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No. 21

ILLINOIS PETROLEUM

December 19, 1931

THE NEED FOR SAND CORING IN THE SOUTHEASTERN  
ILLINOIS OIL FIELD

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INTRODUCTION

In total production and in length of life, the southeastern Illinois oil field ranks high among the oil fields of the United States. At the present time, twenty-six years since production began, it is producing about 15,000 barrels of oil per day. The prices obtained for the oil for the past few months, however, have been considerably lower than the lifting costs at many of the wells, and unless prices rise or lifting costs are lowered these wells will have to be abandoned. Available data suggest that the total amount of oil produced to date, namely some 400,000,000 barrels, is but a fraction of the amount of oil still remaining in the sands. If, by the application of some improved method of recovery, the ultimate production may be increased by 25 per cent or more, and if lifting costs per barrel are thereby reduced below the price obtained so as to leave a margin of profit, the economic benefits to the operators and to the communities affected are obvious. Any method which would permit profitable production at present would yield a correspondingly greater profit at a time of normal prices.

Methods of increasing the recovery of oil may be classified into three main groups, (1) repressuring, (2) water-flooding, and (3) mining. Repressuring consists of forcing natural gas or air into the oil sand at certain key wells and pumping the remaining wells in the usual manner. Closely related to repressuring is the so-called "vacuum" method which consists of reducing the pressure in the sand at the pumping wells by means of a vacuum pump. In the water-flooding method, water is allowed to enter the sand in certain wells and oil is pumped from others. This method has been used successfully on a large scale in the Bradford field in Pennsylvania but has been little used elsewhere. Oil mining has been employed for many years

in Europe but has been used only to a small extent in the United States. It makes possible a higher ultimate recovery than any other method, but its use requires a large initial outlay of capital.

Repressuring has been used on a considerable number of properties in the southeastern Illinois field but the total repressured area is only a small proportion of the entire field. A number of the operators have been considering the feasibility of extending repressuring operations when economic conditions justify increased production, so that the degree of success of repressuring in various localities is of considerable interest. One of the projects in which the State Geological Survey is now engaged is that of assembling geologic, engineering, and economic data with regard to the repressured properties, the findings to be published for the benefit of the industry. However, there is another type of much needed data which are scarce yet which will be practically indispensable in guiding the use of improved recovery methods, that is, data regarding physical conditions, such as porosity, permeability, and saturation in the oil sands. The only practicable way in which these fundamental and necessary data can be obtained is by coring the oil sands and making appropriate tests on the cores.

This paper discusses the information to be gained from studies of sand cores and its application in connection with the use of improved recovery methods. Vacuum, water-flooding, and repressuring are compared and certain points of difference are noted, but a complete treatment is impossible until the desired information is at hand.

#### VARIATIONS IN CHARACTER OF OIL SANDS

Oil is found in a wide variety of geological formations, including loose sands that resemble those of modern ocean beaches and hard compact sandstones and limestones such as are used for building stones. In most cases where detailed information is available concerning a body of oil-bearing rock it is found that there is much variation in size of grain, amount and character of pore space, mineral composition, degree of cementation, and texture, both vertically and laterally. This condition is illustrated in figure 1.

The oil sands of Illinois consist of consolidated sandstones and limestones. There is little need to emphasize to Illinois oil operators the fact that there are great variations in sand conditions from well to well over much of the southeastern field. It is attested by large differences in oil production from adjacent wells and by the intermingling of a considerable number of dry holes with the producing wells. This variation in sand conditions from well to well makes it difficult to estimate accurately the oil reserves and must be considered in order to apply intelligently improved recovery methods such as repressuring. It is evident that, for the solution of problems con-

nected with future production, the more specific and detailed the information we can obtain on sand conditions the better off we are.

Not only do sand conditions vary considerably from well to well in a pool, but general conditions in different pools and in different parts of the country may be very different. For this reason a method of recovery suitable in one place may be unsuitable in another, and as the applicability of any method depends entirely on local conditions, it is desirable that careful study be given to these conditions before choosing and initiating the new method.

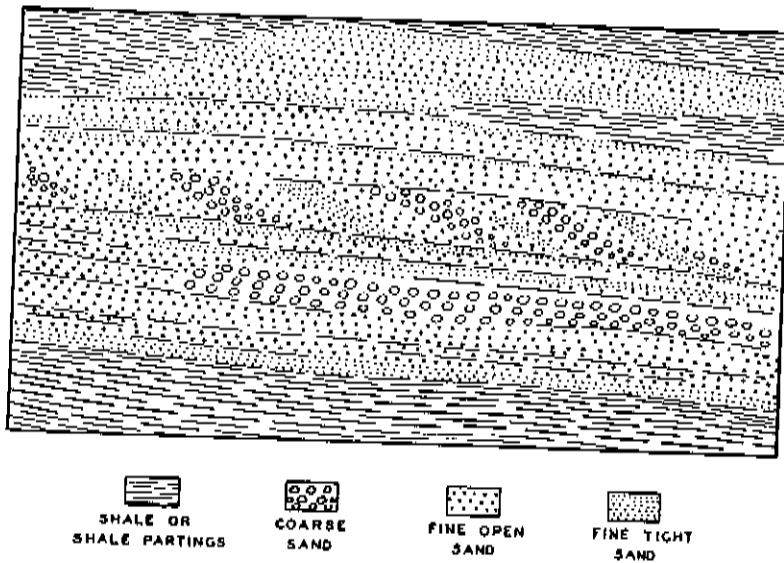


FIG. 1. Sketch showing variations in texture and bedding of oil sand.

#### CORES VS. DRILL CUTTINGS AS A SOURCE OF INFORMATION ON SAND CHARACTER

Something about the character of an oil sand may be determined by drilling it in the ordinary way (by a cable tool) and examining the broken pieces or "cuttings" brought up by the bailer. For two reasons, however, the information is not nearly so complete as that which can be obtained from the core of a sand. First, the sample of broken pieces represents several feet of the thickness of the sand and although sand of various kinds may be present there is no way of telling how the various layers were originally related, whereas from a sand core the variation in character with depth may be determined precisely, and second, tests of porosity and rate of flow may be performed on pieces of core but it is ordinarily impossible to make such tests on drill cuttings.

## PREVIOUS CORING IN SOUTHEASTERN FIELD

A small amount of coring has been done in the southeastern Illinois oil field, most of it on the repressured properties of the Associated Producers Company north of Robinson. Other places in this field in which cores have been taken are in the Siggins pool, Cumberland County,<sup>1</sup> and at Allendale,<sup>2</sup> Wabash County.

## FACTORS INFLUENCING FLOW CONDITIONS IN SAND

The rate of flow of a liquid through a porous solid is influenced by the size and shape of the pore spaces in the solid and by the surface tension of the liquid at its surfaces of contact with the solid. Attempts to establish a relation between the porosity of sands and their permeability, or the rate of flow of a specified fluid under specified conditions of temperature and pressure, cannot succeed because the most important factor, surface tension, has been neglected.

Two illustrations will serve to bring out the reason for the lack of correlation between porosity and rate of flow. First, compare the rate of flow of water through a cylinder full of steel balls 0.1 inch in diameter, packed as closely as possible, with that through a similar cylinder full of balls 0.001 inch in diameter. It is easily shown mathematically that the porosity is exactly the same. The rate of flow in the case of the smaller balls is much less than in the case of the larger balls. This is because under conditions where surface tension is effective, the influence of surface tension varies with the area of interface between solid and liquid, which in this illustration is equivalent to the total surface area of the balls. The total surface area of the smaller balls is 10,000 times that of the larger ones. Second, consider two steel plates through which circular holes are bored at regular intervals. With the plates placed so that the holes are exactly superimposed, forming continuous channels, water will flow through them at a certain rate under given conditions of temperature and pressure. Now let the plates be kept in contact but shifted with respect to each other until the holes are no longer superimposed. As the plates are shifted the rate of flow will continuously decrease until it stops altogether. The porosity or per cent pore space of the steel plates has remained the same from beginning to end of the experiment but the rate of flow has varied enormously. Evidently the degree of continuity of the pore spaces is important.

<sup>1</sup>Lamar, J. E. A study of the core of the Yanaway well No. 33 in the Siggins pool. Illinois State Geol. Survey, Illinois Petroleum No. 15, May 12, 1928.

<sup>2</sup>Moulton, Gail F. Notes on a core bit for cable tools, Illinois State Geological Survey, Illinois Petroleum No. 2, May 29, 1926.

## COMPARISON OF VARIOUS IMPROVED RECOVERY METHODS

In deciding what method of recovery is most applicable under a given set of conditions the relative merits of various methods should be considered and their characteristics compared.

## WATER-FLOODING VS. REPRESSURING

The use of water-flooding gives a greater rate of recovery than that obtained by repressuring and with the use of present methods indications are that the ultimate recovery is also higher for water-flooding than for repressuring, but it is claimed that water-flooding, on the other hand, spoils the oil field for any other type of recovery. Attempts to use the same water repeatedly, as would be desirable in localities where water must be transported long distances, have encountered considerable difficulty, apparently because the iron oxide removed from the sand during the first use of the water is converted into ferric hydroxide which, when the water is used a second time, tends to clog up the pores in the oil sand.

## VACUUM VS. REPRESSURING

Vacuum and repressuring each belong to one general type of improved recovery in which gas acts as a propellant for oil, and a differential pressure greater than normal is artificially set up in the sand. An essential difference between these methods is that in vacuum there is no circulation of gas such as exists when repressuring is used. (A possible exception to this would be in an extremely open sand where air is sucked in through an adjoining well.) As there is no circulation of air, the only additional gas evolved after the vacuum has removed the original gas in the oil is that due to the vapor pressure of the oil itself. When once vacuum is started on a well it is necessary to continue its use unless some other method of improved recovery is initiated. If for any reason the vacuum is broken, the instantaneous inrush of air or water due to atmospheric pressure drives the oil away from the well back into the sand, after which it may take weeks or months to regain the vacuum with resultant flow of oil. In a repressuring system the flow of gas is continuous from intake well to outlet well as long as compressed air is injected. A temporary shut down of the compressors is much less serious than an interruption of vacuum.

An important point of difference between vacuum and repressuring is in the amount of differential pressure attainable. In vacuum it is limited to something below atmospheric pressure, or about 12 pounds per square inch under usual oil field conditions. In repressuring it is common practise to use pressures as high as 300 pounds per square inch or 25 times as great a differential pressure as the maximum attainable by vacuum. If sand conditions are similar, it follows that the area in which the flow of oil is affected

is approximately 25 times as great in the case of repressuring as in that of vacuum.

Another practical consideration is that the use of vacuum tends to drain oil from adjacent properties, so that it is necessary for an operator to install vacuum equipment near a property line at the time vacuum is initiated on the adjacent wells. On the other hand, repressuring tends to force oil toward adjacent wells on adjoining properties. Both methods, therefore, require cooperation between lease owners.

#### CHARACTERISTICS OF REPRESSURING

In repressuring, one intake well may supply pressure for a series of from five to ten pumping wells. A given flow to the various wells may be maintained by using the desired back pressure on each individual well. For instance, if there is a stratum of loose sand between the intake well and a particular pumping well there may be a tendency to channel to that particular well, but by using back pressure at such a pumping well the differential pressure between it and the intake well may be lowered sufficiently to prevent the tendency to channel.

Where no methods of improved recovery are used, the gas-oil ratio is of prime importance, that is, a minimum gas-oil ratio is necessary for a maximum ultimate recovery. This is because the gas acts as a propellant to force the oil to the well. When the gas pressure approaches atmospheric pressure the rate of flow of the oil will likewise approach zero. Where there is a continuous passage of gas, as in repressuring, the gas-oil ratio loses its relation to ultimate recovery, although there may be other reasons for keeping the ratio as low as possible. For instance, a low ratio implies low pressure gradient, that is pressure per unit distance, which is insurance against channeling. Furthermore, there is evidence that pressure gradients higher than a certain critical value may result in excessive formation of oil-water emulsion and also increased corrosion.

Where repressuring is used, the gas may be either air or natural gas. Natural gas is preferable to air because the oxygen constituent of air is absent in natural gas. Nevertheless in many localities its use is prohibitive either because the production of gas is usually low when repressuring is adopted or because it is necessary to use the gas as a fuel for pumping and compressing the air to be used for repressuring. Air used for repressuring generally absorbs sufficient vapor from the oil so that the gas at the pumping well may be used as a fuel gas; the only exception is in a few cases where the carbon dioxide content of the outlet gas is too high to permit combustion. In some cases where air has been used there has been a certain amount of oxidation of the oil which, when associated with salt water or certain sulphur

compounds, has resulted in excessive corrosion both in the pumping and pipeline equipment. Where it is possible to use natural gas instead of air the increased corrosion does not occur. Increased corrosion difficulty also appears to be associated with too rapid a flow of the gas due to high pressure, so that the best preventive measure is to lower the differential pressure by the use of back pressure at the pumping wells.

### APPLICATIONS OF SAND CORE STUDIES

#### RESEARCH ON LAWS OF FLOW

Considerable research has been done on the porosity of oil sand, the size of the sand grains, and the permeability of the sand, as well as on the viscosity of various oils, but comparatively little research has been done on the rate at which air will drive oil through an oil sand or on the ultimate recovery which may be obtained by forcing air through an oil sand. Isolated studies of porosity, grain size, permeability, and viscosity have little bearing on this particular problem because the passage of air and oil through sand is under capillary conditions where flow is primarily along the surface of the particles rather than through the openings. In other words, since the surface tensions of the various materials forming the interface are of different orders of magnitude, surface tension is perhaps the most important factor. From the value of the flow of either air or water through a sand it is impossible to predict even qualitatively the results of the flow of oil through the same sand.

For this reason it is proposed to use representative samples of oil sand to make a comprehensive study of the conditions when repressuring methods are used. The purpose is two-fold, first, to ascertain the increased rate of recovery for various pressure gradients, second, to determine the factors of pressure and time giving the highest ultimate oil recovery. With a knowledge of these two points, it is possible to form a reasonable estimate, for a particular average oil field formation, as to the increased rate of production and the length of time that this increased production can be maintained in order to give the ultimate recovery. To illustrate, for a well producing one barrel of oil per day without repressuring, it will be possible (1) to predict the expected increased rate of production, as for example, two or five barrels per day, and (2) to estimate the length of time that the increased rate of recovery should be maintained, as for example, six months or five years.

#### ESTIMATION OF OIL RESERVES

A knowledge of the amount of oil remaining in a sand is desirable as it makes known a definite upper limit to the amount of oil recoverable by any method. Appropriate tests on samples of oil-sand cores will permit the

compilation of a log showing the percentage of oil contained in various parts of the sand. On the assumption that the sand is constant laterally in saturation and in thickness, the number of barrels of oil per acre may be computed. If a number of cores of the same sand, well distributed over the area of an oil pool, are available, the range of variation in the amount of oil per acre is indicated and the probable error in an estimate of the total amount of oil in the reservoir may be evaluated. It is easily seen that the degree of accuracy of the estimate depends upon the number and distribution of the available cores and upon the rate and amount of the lateral variations in sand thickness and saturation. The more variable the sand conditions the greater will be the number of cores necessary to obtain a reasonably accurate estimate of the oil reserves. It is hoped that as information on sand cores from various parts of the southeastern Illinois oil field accumulates over a period of time it will become possible to estimate oil reserves with an error not greater than 25 per cent.

With estimates of the oil reserves, the rate of recovery by repressuring, and the ultimate recovery to be expected by repressuring, the operators will have information on which to base decisions as to the desirability of repressuring certain areas.

#### SPACING OF WELLS

All of the factors noted above are important in the determination of the optimum distance between wells. If repressuring is to be used, new principles will govern the most economic spacing of wells in a new field. For example, as noted above, the area of flow under repressuring conditions is many times larger than it is when vacuum is used. Laboratory logs of the oil sand, such as may be compiled from core studies, yield information useful in choosing the best locations for wells.

#### SHOOTING OF WELLS

The operator who takes a core of an oil sand has valuable information which is immediately useful. The core will indicate the position of the richer pay streaks and the barren parts of the sand and thus the nitroglycerin shells for shooting can be placed more intelligently than if only the driller's log and sample cuttings are available.

#### PROPOSED CORE STUDIES BY STATE GEOLOGICAL SURVEY

The State Geological Survey is now in position to cooperate with the oil operators in a program of studies of oil sand cores, looking forward to developing improved methods of oil recovery. The Survey possesses a cable tool core barrel which it will loan to operators for the purpose of enabling them to core their oil sands at certain selected new well locations. It will furnish a Petroleum Engineer to supervise the coring and will make the study and laboratory tests on the cores.



## EQUIPMENT FOR CORING WITH STANDARD TOOLS

A cross-section of a modern type cable tool core barrel is shown in figure 2. By the use of "subs" it may be attached to drill stems of various sizes. It consists of (1) an outer core barrel to which the bit is attached and which is raised and lowered like an ordinary bit, and (2) an inner core tube which remains stationary except that it is driven downward as drilling progresses. A maximum of about 5 feet of core may be obtained in one run. The use of the core barrel is not very different from ordinary drilling and with experience the rate of drilling is not materially slackened.

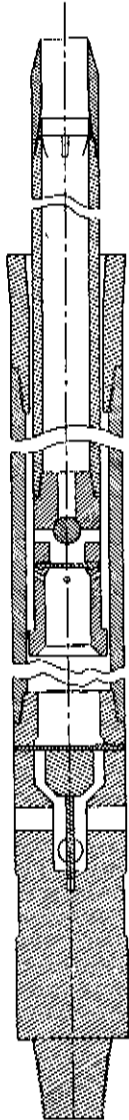


FIG. 2. Longitudinal section of a modern cable tool core barrel.

## LABORATORY TESTS

It is proposed to test cores for porosity, saturation with oil, and texture. Standard methods will be used for determining porosity and saturation. Texture will be determined by direct study with the binocular microscope and by microscopic study and photographs of sections similar to those shown in figure 3.

In addition to the above tests, a careful study will be made of the laws governing the flow of oil, water, air or gas through the sands. Cores of various types will be selected for this study.

The success of the program outlined above depends upon close coöperation between the individual operators and the Survey. This is particularly necessary at the outset in order that representative cores from various parts of the field may be obtained for testing. The cores will become the property of the Survey and will be placed on file at the Survey office in Urbana. Any core will be available for reference to the owner of the well from which it was obtained, and the Survey will gladly furnish full information to the well owner on tests of those cores which he has contributed. It is planned that, whenever sufficient data regarding cores have been accumulated, they will be published for the benefit of the industry.

## CONCLUSION

The accumulation of knowledge of sand conditions resulting from core studies may be expected to be beneficial in the following ways:

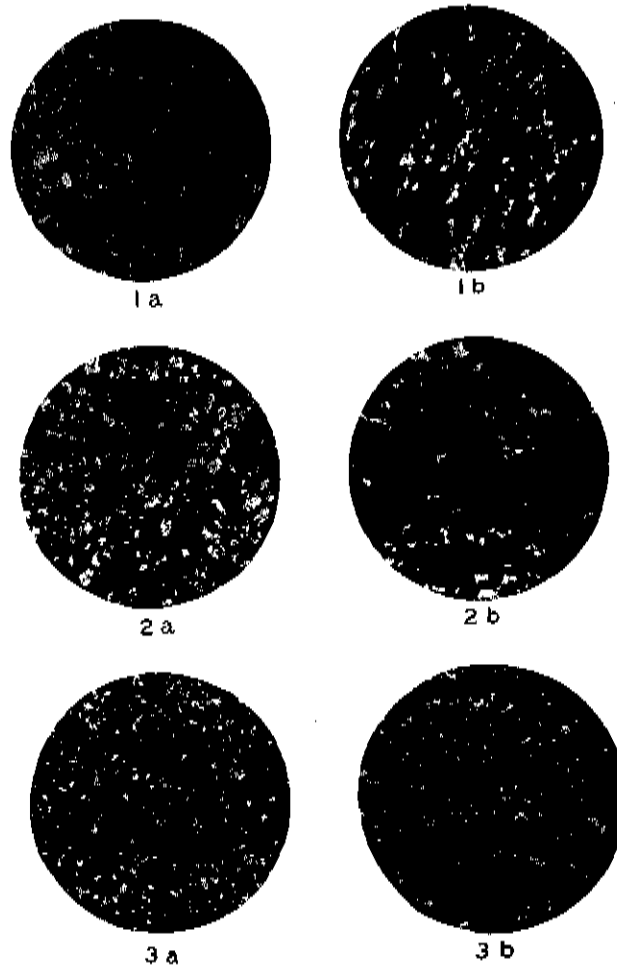


FIG. 3. Photomicrographs of oil sands of three grain sizes, rows 1, 2, and 3; column "a", thin sections, transmitted light; column "b", rough sections, incident light. Approximate magnification,  $\times 20$ .

*Rows 1 and 2.*—Samples of Robinson (lower Pennsylvanian) sand obtained in cleaning out the One Sixth Oil Company's Jim Evans well No. 1, NE.  $\frac{1}{4}$  NW.  $\frac{1}{4}$  sec. 36, T. 8 N., R. 13 W., Crawford County, Illinois.

*Row 3.*—Sample of Carlyle (Chester) sand obtained in cleaning out the Ohio Oil Company's Peter Murphy well No. 8, NE.  $\frac{1}{4}$  SW.  $\frac{1}{4}$  SE.  $\frac{1}{4}$  sec. 3, T. 2 N., R. 3 W., Carlyle field, Clinton County, Illinois.

(1) It will permit more accurate estimates of oil reserves than are now possible.

(2) It will assist in deciding which improved method of recovery is best adapted to conditions in a given area.

(3) If repressuring is to be used it will help to decide what size and kind of equipment to install and what wells to use as input wells.

(4) If new pools are opened it will help to decide the most advantageous spacing for wells.

In addition to the benefits listed above, which depend more or less on an accumulation of data, each core taken will provide immediate guidance in placing the shot to the best advantage.