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PRESSURE MAINTENANCE BY CONJOINT INJECTION OF GAS AND WATER—A WARTIME SUGGESTION

BY

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PRESSURE MAINTENANCE BY CONJOINT INJECTION OF GAS AND WATER—A WARTIME SUGGESTION

By **Frederick Squires**

LITTLE was known of petroleum engineering when the first World War began. H. L. Doherty had not yet discovered that oil when saturated with gas develops a greater fluidity. The need for retaining the original reservoir pressure of an oil pool was not yet appreciated, and the necessity for its corollary, pool unification, had not been sensed. Repressuring with gas and air had only begun. J. O. Lewis had not yet stated his concept of restoring high pressure to oil sands by the injection of gas in order to produce oil from tight sections as well as from open sections of the stratum. Paul D. Torrey had not yet applied Lewis' idea to water flooding by devising his delayed-drilling technique. Water flooding itself was usually done by line flood, which was but a short step in advance of Carll's ancient advice of returning water to a reservoir in the amount of the fluids removed.

A German artillery officer was using the reflection seismograph to locate enemy big guns by earth vibrations caused by their discharge, but the idea had not yet been applied to discovery of oil structures. Electric well logging was unknown. Drilling was generally a cable-tool job although the rotary method had been known since its use at Spindletop. The laboratory was barely on speaking terms with the oil field, and such refinements as core analysis had not yet appeared. Dr. Merriam was per-

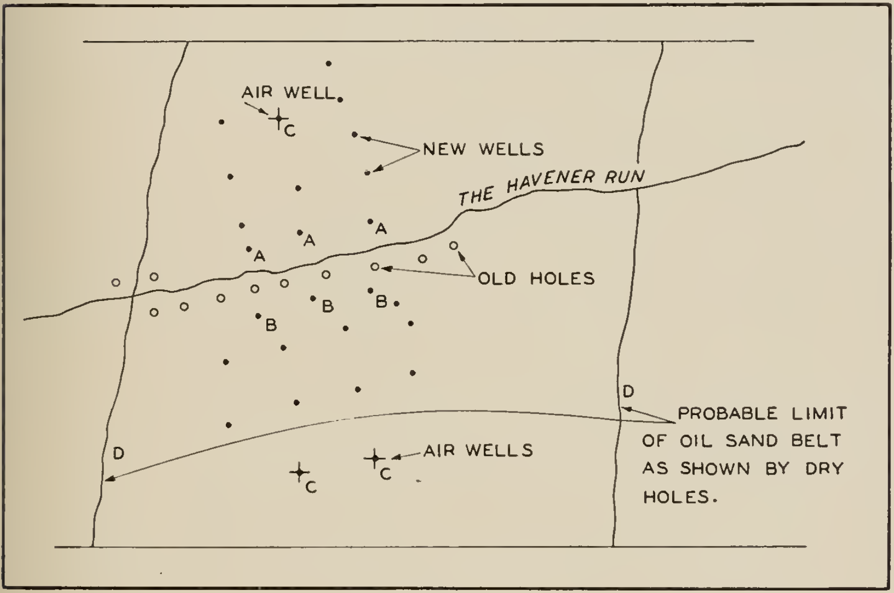


Fig. 1

fecting his absorption gasoline-extraction process but most others were content to use compression and refrigeration. Chemical developments such as acidizing were not in practical use.

Knowledge Gained Between the Wars

Between the wars there was a great advance in comprehension of oil-reservoir conditions. It was realized that many strata containing oil reservoirs slope downward from the surface, that they are under water pressure, and that the measure of the pressure on the oil trap is closely related to the degree of pressure which would be exerted by a continuous body of water extending through the strata from surface to reservoir. From this observation it was deduced that the pressure on the reservoir is hydrostatic. Gas was found to be in solution in the oil in an amount corresponding to that which would be absorbed at the degree of pressure and temperature existing in the reservoir. This dissolved gas reduces the viscosity of the oil. Such a reservoir is in ideal condition for oil production.

When a well is drilled into an oil sand which is under water pressure and which is fully saturated with oil that contains gas in solution the pressure differential between the reservoir and the surface forces oil up and out of the well. The gas comes out of solution in the well bore as the pressure on the flowing oil is reduced proportionally to its depth below the surface. As the oil and gas move out, edge water moves into the pool in an effort to restore equilibrium, and if it were not for the retarding action of friction in the sand, the reservoir fluids would move through the reservoir like water through a bent tube. How fast the pressure in the reservoir falls when wells are allowed to flow wide open depends on the degree of pressure at the water-oil contact in the reservoir, the distance to be traveled, and the permeability of the sand. With few exceptions this

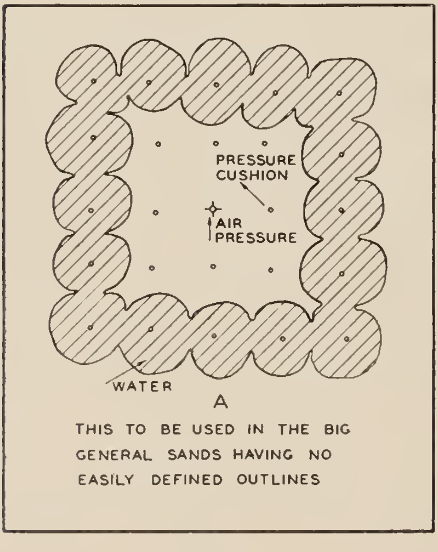


Fig. 2

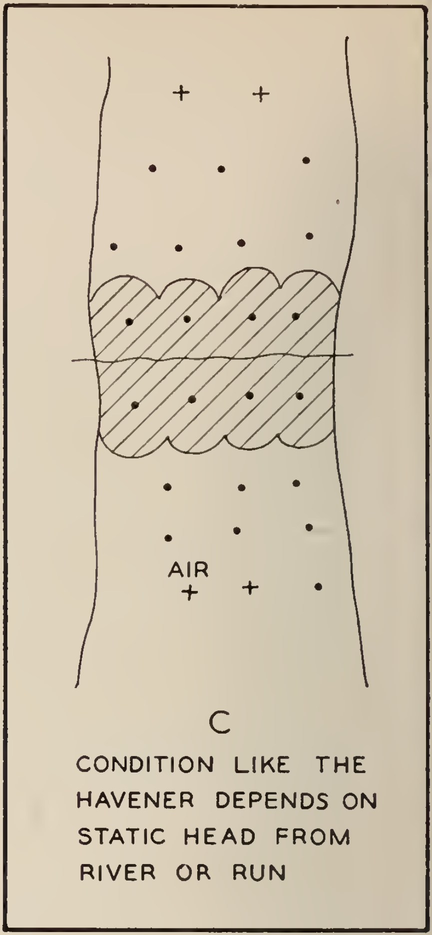
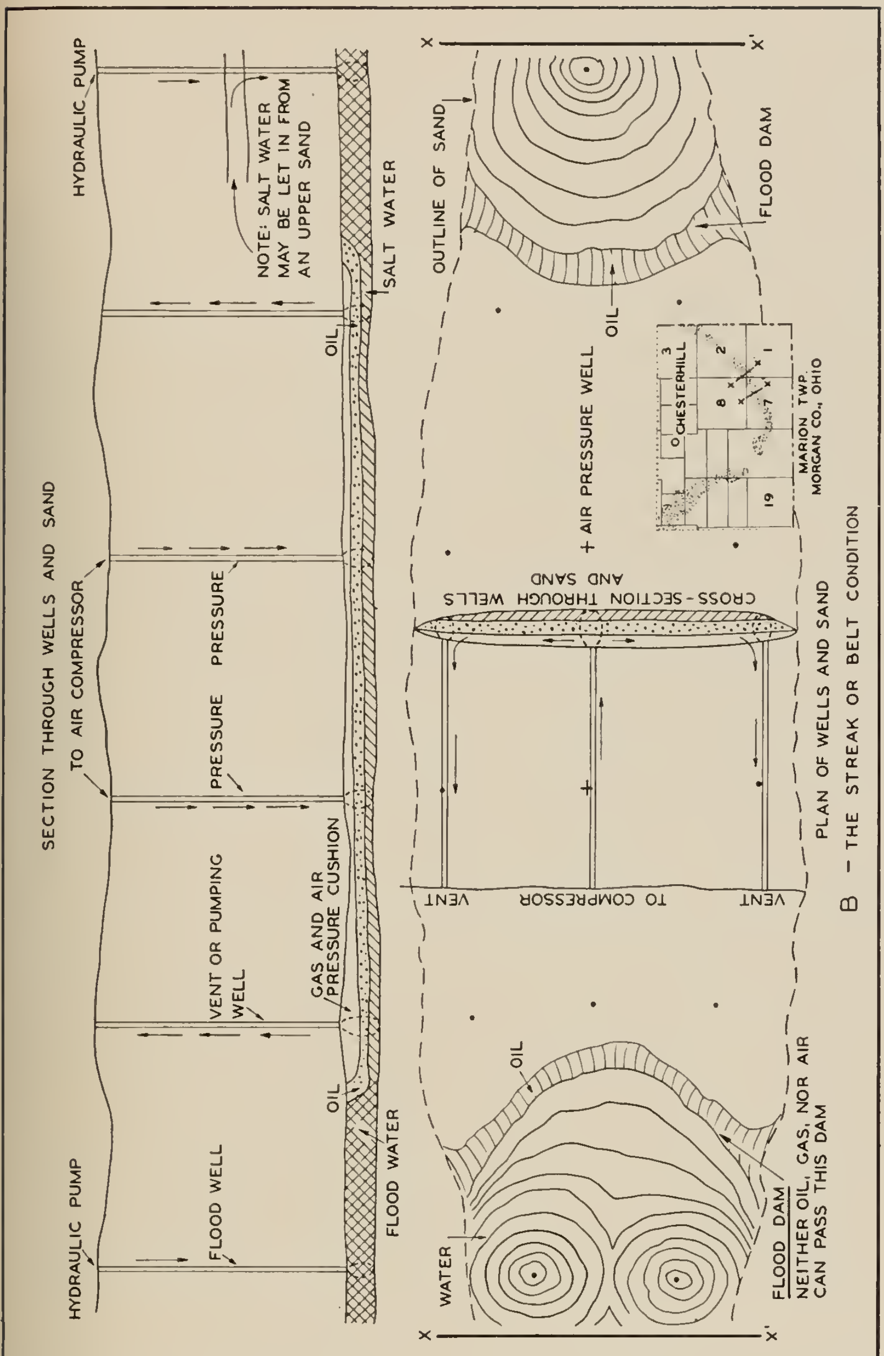


Fig. 4



B – THE STREAK OR BELT CONDITION

Fig. 3

permeability is not high enough to permit sufficient additions from edge water to compensate for the vented oil and gas. So the pressure declines in all directions toward the well. With sufficient decline, gas comes out of solution from oil at constantly increasing distances back from the well, and the viscosity of the gas-freed oil increases. If the permeability is low there will be a lag in water encroachment that will result in diminishing pressure and increasing viscosity from the water at the water-oil contact to the well itself. Gas comes out of solution over widening areas, flowing stops, and pumping will have to begin. Under such conditions it is no longer possible to extract oil efficiently, yet this condition always arose, due to the customary production practices in oil pools before the first World War.

The Problem

The writer began to investigate the conjoint use of gaseous and liquid media to increase pressures on oil sands in an effort to correct some of the evils of the condition just stated and thus to increase production. His earliest conception of the conjoint use of gas and water injection to increase yields from oil sands is best illustrated by the following letter written in Marietta, Ohio, December 15, 1915:

"The following is a description of my 'flood-air pressure' system of obtaining oil and gas from porous strata.

"At one part of the Buck Run belt the over burden on the oil-bearing stratum was partly cut through by the Havener Run, and into the shallow covering above the sand innumerable wells were 'kicked down' in the old times and after being abandoned were left open. During certain seasons of the year the river overflows its banks and backs up the Havener Run so that these old holes let immense quantities of water into the porous sandstone. Leases on and near Havener Run are shown in Fig. 1.

"I noticed nothing unusual about this except that new wells drilled at AAA BBB near the run made nothing but fresh water. We applied air pres-

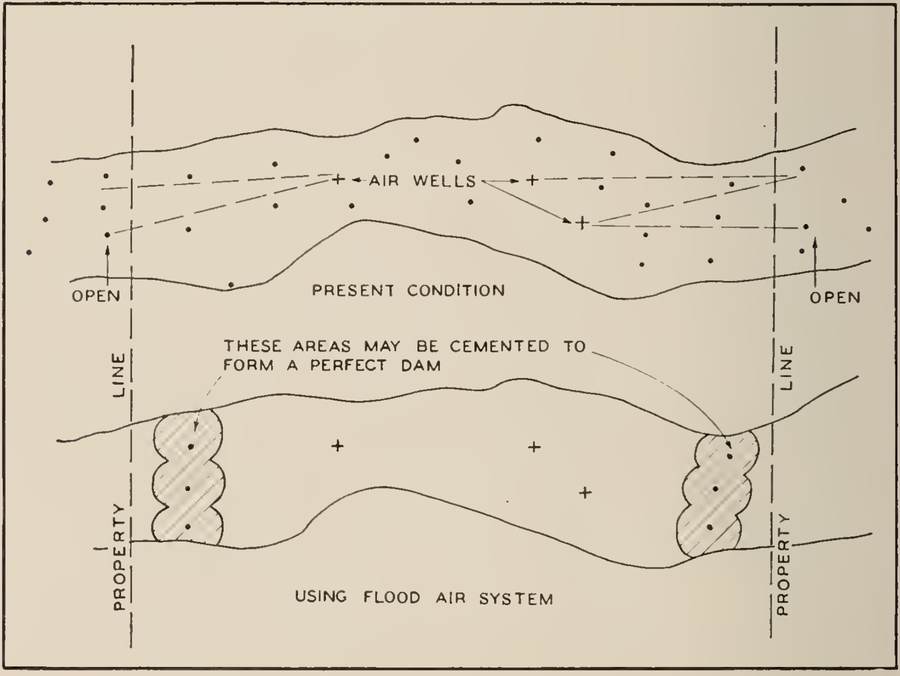


Fig. 5

sure at CCC and almost immediately all the new pumping wells increased their production of oil much faster than any of the several hundred wells at a distance from the run. Also different pressures could be maintained on different sides of Havener Run. From these facts I deduced that the oil between the edges of the sand DD and the run was entrapped by them and driven to the included wells with greater force than was possible where the air could escape along the belt. I will divide the effects of using an inelastic and an elastic pressure fluid into three heads.

"1. A dam or dams including a pressure cushion.

"2. Encroaching flood or floods of inelastic fluids controlled by a counterpressure of elastic fluids.

"3. The raising of the oil level in the sand between dams to prevent by-passing of the elastic fluid.

"In (1) the operator floods with salt water or fresh water under high static pressure or by means of hydraulic pumps a portion of an oil or gas-bearing sand so as to form a barrier, either by itself or by cooperating with the edges of the oil-sand belt, to the escape of (a) the oil or gas and (b) an elastic pressure fluid used to force the oil or gas to the included venting wells. The results are these: the oil or gas can be kept under the operator's own territory until entirely removed through his wells; and high pressures and small losses can be achieved by using the elastic pressure fluid that will carry the oil or gas to the vents. Figs. 2, 3, and 4 illustrate the possible conditions.

"Condition A has been found in Pennsylvania where the leases are mostly rectangular and are drilled around their boundaries in order to 'offset' the wells of the neighboring rectangles similarly drilled.

"Condition B is the most general. Oil sands are usually found in streaks. We have a case in point where the theory of B would find practical application. It is in an oil sand so coarse as to resemble a conglomerate and therefore extremely porous. We are applying air to our part of the streak but our neighbors defeat our intentions entirely by merely leaving their wells open so that all our air passes out and the friction of the sand is so slight that there is little or no pressure on the sand such as is necessary to make the air rush to vents. If anything is happening to the oil at all, it is merely moving off our lease on to our neighbor's and there can be no doubt that the gas is doing this (Fig. 5).

"Condition C would be used where the supply of water was from a river or some similar source which would have enough head above the sand so that it could be depended on to keep the dam tight against the air pressure.

"Encroaching floods of surface water on oil sands are no invention, for the Havener Run has been flooding its sands for 50 years, and surface water in the deep and noncaving wells in Pennsylvania (1,600 ft. through rock and shale) have flooded the sands and driven the oil ahead of it for years under 800-lb. pressure. But the control of encroaching water by

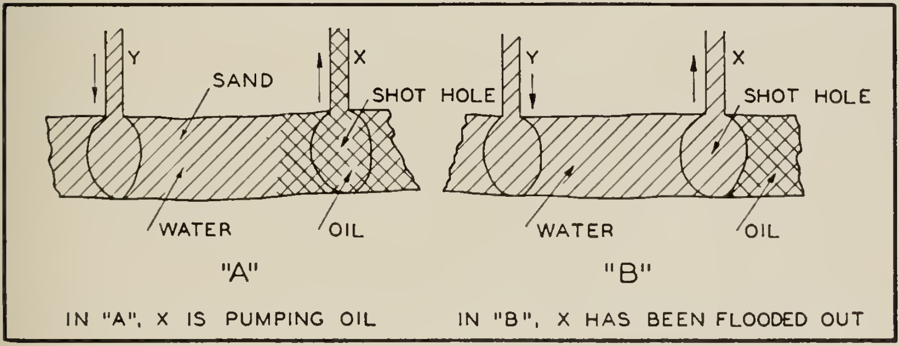


Fig. 6

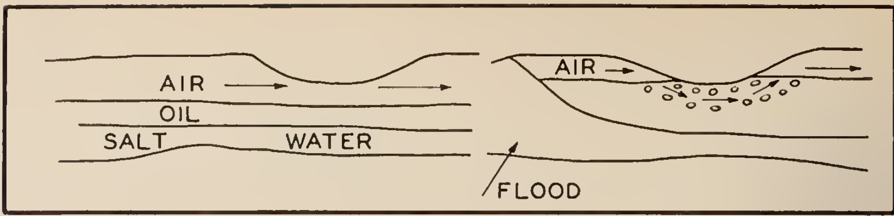


Fig. 7

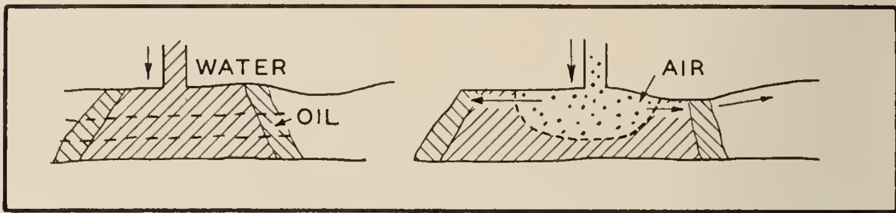


Fig. 8

means of an elastic cushion is brand new. The difficulty heretofore experienced in flooding sands in order to drive oil to wells has been due to the short time allowed to pump off the oil while it was passing under the well and before the water got to the well, and also to the impossibility of getting the oil that is not carried directly to an opening. The advance of the flood is so slow that the gas has time to escape before it through the wells, and there is nothing but friction to retard the flood, since no gas pressures have been set up. The oil and water do not mix, the oil being driven before the water as in Fig. 6—in A well X is pumping oil, in B well X has been flooded out. In my method when the encroaching flood has brought the oil to well X, the air pressure is increased so as to check the flood and give time for the oil to be pumped or flowed off. This is exactly what is being done now at Havener Run. Wells are pumping oil which, had it not been for the counterpressure of the air on the flood, would have been drowned out with water from the run. The reverse of this is often seen in fields after they have been drilled. The wells let off the gas pressure which has been retarding the natural flood of salt water, and when this pressure is released the water rushes in and drowns out the wells, that is, makes them pump nothing but salt water, the oil being forced to another part of the sand and often never found by the drill.

"The process under (2) would be to drive oil or gas by the advance of a liquid under pressure until it reached venting wells, and then to reduce the liquid pressure and to increase the elastic counterpressure until time enough had elapsed to remove the oil. Then the advance of the liquid would be continued until another favorable point was reached. (Note that flooding sands with fresh water is unlawful in one or two states but there is no law against using salt water which is found in the sands themselves.)

"It often happens that after air pressures have been used for some time the upper parts of the sand become quite cleared of oil and the air 'blows' through from the pressure well to the venting well without moving the oil at all. Methods have been devised for lowering the casing in the venting wells so that it extends almost to the bottom of the sand in order to insure the pressure air traversing the fluid. An incidental advantage of flood air is that the encroachment of the flood raises the fluid level (oil and water) and in cases of inequality in the roof of the sand the oil may cut off the air passage entirely and so cause the air to strike directly on the oil (Fig. 7). Alternating air and water pressures into the same well will accomplish the same result through a limited space."

The method illustrated in Fig. 3 was put into operation on the Howard farm in 1916.

The disclosures related in the letter of December 15, 1915, resulted in the U. S. Patent No. 1198078, granted September 12, 1916, the first claim of which reads, "the method of recovering oil and gas which consists in forming a liquid dam under pressure in the oil-bearing sand to prevent the escape of the entrapped oil and gas and applying pressure independent of the liquid to said oil and gas to vent them."

Combination of Idea of Conjoint Injection With Present-Day Knowledge of Reservoir Behavior

Water under static head is the prime mover in producing oil and gas from most oil-field reservoirs. It makes gas a secondary mover by compressing it and keeping it in solution in the oil. The combination of energy from hydrostatic head and fluidity from dissolved gas provides the ideal motive power for venting oil as long as the reservoir retains sufficient pressure, but abruptly ceases to work when the pressure is lowered below a critical point. Because the reservoir is in its ideal condition to vent oil when under original pressure and is ineffective as soon as the pressure is sufficiently lowered, the logical procedure must be to bring it back to its original ideal state by injecting the same elements, water and gas, which produced the former perfect setup. Such a method is advocated in the patent described above and is made still more pertinent by the new knowledge of reservoir behavior learned since the first World War.

Between the first and the present World Wars three pressure-maintenance production practices have been developed which lead to conjoint injection of water and gas as their logical culmination. These are pressure maintenance by (1) restriction of output of gas, oil, and water; (2) restriction of output combined with water injection; and (3) restriction of out-

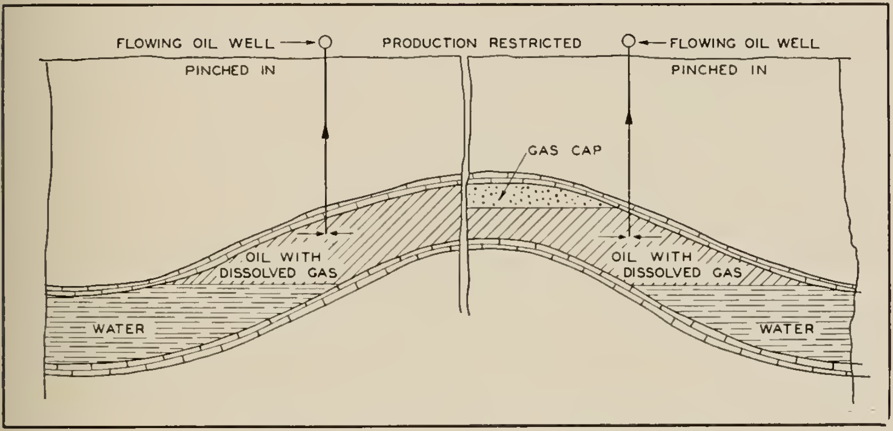


Fig. 9: Pressure maintenance by restriction of oil and gas production

Fig. 9 illustrates a section through an oil reservoir, showing the relations of gas, oil, water, and wells to the oil production. On the right is shown a gas cap with oil below and water at the bottom. In each case the amount flowing from the well is regulated to retard as much as possible the pressure drop caused by unloading the reservoir. In it an attempt is made to balance oil and gas withdrawal to the influx of edgewater. The difficulty encountered is that when oil and gas are withdrawn, the water encroachment forces oil into the abandoned part of the gas cap, and such oil can never be recovered from the sand put combined with injection of gas.

(1) Pressure Maintenance by Restriction of Output (or Retarding of Pressure Drop) (See Fig. 9)

This procedure would be more efficient were there no obstacle to the free flow of the fluids from the edge water through the sand, to and out of the well. It is less efficient with greater distances or with lesser permeabilities in the strata through which the fluids must pass. Almost never is the permeability of the sand in a field of average size so high that water can flow in from the edge as fast as oil and gas flow out through wide-open flowing wells. In order to maintain as nearly as possible the original reservoir pressure, it is now common practice to pinch in the flowing wells in an effort to conserve the pressure by balancing the output of the wells with the advance of edge water. This is seldom possible, the best result obtainable in practice being a slowing down of the rate of pressure loss.

Gradually the pressures fall to points at which gas is released from solution in the oil, farther and farther back from the well, increasing the viscosity of the oil at the very time that there is less power to move it. A lag is set up between the propulsive action at the edge water oil contact and the well so that increasing areas of sand between are under decreasing pressure in the direction of the well. Eventually the oil in areas surrounding the output wells is without any appreciable motive power. Before this condition is reached, however, the

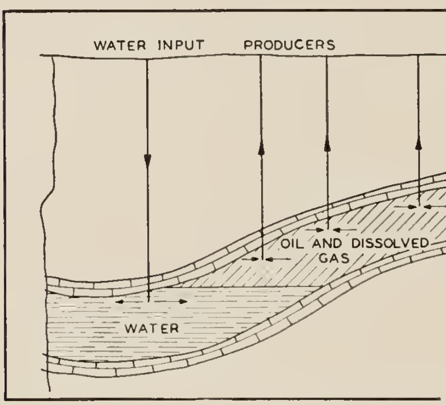


Fig. 10: Pressure maintenance by water injection and restriction of oil and gas production

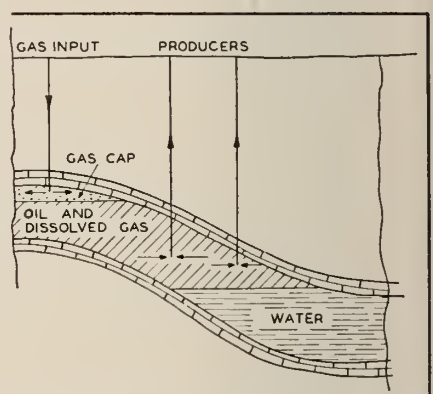


Fig. 11: Pressure maintenance by gas injection and restriction of oil and gas production

Fig. 10 illustrates a section through half an oil field on an anticlinal closure in which oil with its dissolved gas occupies the higher part and water under pressure occupies the lower part. Pressure maintenance to overcome the drop due to withdrawal through the producing wells and the lag due to friction encountered in the movement of oil and water through the sand is accomplished by injecting water from the surface into the water in the structure. The success of this practice usually depends on a restriction of withdrawal of oil and gas from the producing wells because it is difficult to balance input with output under conditions of open flow. All gas withdrawn is lost to the reservoir. The application of this method is best illustrated in the East Texas pool

Fig. 11 is a simplified diagrammatic illustration of the process of injecting gas into an anticlinal structure in order to increase ultimate production of oil. Gas is injected into an existing gas cap. If no gas cap were present, the top of the structure would be occupied by oil saturated with dissolved gas, and the pressure-making gas would be discharged into the oil. The procedure is usually combined with restrictions on oil withdrawals in order to prevent rapid increase in gas-oil ratios. Edgewater encroachment cannot make up for the void caused by the removal of oil. The process is well illustrated at Louden, Illinois

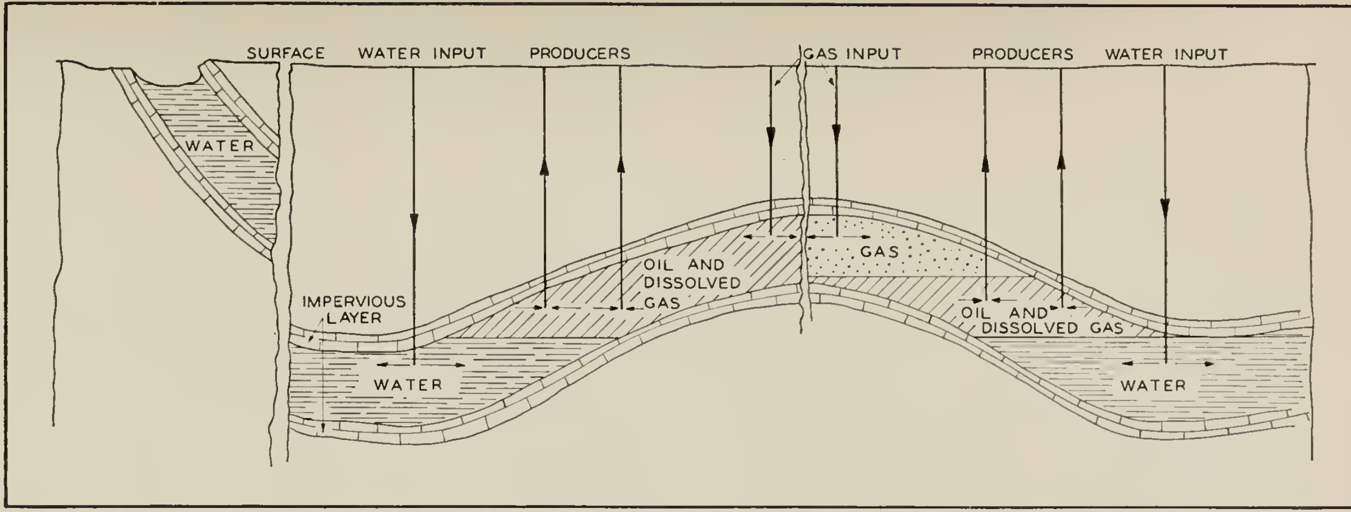


Fig. 12: Pressure maintenance by conjoint use of gas and water to maintain reservoir pressure

Fig. 12 is intended to illustrate the similarity between the potentialities of an anticlinal structure containing gas, oil, and water in its virgin condition and one in a condition restored by injecting gas and water at appropriate points. It is believed that the pressure existing in a virgin pool is produced by the static head of water entering the stratum at the surface. This is shown on the left side of the diagram. Gas and oil are forced to the high part of the trap. If the pressure is beyond the critical point, gas is absorbed by the oil until all the gas is taken up or until the oil is saturated. Any additional gas, having nowhere else to go, accumulates above the oil in a gas cap. Wells marked "producers" vent oil and dissolved gas, and the water moves in an effort to restore equilibrium, which effort is partially defeated by the retarding effect of friction with the sand. Injection of water and gas are depended on to restore original conditions process has proved to be far more efficient than production under unrestricted flow.

(2) Pressure Maintenance by Output Restriction and Water Injection (See Fig. 10)

Pressure maintenance by injection of water into the inward moving edge water surrounding or adjoining an oil pool and a restriction of oil production to equal the volumes of encroaching water, as is being done in East Texas, is now an approved production practice.

Carll recommended it in the early days of oil production. It is a principle suggested by natural water encroachment and borrowed from line-drive flooding. The present-day need for underground disposal of large quantities of salt water that is pumped from other oil-producing horizons gives a new supply of flooding fluid and a new reason for water injection. In theory, the water around the pool must be constricted by its own inflow and by injection of water from the surface or upper sands to such an extent that the oil and gas within the reservoir remain constantly under the original pressure. But, in practice, whenever the distances are great and the sands are of low permeability, pressures are bound to decrease toward the center of the pool to such an extent that part of the oil gives up its gas from solution, with a consequent loss in motive power which partly defeats the purpose of the method. Also, since only water is injected, all gas not used for fuel is wasted. Where the sands are highly permeable, as in the East Texas field, the augmented water pressure may keep the whole body of oil under sufficient pressure to hold the gas in solution until it flows with the oil from the wells. Degree of permeability and amount of pressure is the measure of efficiency of this production method.

Oil production must also be restricted except in pools with sand of such high permeability and under

Fig. 13 shows by well locations, contours, and section, a picture of an Illinois oil pool, and illustrates the way conjoint injection of water and gas may be used to regain original reservoir energy. The section is diagramatic only. Wells shown on it do not repeat on contour drawing and vice versa. Such a pool is not too large in extent to be influenced all over by artificial means. Water from upper sands as well as from the oil-producing sand may be used, and the available volume of this water is practically limitless. Gas vented from the oil-producing formation may be augmented by air so that the availability of this pressure restoring medium also becomes unlimited

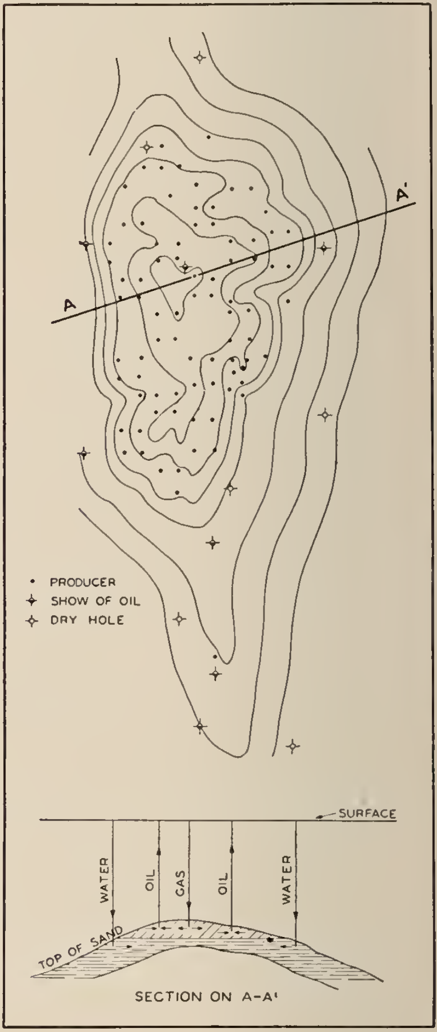


Fig. 13: Well density and contours showing structure

such high water pressure that the injected and encroaching water follows up the removal of oil to the point that the sand is kept completely saturated above the critical pressure throughout the entire life of the wells. Such a condition seldom exists because the permeability of a sand body is never uniformly high and this is a requisite for completely successful results. In general, however, this production method, as best illustrated in East Texas, is an important improvement.

(3) Pressure Maintenance by Output Restriction and Gas Injection (See Fig. 11)

This phase of pressure maintenance is the practice of injecting gas into an existing gas cap overlying gas-saturated oil or into the gas-saturated oil itself. Where water under pressure is present around and below the oil and there is a gas cap above it, increased or maintained pressures on the gas cap keep the underlying water from raising oil into the gas sand from which it cannot be recovered. Gas pumped into the gas cap or pumped in to form a gas cap of its own, vents oil on the same principle as the seltzer bottle. Later comes the process of venting oil by the movement of gas through the sand. The movement of gas from input to output wells increases production by absorbing and carrying along with it the lighter constituents of the oil and by blowing oil to the wells in the direction of gas travel.

A considerable part of the gas produced is not available for return to the formation because it requires prohibitive amounts of machinery, because part of the gas must be used for fuel, and because its heavy vapors are commonly removed in gasoline plants. Consequently, there is never enough gas returned to make up for oil and gas withdrawals so that the reservoir pressure is gradually reduced. Even if gas were returned in sufficient amount to compensate for the water, oil, and gas taken out, the slow rate of absorption of gas in oil would cause expansion of the gas cap and increased gas-oil ratios. Natural edge-water encroachment is seldom fast enough to make an appreciable reduction in the amount of gas required. The problem is usually solved by reducing the withdrawal of the oil and water to the point at which it does not lower the reservoir pressure. This takes more time to deplete the pool, and time costs money.

The efficiency of the method of pressure maintenance by gas injection depends on the proportion of oil in the sand that can be vented by means of gas. This is usually much less than the proportion that can be vented by water. Also in practice, pressure maintenance by gas injection has a very short life span as compared to the producing life of the field, beyond which span it is impossible to maintain pressures high enough to keep original gas in solution without producing too high a gas-oil ratio. Because the amount of oil in the reservoir is constantly decreasing and a constant amount of gas is being pumped in, more and more gas stays out of solution and exists as free gas in caps resulting in an increasing gas-oil ratio. The process eventually changes into a repressuring operation. In many pools distances from edge water to edge water are so great that water encroachment has little influence. Pressure maintenance by gas injection is, however, a great improvement over primary methods of production as has been proved in the Louden pool in Illinois.

Pressure Maintenance by Conjoint Water and Gas Injection (See Fig. 12)

A reservoir that contains water under pressure around its lower perimeter, contacting a central oil body that is charged with gas in solution, either with or without a gas cap, is in the ideal condition for giving up its oil. When pierced by wells, the oil flows, and at no later time is so efficient a means for capturing oil provided. Since this is the ideal setup, the ideal solution for a continuance of similar results must be the provision of means for keeping the pool in its original condition. The logical procedure then must be the conjoint injection of gas and water, each forced into the stratum in the areas where each kind of fluid was originally found.

Such a method combines all the advantages of the restricted output, the gas injection, and the water-injection-maintenance methods just described. Conjoint injection has the added advantages of halving distances and doubling areas of pressure. The water boundary is contracted by adding enough water to keep the diminishing area of oil sand always completely saturated at the original pressure, and gas is returned in the amount currently liberated with the oil. Thus greater quantity of oil may be withdrawn without lowering pressures. The wells might be kept flowing for their entire life, and the quantity cf oil and gas removed at all times might be held more nearly to the initial production of the wells. Since water can be injected in a wide circumference, great quantities can be used without causing a too-rapid invasion of the oil-filled center of the field, resulting in a duplication of natural encroachment with its well-known long production life.

Unitization

The physical elements involved in retaining the ideal conditions of a virgin field have been described. In order to carry out the method successfully, a field must be operated as a unit. However, when there is diverse ownership, unitization is often difficult to obtain.

Unitization should be easier to bring about now than it has been in the past for these good reasons: Its value is known, the inevitable shortage makes efficient extraction of oil imperative, and the war emergency appeals at the same time to enlightened self-interest and patriotic duty to produce for victory.

Acknowledgment

They used to say at college that the pitcher can be no better than his support. Such a statement is true of the petroleum engineer, and it is for this reason that the writer wishes to acknowledge with thanks the encouragement and direction of M. M. Leighton, chief of the Illinois Geological Survey; A. H. Bell, head of the Oil and Gas Division, and its other members, C. W. Carter, Carl A. Bays, Stuart Folk, William H. Easton, E. P. DuBois, Paul Luckhardt, Wayne Meents, and J. S. Yolton.