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TRANSPARENT MODEL OF RESERVOIR SHOWING DISPLACEMENT OF OIL BY CONJOINT USE OF GAS AND WATER

By

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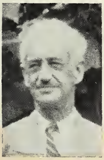
SIMULTANEOUS INJECTION of gas and water into an oil reservoir as a means of maintaining initial pressure and production rate throughout the life of an oil pool is explained and illustrated by means of a model oil reservoir. By injecting gas into the cap and water into the water table the water-oil and oil-gas interfaces remain horizontal and the injection procedure results in a steady displacement of oil with less fingering or channeling, assuring maximum oil recovery from the reservoir.

IN MOST oil-bearing structures, gas, oil and water are under pressure, and except for dissolved gas and connate water, are arranged in nearly horizontal layers according to their respective specific gravities. When wells are drilled into such an oil-bearing reservoir, the oil flows because of the differential pressure between the reservoir and the earth's surface. The outflow of oil and gas lowers the pressure in the drilled area, and this sets up an inward motion of the surrounding fluids toward the well bore. Reservoir pressures can be maintained only when there is sufficient inflow from an outside source through sufficiently permeable intervening sand to equal the outflow of gas and oil from the wells. Under all other conditions the reservoir pressure constantly decreases. This is true whether the pressure is due to diminishing static head or to expansion of the impounded fluids. Production rate decreases as the pressure declines.

The rate of flow of oil depends on pressure differential. Whenever the differential is not enough to raise oil to the surface, the flow stops. Wells then must be pumped, and eventually the pressures become so weak that they move little or no oil to the wells.

The diminution of the volume of oil produced bears a fairly close relationship to the pressure decline, yet the pressure decline is not proportional to the volume of oil remaining in the sand; for while the pressure differential is falling from maximum to zero, the volume of oil in the reservoir falls from maximum to a substantial fraction of the original amount. It is therefore important, both in quantity of oil produced



About the Author

FREDERICK SQUIRES, petroleum engineer for the Illinois State Geological Survey, is credited with the first successful applications of repressuring and intentional water flooding in the Illinois oil fields. He holds degrees from Williams College and the School of Mines of Columbia University. He formerly was partner and field manager of Squires Brothers, Remlik Oil Company and Dinsmor Oil Company, which were organized at the inception of secondary recovery. At present he is chairman of the Illinois - Indiana - Kentucky Section of the Eastern District Standing Sub-Committee on Secondary Recovery Methods, API. He has invented several oil field processes and has contributed a number of technical papers on petroleum engineering.

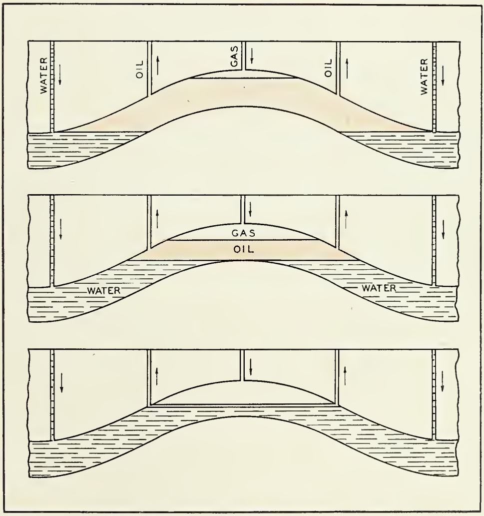


Figure 1. The uppermost section shows the earliest phase of conjoint use. The middle section shows the increase in the areas of water and gas and the corresponding decrease in oil area. The lowest section shows the completion of the process wherein water and gas have almost entirely displaced the oil at the oil producing wells.

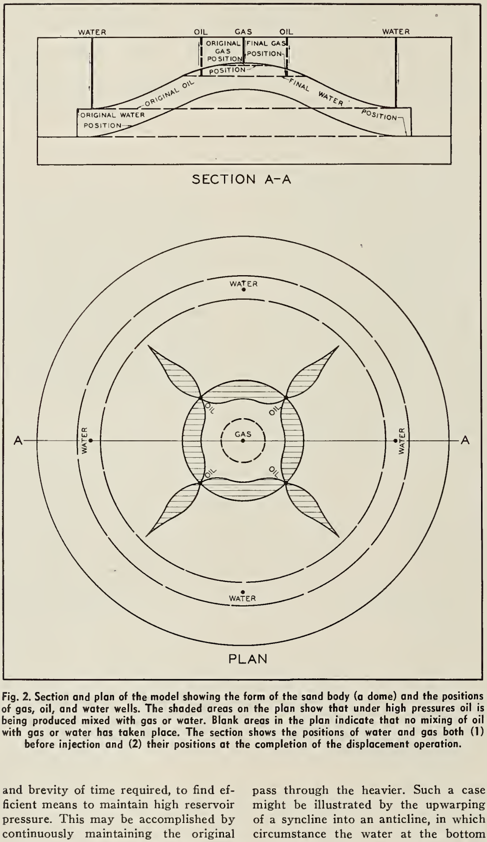


Fig. 2. Section and plan of the model showing the form of the sand body (a dome) and the positions of gas, oil, and water wells. The shaded areas on the plan show that under high pressures oil is being produced mixed with gas or water. Blank areas in the plan indicate that no mixing of oil with gas or water has taken place. The section shows the positions of water and gas both (1) before injection and (2) their positions at the completion of the displacement operation.

and brevity of time required, to find efficient means to maintain high reservoir pressure. This may be accomplished by continuously maintaining the original reservoir pressure by artificial means, which has been attempted in two ways: (1) by injecting gas alone; and (2) by injecting water alone. Actually, there would be a greater advantage in injecting both at the same time, each in the right place.

In virgin reservoirs, the three fluids have followed the laws of gravity in their stratification. Were they rearranged in any different way, in time each would again find its own level. To do so the lighter fluid would have to pass through the heavier. Such a case might be illustrated by the upwarping of a syncline into an anticline, in which circumstance the water at the bottom would be raised to the top and the gas would find itself below the oil. This would cause movement and readjustment according to gravity.

Such a readjustment may be brought about by artificial means. If gas were injected into the top and bottom of an oil-containing structure, the gas in the bottom would make its way to the top through the water and oil. If water were injected into the top and bottom of the structure, the water in the top would make its way to the bottom. In each case part of the fluid would be passing through oil in order to reach its own level. On the other hand, if gas were injected into the top and water into the bottom, there would be no change in stratification. The result would be to keep the water-oil and oil-gas interfaces horizontal, and to squeeze the oil by increasing the pressure above and below it (Figure 1).

In field production this method would not always be practical but would lend itself best to high-gravity oil, high-porosity sands, and steep structure with edge water and gas cap. Some McClosky pools, the Johnsonville for example, have most of these characteristics.

The Transparent Model

It is very difficult to picture the underground reactions of gas, oil, and water because they are not visible, but it is easy to make a transparent model of an oil field and see what goes on in it, under selected conditions. The problem is of course oversimplified in a model, and results are not directly comparable to field conditions, yet such a study is useful in analyzing oil field problems.

A plan and section of a simplified oil structure and the surrounding strata was drawn, from which a wooden model was built. Several different arrangements of input and producing wells were considered for use in a transparent model and the one adopted is illustrated in Figure 2.

The plan presented in Figure 2 shows gas, oil and water wells located so that oil may be displaced downward by gas and upward by water, keeping the gas-oil contact and water-oil contact horizontal. If gas and water are injected at the proper rates, these two contacts will come together at the level of the bottom of the oil well when the last of the oil has been produced. Because of the high gravity of the oil, the high permeability of the sand, and the steepness of the structure, this was easy to accomplish in the model. It is, of course, impossible to reproduce these conditions exactly in actual production from the average oil-bearing structure because the contact

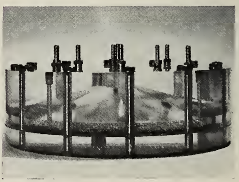


Figure 3. View from the side, showing the transparent model. The structure is evident as well as the glass beads representing the sand.

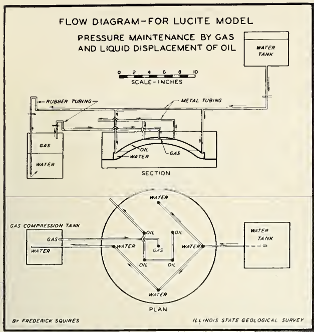


Figure 4. Diagram showing the way the transparent model is equipped to perform the displacement operation. The elevated water tank on the right furnishes the hydrostatic head which produces the displacement gas and water pressures. Water pressure is applied directly to the water input wells. Gas is compressed in the closed tank at the left by means of the static water pressure and conducted thence to the gas input well. The degree of gas pressure with relation to water pressure may be changed by raising or lowering the closed tank.

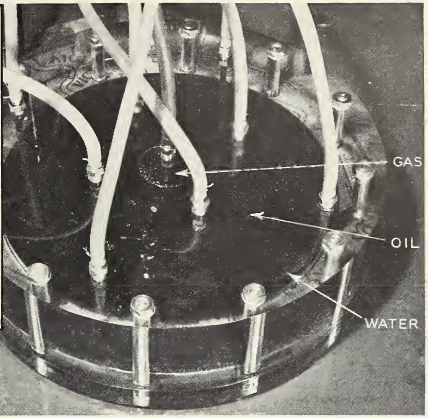
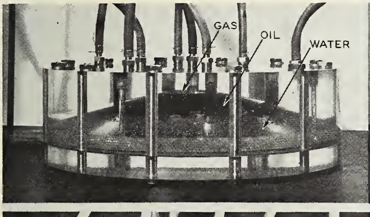


Figure 5. This shows the sand almost full of oil but with gas cap at the top of the structure and water at the extreme lower and outer edge.



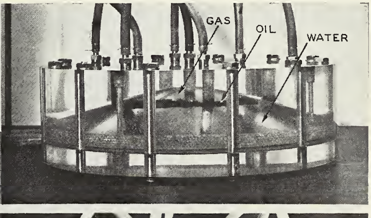


Figure 6. These are two views of the squeeze—the gas cap and water edge having been enlarged and part of the oil vented.

Figure 7. This shows a later phase of the squeeze wherein both gas cap and water boundary have enlarged and the oil is in the immediate area of the oil wells.

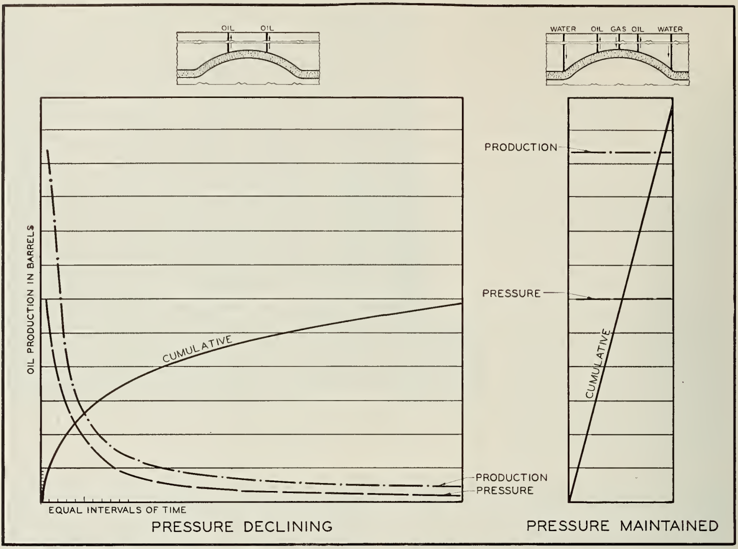


Figure 8. These two graphs show by contrast with each other the difference in results in amount of oil production and time required of (1) open natural flow with declining pressure; and (2) maintained production with artificially maintained reservoir pressure. (It is assumed that the ultimate oil production by natural pressure will be one-half that obtained by maintained conjoint pressure since the latter combines primary and secondary results.)

planes between the different liquids are never perfectly horizontal but are warped and dip toward the producing wells.

After the plan shown in Figure 2 was chosen, the transparent plastic model shown in Figure 3 was made and drilled to comply with it. The model was then connected up to the pressure sources as shown diagrammatically in Figure 4.

The operation is shown by Figures 5, 6 and 7, which illustrate the progress of the venting of oil by the introduction of water at the lowest part of the dome, gas at the highest part, and the withdrawal of oil from the intervening oil wells. Figure 5 shows the sand practically full of oil, with only a narrow circumference of water, and a very small gas cap. Figures 6 and 7 show progress of water updip and gas downdip, resulting in a diminishing area of oil between. The views taken from the side in these figures show the stratification of the three fluids. With low pressures there was no "fingering" or channeling of the gas or water direct to the oil well, but when pressures were raised, fingering occurred. It followed quite closely the fingering shown diagrammatically in Figure 2. When fingering begins, the method changes from displacement to gas drive and/or water drive, a condition that should be avoided as long as possible. This can be retarded by using long distances between unlike wells and short distances between like wells. (Like wells means (1) gas input wells, or (2) water input wells, or (3) oil-producing wells.) A glance at the pattern of fingering shown on the drawing, Figure 2, explains the reasons for this method of well spacing. When fingering from either gas or water begins, it can be stopped or retarded by lowering the pressure on the input wells which produce it.

The available volumes of the pressure media, air and water, are limitless. Their conjoint use conserves the gas which would have been wasted in a waterflood and takes care of salt water disposal. It greatly reduces distances and time as compared with either of the single injection methods. The need for improvement in production methods is driven home by the startling differences between the two oil-production graphs, one showing history in time and volume under pressure decline, and the second showing the history of the same well when constant pressure is maintained by conjoint injection of gas and liquid (Figure 8).

Petroleum engineers will do well to consider the conjoint use of gas and water for oil production as a means of continuing initial pressure and production rate throughout the life of an oil pool.

Acknowledgments

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