W.	do.	Drake	200	120	5	24	11	Gas	20	18	35	63	54	1937
do.	950	25	do.	15	7 N.	13 W.	do.	Hill-Stentz	200	60	2	22	5	Air and gas	60	21	9	24	15	1937
do.	950	25	do.	33 and 34	7 N.	13 W.	do.	Woodworth	460	35	1	39	3	Air	80	13	32	40	37	1932
do.	950	20	do.	11	7 N.	13 W.	Tide Water Associated Oil Co.	Culver	30	20	1	3	2	Gas	25	14	2	6	5	1937
do.	975	25	do.	16	7 N.	13 W.	do.	J.Randolph	190	70	2	13	4	Air	125	50	6	17	8	1936
do.	950	25	do.	11	7 N.	14 W.	do.	Rutherman	30	12	1	5	2	do.	60	9	4	12	6	1936
do.	950	25	do.	24	7 N.	13 W.	do.	Tracy	80	16	1	5	1	Air and gas	45	23	2	6	4	1936
do.	975	20	do.	14	6 N.	13 W.	do.	Birch	80	20	1	10	2	Gas	30	16	8	17	14	1936
do.	975	30	do.	16	6 N.	13 W.	do.	Good	80	15	1	13	2	do.	22	15	10	18	9	1936
do.	975	30	do.	17	6 N.	13 W.	do.	Murphy	60	7	1	9	1	do.	40	10	3	4	3	1936
do.	975	30	do.	11	7 N.	13 W.	do.	Howard	110	30	2	9	3	do.	30	60	13	27	10	1935
do.	975	20	do.	9 and 10	7 N.	13 W.	do.	Wattleworth	120	100	3	11	10	do.	36	50	5	13	5	1935
do.	1,000	25	do.	9 and 10	7 N.	13 W.	do.	T.Randolph	80	60	1	11	6	do.	27	21	2	7	4	1935
do.	950	30	do.	10 and 15	7 N.	13 W.	do.	Ikemire	120	80	3	14	8	do.	20	40	6	27	17	1934
do.	975	20	do.	10	7 N.	13 W.	do.	E. Stifle	100	100	6	14	14	do.	20	55	11	47	25	1934
do.	975	25	do.	12	7 N.	14 W.	do.	Drake No. 2	80	25	1	6	2	Air	65	15	3	7	5	1934
do.	975	35	do.	10	7 N.	13 W.	do.	P. Drake	60	60	2	9	9	Gas	20	8	6	20	14	1933
do.	950	25	do.	10	7 N.	13 W.	do.	Henry	80	65	4	10	8	do.	35	55	13	35	24	1932
do.	950	25	do.	18	7 N.	13 W.	do.	Clark	80	60	2	9	7	do.	50	20	20	66	24	1932
do.	950	35	do.	8	7 N.	13 W.	do.	Stifle No. 1	160	80	6	19	9	Air	125	26	8	17	6	1932
do.	925	25	do.	21 and 28	7 N.	13 W.	do.	Dees-Mason	210	75	2	13	6	Gas	60	36	12	32	12	1929
do.	975	20	do.	6	7 N.	12 W.	American Oil Development Co.	Athey	187	25	2	2	2	Air	90	95	2	8/	1	1937
do.	975	20	do.	31	8 N.	12 W.	do.	Wood	146	70	4	15	8	do.	75	100	16	25	25	1937
do.	900	30	do.	2	7 N.	13 W.	Arkansas Fuel Oil Co.	McClain	100	40	1	11	4	Gas	30	21	9	20	11	1937
do.	900	30	do.	3	7 N.	13 W	do.	Ikemire	80	40	2	7	4	Air and gas	85	25	4	5	5	1929
do.	1,000	20	do.	23 and 24	8 N.	13 W.	Bell Bros.	Hill	160	20	2	2	2	Air	160	50 1/	1	8/	2	1928
do.	1,000	25	do.	24	8 N.	13 W.	do.	Johnson	78	25	2	7	3	do.	100	50 1/	4	8/	6	1929
do.	975	30	do.	31	8 N.	12 W.	The Ohio Oil Co.	Lewis-Fawley	202	60	2	20	5	Gas	80	26	9	17	11	1932
do.	975	30	do.	17 and 18	7 N.	12 W.	do.	Wilson	240	60	3	26	6	Air	60	19	17	28	17	1929

TABLE 2. - Active gas-injection operations in Illinois (cont'd.)

July 31, 1943

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								Robinson field												
Robinson	950	30	Crawford	29	7 N.	12 W.	Tide Water Associated Oil Co.	Horning-McCane	70	30	2	7	3	Air	65	45	7	18	7	1936
Do.	950	30	do.	18	7 N.	12 W.	do.	Barrick No. 3	100	10	1	14	2	Air and gas	45	22	8	9	7	1936
Do.	950	30	do.	11	7 N.	12 W.	do.	Correll	120	35	1	8	3	Air	170	9	5	13	6	1926
Do.	950	30	do.	10	7 N.	12 W.	do.	Newlin	35	20	1	2	2	do.	190	20	4	8	2	1926
Do.	950	30	do.	9	7 N.	12 W.	do.	Meserve	350	100	6	32	10	do.	160	25	19	39	12	1926
Do.	950	30	do.	9 and 10	7 N.	12 W.	do.	Conrad	100	20	3	16	3	do.	160	25	10	14	8	1926
Do.	950	30	do.	10	7 N.	12 W.	do.	Austin	140	70	2	9	6	do.	160	35	11	38	8	1926
Do.	950	30	do.	10	7 N.	12 W.	do.	Sankey	40	15	1	5	2	do.	125	20	5	11	3	1926
								Totals:	10,669	3,961	194	1,304	403			2,556	1,026	1,877	1,393	
								Salem field												
Bethel Aux Vases	1,725 1,800	45 45	Marion	4,5,6,7,8,9,17 29,30,31,32,33	1 N. 2 N.	2 E. 2 E.	The Texas Co.	Salem	6,353	3,912	44 11/	450	240 1/	Gas	30-240	7,580	8/	8/	8/	1939
								Totals:	6,353	3,912	44	450	240 1/			7,580				
								Siggins field												
Casey	400	25	Cumberland	13	10 N.	10 E.	Bell Bros.	Queen	80	35	5	34	7	Air	35	2	8/	8/	18	1928
								Totals:	80	35	5	34	7			2			18	
								Walpole field												
Aux Vases	3,075	20	Hamilton	27 and 34	6 S.	6 E.	The Texas Co.	Walpole	320	60	6	15	3	Gas	400	158	680	No increase	556	1943
								Totals:	320	60	6	15	3			158	680		556	

1/ Estimated.

2/ Oil production for the affected wells only.

3/ 3 input zones.

4/ 2 input zones.

5/ Estimated reservoir volumes affected:

Weiler	-	176,800 acre-ft.
Paint Creek	-	62,150 acre-ft.
Bethel	-	46,450 acre-ft.
Total		285,400 acre-ft.

6/ 170 input zones.

7/ 759 producing zones.

8/ Information not available.

9/ Estimated reservoir volumes productive:

Waltersburg	-	20,000 acre-ft.
Cypress	-	61,000 acre-ft.
Weiler	-	5,000 acre-ft.
Bethel	-	51,000 acre-ft.
Aux Vases	-	22,000 acre-ft.
O'Hara	-	300 acre-ft.
McClosky	-	6,600 acre-ft.
Total		165,900 acre-ft.

10/ 80 input zones.

11/ 75 input zones.

that of adjacent properties. A high oil recovery by primary methods of production usually is indicative of a high oil recovery by secondary-recovery methods.

DESCRIPTION OF FOUR GAS-INJECTION PROJECTS IN ILLINOIS

Tide Water Associated Oil Co. Henry Project

Tide Water Associated Oil Co. has developed an air and gas drive on 700 productive acres in the north-central part of the Robinson field, Crawford County, Ill. The oil-producing member is the Robinson sand, which occurs at an average depth of 975 feet. The sand averages 25 feet in thickness.

History

Most of the oil wells on the leases included in the Henry project were drilled in 1907 and 1908. The wells produced initially at rates ranging from 5 to 300 barrels of oil daily and averaging 75 barrels. The absence of an active water drive in the Robinson sand and of large quantities of gas associated with the oil accounted for a reduced daily oil-producing rate of 3 barrels per well in 1911. The normal decline in the rate of oil production was interrupted in 1919 by the application of vacuum (15 to 25 inches of mercury), and although it did not cause a substantial increase in the oil-recovery rate the operation resulted in an increased yield of natural gasoline from the solution gas and light hydrocarbon fractions that were released from the crude oil. Vacuum was maintained on the sand after gas injection was begun in May 1934.

As the chief propulsive force originally in the oil sand was supplied by the expansion of gas liberated from solution, the rapid decline in individual well-production rates indicates that the reservoir pressure was low or that the oil was greatly undersaturated. High primary recovery of the oil contained in the sand could not be expected, therefore, and less than 25 percent of the original oil in place was recovered before vacuum operations were begun.

Characteristics of Oil Sand

Most of the oil wells on the Henry project were drilled before the practice of taking cores had been developed and before the importance of accurate information regarding the reservoir was recognized. Drillers' logs and the analyses of cores from two wells drilled in recent years reveal that two lenses are present in most wells and that a lenticular gas sand was penetrated by half of the wells. The gas sand, when present, is above the oil sand and is at an average depth of 900 feet. The gas sand is 2 to 12 feet in thickness. As the gas in the lenticular gas sand has been exhausted and as the casing in all oil wells is set above the top of that sand, it has been difficult to isolate it from the lower oil-productive lenses before secondary-recovery methods are applied. The second and third lenses are at depths of 945 and 975 feet, and their combined thickness averages 25 feet.

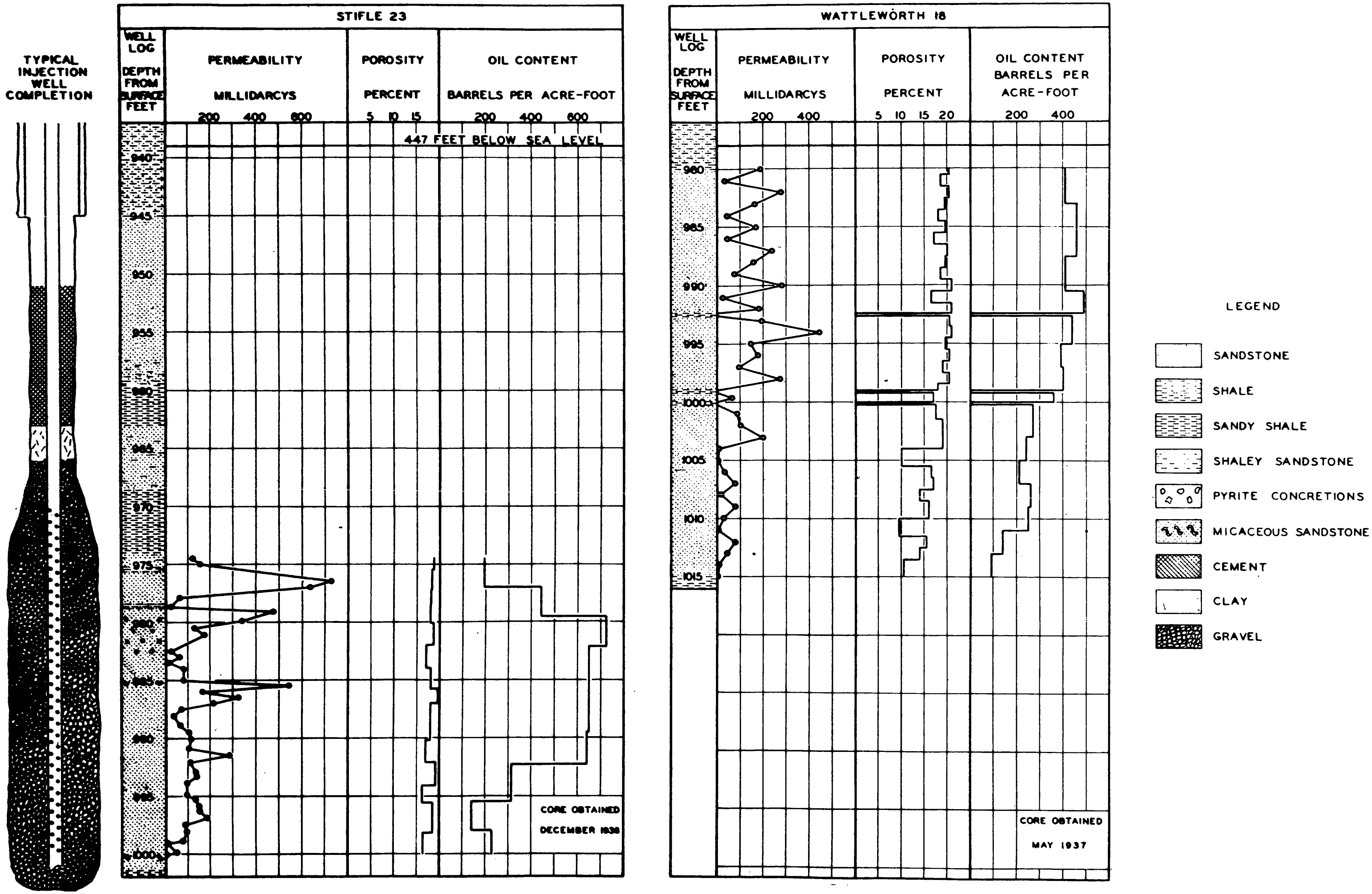

FIGURE 2.- Analyses of Robinson-sand cores from wells in sec. 10, T. 7 N., R. 13 W., Crawford County, Ill.

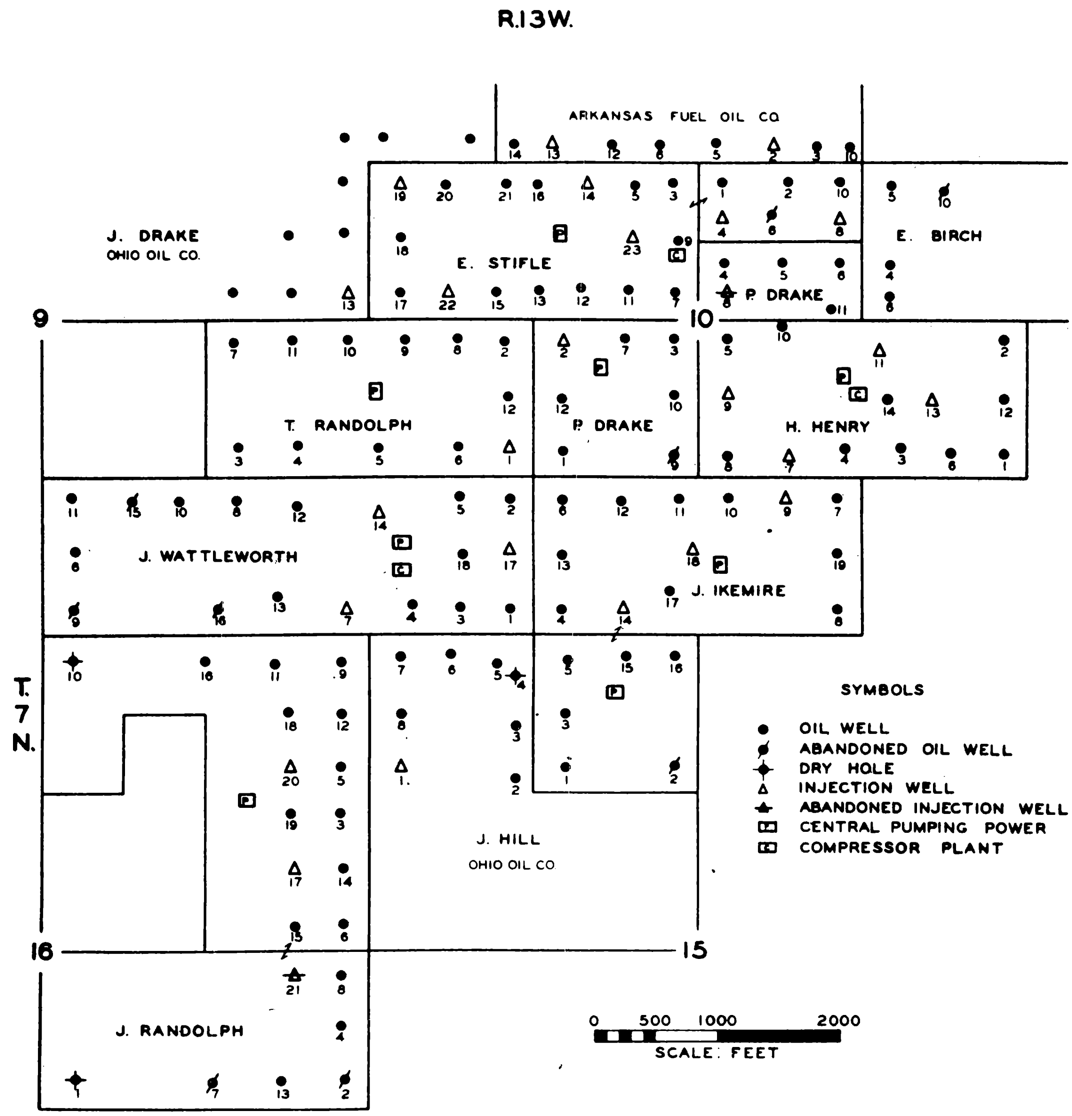

FIGURE 3.- Map of Tide Water Associated Oil Co. Henry gas-injection project, Crawford County, Ill., July 31, 1943.

Shale breaks from 10 to 40 feet in thickness separate the lenses, and one to three mica and shale streaks, 1 to 6 inches thick, frequently are found in the two lenses containing oil, further subdividing the sand.

Porosity, permeability, and oil-saturation profiles shown in figure 2 constitute the available core-analysis data. The average porosity of the cores was 17.9 percent. The permeability of the core samples averaged 123 millidarcys and ranged as high as 729 millidarcys. The average oil saturation of the sand varied widely but probably did not exceed 35 percent of the average pore volume.

Development

A surface map indicating the extent of development of the eight leases comprising the Henry project on July 31, 1943, is shown in figure 3. Air- and gas-injection wells on adjacent leases north and south of the project also are shown because they affect the operation. The location of closely spaced wells along lease lines with inside areas left undrilled are features common to many areas in the Robinson field, as are the numerous dry holes and early abondonments.

Development of the Henry project was begun in September 1932 and proceeded slowly with the experimental injection of air into the Robinson sand through an old oil well - Henry No. 9. The oil well was converted to an injection well by cleaning out the shot hole and setting a tubing packer above the top of the sand. Oil production from 2 of the 11 wells on the Drake lease increased 400 percent for the remainder of 1932 as a result of the injection of air. Injection through Henry well No. 9 was discontinued early in 1933, and in June 1933 Drake well No. 2 was selected as an input well for further experimentation. The number of wells affected by this injection is not known, but production from the Drake lease in 1933 was double that of the previous year. At least one well on the T. Randolph lease also benefited by the injection. Neither injection well was used again for over a year.

For the purpose of this report development of the Henry project is considered to have started in May 1934 with the injection of air into Stifle well No. 8. By the end of 1934 eight injection wells, affecting an area estimated at 130 acres, were in operation. Subsequent development to August 1, 1943, is shown in table 3. On that date there were 21 active injection wells, which had affected 555 acres or 79 percent of the total productive area of the leases included in this project.

Well-Completion Methods

All but three oil wells on the Henry project were drilled about 35 years ago and shot with 2 to 4 quarts of nitroglycerin per foot of sand. Ten-inch drive pipe usually was set at 90 feet, 8-1/4-inch casing was set at approximately 400 feet, and an oil string of 6-1/4-inch casing was set about 25 feet above the first Robinson lens (the gas sand) at 875 feet. No change was made in the casing program for oil wells when gas injection was begun. All of the oil wells are pumped through 2-inch tubing by three central powers, and a vacuum on the sand is pulled through the casing of most oil wells by the same compressors that supply the air-gas mixture under pressure to the injection wells.

TABLE 3. - Development of the Tide Water Associated Oil Co. Henry project

Date	Affected area, acres	Active gas-injection wells: Number	Active gas-injection wells: Spacing,1/ acres per well	Active oil wells: Number	Active oil wells: Spacing,1/ acres per well	Compressors in operation	Remarks
Jan. 1, 1935	130	8	87.5	103	6.8	2	8 oil wells were converted to injection wells prior to 1935.
Jan. 1, 1936	190	10	70.0	101	6.9	2	2 oil wells were converted to injection wells in 1935.
Jan. 1, 1937	305	2/15-1/2	45.2	96	7.3	3	5 oil wells were converted to injection wells (1 in 1937) and 1 oil well was drilled in 1936.
Jan. 1, 1938	420	2/17	41.2	98	7.1	3	1 oil well was converted to an injection well and 2 oil wells were drilled in 1937.
Jan. 1, 1939	460	18	38.9	97	7.2	3	1 oil well was converted to an injection well in 1938.
Jan. 1, 1940	465	18	38.9	97	7.2	3	
Jan. 1, 1941	465	18	38.9	97	7.2	3	
Jan. 1, 1942	505	18	38.9	93	7.5	3	3 oil wells were converted to injection wells, 1 injection well was converted to an oil well, and 2 oil wells and 2 injection wells were abandoned in 1941.
Jan. 1, 1943	535	18	38.9	93	7.5	3	
Aug. 1, 1943	555	21	33.3	90	7.8	3	3 oil wells were converted to injection wells in 1943.

1/ Computed for a productive area of 700 acres.
2/ Offset operations added 1/2 injection well in both 1936 and 1937.

All gas-injection wells are old oil wells. In the early stages of the project's development, the conversion from an oil well to an injection well was accomplished by cleaning out the shot hole and setting a burlap packer (on 2-inch tubing) below the 6-1/4-inch casing seat and above the top Robinson lens. This method seldom was successful because the walls of the old oil wells caved and prevented a tight seating of the packer. Only 4 of the injection wells are completed in this manner at the present time. The tubing and oil strings were removed from 5 other wells, the oil strings reset without packers, and air and gas injected through the casing. The remainder of the injection wells (12 wells) were completed with 2-inch tubing cemented in place. A normal completion of this kind included setting on bottom a string of 2-inch tubing, which had the lower 10 to 20 feet perforated, and filling the shot hole with gravel to a point above the top perforations. A 1- to 2-foot clay bridge was added and the tubing cemented with 6 to 8 sacks of cement.

Operating Practice

Three Ingersoll-Rand, horizontal compressors furnish compressed air and gas for the Henry project. Two of the compressors have been converted from two-stage to low-stage compression and compress only the return air-gas mixtures from oil wells. The third compressor has two stages (11- by 5-1/2- by 16-inch); the smaller cylinder is used to supply air to injection wells on the J. Randolph lease, and the low-pressure cylinder is used to compress air-gas mixtures produced by part of the oil wells. A vacuum of about 18 inches of mercury is pulled on the oil sand in most of the oil wells by the low-pressure cylinders at the three compressor plants, and the air-gas mixture is discharged to the pressure system at 60 to 70 pounds per square inch. Traps to collect scale and water have been installed in the vacuum lines at the three plants in addition to the customary water-trap installations on the discharge lines of the compressors.

Initial injection of air into the Robinson sand was begun in May 1934, but the produced gas was not recycled until 9 months later, when the operator determined that the air-gas mixture produced by the oil wells was not explosive. Since 1935 the volume of air-gas mixture produced on the Henry project has not been sufficient to supply all of the injection wells, therefore only air has been introduced into the oil sand under the J. Randolph lease. Fuel requirements of central power and compressor engines and losses in the reservoir have made it necessary to supplement the recycled mixture with air for 2 or 3 months each year.

The low injection pressures on this project have not caused excessive channeling of the injection medium through the sand. One well on the J. Randolph lease, where injection pressures are higher, has been disconnected from the vacuum system because channeling could not be controlled.

TABLE 4. - Volumes of gas injected[1] and oil produced by months - Tide Water Associated Oil Co. Henry Project
(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60°F.)

	1934		1935		1936		1937		1938	
	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.
January..			9,765	2,615	10,757	2,209	12,916	4,016	9,639	3,652
February.			8,700	2,647	10,108	1,811	12,294	4,010	11,109	3,337
March....			10,058	3,213	14,546	2,236	14,494	4,621	12,901	3,407
April....			7,162	3,098	14,031	2,590	11,161	4,486	12,914	4,044
May......	2,770	1,732	6,648	2,960	17,097	3,117	15,223	4,581	12,660	4,248
June.....	8,160	1,665	5,906	2,906	17,150	3,358	12,480	4,345	12,748	3,877
July.....	)	2,095	5,420	2,865	17,328	3,548	12,946	3,999	13,565	4,068
August...	)	2,503	5,455	2,692	14,911	3,360	13,304	4,530	13,276	3,945
September	)2/56,488	2,555	8,188	2,539	15,032	2,948	14,551	4,055	11,880	3,670
October..	)	2,535	7,905	2,665	13,742	3,138	13,242	4,162	12,400	3,709
November.	)	2,405	7,725	2,588	12,676	3,204	14,993	3,822	10,315	3,675
December.	)	2,445	8,959	2,519	12,369	3,496	20,915	3,698	10,279	3,483
Total.	2/67,418	17,935	91,891	33,307	169,747	35,015	168,519	50,325	143,686	45,115

1/ Volumes of gas computed from occasional tests.
2/ Estimated.

TABLE 4. - Volumes of gas injected[1/] and oil produced by months - Tide Water Associated Oil Co. Henry Project
(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60°F.) (Cont'd.)

	1939		1940		1941		1942		1943	
	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.
January..	8,484	2,735	)	2,717	8,029	3,110	)	3,007	9,037	3,321
February.	7,940	2,520	)2/24,300	2,457	7,282	2,663	)2/25,980	2,852	8,900	2,848
March....	8,800	2,777	)	2,761	8,129	3,104	)	3,068	10,013	3,213
April....	8,471	2,805	8,022	2,711	7,759	2,868	8,597	2,782	9,679	3,024
May......	8,852	3,017	)	2,996	)	3,048	)	2,938	10,075	3,143
June.....	9,620	2,726	)	3,003	)	2,777	)	2,851	11,160	3,009
July.....	9,570	2,836	)	3,236	)	3,025	)	3,029	13,298	3,124
August...	8,933	2,793	)2/64,680	3,180	)2/69,100	3,003	)2/65,028	3,016		
September	8,820	2,934	)	3,004	)	3,023	)	3,180		
October..	8,885	3,027	)	3,196	)	3,255	)	3,319		
November.	8,250	2,620	)	3,065	)	3,127	)	3,310		
December.	8,525	2,578	)	3,076	)	3,275	)	3,262		
Total.	105,150	33,368	2/97,002	35,402	2/100,299	36,278	2/99,605	36,614	72,162	21,682

1/ Volumes of gas computed from occasional tests.
2/ Estimated.

The rate at which air or air-gas mixture is injected into each well is controlled by a globe or gate valve in a 1/4-inch bypass around a stop on the upstream side of the meter run at each well. Meter runs consist of 2-inch pipe, flange taps, and flanges containing either 3/8- or 1/2-inch orifice plates. The static pressure and pressure differential across the orifice plate in each meter run are measured about once each month with a pressure gage and a manometer, and the rate of injection is computed. Recently flow measurements have been made weekly to permit closer control of the injection rate.

Minor corrosion problems, common to this area, have not been aggravated perceptibly by the injection of air. Well records indicate that the casing and tubing in several wells have been replaced once or twice before air-gas injection was begun. The corrosion resulting in those replacements was caused by small amounts of hydrogen sulfide in the presence of water.

Orsat analyses of air-gas mixtures produced by six oil wells nearest the injection wells on the J. Randolph lease were made October 22, 1943. These analyses show that the gas contained unusually large amounts of carbon dioxide (see table 5). Although some oxidation of the oil may have occurred, the operator reported that no trouble has been experienced with the plugging of sand faces in the producing wells by the precipitation of insoluble residues.

TABLE 5. - Orsat analyses of gas produced from oil wells in the Robinson field - Henry project, J. Randolph lease

Well No.	Percent by volume of sample analyzed	
	O_2	CO_2
3	10.6	7.6
5	10.8	7.0
6	.2	8.0
12	3.7	13.7
14	2.8	4.8
15	5.3	8.4

The air-gas mixtures tested were produced from oil wells selected because of their proximity to the injection wells being supplied air on the Henry project. The operator considered none of the mixtures explosive, and these mixtures, as well as produced by 16 other wells, were being compressed for injection. An analysis of the air-gas mixture on the discharge side of the compressor revealed that 5.2 percent of the sample was oxygen and 7.7 percent carbon dioxide. The percentage of excess nitrogen in this sample was not determined, but the proportion of natural gas in the injection medium probably was 50 percent or less.

The general characteristics and distillation analysis of a crude-oil sample taken from a run tank on the Henry lease are shown in table 6. The gravity of the oil is 35.2° A.P.I., and the viscosity at a formation temperature (measured in June 1943) of 84° F. is 52 seconds Saybolt Universal, or 6.8 centipoises.

TABLE 6. - Chemical and physical properties of crude oil produced on Tide Water Associated Oil Co. Henry project from Robinson sand

GENERAL CHARACTERISTICS

Sulfur, percent, 0.19
Saybolt Universal viscosity at 100°F., 47 sec.
Saybolt Universal viscosity at 84°F., 52 sec.

Specific gravity, 0.849
A.P.I. gravity, 35.2°
Color, greenish black

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 752 mm. First drop, 26°C. (79°F.)

Fraction No.	Cut °C.	at- °F.	Per- cent	Sum, per- cent	Sp. gr., 60/60°F.	°A.P.I., 60°F.	C.I.	S.U. visc., 100°F.	Cloud test, °F.
1	50	122	1.8	1.8)					
2	75	167	2.3	4.1)	0.659	83.2	-		
3	100	212	5.4	9.5	.715	66.4	19		
4	125	257	6.1	15.6	.739	60.0	21		
5	150	302	5.1	20.7	.758	55.2	23		
6	175	347	4.9	25.6	.777	50.6	25		
7	200	392	4.7	30.3	.795	46.5	27		
8	225	437	4.8	35.1	.812	42.8	30		
9	250	482	5.8	40.9	.826	39.8	31		
10	275	527	6.4	47.3	.839	37.2	32		
Distillation continued at 40 mm.									
11	200	392	2.8	50.1	0.852	34.6	35	41	15
12	225	437	5.6	55.7	.860	33.0	35	47	35
13	250	482	5.3	61.0	.871	31.0	37	60	50
14	275	527	5.4	66.4	.883	28.8	39	95	65
15	300	572	5.9	72.3	.895	26.6	42	180	90
Residuum			27.6	99.9	0.954	16.8			

Carbon residue of residuum, 7.5 percent; carbon residue of crude, 2.1 percent.
Base of crude: Intermediate

APPROXIMATE SUMMARY

	Percent	Sp. gr.	°A.P.I.	Viscosity
Light gasoline	9.5	0.691	73.3	
Total gasoline and naphtha	30.3	0.742	59.2	
Kerosine distillate	10.6	.820	41.1	
Gas oil	13.3	.848	35.4	
Nonviscous lubricating distillate	9.9	.862-.884	32.7-28.6	50-100
Medium lubricating distillate	6.6	.884-.898	28.6-28.1	100-200
Viscous lubricating distillate	1.6	.898-.901	26.1-25.6	Above 200
Residuum	27.6	.954	16.8	
Distillation loss	.1			

Results

The cumulative oil production, before the initial injection of air in May 1934, has been estimated at 125 barrels per acre-foot. From May 1934 through July 1943 the total recovery of oil was 20 barrels per acre-foot. By assuming that none of the eight leases forming this project would have exceeded its economic limit of operation by the end of July 1943, the oil gained by air and gas injection amounted to 12 barrels per acre-foot. The oil gained each year for a calculated normal decline in the production rate of 4.85 percent per year is given in table 7. The decline rate was calculated for the period of settled oil production between the years 1923 and 1932 (see fig. 4).

TABLE 7. - Oil-production statistics - Henry project

Year	Oil production, bbl.		Estimated oil gained, bbl.
	Normal decline	Actual	
1934 1/...	12,129	17,935	5,806
1935.....	17,311	33,307	15,996
1936.....	16,471	35,015	18,544
1937.....	15,672	50,325	34,653
1938.....	14,912	45,115	30,203
1939.....	14,189	33,368	19,179
1940.....	13,501	35,402	21,901
1941.....	12,846	36,270	23,424
1942.....	12,223	36,614	24,391
1943 2/...	6,784	21,682	14,898
	136,038	345,033	208,995

1/ Last 8 months. 2/ First 7 months.

Oil production by leases is illustrated graphically in figure 5. The degree to which the leases responded to air and gas injection generally appears to have been in the order of their past productivities. The Henry lease was the most prolific and had the greatest increase in oil recovery. The T. Randolph lease showed the greatest improvement, moving in rank from eighth in primary recovery of oil to fourth in percentage recovery during air and gas injection.

Between May 1934 and August 1943 approximately 1,115,500,000 cubic feet of air and gas were injected into the Robinson sand at a differential pressure of about 50 pounds per square inch between injection and oil wells. During this period 3,230 cubic feet of air and gas were injected for each barrel of oil produced, or 5,340 cubic feet for each barrel of oil gained by the injection. The driving medium was injected at an average daily rate of 650 cubic feet per vertical foot of sand, per injection well. The volume of oil gained by the air and gas drive was 299 barrels per acre. An estimate of the oil recovery indicated that 65 percent or more of the original oil content of the sand, measured at stock-tank conditions, had not been recovered on August 1, 1943.

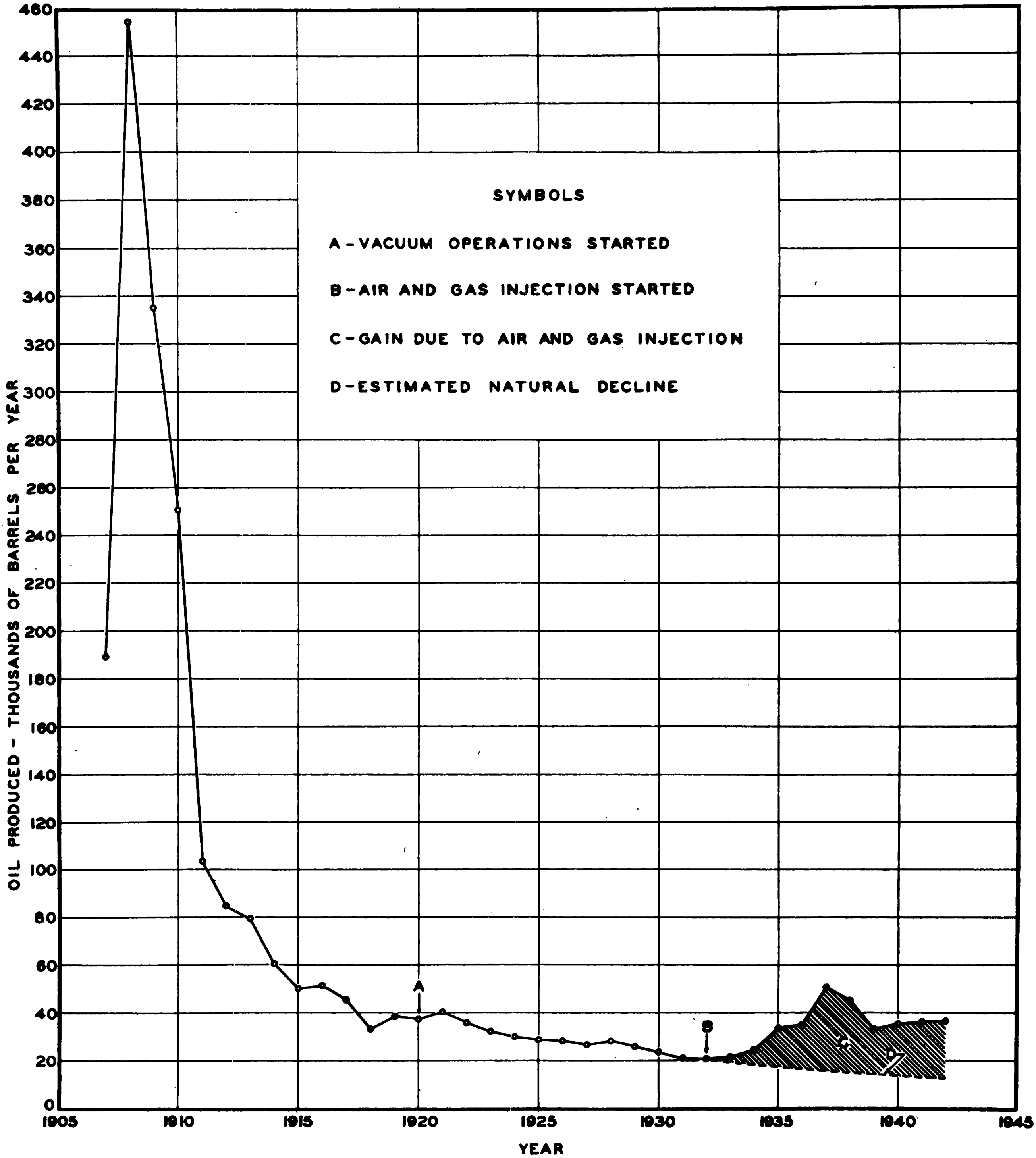

FIGURE 4.- Production-decline curve, Tide Water Associated Oil Co., Henry project, Crawford County, Ill.

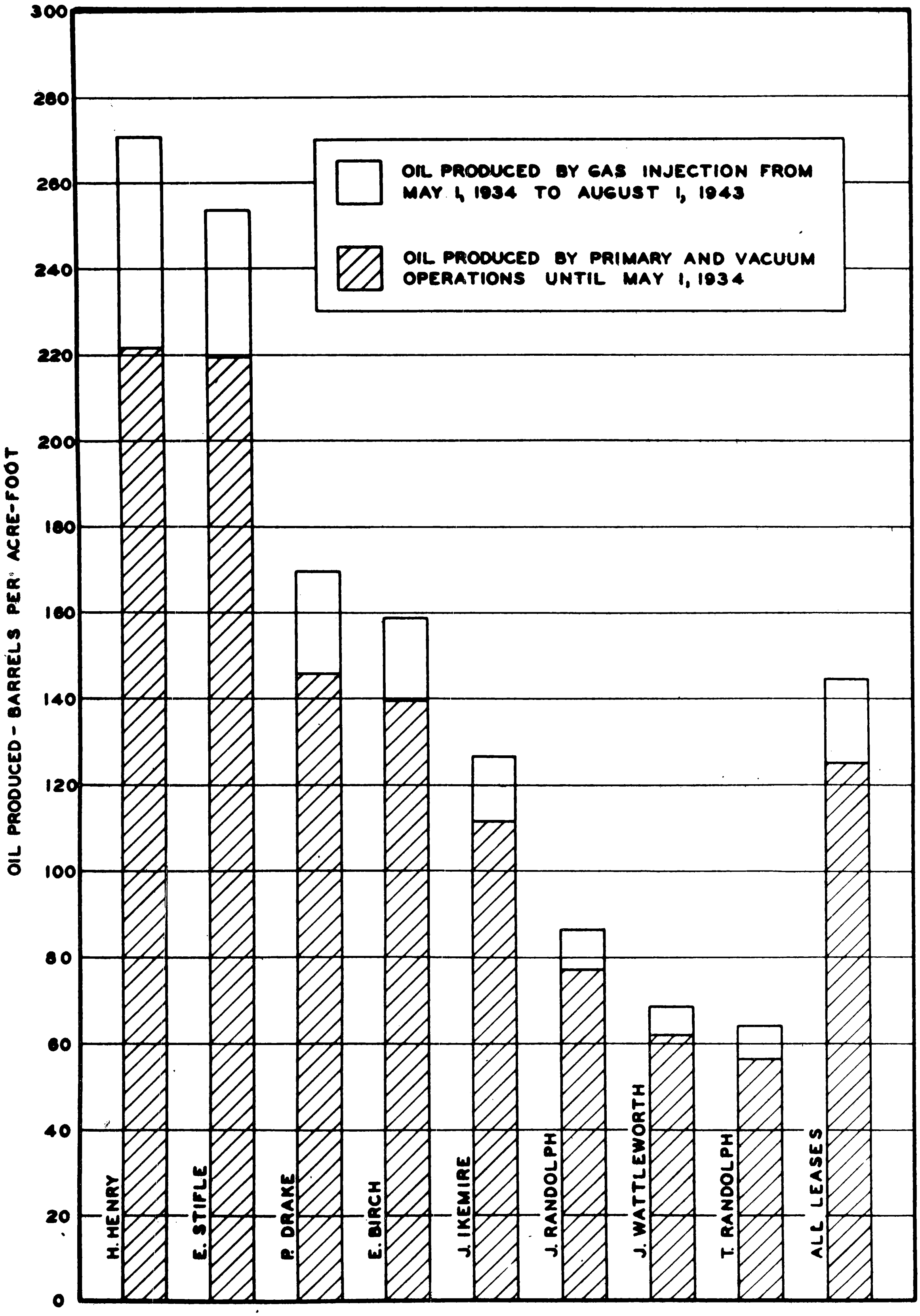

FIGURE 5.- Comparative oil production by leases before and after gas injection, Henry project, Crawford County, Ill.

TABLE 8. - Summary of operations for the Tide Water Associated Oil Co. Henry project, Crawford County, Ill.

Year	Gas injected[1/] M cu. ft.	Average injection pressure, lb. per sq. in.	Average vacuum on oil wells, lb. per sq. in.	Ratio of oil wells to injection wells	Estimated area affected, acres	Cumulative oil production, bbl. per acre	Estimated cumulative oil gained, bbl. per acre	Ratio of gas injected to oil produced, cu. ft. per bbl.	Ratio of gas injected to oil gained, cu.ft.per bbl.	Horsepower of compressor prime movers
1934[2/]	67,418	42	8	12.9	130	25.6	8.3	3,760	11,610	140
1935	91,891	35	8	10.1	190	73.2	31.1	2,760	5,740	140
1936	169,747	49	8	6.2	305	123.2	57.6	4,850	9,150	230
1937	168,519	41	8	5.8	420	195.1	107.1	3,350	4,860	230
1938	143,686	47	8	5.4	460	259.6	150.3	3,180	4,760	230
1939	105,150	44	8	5.4	465	307.2	177.7	3,150	5,480	230
1940	97,002	40	8	5.4	465	357.8	209.0	2,740	4,430	230
1941	100,299	34	8	5.2	505	409.6	242.4	2,770	4,280	230
1942	99,605	33	8	5.2	535	461.9	277.3	2,720	4,080	230
1943[3/]	72,162	35	8	4.3	555	492.9	298.6	3,330	4,840	230
Total ..	1,115,479					492.9	298.6			
Average.		40	8					3,230	5,340	

1/ Computed from occasional tests. 2/ Last 8 months of 1934 3/ First 7 months of 1943.

Tide Water Associated Oil Co. reported that the development cost for the Henry project was about $50.00 per acre. Absence of an extensive drilling program and the saving realized by using salvaged and second-hand materials are reflected in the low cost. The same development would require more capital if it were attempted with the advanced cost of labor and material that prevailed in 1943.

The Ohio Oil Co. Warnock Project

The Ohio Oil Co. Warnock gas-injection project in the Robinson oil field, Crawford County, Ill., encloses an oil-productive area of 630 acres. The Robinson sand is at an average depth of 893 feet, and is 13 to 50 feet thick.

History

The leases comprising the Warnock project were originally developed between 1906 and 1916. Of 118 wells drilled during the original development of these leases, 29 wells either were nonproductive when drilled or were abandoned as noncommercial oil producers within a few years after they were drilled. Completed wells flowed at an initial daily rate of 1 to 200 barrels of oil and averaged approximately 40 barrels. It was necessary to pump most of the oil wells within 1 month after completion which indicated that the original reservoir pressure was low. By 1925 the daily oil production had decreased to an average of 0.63 barrel per well. The Robinson sand was subjected to vacuum the following year (1926), and although a small increase in the oil-producing rate was observed the more important immediate benefit was the increase in production of "wet" gas. Vacuum operations were maintained after gas injection was begun in 1936, and in July, 1943, approximately half of the oil wells still were on vacuum.

Characteristics of Oil Sand

No wells were drilled on the leases included in the Warnock project after 1916, therefore core-analysis information was not available. Consistent results of the analyses of core samples of the reservoir in other parts of the field indicate that the Robinson sand will average 25 feet in thickness. The porosity of the sandstone ranged from 17 to 19 percent. The permeability of the samples ranged from 0 to 2 darcys and averaged over 100 millidarcys.

Development

A map giving the location of producing and injection wells on the leases included in the Warnock project on July 31, 1943, is shown as figure 6. The undrilled areas, the large number of abandoned wells, and the lack of uniform spacing of oil wells prevented the development of repeating spacing patterns when gas injection was begun.

Air first was injected into the Robinson sand through Warnock fee well No. 4, an old oil well, on May 16, 1936. The injection affected offset producing wells within 1 month. Other oil wells were converted to injection

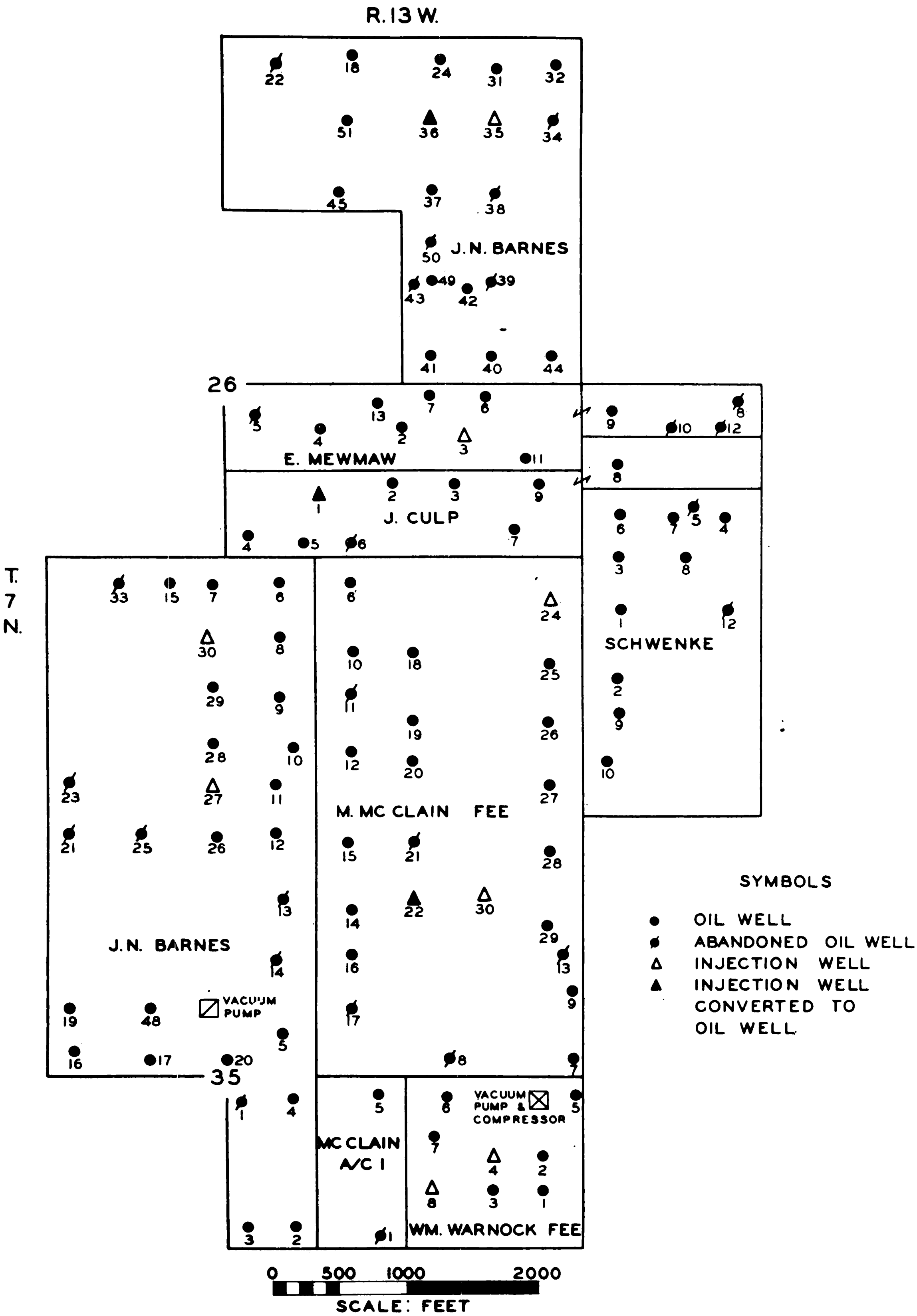

FIGURE 6.- Map of The Ohio Oil Co. Warnock gas-injection project, Crawford County, Ill., July 31, 1943.

wells, and by the end of 1936 six injection wells, spaced 105 acres per well, were in operation. The yearly status of the development of the project is given in table 9. On August 1, 1943, air was being injected through eight wells, spaced 78.8 acres per well, and had affected an area estimated to be 300 acres, or 48 percent of the productive area of the properties included in the Warnock project.

Well-Completion Methods

No wells have been drilled on the leases comprising the Warnock project since 1916, and oil wells are cased as they were originally - 10-inch drive pipe set at an average depth of 77 feet, 8-1/4-inch pipe set at an average depth of 386 feet, and 6-1/4-inch pipe set approximately 35 feet above the top of the Robinson sand at an average depth of 858 feet. The producing wells are equipped with 2-inch tubing and pumped by central powers. Eighty-one oil wells, spaced 7.8 acres per well, were active on July 31, 1943.

Injection wells are converted oil wells with no change in the casing program except to replace corroded pipe with new pipe. The oil sand in converted wells originally was shot with 2 to 4 quarts of nitroglycerin per foot of sand, but no additional explosives were used because shot holes had become enlarged by caving over a period of 20 to 30 years. During conversion shot holes were cleaned out, and a 2- by 10- by 6-1/4-inch anchor packer was run in the hole on 2-inch tubing. The packer was set in the lower part of the 6-1/4-inch casing, and a perforated anchor on the tubing (set on bottom) was placed opposite the sand face. Perforated anchors in injection wells are approximately 4 feet in length.

Operating Practice

A vacuum pump and compressor plant is located on the Warnock lease, and a second vacuum pump is housed on the Barnes lease. Both vacuum pumps (22- by 8-inch) are belt-driven by 35 horsepower gas engines. The pumps pull a vacuum ranging from 25 to 27 inches of mercury on about half of the oil wells on the project and discharge into a fuel line at a pressure of 1 to 2 pounds per square inch. A trap to remove scale and water is on the intake side of each pump. During the first 5 years of gas injection the quantity of air-gas mixture produced was adequate for fuel and reinjection, although it was necessary to supplement the mixture with air several months each year. Since 1941 the oil wells on vacuum have produced only enough gas to provide fuel for central-power, compressor, and vacuum-pump engines, and air has been used exclusively as the injection medium. The air-gas mixtures produced by the other oil wells are deficient in gas and are vented to the atmosphere.

TABLE 9. - Development of The Ohio Oil Co. Warnock project

Date	Estimated area affected, acres	Active gas-injection wells		Active oil wells		Compressors in operation	Remarks
		Number	Spacing,1/ acres per well	Number	Spacing,1/ acres per well		
Jan. 1, 1937	240	6	105.0	83	7.6	1	8 oil wells were converted to injection wells and 2 injection wells converted to oil wells in 1936.
Jan. 1, 1938	280	7	90.0	82	7.7	1	1 oil well was converted to an injection well in 1937.
Jan. 1, 1939	300	8	78.8	81	7.8	1	1 oil well was converted to an injection well in 1938.
Jan. 1, 1940	300	8	78.8	81	7.8	1	
Jan. 1, 1941	300	8	78.8	81	7.8	1	
Jan. 1, 1942	300	9	70.0	80	7.9	1	1 oil well was converted to an injection well in 1941.
Jan. 1, 1943	300	8	78.8	81	7.8	1	1 injection well was converted to an oil well in 1942.
Aug. 1, 1943	300	8	78.8	81	7.8	1	

1/ Computed for a productive area of 630 acres.

An Ingersoll-Rand two-stage compressor (8-1/2- by 4-1/2- by 10-inch), belt-driven by a 35-horsepower gas engine, provides compressed air for the project at a discharge pressure of approximately 160 pounds per square inch. The compressed air is inter- and after-cooled by discharging the air through water-cooled coils of 2-inch pipe, and water condensed from the air is removed in two stages by passing the cooled air through traps originally used in the extraction of gasoline from the produced gas. Compressed air is distributed from the high-pressure trap to the injection wells at approximately atmospheric temperature.

Since air first was introduced into the Robinson sand in May 1936 the injection pressure has averaged 106 pounds per square inch. At this pressure each injection well has affected an area of about 40 acres of sand, or approximately twice the area affected by injection wells on those projects in the Robinson field where injection pressures range from 25 to 40 pounds per square inch. Core analyses of the oil sand under the Warnock project are not available, but analyses of core samples from other parts of the field indicate that the permeability of the sand probably will average 125 millidarcys. In such a permeable sand, therefore, the high injection pressures used on the Warnock project have caused channeling of the injection medium to several of the producing wells, and it has been necessary to disconnect these wells from the vacuum system. Control over channeling has been made possible, to some extent, by reducing the injection rates of injection wells responsible for the channeling.

Six injection wells have 18-foot meter runs of 2-inch pipe, and two wells are equipped with 21-foot meter runs. The 21-foot meter runs are provided with 6-1/4-inch traps to collect water present in the injection medium and are located below the meter runs which are elevated about 2-1/2-feet above the surface of the ground. A 1/4-inch bypass around a stop on the upstream side of each meter run includes a gate valve to regulate the rate of flow of injection medium. Flanges, flange taps, and either 1/8- or 1/4-inch orifice plates are part of the meter runs. Flow measurements are made monthly with a portable manometer and pressure gage, and the rate of injection is computed. Volumes of gas injected and oil produced monthly are given for the gas-injection period in table 10. Gas-injection figures are estimations based on recommendations of the operators' personnel, or they are interpolations of available data.

The use of air as an injection medium does not seem to have increased the rate of corrosion of subsurface and surface equipment. Corrosion of equipment before air injection was caused by water and small quantities of hydrogen sulfide associated with the oil and gas in the reservoir.

TABLE 10. - Volumes of gas injected[1/] and oil produced by months - The Ohio Oil Co. Warnock project

(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1936		1937		1938		1939	
	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.
January...			1,872	1,144	725	1,330	2,201	873
February..			1,694	952	770	1,031	2,005	799
March.....			1,931	994	992	1,030	2,378	770
April.....			645	1,044	1,524	1,288	2,292	940
May.......	125	1,023	961	1,358	2,102	1,081	1,279	749
June......	195	824	789	1,106	2,076	1,085	1,449	757
July......	1,093	833	1,237	1,380	2,108	1,359	1,345	957
August....	1,595	1,038	1,111	1,094	1,767	1,117	1,311	756
September.	1,387	832	1,124	1,096	1,872	1,124	1,161	951
October...	1,739	1,078	1,107	1,365	1,479	1,414	689	754
November..	1,677	882	845	1,088	1,077	1,176	1,235	757
December..	1,026	880	666	1,097	1,922	1,396	1,185	952
Total..	8,837	7,390	13,982	13,718	18,414	14,431	18,530	9,925

See footnotes on page 35.

TABLE 10. - Volumes of gas injected[1] and oil produced by months - The Ohio Oil Co. Warnock project (Cont'd.)
(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1940		1941		1942		1943	
	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.	Gas injected, M cu. ft.	Oil produced, bbl.
January...	)	756	)	959	)	1,269	2,877	1,012
February..	)	773	)	984	)2/5,640	1,032	2,372	1,008
March.....	)	967	)2/7,500	1,286	)	1,038	2,362	1,301
April.....	)	772	)	1,034	2,102	1,047	2,658	1,055
May.......	)	849	1,975	1,293	1,905	1,313	2,771	1,031
June......	)2/18,100	1,164	2,104	1,037	1,478	1,053	1,931	1,273
July......	)	921	2,060	1,038	1,813	1,046	2,765	1,043
August....	)	1,128	2,000	1,302	1,630	1,314		
September.	)	908	1,844	1,049	1,446	1,032		
October...	)	914	1,649	1,052	2,409	1,268		
November..	)	1,145	1,680	1,310	2,668	1,016		
December..	)	935	1,760	1,045	2,605	1,281		
Total..	2/18,100	11,232	22,572	13,389	23,696	13,709	17,736	7,723

1/ Volumes of gas computed from occasional tests.
2/ Estimated.

The injection of air into the Robinson sand has caused some oxidation of the oil, but no study was made to determine the extent of oxidation. Soon after the initial injection of air in 1936, the injection medium channeled to Mewmaw well No. 3 and an analysis of the produced gas showed the carbon dioxide content to be 14.2 percent by volume. The well was not produced after December 1936 but has not been plugged. Analyses of samples of the gas produced by all oil wells in 1937 showed a maximum carbon dioxide content of 3.4 percent. Recent Orsat analyses of the produced gas indicated that the amount of carbon dioxide present in a composite sample had increased to 4.9 percent. Analyses of the gas produced by individual wells supplying part of the composite sample in November 1943 are given in table 11.

TABLE 11. - Orsat analyses of gas produced from oil wells in the Robinson field - Warnock project

Lease	Well No.	Percent by volume of sample analyzed	
		O_2	CO_2
J. N. Barnes	6	13.4	6.6
Do.	24	3.9	11.9
Do.	26	12.0	1.6
Do.	29	13.6	1.8
Do.	31	.2	.4
Do.	32	9.2	7.0
Do.	36	.3	.6
J. Culp	7	5.6	3.6
M. McClain, fee ...	25	11.0	1.4
Do.	28	8.9	7.4
Do.	29	10.8	.6
E. Mewmaw	7	2.0	7.8
Do.	11	.6	1.4
Schwenke	1	2.8	1.6
Wm. Warnock, fee ..	3	6.4	6.6
Do.	7	7.7	10.0

When the tests were made, none of the oil wells listed in table 11 were producing mixtures of air and gas that are considered explosive by the operator. The mixtures were not recycled, however, because the volume produced was inadequate for both fuel and injection. An analysis of a composite sample of air-gas mixture taken from the discharge side of a vacuum pump showed that 5.0 percent of the sample was oxygen and 4.9 percent carbon dioxide.

The general characteristics and distillation analysis of a sample of crude oil from a run tank on the J. N. Barnes lease are given in table 12. The gravity of the oil is 33.8° A.P.I., and the viscosity at a formation temperature (measured in June 1943) of 84° F. is 59 seconds Saybolt Universal, or 8.5 centipoises.

TABLE 12. - Chemical and physical properties of crude oil produced on The Ohio Oil Co. Warnock project from Robinson sand

GENERAL CHARACTERISTICS

Sulfur, percent, 0.17
Saybolt Universal viscosity at 100°F., 53 sec.
Saybolt Universal viscosity at 84°F., 59 sec.

Specific gravity, 0.856
A.P.I. gravity, 33.8°
Color, greenish black

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 753 mm. First drop, 31°C. (88°F.)

Fraction No.	Cut °C.	at- °F.	Percent	Sum, percent	Sp. gr., 60/60°F.	°A.P.I., 60°F.	C.I.	S.U. visc., 100°F.	Cloud test, °F.
1	50	122	0.5	0.5)					
2	75	167	2.2	2.7)	0.675	78.1	-		
3	100	212	2.9	5.6	.723	64.2	23		
4	125	257	5.1	10.7	.740	59.7	22		
5	150	302	5.4	16.1	.757	55.4	22		
6	175	347	5.5	21.6	.775	51.1	24		
7	200	392	5.0	26.6	.792	47.2	26		
8	225	437	5.3	31.9	.808	43.6	28		
9	250	482	5.8	37.7	.821	40.9	29		
10	275	527	7.0	44.7	.835	38.0	31		
Distillation continued at 40 mm.									
11	200	392	2.7	47.4	0.849	35.2	33	41	15
12	225	437	5.9	53.3	.856	33.8	33	46	30
13	250	482	6.3	59.6	.869	31.3	36	59	50
14	275	527	5.3	64.9	.881	29.1	38	93	65
15	300	572	6.9	71.8	.890	27.5	39	165	85
Residuum			28.0	99.8	.955	16.7			

Carbon residue of residuum, 8.0 percent; carbon residue of crude, 2.2 percent.
Base of crude: Intermediate

APPROXIMATE SUMMARY

	Percent	Sp. gr.	°A.P.I.	Viscosity
Light gasoline	5.6	0.700	70.6	
Total gasoline and naphtha	26.6	0.752	56.7	
Kerosine distillate	11.1	.815	42.1	
Gas oil	14.6	.845	36.0	
Noviscous lubricating distillate	10.6	.860-.882	33.0-28.9	50-100
Medium lubricating distillate	8.4	.882-.894	28.9-26.8	100-200
Viscous lubricating distillate	.5	.894-.895	26.8-26.6	Above 200
Residuum	28.0	.955	16.7	
Distillation loss	.2			

Results

The total oil produced by the Warnock project during primary and vacuum operations, to the beginning of gas injection in May 1936, was 1,334 barrels per acre. The cumulative oil production during gas injection to August 1, 1943, was 145 barrels per acre. An estimate of the oil gained as a result of gas injection was made by extrapolating a production-decline curve (see fig. 7) and computing the oil gained as the difference between actual oil production under gas injection and that expected under vacuum. An estimate of the quantity of oil gained each year for the gas-injection period between April 1936 and August 1943 is shown in table 13. The decrease in oil production during 1939 and 1940 was a result of State proration, which was in effect between February 1939 and December 1940.

TABLE 13. - Oil-production statistics - Warnock project

Year	Oil production, bbl.		Estimated oil gained, bbl.
	Normal decline	Actual	
1936 1/	6,240	7,390	1,150
1937	8,700	13,718	5,018
1938	8,100	14,431	6,331
1939	7,500	9,925	2,425
1940	6,950	11,232	4,282
1941	6,450	13,389	6,939
1942	6,000	13,709	7,709
1943 2/	3,200	7,723	4,523
Total	53,140	91,517	38,377

1/ Last 8 months. 2/ First 7 months.

Between May 1936 and August 1943, approximately 142,000,000 cubic feet of air and gas were injected into the Robinson sand at an average pressure of 106 pounds per square inch. A vacuum averaging 20 inches of mercury was maintained on over half of the oil wells, so that the average differential pressure between the injection pressure and the pressure in most of the oil wells has been 116 pounds per square inch. The ratio of cumulative gas injected to oil produced was 1,550 cubic feet per barrel or approximately 3,700 cubic feet of gas for each barrel of oil estimated to have been gained. The injection medium has been introduced at an average daily rate of approximately 340 cubic feet per foot of sand per injection well. The estimated volume of oil gained by gas injection was 61 barrels per acre. The cumulative oil production since 1906 was 1,479 barrels per acre.

The cost of developing the Warnock gas-injection project probably was less than that of the other three projects discussed in this report. No wells were drilled during the development of this project, which, in itself, was a major reduction in expense. Second-hand material and equipment were used when feasible, and the purchase of new equipment was held to a minimum. The investment per acre in developing a project today at the higher costs of labor and materials would be greater than the original investment on the Warnock project.

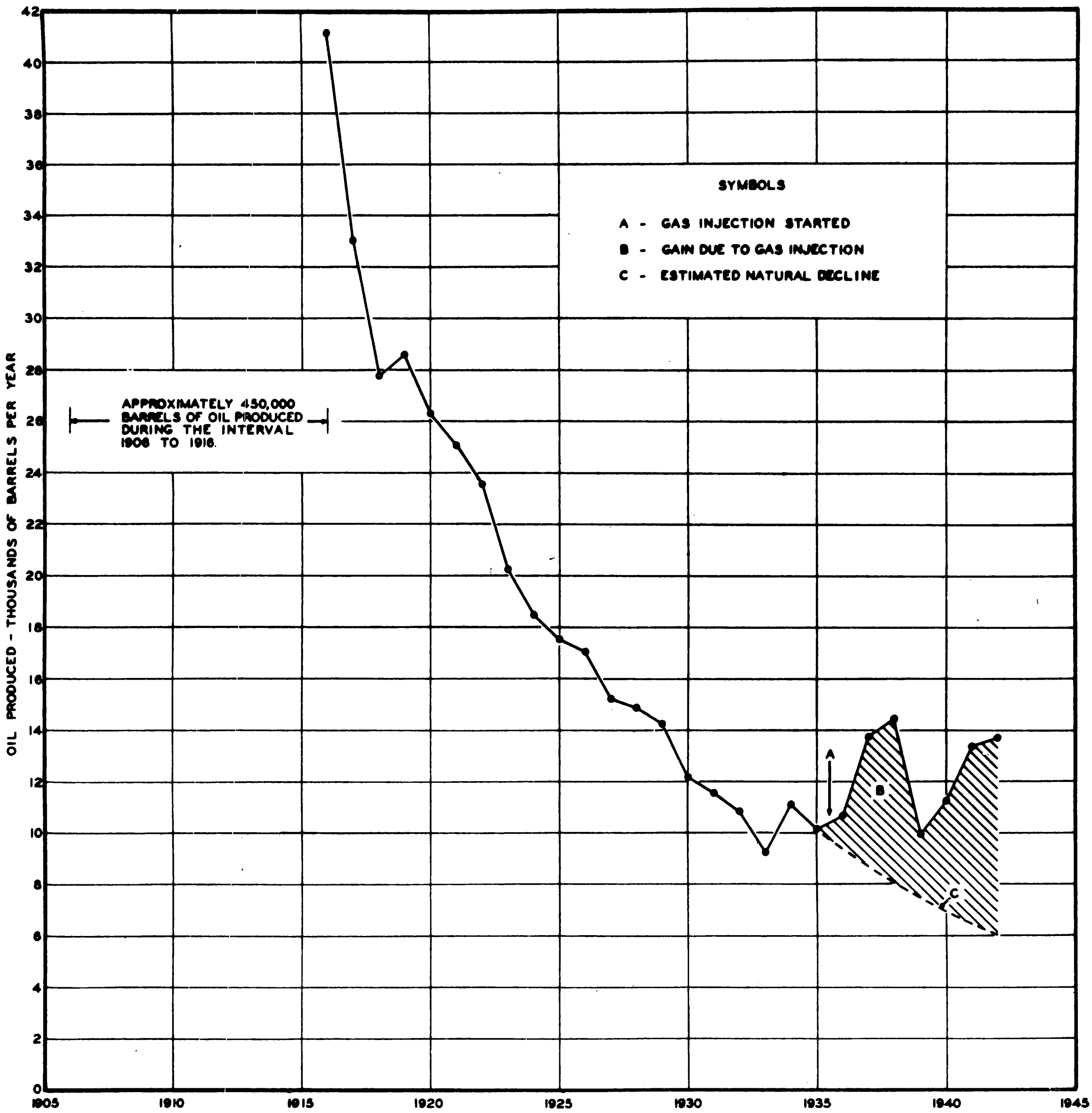

FIGURE 7.- Production-decline curve, The Ohio Oil Co., Warnock project, Crawford County, Ill.

TABLE 14. - Summary of operations for The Ohio Oil Co. Warnock project, Crawford County, Ill.

Year	Gas injected,1/ M cu. ft.	Average injection pressure, lb. per sq. inch	Injection-well spacing, acres per well	Oil-well spacing, acres per well	Estimated area affected, acres	Cumulative oil production, bbl. per acre	Cumulative oil gained, bbl. per acre	Ratio of gas injected to oil produced, cu. ft. per bbl.	Ratio of gas injected to oil gained, cu. ft. per bbl.	Horsepower of compressor and vacuum pump prime movers
1936 2/	8,837	80	105.0	7.6	240	11.7	1.8	1,200	8,500	105
1937	13,982	99	90.0	7.7	280	33.5	9.7	1,020	2,790	105
1938	18,414	103	78.8	7.8	300	56.4	19.7	1,280	3,050	105
1939	18,530	121	78.8	7.8	300	72.2	23.6	1,870	10,270	105
1940	18,100	119	78.8	7.8	300	90.0	30.4	1,610	5,430	105
1941	22,572	113	70.0	7.9	300	111.2	41.4	1,690	3,970	105
1942	23,696	104	78.8	7.8	300	133.0	53.6	1,730	3,850	105
1943 3/	17,736	108	78.8	7.8	300	145.3	60.8	2,300	5,210	105
Total	141,867					145.3	60.8			
Average		106						1,550	4,330	

1/ Computed from occasional tests.
2/ Last 8 months of 1936.
3/ First 7 months of 1943.

The Ohio Oil Co. Plymouth Project

The Ohio Oil Co. is injecting air into the Hoing sand in the Colmar and Plymouth oil fields of Hancock and McDonough Counties in west-central Illinois. The Hoing sand is at an average depth of 463 feet in the Colmar field and averages 12 feet in thickness. One and one-half miles southwest, in the Plymouth field, the sand occurs at an average depth of 430 feet and averages 11 feet in thickness.

The Hoing sand in each field was subjected to vacuum in 1926, before air-injection operations were begun, and a substantial increase in the rate of oil production was obtained. Air injection, which was begun in the Plymouth field in 1934 and in the Colmar field the following year, resulted in still greater rates of oil recovery. Oil production from each field has declined for the last few years at a rate exceeding the decline rate for the period preceding vacuum operations; the production rate in 1943, however, almost doubled that in 1925.

The distance between fields has made desirable the maintenance of separate compressor plants, centrally located with respect to each field. The old vacuum pipe-line systems were used, wherever feasible, for distribution of air to the various injection wells. Although secondary-recovery practices are identical, the available historical and operating data for each field will be presented separately. All but 200 acres of the Colmar oil field, with a productive area of approximately 1,600 acres, and the Plymouth oil field, with a productive area of 410 acres, are included in the two projects.

The Plymouth project lies in secs. 19 and 20, T. 4 N., R. 4 W., McDonough County, Ill., and sec. 24, T. 4 N., R. 5 W., Hancock County, Ill., and encloses a productive area of 410 acres. Oil wells are produced from the southern and southeastern flank, near the crest of an anticlinal structure.[17] The structure also is productive on the northeastern flank in the Colmar field, but Flood[18] reported that the sand probably is not connected between the two fields. A map giving the location of producing and injection wells is shown as figure 8. There is no spacing relationship for oil wells and injection wells, but oil wells generally are 440 feet apart.

History

Original development of the Plymouth oil field was begun in 1915, when Peter Hamm well No. 1 was completed in the Hoing sand and flowed at a daily rate of 280 barrels of oil. By the end of 1916 the field was developed completely. Initially the wells produced 2 to 280 barrels of oil daily and averaged 35 barrels, but by 1925 the average daily oil production had declined to approximately 0.7 barrel per well. In May 1926 vacuum was applied to the Hoing sand, and almost immediately the average daily oil production

17/ Hinds, Henry, Oil and Gas in Colchester and Macomb Quadrangles: Illinois State Geol. Survey, Bull. No. 23, 1917, pp. 45-50.

18/ Flood, Millard H., petroleum engineer, The Ohio Oil Co., Robinson, Ill.

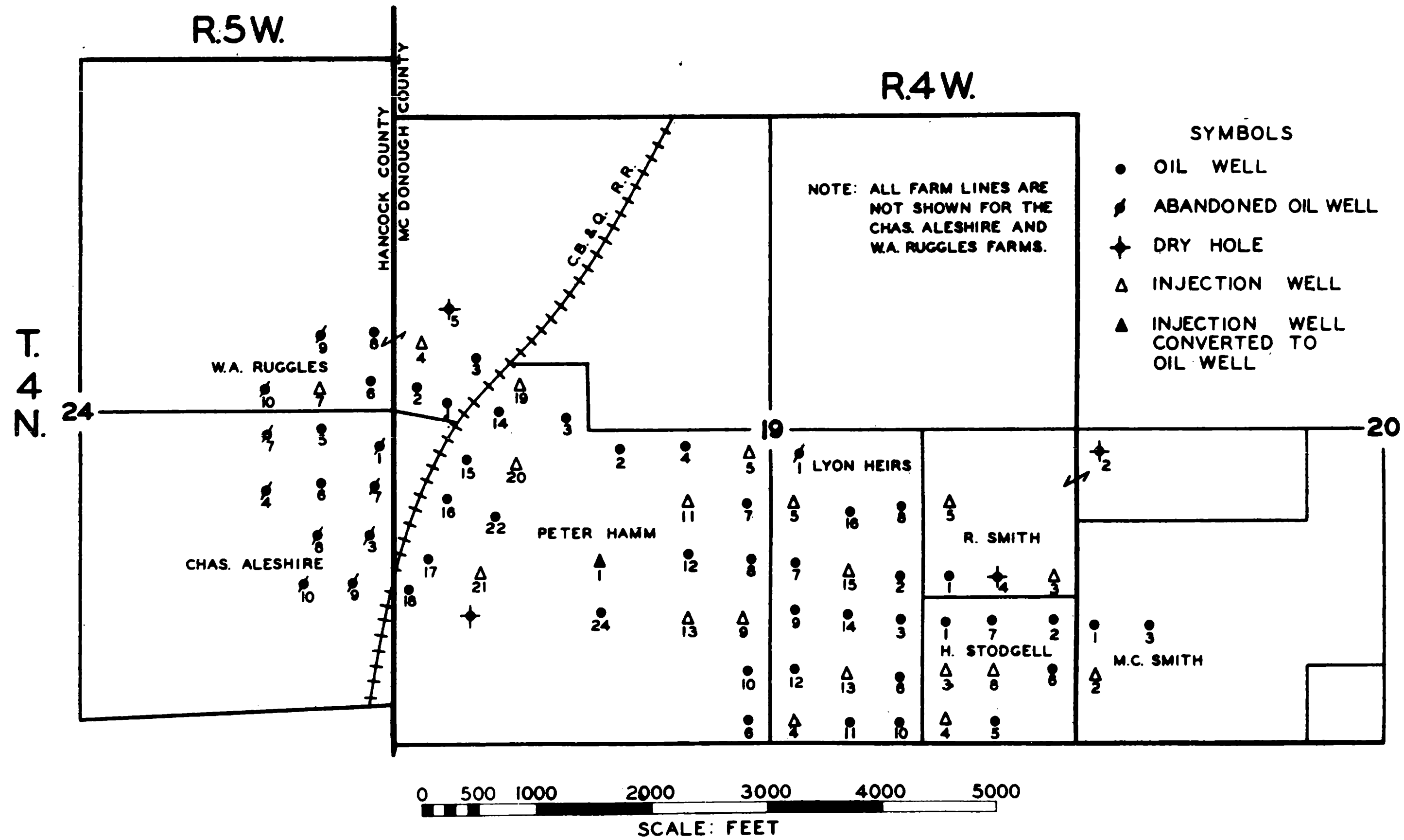

FIGURE 8.- Map of The Ohio Oil Co. Plymouth air-injection project, Hancock and McDonough Counties, Ill., July 31, 1943.

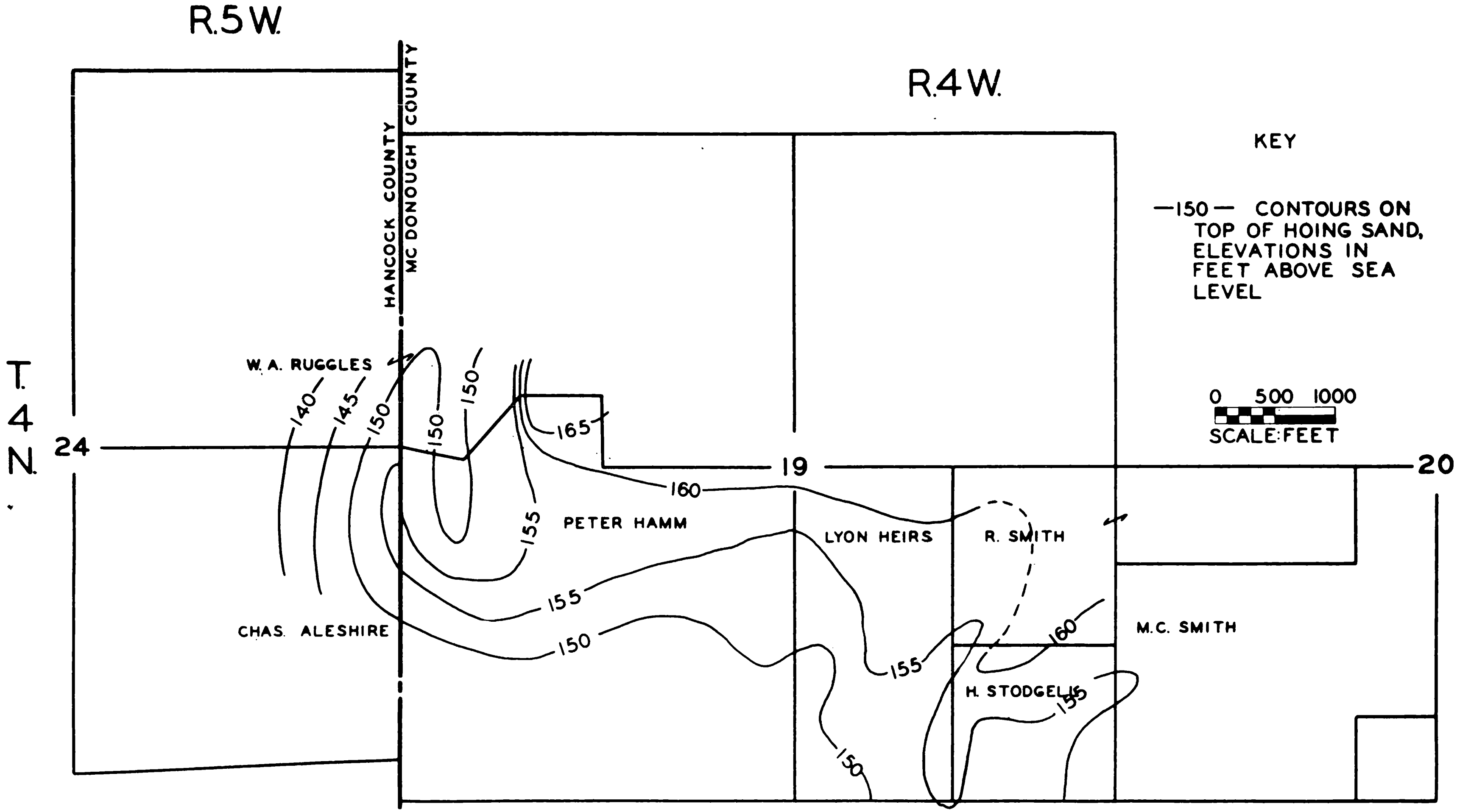

FIGURE 9.- Structure map of Plymouth oil field, Hancock and McDonough Counties, Ill.

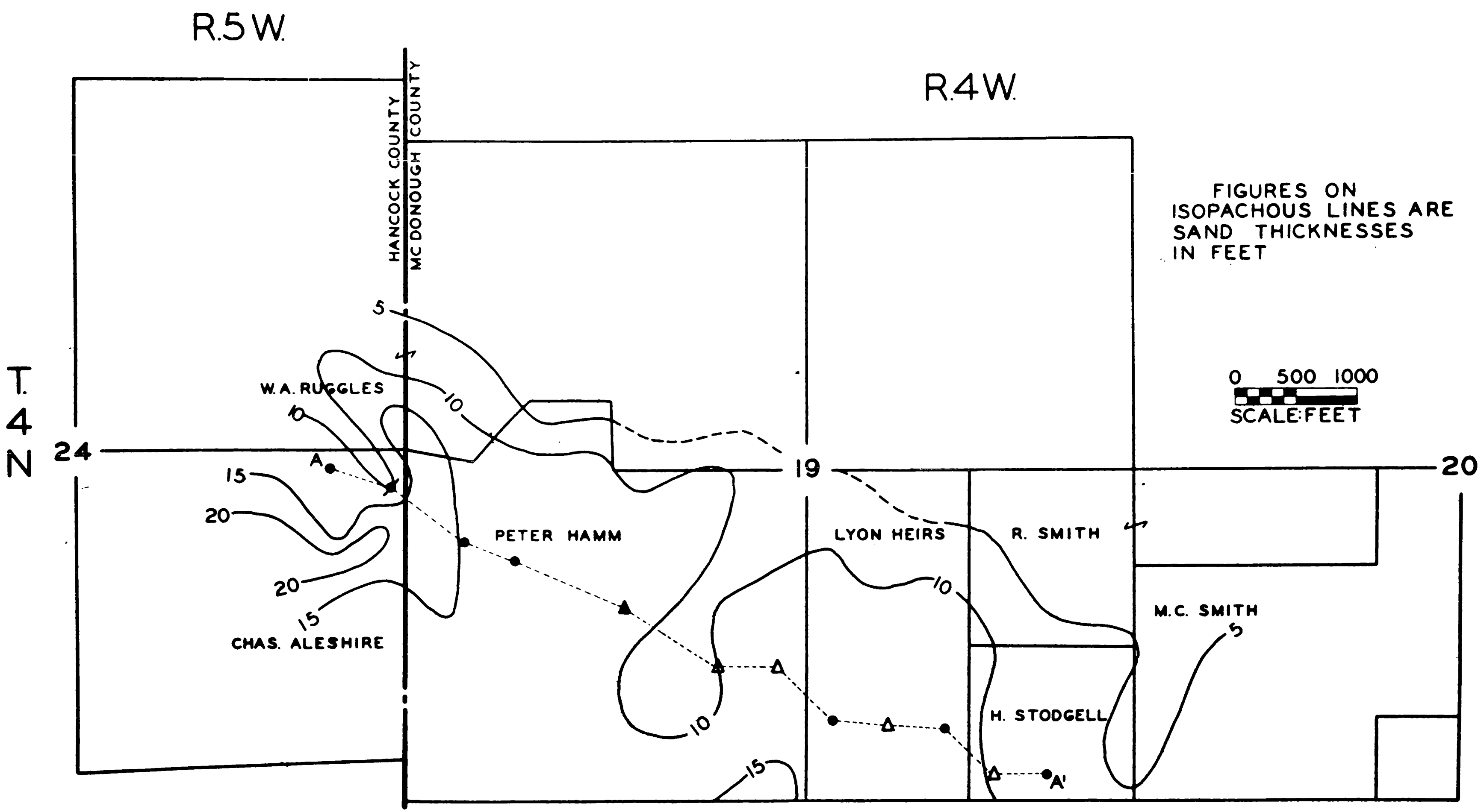

FIGURE 10.- Isopachous map of Hoing sand, Plymouth field, Hancock and McDonough Counties, Ill.

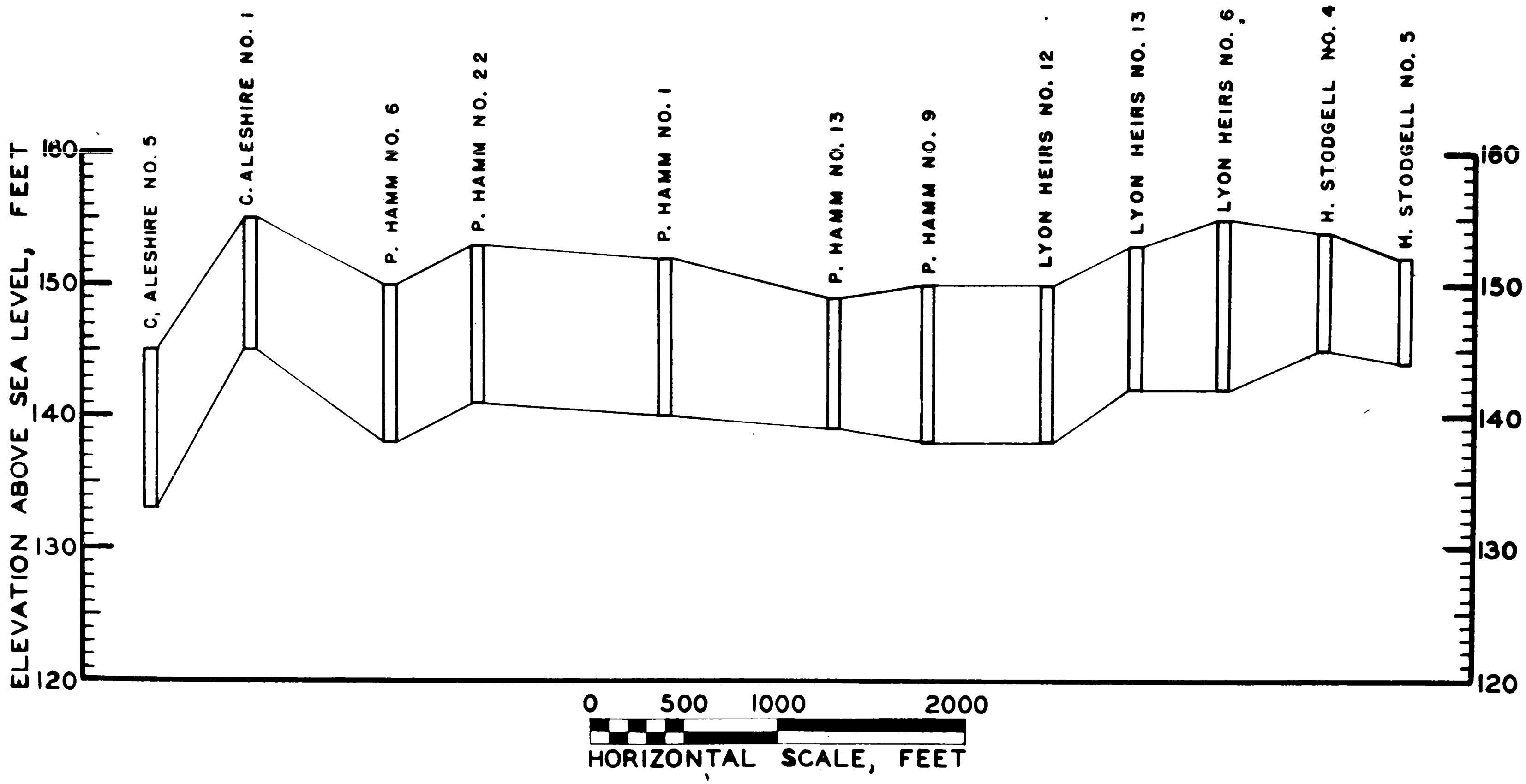

FIGURE 11.- Northwest-southeast cross section A-A' of Hoing sand, Plymouth oil field, Hancock and McDonough Counties, Ill.

increased from 0.68 to 0.83 barrel per well. A daily oil-producing rate of about 0.9 barrel per well was maintained until January 1931, when production was prorated. The low oil-producing rate allocated to the Colmar and Plymouth fields during the proration period resulted in the suspension of vacuum operations until oil-producing restrictions were removed in November 1931. Vacuum was discontinued after air injection was begun on February 10, 1934.

Production records indicate that in 1915 only enough gas was produced with the oil in the Colmar and Plymouth fields to provide fuel for two gas engines. No evidence of important water encroachment in the sand was observed, and because gas dissolved in the oil under pressure supplied the principal propulsive force to drive the oil to the producing wells, the recovery of oil by primary producing methods was small.

Characteristics of Oil Sand

No wells were drilled in the Plymouth oil field after 1916, therefore core analyses of the oil sand are not available. Drillers' logs indicate that the Hoing sand is 4 to 22 feet thick. Characteristics of the producing zone probably are comparable to those of the Hoing sand in the Colmar field. Structural and isopachous maps and a cross section of the Hoing sand are illustrated in figures 9, 10 and 11.

Development

Injection of air into the Hoing sand was begun on February 10, 1934, after Hamm well No. 1, an old oil well, was prepared as an injection well. The well received air from a portable compressor at a daily rate of 80,000 cubic feet and a pressure of 45 pounds per square inch. Eight additional oil wells were converted to injection wells by June 1, 1934, and the daily injection rate was reduced to 40,000 cubic feet per well at a maximum pressure of 50 pounds per square inch. At the end of the year 16 oil wells had been converted to injection wells. Development of the Plymouth project may be followed in table 15 to August 1, 1943, when 19 injection wells (with a spacing of 22 acres per well) and 42 oil wells (spaced 9.8 acres per well) were in operation.

The initial rate of air injection into the Hoing sand proved to be excessive, and channeling was evident. Wells nearest the injection wells usually were affected within a week of the first injection of air. On December 14, 1934, the compressor plant was shut down to reduce the delivery rate of the two compressors. While plant adjustments were being made, 1/8-inch orifice plates were installed in the meter run at each injection well as a means of regulating air-injection rates and, to some extent, reservoir pressure. This method of regulation later was proved unsuccessful and it was abandoned. Air injection was resumed on May 1, 1935, at an average daily injection rate of approximately 10,000 cubic feet per well. Since that time the daily injection rate has ranged from 9,000 to 12,000 cubic feet per well.

TABLE 15. - Development of The Ohio Oil Co. Plymouth project

Date	Active air-injection wells		Active oil wells		Compressors in operation	Remarks
	Number	Spacing,1/ acres per well	Number	Spacing,1/ acres per well		
May 1, 1935 2/	16	25.6	46	8.9	2	16 oil wells were converted to injection wells in 1934.
Jan. 1, 1936	19	21.6	43	9.5	2	3 oil wells were converted to injection wells in 1935.
Jan. 1, 1937	18	22.8	44	9.3	2	1 injection well was converted to an oil well in 1936.
Jan. 1, 1938	18	22.8	44	9.3	2	
Jan. 1, 1939	18	22.8	44	9.3	2	
Jan. 1, 1940	19	21.6	42	9.8	2	1 oil well was abandoned and 1 oil well converted to an injection well in 1939.
Jan. 1, 1941	19	21.6	42	9.8	2	
Jan. 1, 1942	19	21.6	42	9.8	2	
Jan. 1, 1943	19	21.6	42	9.8	2	
Aug. 1, 1943	19	21.6	42	9.8	2	

1/ Computed for a productive area of 410 acres.
2/ Compressor plant not in operation from December 14, 1934, to May 1, 1935.

Well-Completion Methods

All wells included in this project were drilled in 1915 and 1916 and shot with 2 to 4 quarts of nitroglycerin per foot of sand. The casing usually consisted of a surface string of 8-1/4-inch drive pipe set at a depth of approximately 30 feet and 6-1/4-inch pipe set about 240 feet above the top of the Hoing sand at an average depth of 190 feet. During development of the Plymouth project no additional explosives were used in the oil wells, and the wells are still cased in the same manner. Oil wells are equipped with 2-inch tubing set on bottom and pumped by central power.

All of the air-injection wells are old oil wells. Oil wells were converted to injection wells by cleaning out the shot hole and setting on bottom tubing with a perforated anchor and an anchor packer. The perforated section of tubing, about 4 feet in length, was placed opposite the sand, and the anchor packer was set in the lower part of the 6-1/4-inch casing. Ordinarily the 6-1/4-inch casing was pulled during conversion, and damaged joints were replaced with good pipe. This method of completing injection wells is both rapid and simple and is applicable particularly to the Plymouth field, where the shot holes must be cleaned out frequently.

Operating Practice

A compressor plant on the east line of the Peter Hamm lease in the center of the Plymouth field is composed essentially of two horizontal two-stage compressors and their prime movers. One compressor is a Worthington Feather Valve (10-1/2- by 4-3/4- by 12-inch) and the other an Ingersoll-Rand Imperial (8-1/2- by 4-1/2- by 10-inch). Both compressors discharge into a common header at an average pressure of 50 pounds per square inch. Water accumulation is removed from the header by means of a valve at the end of the header. Each compressor is belt-driven by a 30-horsepower oil engine.

A part of the old vacuum pipe-line system was converted to a distribution system for the injection medium. The main pressure line - 3-inch pipe approximately 1 mile in length - extends east-west through the center of the field, and 2-inch lateral lines tie into the 3-inch trunk line to conduct air to the injection wells. Traps for removing water are located at low points in the system.

Measurements to determine the rate of flow of the air injected into the Hoing sand are made at a meter run at each input well. The meter runs consist of 20 feet of 2-inch pipe and tapped flanges containing 1/8-inch orifice plates. All meter runs are elevated about 2-1/2 feet above the surface of the ground to minimize the accumulation of water near the orifice and to facilitate the measurement of flow rates. Flow measurements are made monthly with a portable manometer and pressure gage, and the individual injection rates are computed. A record of the air injected and oil produced monthly is given in table 16.

TABLE 16. - Volumes of air injected[1] and oil produced by months on The Ohio Oil Co. Plymouth project

(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1934		1935		1936		1937		1938	
	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.
January..			Pressure Plant	2,475	)	2,478	)	2,594	)	2,450
February.	1,350	1,739	Shut Down	2,549	)	1,223	)2/15,000	2,352	)	2,541
March....	)	2,438	12-14-34 to	2,048	)2/22,000	3,089	)	3,336	)2/27,500	3,142
April....	)	2,588	5-1-35	1,400	)	3,035	4,734	3,474	)	2,442
May......	)	3,485	6,327	2,282	6,783	3,113	)	2,641	)	2,286
June.....	)	3,316	7,035	3,393	5,658	3,511	)2/15,000	2,088	5,445	2,896
July.....	)2/106,400	3,696	)	3,567	5,143	2,979	)	2,935	)	2,560
August...	)	4,257	)	3,233	6,067	2,692	5,273	3,591	)	2,638
September	)	3,827	)	3,066	2/5,500	3,158	2/5,500	3,399	)2/33,000	2,607
October..	)	3,951	)2/39,000	3,608	4,077	3,062	5,614	2,586	)	1,741
November.	)	3,527	)	2,844	)	3,134	)	3,031	)	2,518
December.	)	2,529	)	2,832	)2/11,000	3,324	)2/10,000	2,270	)	2,448
Total.	107,750	35,353	52,362	33,297	66,288	34,798	60,621	34,297	65,945	30,269

1/ Volumes of air computed from occasional tests. 2/ Estimated.

TABLE 16. - Volumes of air injected1/ and oil produced by months on The Ohio Oil Co. Plymouth project (Cont'd.)
(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1939		1940		1941		1942		1943	
	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.
January..	5,100	2,029	)	1,825	)	2,313	)	2,415	2/6,000	1,719
February.	)	2,103	)	2,157	)	2,144	)	2,031	5,561	1,744
March....	)	2,565	)2/37,800	2,598	)	2,293	)2/26,000	1,920	6,727	2,390
April....	)	2,222	)	2,482	)	2,491	)	1,933	6,408	1,939
May......	)	2,755	)	2,673	)	2,418	6,526	2,512	5,641	1,907
June.....	)2/60,500	2,417	)	2,260	)2/78,000	2,438	)	1,833	6,279	2,406
July.....	)	2,360	6,362	2,466	)	2,160	)	2,075	5,707	1,835
August...	)	2,586	)	2,613	)	2,111	)	2,543		
September	)	2,430	)	2,372	)	1,993	)2/45,500	2,483		
October..	)	2,509	)2/31,500	2,550	)	2,238	)	1,954		
November.	)	2,463	)	2,230	)	1,944	)	1,656		
December.	)	2,125	)	2,353	)	2,249	)	2,139		
Total.	65,600	28,564	75,662	28,579	78,000	26,792	78,026	25,494	42,323	13,940

1/ Volumes of air computed from occasional tests. 2/ Estimated.

Excessive channeling of air through the more permeable sections of the sand has occurred several times; but two corrective measures have been applied successfully, and serious channeling of air to producing wells has been overcome. One consisted of raising fluid levels in the oil wells as high as 100 feet above the top of the sand. Although the back pressure on the sand obtained by controlling fluid levels was adequate for reducing channeling, the operating practice required close supervision and was abandoned in favor of the method now in use. Under the new procedure back pressure is maintained in the casing and on the sand face by installing 1/4-inch brass petcocks in the 8-1/4-inch casing through which air-gas mixtures entering the well bores are exhausted to the atmosphere. The small-diameter petcocks, which remain open, effect a back pressure by maintaining a maximum or critical velocity of the air-gas mixtures that escape through them.

The operator reported that the use of air as an injection medium has not affected noticeably the rate of corrosion of surface and subsurface equipment. Before the injection of air into the Hoing sand, corrosion of equipment was caused by hydrogen sulfide and water produced with the oil.

Orsat analyses of the air-gas mixtures produced to the atmosphere by 8 of the 42 oil wells were made on October 26, 1943. The tests were conducted on the mixtures produced from wells located near injection wells. Results of the tests are presented in table 17.

TABLE 17. - Orsat analyses of gas produced from oil wells in the Plymouth field

Lease	Well No.	Percent by volume of sample analyzed	
		O_2	CO_2
C. S. Aleshire	5	16.8	1.0
W. A. Ruggles	6	18.7	.4
Peter Hamm	2	17.4	.8
Do.	8	17.0	1.0
Do.	14	18.4	.4
Do.	17	16.1	1.4
Lyon Heirs	6	18.9	.3
Do.	14	17.2	1.0

General characteristics and the results of a distillation analysis of a sample of crude oil taken from the oil and water separator on the Hamm lease are given in table 18. The gravity of the oil is 35.4° A.P.I., and the viscosity of the oil at a formation temperature (measured in June 1943) of 68° F. is 63 seconds, Saybolt Universal, or 9.3 centipoises.

TABLE 18. - Chemical and physical properties of crude oil produced on The Ohio Oil Co. Plymouth project from Hoing sand

GENERAL CHARACTERISTICS

Sulfur, percent, 0.26
Saybolt Universal viscosity at 100°F., 48 sec.
Saybolt Universal viscosity at 68°F., 63 sec.
Specific gravity, 0.848
A.P.I. gravity, 35.4°
Color, greenish-black

DISTILLATION, BUREAU OF MINES HEMPEL METHOD
Distillation at atmospheric pressure, 753 mm. First drop, 33°C. (91°F.)

Fraction No.	Cut °C.	at- °F.	Per-cent	Sum, per-cent	Sp. gr., 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc., 100°F.	Cloud test °F.
1	50	122	0.7	0.7)					
2	75	167	1.8	2.5)	0.662	82.2	-		
3	100	212	3.5	6.0	.709	68.1	16		
4	125	257	6.4	12.4	.731	62.1	18		
5	150	302	5.0	17.4	.748	57.7	18		
6	175	347	5.0	22.4	.765	53.5	19		
7	200	392	5.5	27.9	.782	49.5	21		
8	225	437	5.5	33.4	.798	45.8	23		
9	250	482	5.5	38.9	.812	42.8	24		
10	275	527	6.5	45.4	.826	39.8	26		

Distillation continued at 40 mm.

Fraction No.	Cut °C.	at- °F.	Per-cent	Sum, per-cent	Sp. gr., 60/60°F.	°A.P.I. 60°F.	C.I.	S.U. visc., 100°F.	Cloud test °F.
11	200	392	4.5	49.9	0.840	37.0	29	39	20
12	225	437	5.9	55.8	.851	34.8	30	46	35
13	250	482	5.6	61.4	.865	32.1	34	58	55
14	275	527	6.0	67.4	.878	29.7	37	87	70
15	300	572	5.3	72.7	.890	27.5	39	160	85
Residuum			27.1	99.8	0.956	16.5			

Carbon residue of residuum, 9.0 percent; carbon residue of crude, 2.4 percent.
Base of crude: Intermediate

APPROXIMATE SUMMARY

	Percent	Sp. gr.	°A.P.I.	Viscosity
Light gasoline	6.0	0.691	73.3	
Total gasoline and naphtha	27.9	0.741	59.5	
Kerosine distillate	11.0	.805	44.3	
Gas oil	15.9	.838	37.4	
Nonviscous lubricating distillate	10.6	.856-.880	33.8-29.3	50-100
Medium lubricating distillate	7.3	.880-.895	29.3-26.6	100-200
Viscous lubricating distillate	-	-	-	Above 200
Residuum	27.1	.956	16.5	
Distillation loss	.2			

Results

The estimated cumulative oil production for the Plymouth project before the initial injection of air in February 1934 was 84.5 barrels per acre-foot, and the cumulative oil production during air-injection operations to August 1, 1943, was 65.9 barrels per acre-foot. An estimate of the oil gained for a 4-percent decline in the rate of oil production under vacuum operations is given in table 19. Because of the difficulty of extrapolating a decline curve for this project (see fig. 12), the 4-percent decline rate was adopted on the recommendation of engineers familiar with operations in this field.

TABLE 19. - Oil-production statistics - Plymouth project

Year	Oil production, bbl.		Estimated oil gained, bbl.
	4-percent decline	Actual	
1934 1/	20,780	35,353	14,573
1935	21,767	33,297	11,530
1936	20,896	34,798	13,902
1937	20,060	34,297	14,237
1938	19,258	30,269	11,011
1939	18,488	28,564	10,076
1940	17,748	28,579	10,831
1941	17,038	26,792	9,754
1942	16,356	25,494	9,138
1943 2/	9,160	13,940	4,780
Total	181,551	291,383	109,832

1/ Last 11 months. 2/ First seven months.

Oil production by leases is illustrated graphically in figure 13. Insufficient evidence was available to explain the relatively poor response of the Lyon Heirs and Hamm leases to air injection. Four of the first six injection wells placed in operation early in 1934 were on Lyon Heirs and Hamm leases. The initial injection rates were relatively high, ranging from 3,500 to 7,000 cubic feet of air per foot of sand daily. Oil production from the five other leases during air injection exceeded that for the period of primary vacuum operations.

From February 1934 to August 1943 approximately 692,500,000 cubic feet of air were injected into the Hoing sand at an average pressure of 28 pounds per square inch. A volume of 2,380 cubic feet of air was injected for each barrel of oil produced, or 6,310 cubic feet of air for each barrel of oil estimated to have been gained by August 1, 1943. The driving medium was injected at an average daily rate of approximately 1,040 cubic feet per vertical foot of sand exposed in each well. The estimated volume of oil gained by the injection of air was 268 barrels per acre. The cumulative oil production (on August 1, 1943) for all of the leases comprising this project was about 1,600 barrels per acre.

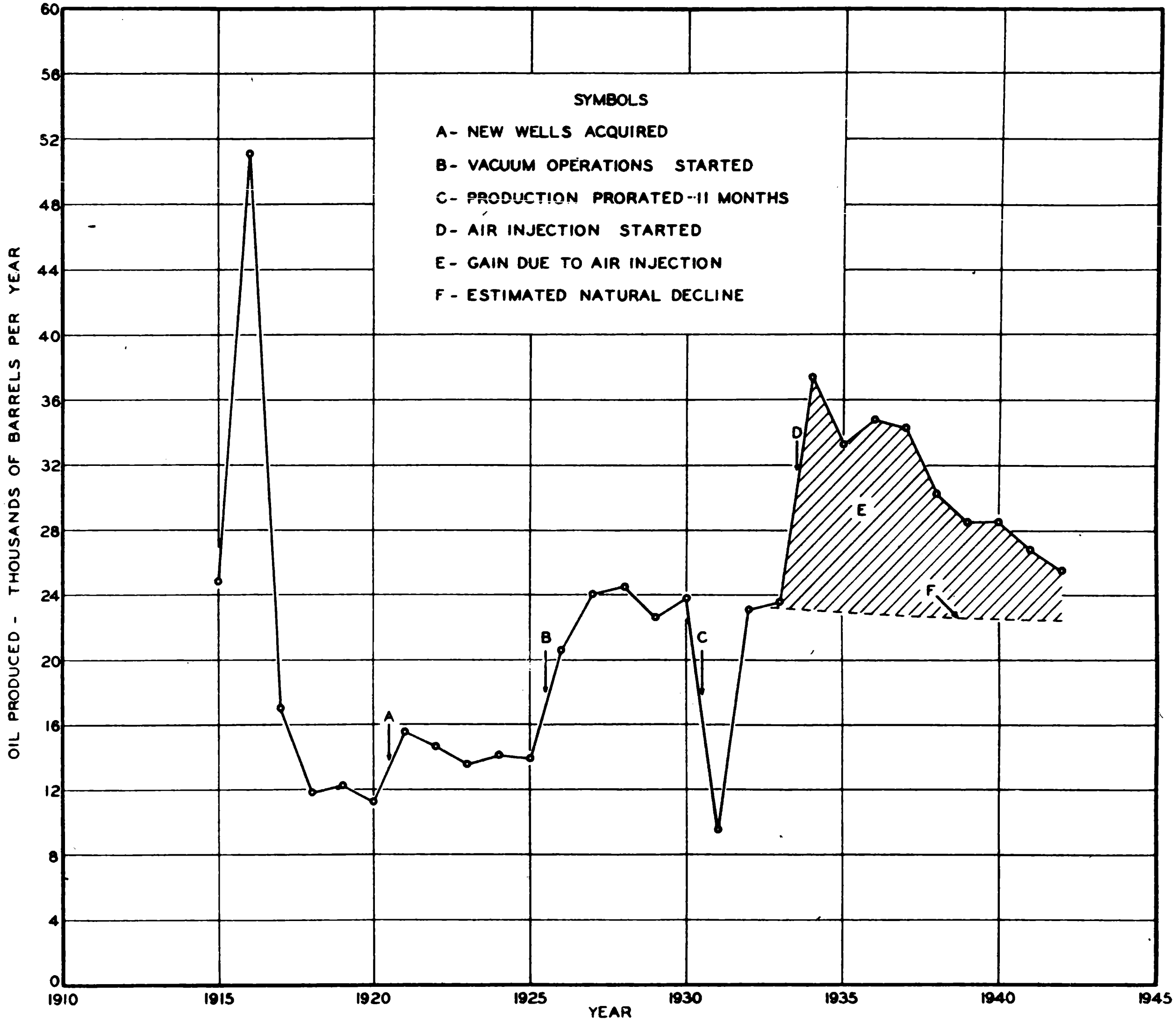

FIGURE 12.- Production-decline curve, The Ohio Oil Co., Plymouth project, Hancock and McDonough Counties, Ill.

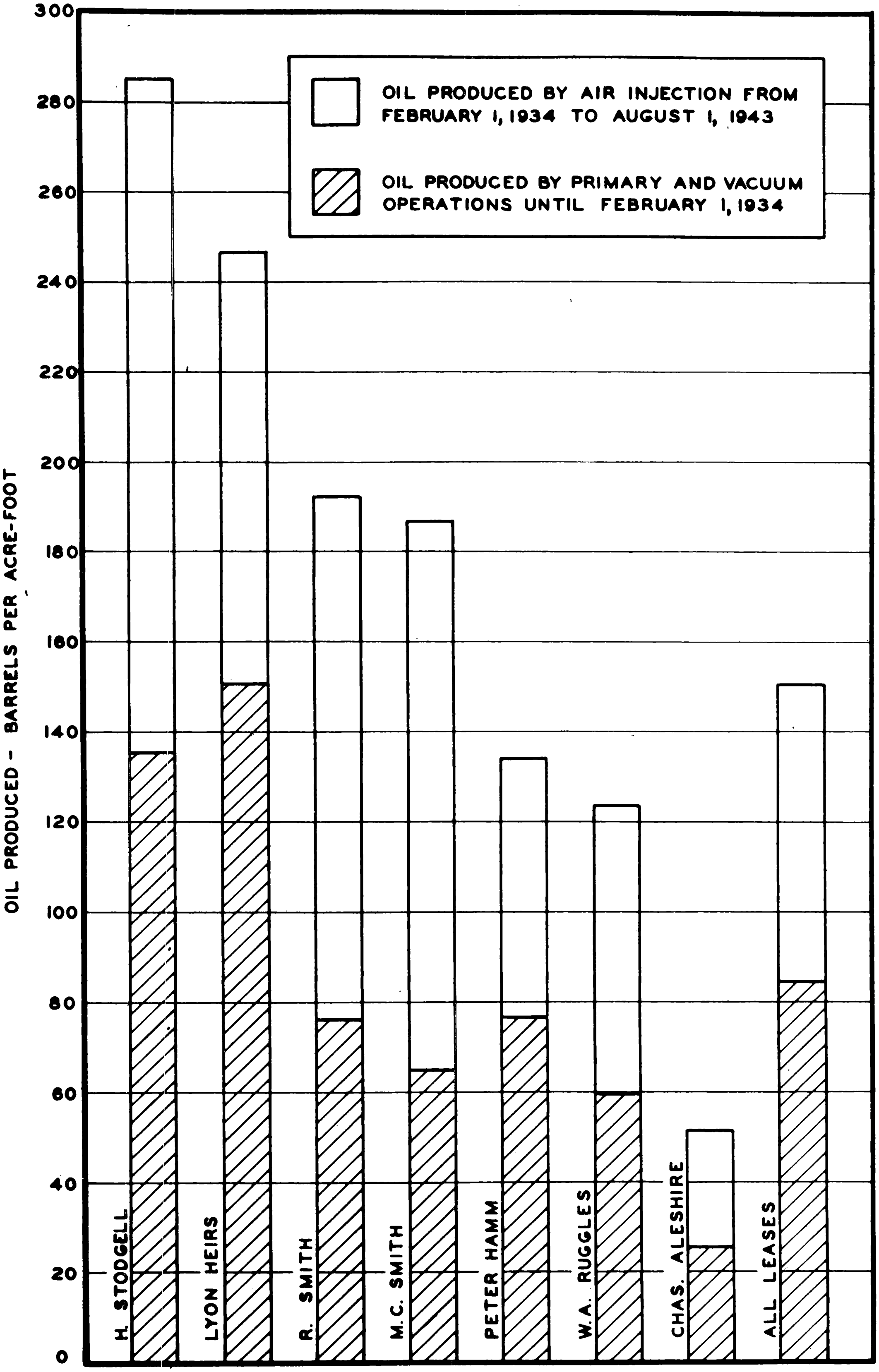

FIGURE 13.- Comparative oil production by leases before and after air injection, Plymouth project, Hancock and McDonough Counties, Ill.

TABLE 20. - Summary of operations for The Ohio Oil Co. Plymouth project, Hancock and McDonough Counties, Ill.

Year	Air injected,1/ M cu. ft.	Average injection pressure, lb. per sq. in.	Injection-well spacing, acres per well	Oil-well spacing, acres per well	Repressured area, acres	Cumulative oil production, bbl. per acre	Estimated cumulative oil gained, bbl. per acre	Ratio of air injected to oil produced, cu. ft. per bbl.	Ratio of air injected to oil gained, cu. ft. per bbl.	Horsepower of compressor prime movers
1934 2/	107,750	45	25.6	8.9	410	86.2	35.5	3,050	7,390	60
1935	52,362	36	21.6	9.5	410	167.4	63.7	1,270	4,540	60
1936	66,228	27	22.8	9.3	410	252.3	97.6	1,900	4,760	60
1937	60,621	26	22.8	9.3	410	336.0	132.3	1,770	4,260	60
1938	65,945	24	22.8	9.3	410	409.8	159.1	2,180	5,990	60
1939	65,600	22	21,6	9.8	410	479.5	183.7	2,300	6,510	60
1940	75,662	25	21.6	9.8	410	549.2	210.1	2,650	6,990	60
1941	78,000	24	21.6	9.8	410	614.5	233.9	2,910	8,000	60
1942	78,026	23	21.6	9.8	410	676.7	256.2	3,650	8,540	60
1943 3/	42,323	24	21.6	9.8	410	710.7	267.9	3,360	8,850	60
Total	692,517					710.7	267.9			
Average		28						2,380	6,310	

1/ Computed from occasional tests.
2/ Last 11 months of 1934.
3/ First 7 months of 1943.

The Ohio Oil Co. Colmar Project

The Colmar project, in secs. 9, 10, 14, 15, and 16, T. 4 N., R. 4 W., McDonough County, Ill., encloses a productive area of 1,420 acres. Oil is produced from the Hoing sand on the northeastern flank of an anticline about 1-1/2 miles from the crest of the structure. Wells encountered the top of the sand at an average depth of 463 feet in the Colmar oil field, an average of 33 feet deeper than those drilled in the Plymouth oil field, before penetrating the sand. The top of the sand, however, is 60 to 70 feet lower on the sturcture in the Colmar field. The Hoing sand in the Colmar oil field averages 12.4 feet in thickness.

History

Most of the wells in the Colmar field were drilled in 1914 and 1915. The wells originally produced from less than 1 to 150 barrels of oil daily and averaged 20 barrels daily. The daily oil-producing rate of wells in the Colmar field, as in the Plymouth field, declined to a fraction of a barrel per well by 1925. Vacuum was applied to the Hoing sand in May 1926, and the average daily oil production per well increased from 0.41 barrel in 1925 to 0.54 barrel in 1926. An average daily oil-producing rate of 0.61 barrel per well was maintained until January 1931, when Illinois oil production was prorated. Vacuum operations were suspended until oil-producing restrictions were removed in November 1931 and then were discontinued after air injection was begun in July 1935.

A slow encroachment of water was reported in the north and northwestern part of the field, but as the water drive was ineffective in the Hoing sand and too little energy was provided by the small volume of gas initially associated with the oil, a low recovery of oil was achieved by primary methods.

Characteristics of Oil Sand

Wells drilled during 1943 for a pilot water-flooding project on the Hendricks and McFadden leases provided mush of the available information on the reservoir. Analyses of core samples from these wells, supported by drillers' logs of other wells in the field, reveal that the Hoing sand is 7 to 26 feet thick. The average thickness of the sand is 12.4 feet.

The average porosity of the cores taken from nine wells in the water-flooding area was 18.3 percent. The average permeability of the core samples was a little more than 1 darcy. The sand in six of the wells was cored using an oil-base drilling fluid. The average oil content of these cores was 52.5 percent of the average pore volume of the cores, whereas the average oil saturation of the sand cored in three other wells, using a water-base drilling fluid, was 26.8 percent of the average pore volume. The average water saturation was 22.8 percent of the pore volume of sand cored with oil and 51.9 percent of the pore volume of sand cored with water. The oil-saturation figures cited above do not include values for the lower 2 or 3 feet of sand, which have a water content of approximately 70 percent. A core log

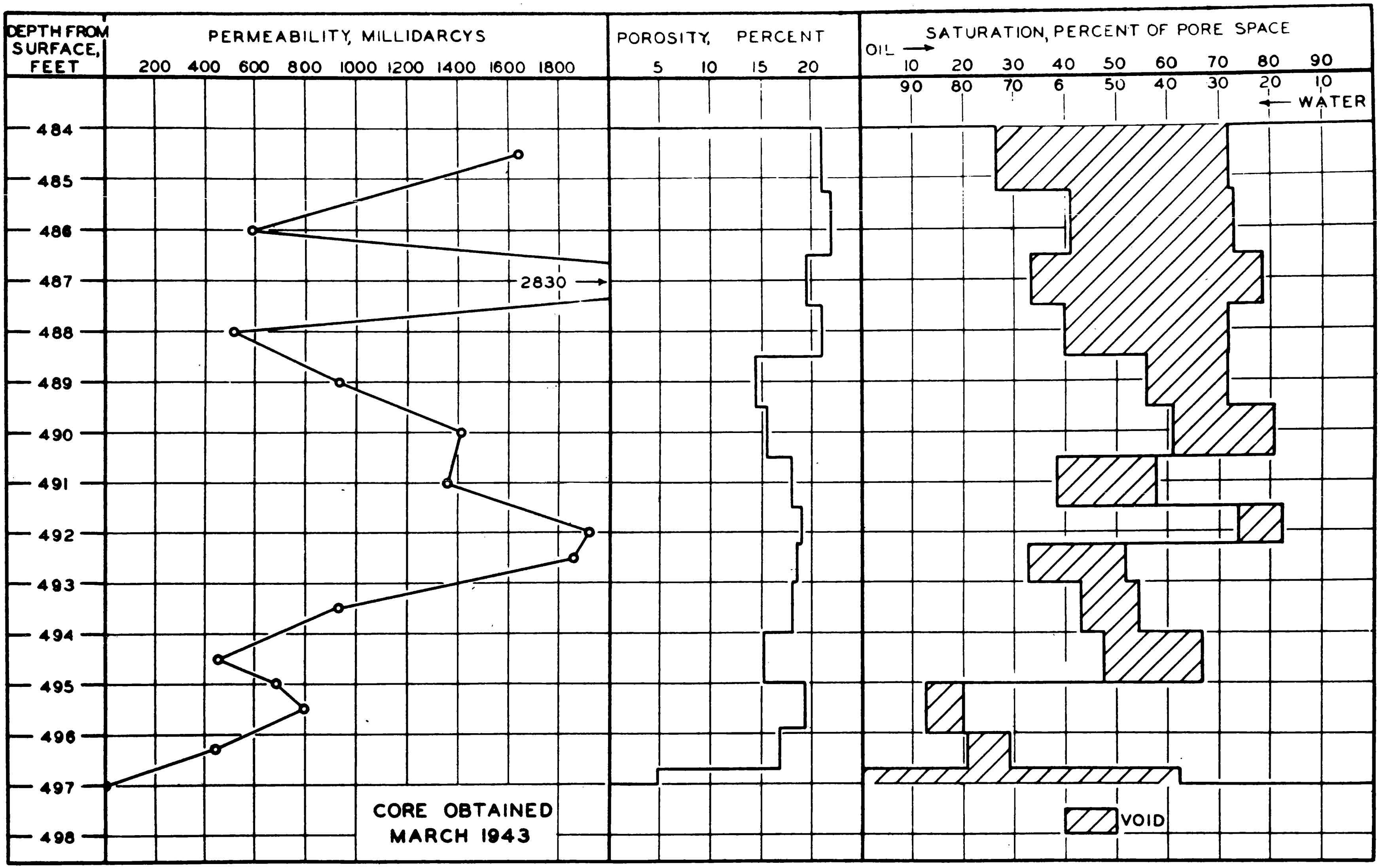

FIGURE 14.- Analysis of Hoing-sand core from well in sec. 15, T. 4 N., R. 4 W., McDonough County, Ill.

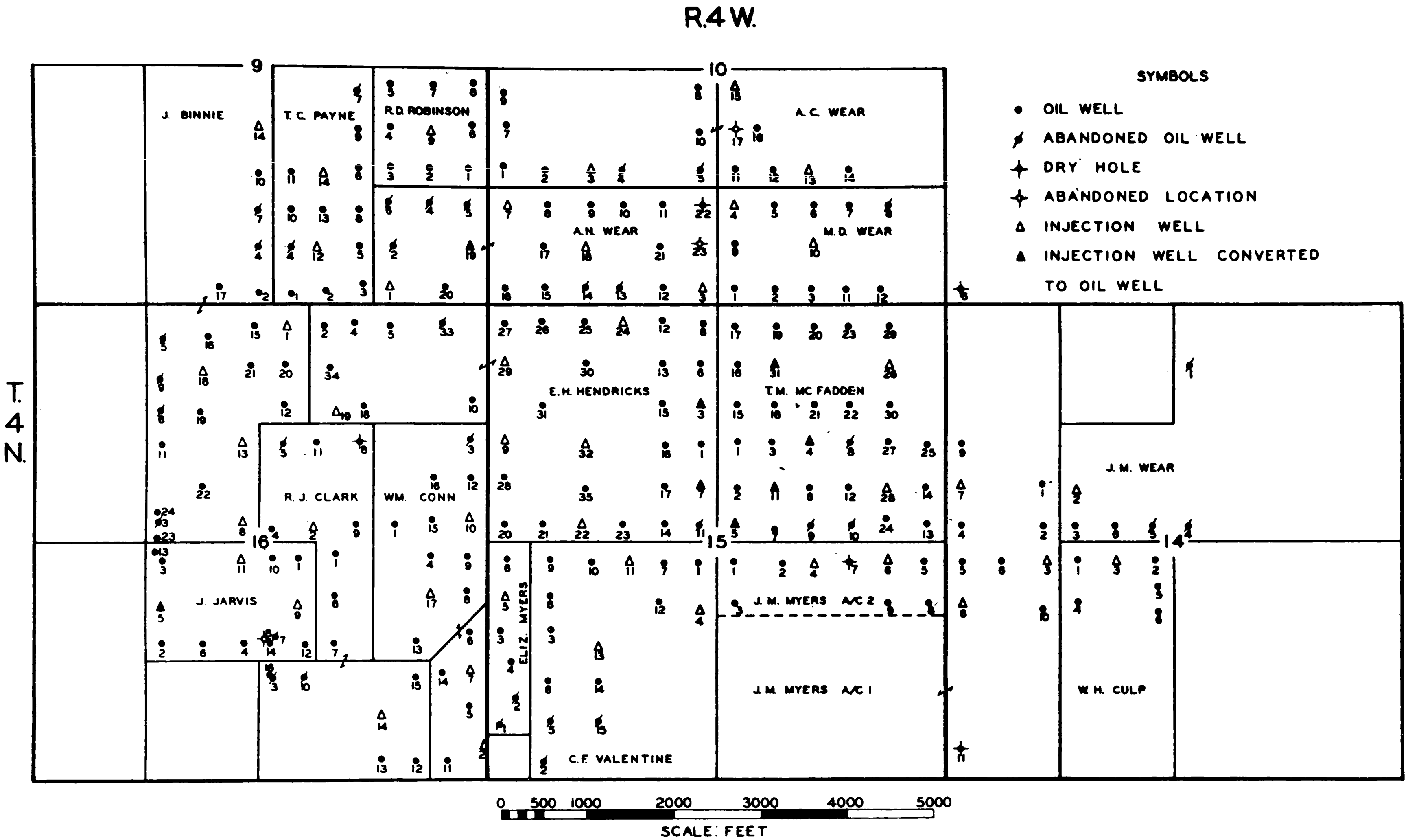

FIGURE 15.- Map of The Ohio Oil Co. Colmar air-injection project, McDonough County, Ill.

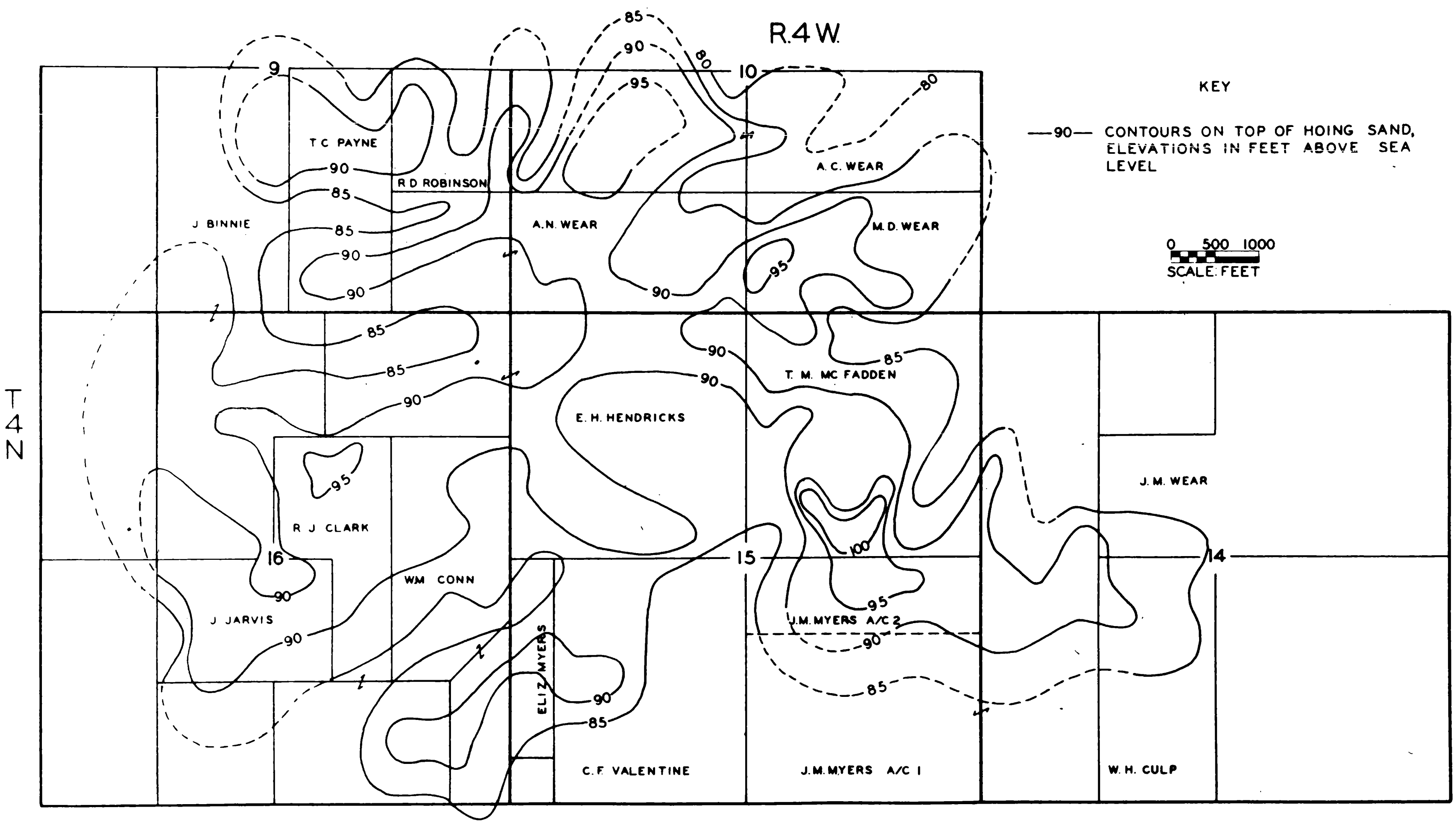

FIGURE 16.- Structure map of Colmer oil field, McDonough County, Ill.

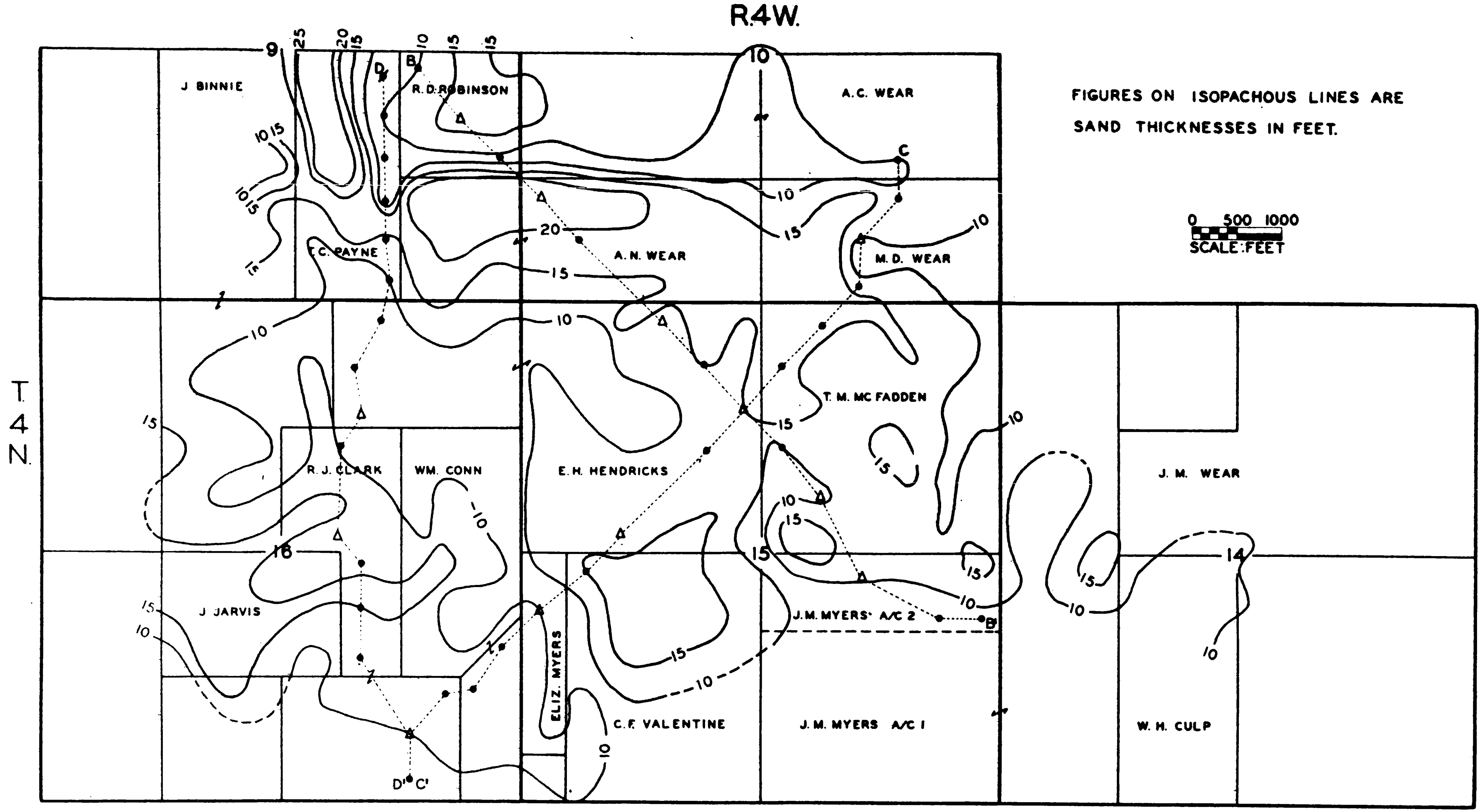

FIGURE 17.- Isopachous map of Hoing sand, Colmar oil field, McDonough County, Ill.

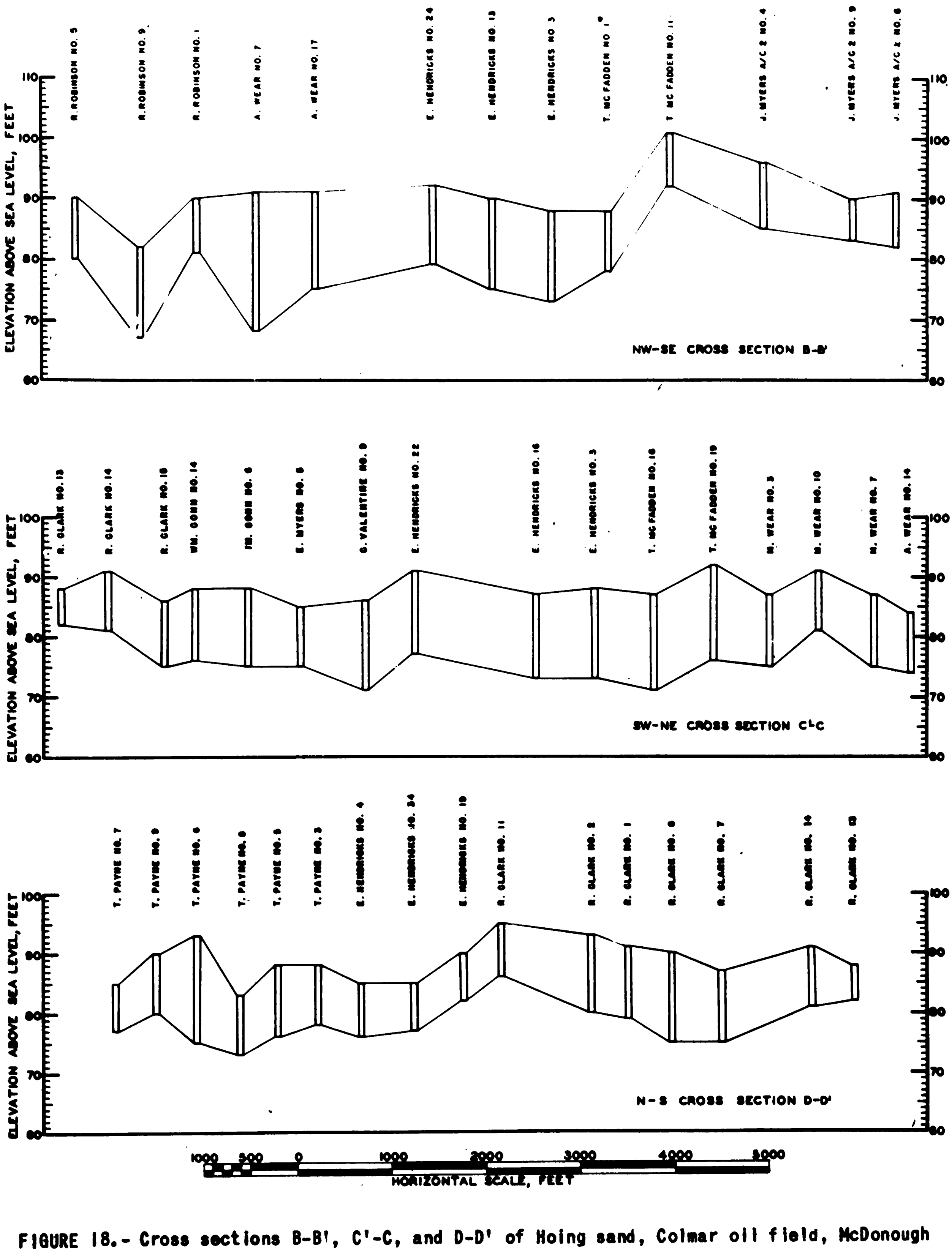

FIGURE 18.- Cross sections B-B', C'-C, and D-D' of Hoing sand, Colmar oil field, McDonough County.

prepared from the results of analyses of samples cored with oil in the McFadden well No. Q-10 is shown in figure 14. It is believed that similar sand characteristics exist for the Hoing sand in the Plymouth oil field.

Development

A surface map of the Colmar project (see fig. 15) shows the locations of producing and air-injection wells on July 31, 1943. Figures 16 to 18 give maps and cross sections of the Colmar field. Air-injection patterns seldom are complete, and never are repeating because the leases comprising this project were not fully developed by drilling. The complete pattern, when it occurs, is an inverted five-spot, with the injection well in the center of four oil wells. The injection well is 440 feet from each producing well in the pattern.

Development of the Colmar project was begun more than a year after the first injection of air into the Hoing sand in the Plymouth oil field, and the operator's experience with high injection rates and their detrimental effects on the sand in that field resulted in the use of lower initial injection rates in the Colmar field. Hendricks well No. 32, an old oil well, was chosen as the first injection well, and air was introduced into the Hoing sand through it on July 2, 1935, at a daily rate of 14,000 cubic feet. By the end of the year 46 injection wells, spaced 30.9 acres per well, were in operation. Annual development of the Colmar project to August 1, 1943, when the number of injection wells was reduced to 44, with a spacing of 32.3 acres per well, is summarized in table 21.

Well-Completion Methods

Most of the oil wells in the Colmar project were drilled in 1914 and 1915, and the completion practices were similar to those described under the Plymouth project. Three wells were drilled after 1935, in addition to those drilled during 1943, in an area of approximately 70 acres for the pilot water flood begun in June 1943.

All of the air-injection wells are old oil wells that were converted to injection wells in the same manner as for the Plymouth project.

TABLE 21. - Development of The Ohio Oil Co. Colmar project

Date	Active air-injection wells: Number	Active air-injection wells: Spacing,[1] acres per well	Active oil wells: Number	Active oil wells: Spacing,[1] acres per well	Compressors in operation	Remarks
Jan. 1, 1936	46	30.9	173	8.1	3	46 oil wells were converted to injection wells and 1 oil well was drilled in 1935.
Jan. 1, 1937	47	30.2	173	8.2	3	1 oil well was converted to an injection well and 1 oil well was drilled in 1936.
Jan. 1, 1938	47	30.2	174	8.2	3	1 oil well was drilled in 1937.
Jan. 1, 1939	49	29.0	172	8.3	3	3 oil wells were converted to injection wells, and 1 injection well was converted to an oil well in 1938.
Jan. 1, 1940	49	29.0	172	8.3	3	1 oil well was converted to an injection well and 1 injection well to an oil well in 1939.
Jan. 1, 1941	48	29.6	173	8.2	3	2 oil wells were converted to injection wells and 3 injection wells to oil wells in 1940.
Jan. 1, 1942	48	29.6	173	8.2	4	
Jan. 1, 1943	48	29.6	173	8.2	4	
Aug. 1, 1943	44	32.3	177	8.0	4	4 injection wells were converted to oil wells in 1943.

1/ Computed for a productive area of 1,420 acres.

Operating Practice

A compressor plant is located on the Hendricks lease near the center of the field. The plant is composed essentially of four Ingersoll-Rand, horizontal, twin-cylinder (8-1/2- by 10-inch) compressors and their prime movers. The prime movers consist of one 35-horsepower and three 30-horsepower oil engines. The compressor cylinders operate under single-stage compression and discharge into the same header at an average pressure of 50 pounds per square inch. Moisture is condensed from the compressed air by reducing its temperature at the plant. A cooling coil, consisting of approximately 100 feet of 8-1/4-inch pipe arranged in a U shape, was constructed outside the compressor building. After compression, air from the header flows through the coil where its temperature is reduced by the transfer of heat to the coil, and moisture is condensed. The water that accumulates in the coil is blown periodically to the atmosphere. The heat lost by radiation does not decrease the temperature of the air substantially, however, because at the customary rate of flow of air through the coil, the differential between the temperature of the atmosphere and that of the coil usually is too small to effect a large reduction in temperature.

The compressed-air distribution system consists of four 3-inch trunk lines, 2-inch lateral lines from the trunk lines to injection wells, and traps to remove water. Three 3-inch lines, 1 to 1.5 miles in length and 0.5 mile apart, are laid north-south and connected by another 3-inch line about 1 mile long, laid east-west through the center of the field. Air is supplied to the injection wells through 2-inch lines connected at convenient points to the 3-inch lines.

Back pressure on the highly permeable Hoing sand is maintained in both the Colmar and Plymouth oil fields to minimize excessive channeling of the injection medium. In the Colmar field, as in the Plymouth field, back pressure is maintained by venting to the atmosphere at restricted rates the air and gas produced through the casing of the oil wells. On the whole, the precautions taken for preventing excessive channeling have been satisfactory, but channeling of the air to one or more producing wells occurs ocasionally. Water is injected into the sand through the nearest injection well as a temporary corrective measure for persistent channeling. As much as 3,000 barrels of water have been injected into the sand through one well in several treatments.

The pressure within the reservoir has varied widely during air injection. A large number of fluid-level measurements made in 1938 indicate that the bottom-hole pressures at that time averaged approximately 15 pounds per square inch but ranged from 6 to 22 pounds per square inch. Fluid-level measurements made in the last 2 years verified that bottom-hole pressures have continued to vary appreciably from one well to another. The lack of uniformity of reservoir pressure probably has resulted in the migration of oil from high- to low-pressure producing areas, especially where the high-pressure areas are structurally high.

The rate of air injection is determined in the same manner as was described for the Plymouth project. A record of the air injected and oil produced for the Colmar project is given in table 22. The values for the volumes of air injected are estimates based on monthly flow tests, and several of the air-injection figures either are interpolations of the available data or were recommended by production men in the field.

As in the Plymouth oil field, water and the small quantities of hydrogen sulfide associated with the oil in the reservoir caused most of the corrosion of subsurface and surface equipment before air-injection operations were begun. The rate of corrosion of equipment has not been affected perceptibly during air injection.

Orsat analyses of gas produced from 30 of the 177 oil wells on this project were made October 25 and 26, 1943. Results of the tests, which are given in table 23, are not considered conclusive proof that oxidation of the oil has occurred. The operator reported that no evidence of sand plugging with solid oxidation products has been found.

The general characteristics and distillation analysis of a sample of crude oil taken from the oil and gas separator on the Hendricks lease are shown in table 24. The gravity of the oil is 35.8° A.P.I., and the viscosity at a formation temperature (measured in June 1943) of 68° F. is 60 seconds Saybolt Universal, or 8.6 centipoises.

Results

The estimated cumulative oil production for the Colmar project before the initial injection of air in July 1935 was 65.4 barrels per acre-foot, and the cumulative oil production during air injection to August 1, 1943, was 43.9 barrels per acre-foot. An estimate of the oil gained for a 4-percent decline in the rate of oil production during vacuum operations is given in table 25. Because of the difficulty of extrapolating a decline curve for this project (see fig. 19), the 4-percent decline rate was adopted on the recommendation of engineers familiar with operations in this field.

All except two of the leases comprising the Colmar project have produced more oil during secondary-recovery than during primary operations. Such unusual results are misleading, however, unless it is recognized that the initial energy in the reservoir was very limited. The original oil content of the Hoing sand was over 500 barrels per acre-foot, and the total primary recovery of oil from the sand in the Colmar field was approximately 41 barrels per acre-foot; therefore less than 10 percent of the oil originally present was produced during the primary-recovery period between 1914 and 1926. The proportion of oil recovered from each lease in the project during primary- and secondary-recovery operations is given in figure 20. Generally leases responded to secondary-recovery operations in a manner indicated by their past productivity; that is, a lease with high oil recovery during primary production usually realized a correspondingly high oil recovery during secondary-recovery operations. One notable exception is the Myers a/c 2 lease which had a higher oil recovery during air injection than during both primary and vacuum operations.

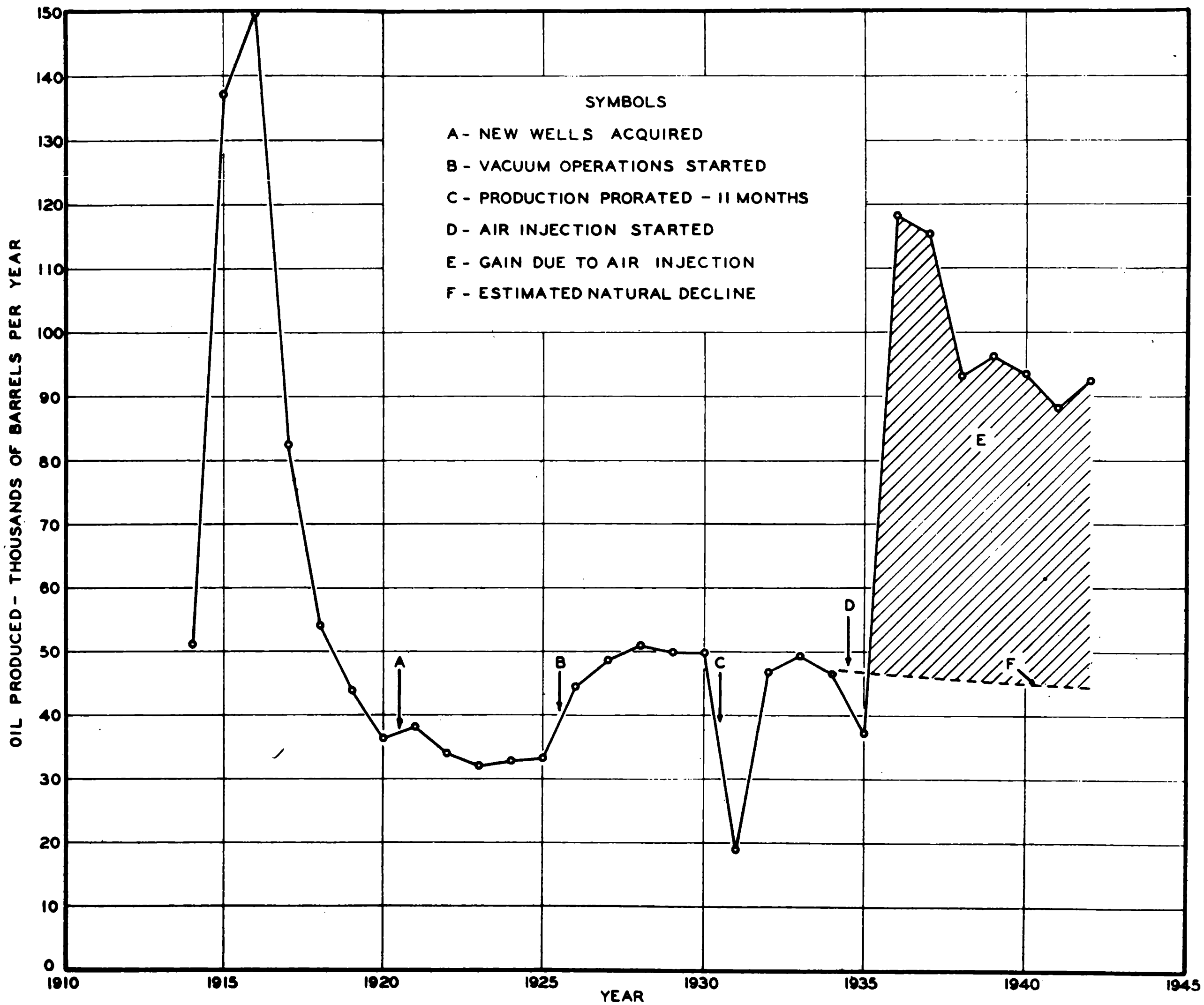

FIGURE 19.- Production curve, The Ohio Oil Co., Colmar project, McDonough County, Ill.

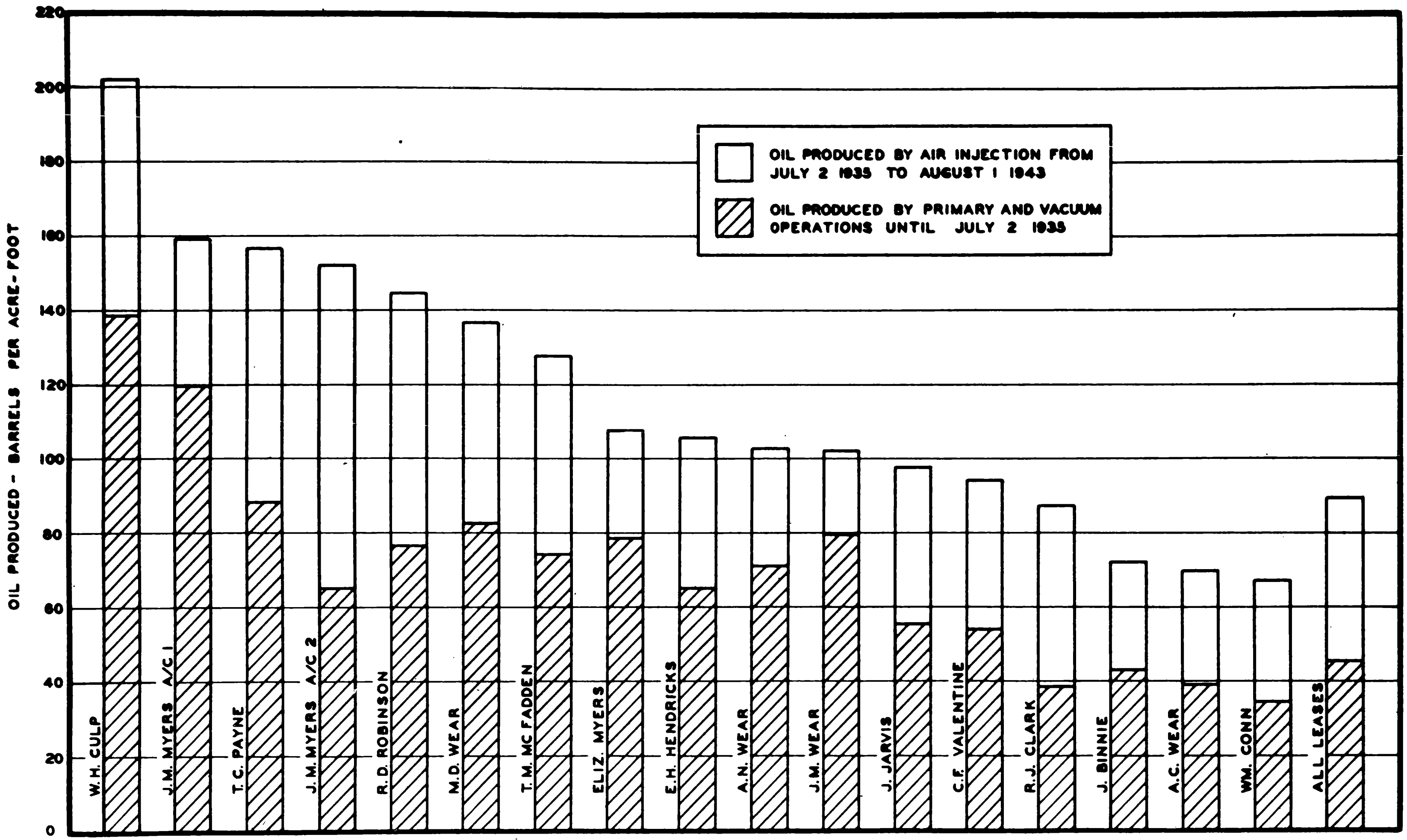

FIGURE 20.- Comparative oil production by leases before and after air injection, Colmar project, McDonough County, Ill.

TABLE 22. - Volumes of air injected[1] and oil produced by months on The Ohio Oil Co. Colmar project

(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1935		1936		1937		1938		1939	
	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.
January..			)	7,436	6,383	9,682	)	8,507	17,146	7,729
February.			)	5,616	) [2]8,000	9,160	)	9,500	)	7,048
March....			) [2]40,000	8,500	)	10,554	)	9,006	)	8,541
April....			)	9,640	2,745	9,616	)	7,884	)	7,706
May......			11,600	11,829	)	10,014	)	7,157	)	8,684
June.....			10,148	11,738	) [2]21,000	9,675	) [2]180,000	7,756	) [2]176,000	8,758
July.....	)	2,716	11,365	11,733	)	10,002	)	6,961	)	8,118
August...	)	1,859	11,455	11,425	12,065	10,022	)	6,987	)	8,325
September	) [2]60,000	2,498	)	11,041	15,201	9,551	)	6,774	)	8,088
October..	)	4,091	)	10,136	14,319	8,682	)	7,836	)	8,135
November.	)	4,879	) [2]40,000	9,686	[2]14,000	9,060	)	6,979	)	7,392
December.	)	5,639	)	9,527	14,344	9,546	)	7,805	)	7,654
Total..	60,000	21,682	124,568	118,307	108,057	115,564	180,000	93,152	193,146	96,178

See footnotes on page 56.

TABLE 22. - Volumes of air injected[1] and oil produced by months on The Ohio Oil Co. Colmar project (Cont'd.)
(Pressure base, 14.4 lb. per sq. in. abs.; temperature base, 60° F.)

	1940		1941		1942		1943	
	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.	Air injected, M cu. ft.	Oil produced, bbl.
January...	)	7,538	)	7,123	)	8,587	2/21,000	6,327
February..	)	7,931	) 2/36,000	6,932	) 2/88,000	7,217	20,208	6,427
March.....	) 2/68,000	8,170	18,407	6,973	)	7,141	21,833	8,287
April.....	)	8,526	)	7,539	)	7,233	21,510	6,720
May.......	19,809	8,703	)	8,068	)	9,039	20,128	6,568
June......	)	7,239	) 2/90,000	7,464	) 44,075	7,154	20,208	8,010
July......	)	8,174	)	7,842	)	7,071	19,651	6,042
August....	)2/119,000	8,249	)	7,260	)	8,770		
September.	)	7,159	22,323	7,495	)2/154,000	8,689		
October...	)	7,470	)	7,715	)	6,919		
November..	)	6,941	) 2/54,000	7,010	)	6,477		
December..	)	7,379	)	6,798	)	8,163		
Total..	206,809	93,479	220,730	88,219	286,075	92,460	144,538	48,381

1/ Volumes of air computed from occasional tests.
2/ Estimated.

TABLE 23. - Orsat analyses of gas produced from oil wells in the Colmar field

Lease	Well No.	Percent by volume of sample analyzed	
		O_2	CO_2
J. Binnie	10	9.8	4.8
Do.	23	13.2	3.4
Wm. Conn	5	5.1	7.8
Do.	8	16.5	2.5
W. H. Culp	1	17.9	.0
E. H. Hendricks	18	15.4	2.4
Do.	25	18.0	.8
Do.	31	11.8	4.0
Do.	35	18.5	.3
J. Jarvis	1	17.1	1.4
Do.	6	.2	11.0
Do.	12	11.9	4.8
T. M. McFadden	24	18.2	.8
Do.	29	14.8	2.2
J. M. Myers a/c 1	2	18.1	.8
Do.	4	14.3	2.8
J. M. Myers a/c 2	1	14.2	2.8
Do.	9	15.4	2.4
T. C. Payne	13	16.6	1.4
R. D. Robinson	1	5.4	7.4
C. F. Valentine	6	9.4	5.4
Do.	9	16.3	2.3
A. N. Wear	9	17.2	1.6
Do.	12	14.2	3.0
Do.	16	9.4	5.2
Do.	21	11.2	4.4
M. D. Wear	3	18.7	.7
Do.	7	14.6	2.2
Do.	9	19.0	.4

TABLE 24. - Chemical and physical properties of crude oil produced on The Ohio Oil Co. Colmar project from Hoing sand

GENERAL CHARACTERISTICS

Sulfur, percent, 0.25
Saybolt Universal viscosity at 100°F., 48 sec.
Saybolt Universal viscosity at 68°F., 60 sec.
Specific gravity, 0.846
A.P.I. gravity, 35.8°
Color, greenish black

DISTILLATION, BUREAU OF MINES HEMPEL METHOD

Distillation at atmospheric pressure, 752 mm. First drop, 27°C. (81°F.)

Fraction No.	Cut °C.	at- °F.	Per-cent	Sum, per-cent	Sp. gr., 60/60°F.	°A.P.I., 60°F.	C.I.	S.U. visc., 100°F.	Cloud test, °F.
1	50	122							
2	75	167	2.6	2.6	0.652	85.5	-		
3	100	212	4.0	6.6	.705	69.2	14		
4	125	257	6.2	12.8	.731	62.1	18		
5	150	302	5.1	17.9	.748	57.7	18		
6	175	347	5.2	23.1	.765	53.5	19		
7	200	392	5.0	28.1	.781	49.7	21		
8	225	437	4.9	33.0	.798	45.8	23		
9	250	482	5.9	38.9	.812	42.8	24		
10	275	527	6.6	45.5	.826	39.8	26		
Distillation continued at 40 mm.									
11	200	392	3.6	49.1	0.843	36.4	30	40	15
12	225	437	6.1	55.2	.852	34.6	31	46	35
13	250	482	5.9	61.1	.864	32.3	33	58	55
14	275	527	5.5	66.6	.876	30.0	36	85	70
15	300	572	5.5	72.1	.890	27.5	39	145	90
Residuum			27.7	99.8	.955	16.7			

Carbon residue of residuum, 8.2 percent; carbon residue of crude, 2.3 percent.
Base of crude: Intermediate

APPROXIMATE SUMMARY

	Percent	Sp. gr.	°A.P.I.	Viscosity
Light gasoline	6.6	0.684	75.4	
Total gasoline and naphtha	28.1	0.738	60.2	
Kerosine distillate	10.8	.806	44.1	
Gas oil	15.3	.839	37.2	
Nonviscous lubricating distillate	11.0	.856-.879	33.8-29.5	50-100
Medium lubricating distillate	6.9	.879-.897	29.5-26.3	100-200
Viscous lubricating distillate	-	-	-	Above 200
Residuum	27.7	.955	16.7	
Distillation loss	.2			

TABLE 25. - Oil-production statistics - Colmar project

Year	Oil production, bbl. 4-percent decline	Oil production, bbl. Actual	Estimated oil gained, bbl.
1935[1]	22,379	21,782	Minus 697
1936	42,967	118,307	75,340
1937	41,248	115,564	74,316
1938	39,598	93,152	53,554
1939	38,014	96,178	58,164
1940	36,493	93,479	56,986
1941	35,033	88,219	53,186
1942	33,632	92,460	58,828
1943[2]	18,834	48,381	29,547
Total	308,198	767,422	459,224

1/ Last 6 months. 2/ First 7 months.

From July 1935 to August 1943 approximately 1,524,000,000 cubic feet of air were injected into the Hoing sand at an average pressure of 32 pounds per square inch. About 2,000 cubic feet of air were injected for each barrel of oil produced or 3,320 cubic feet of air for each barrel estimated to have been gained by August 1, 1943. The driving medium was injected at an average daily rate of approximately 800 cubic feet per vertical foot of sand exposed in each well. The estimated volume of oil gained by the injection of air into the Hoing sand was 323 barrels per acre. The cumulative oil production (on August 1, 1943) was 1,345 barrels per acre.

The Ohio Oil Co. reported that the development cost for the Colmar and Plymouth projects was approximately $55,000, or about $30.00 per acre. The low cost may be attributed chiefly to the absence of extensive drilling programs, but two other contributing factors were the inexpensive method of converting old oil wells to injection wells and the utilization of the vacuum pipe-line systems in air injection. Labor and material costs prevailing in 1943 would increase the capital requirements for the same development.

TABLE 26. - Summary of operations for The Ohio Oil Co. Colmar project, McDonough County, Ill.

Year	Air injected,1/ M cu. ft.	Average injection pressure, lb. per sq. in.	Injection-well spacing, acres per well	Oil-well spacing, acres per well	Repressured area, acres	Cumulative oil production, bbl. per acre	Estimated cumulative oil gained, bbl. per acre	Ratio of air injected to oil produced, cu. ft. per bbl.	Ratio of air injected to oil gained, cu. ft. per bbl.	Horsepower of compressor prime movers
19352/	60,000	45	30.9	8.1	1,420	15.3	0.0	2,770	-	90
1936	124,568	33	30.2	8.2	1,420	98.6	52.6	1,050	1,650	90
1937	108,057	39	30.2	8.2	1,420	171.0	104.8	940	1,450	90
1938	180,000	33	29.0	8.3	1,420	245.6	142.6	1,930	3,360	90
1939	193,146	28	29.0	8.3	1,420	313.3	183.6	2,010	3,320	90
1940	206,809	27	29.6	8.2	1,420	379.1	223.7	2,210	3,630	90
1941	220,730	26	29.6	8.2	1,420	441.3	261.2	2,500	4,150	125
1942	286,075	27	29.6	8.2	1,420	506.4	302.6	3,090	4,860	125
19433/	144,538	24	32.3	8.0	1,420	540.4	323.4	2,990	4,890	125
Total	1,523,923					540.4	323.4			
Average		32						1,990	3,320	

1/ Computed from occasional tests.
2/ Last 6 months of 1935.
3/ First 7 months of 1943.