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METHOD OF CONTROLLING RECOVERY FROM OIL SANDS

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Fig. 1

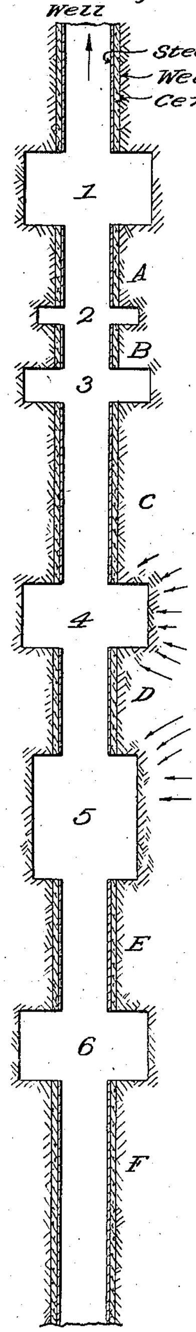
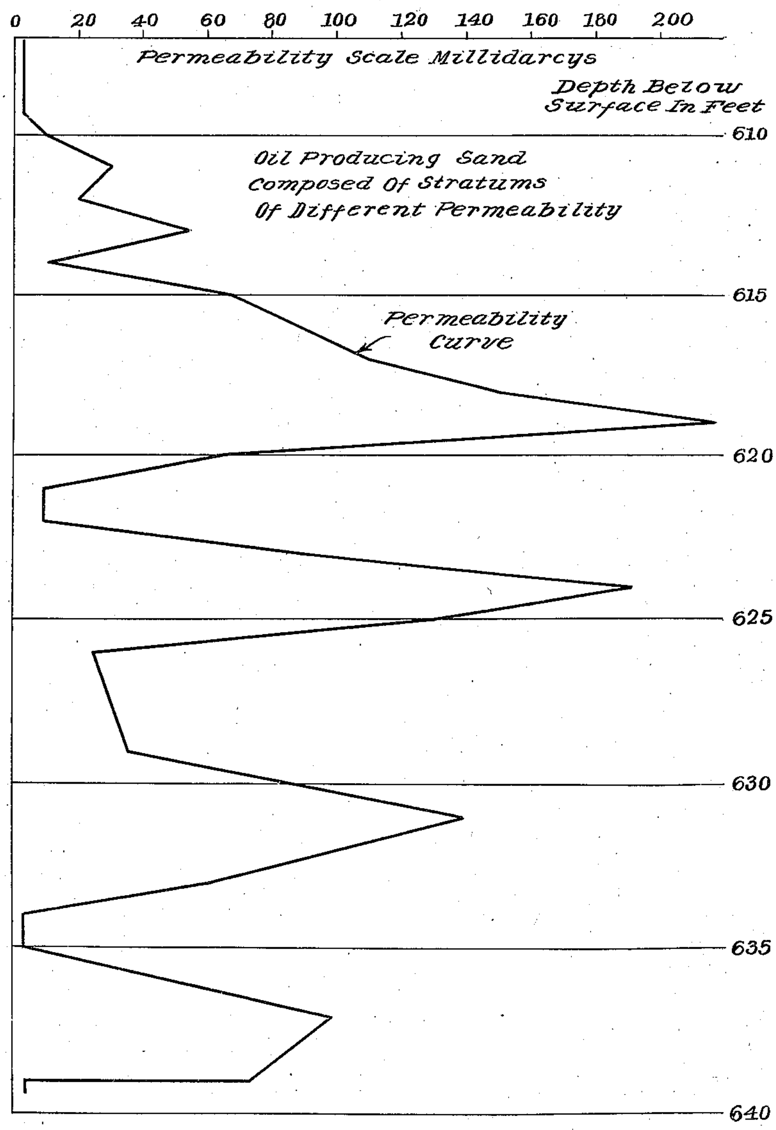


Fig. 2



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METHOD OF CONTROLLING RECOVERY FROM OIL SANDS

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12 Claims. (Cl. 166—21)

This invention relates to a method of controlling the flow of oil into a recovery well from an exposed oil-bearing sand or horizon, with the aim of securing the greatest possible recovery of oil from the entire thickness thereof.

An oil sand or producing horizon consists of a number of juxtaposed oil-containing productive stratums or layers, which may be regarded as reservoir units, and which possess different permeabilities owing to the varying conditions of deposition affecting the sizes and arrangement of sand grains and the cementing materials. Shale laminations and barren layers of very low permeability may be interposed between some of the productive stratums tending to separate them from each other, but will not necessarily form continuous seals owing to cracks and faults. Thus the conditions of pressure and temperature prevailing in the sand are likely to be substantially uniform unless disturbed by methods of recovery heretofore generally used.

Prior to the recovery of oil from a virgin sand, an equilibrium condition of formation pressure exists in the sand and each of the component oil-containing stratums is completely saturated with liquid (oil, dissolved and liquefied gas, and water) except for the volume which may be occupied by free gas.

When a recovery well pierces such an oil sand, all of the constituent reservoir units are subjected to nearly the same formation pressure and different rates of flow of oil into the well are established for the various reservoir units dependent on their different permeabilities. The result is a high rate of depletion in the more highly permeable units and a low rate in the units of low permeability, since the lower the permeability the greater the resistance to flow of oil under any given pressure and temperature.

As production continues, serious by-passing of gas begins in the most highly permeable stratums when the saturation thereof has been lowered to about 85%, which means that a large volume of gas passes into the well for each barrel of oil recovered and that the reservoir pressure available for forcing oil into the well from each stratum becomes seriously decreased. By the time the saturation of the most highly permeable stratums has fallen to say 60–65%, by-passing will have become so great that little if any further recovery of oil occurs.

Laboratory tests on cylindrical core samples initially saturated with oil and subjected to radial flow conditions under gas pressure, by injection of air into an axial hole, the ends of the sample being sealed, have shown, for example, that air was required to the extent of 15 cubic feet per barrel of recovered oil when the liquid saturation had diminished to a value of 85%. At 75% saturation, 400 cu. ft./barrel were required; at 65%, 4,560 cu. ft./barrel; and at 60%, 15,000 cu. ft./barrel. These figures were obtained from tests using refined oil; and crude oils will show much higher gas to oil ratios.

By-passing takes place because of the fact that the sand in any given stratum contains passageways of different sizes, some being in the nature of fine capillaries and some being relatively large. When the larger passageways have been cleared of oil, the available gas passes directly therethrough without driving oil, and without causing recovery of the oil contained in the fine capillaries, which may constitute 60–65% of the total original liquid saturating the stratum. The reservoir gas, following lines of least resistance, flows vertically by diffusion and through cracks and faults from the stratums of low permeability to nearby stratums of high permeability and becomes vented into the well before any substantial recovery of oil has been secured from such stratums of low permeability.

The result is that when the primary period of production has reached the point that little oil is being recovered from the sand, the original liquid saturation value for the entire vertical thickness of the sand in the neighborhood of each well may have been reduced by not over 10%.

The accompanying drawing shows in diagrammatic fashion a vertical section through a representative oil producing sand and recovery well. The permeability curve indicates the permeability of the various stratums making up the sand, the data being that for a sand in Nowata County, Oklahoma, as determined by core analyses.

The sand thickness of 32 feet is not of uniform permeability, as the drawing clearly shows, the permeabilities varying within the range of about 1 to 220 millidarcys. The permeability curve takes the form of alternating peaks and valleys, indicating a succession of stratums which progressively increase and decrease in permeability, so that the sand may be regarded as composed of horizontal zones of relatively high permeability interposed between zones of relatively low permeability.

For purposes of analysis, the total sand thickness may be divided into convenient unit thicknesses of one-half foot, or small multiples thereof, and an average permeability value assigned to each. The first two columns of the following table show, respectively, the average permeability value for each unit (or plurality of units summed together and averaged), arranged in descending order of magnitude, and the corresponding rock thicknesses.

1	2	3	4	5	6
Permeability in millidarcys	Thickness in feet	Porosity in percent	Per cent oil depletion—		Recovery of oil at end of 1936, in barrels per day per foot of thickness
			1907–1932	1907–1936	
180	1.5	20	14.7	20.8	10.7
162	1.0	20	13.2	19.2	10.2
120	0.5	20	9.7	13.9	7.2
115	2.0	16	9.4	13.3	5.6
110	2.5	20	9.0	12.7	6.7
80	4.0	26	6.5	9.3	6.2
70	1.0	20	5.6	8.0	4.2
65	2.0	15	5.2	7.5	2.9
60	1.0	22	4.9	7.0	4.0
50	2.0	20	4.0	5.8	3.0
45	2.5	14	3.7	5.2	2.6
30	2.5	23	2.4	3.4	2.0
25	2.0	7	2.0	2.9	0.5
20	2.0	14	1.6	2.3	0.8
10	3.0	10	0.84	1.8	0.3
2	2.5	10	0.17	0.23	0.1

Column 3 of the table shows the average percentage porosity of each of the units, the porosity ranging from 7% to 26%, with a mean value of 18%. These values clearly indicate that the potentially recoverable oil is not restricted to the stratums of high permeability, since the entire sand thickness was originally completely saturated with fluid and the stratums of lowest permeability average around one-half the porosity of the stratums of highest permeability.

During the period of 1907–1932, a 70 acre tract in this field was subjected to primary recovery of oil from the oil-bearing sand to which reference is being made, by means of 11 recovery wells drilled in 1907. By "primary recovery" is meant recovery of oil under the driving force only of the natural pressure existing in the formation, there being no repressuring. The estimated total original liquid saturation of the sand in this tract (assuming the voids in all stratums to be filled with liquid) was about 3,000,000 barrels. The actual recovery of oil totalled only about 170,000 barrels during the primary recovery period (1907–1932), thus amounting to only about 6% of the original total liquid present.

In an effort to increase the rate of recovery, which had by this time become quite low, additional recovery wells were drilled to make a total of 32 for the 70 acre tract. At the same time 14 injection wells were drilled for repressuring purposes, by means of which air under pressure was injected into the sand to drive the oil to the recovery wells. Beginning in January, 1933, repressuring was utilized, thus inaugurating a "secondary recovery" period. During the four year period of 1933–1936, a total of about 70,000 barrels of oil was recovered, making a total for the full 1907–1936 period of about 240,000 barrels. Thus at the end of 1936, oil had been recovered during approximately 30 years time amounting to only about 8% of the original total. With present recovery methods being continued, to total recovery much in excess of about 10% can hardly be expected, inasmuch as the stratums of high permeability have been depleted to the point where serious by-passing of pressure gas has commenced and very little pressuring of the low permeability units can occur.

Referring again to the table, column 4 shows the estimated percentage of oil depletion for each of the permeability units at the end of the 1907–1932 period of primary recovery, and column 5 shows the estimated oil depletions at the end of the full 1907–1936 period following four years of secondary recovery. These figures were arrived at in the following way: The original oil saturation or content of each unit in barrels was computed from its thickness, porosity and area, assuming all voids filled with liquid. The total amount in barrels actually recovered during the period (determined from production records) was apportioned to the various units by multiplying in each case by the "operating factor" for the unit in question. The operating factor of each unit was calculated by multiplying together the permeability, thickness, and porosity values of the unit and dividing the product by the sum of the products for all units. Since the rate of flow into the recovery wells from each unit is proportional to the permeability of the unit and to the amount of oil in the unit, as well as to the pressure, it is evident that said operating factor expresses the proportion of total flow contributed by each unit. Having thus calculated the total amount in barrels recovered from each unit, the amount recovered from each unit divided by the original fluid content of the unit gives a quotient which expresses the fractional depletion of the unit during the period. Multiplying by 100 gives the percentage depletion. The table shows that the percentage oil depletion at the end of 1932 ranged from 14.7% for the highest permeability rock unit down to 0.17% for the lowest permeability unit; while at the end of 1936 the respective values had become 20.8% and 0.23%. These values are average values for the entire tract area. The percentage depletions in the near vicinity of each recovery well, especially as regards the units of high permeability, are substantially greater.

Column 6 of the table shows the rate of recovery of oil from each of the permeable units at the end of 1936, expressed in barrels per day per foot of thickness. The total recovery per day of 118 barrels was prorated between the permeable units by multiplying this total by the "operating factor" of each unit. The resultant value for each unit was divided by the thickness of the unit to give the results shown in column 6. These figures show in striking manner the unequal rates of oil flow and recovery from the different stratums under present conditions of uncontrolled recovery. Thus the rate of recovery from the 50 millidarcy sand is less than one-third of that from the 180 millidarcy sand, although the average porosities and initial saturation are the same; while the rate for the 2 millidarcy sand is less than 1% as great, although the porosity and initial saturation is half as great.

The foregoing data is presented in order to emphasize the importance of the fact that under present methods efficient recovery of oil is not being obtained and that tremendous additional quantities of oil can be obtained by proper control of recovery. This can only be fully appreciated by understanding the factors involved, and especially the fact that as uncontrolled depletion of an oil sand takes place there is not a uniform depletion throughout, but a comparatively rapid depletion in the component stratums of higher permeability and a slow and small depletion in stratums of lower permeability.

My invention aims to overcome the undesirable features of uncontrolled recovery by providing a method whereby the flow of oil from an exposed sand into an oil well is deliberately controlled so as to minimize differences in the rate of depletion of the component stratums by decreasing the rate for the higher permeability stratums and increasing the rate for the lower permeability stratums.

According to my method, the wall of the recovery well is sealed where stratums of higher permeability are exposed, so as to only permit the direct entry of fluid into the wall from the stratums of lower permeability.

Referring to the drawing, wherein Fig. 1 illustrates a typical recovery well to which my invention has been applied, and Fig. 2 is a diagram indicating the relative permeability of the stratums at different depths, the vertical thickness of the sand, after determining and charting the permeabilities at the various depths, is divided into operating zones, designated by the letters A to F, corresponding to the regions of minimum permeability. These zones are made up of the stratums of relatively high permeability, bounded by the interposed stratums of relatively low permeability (represented by the valleys of the permeability curve). The well wall is sealed except at zones (indicated by the numerals 1 to 6) located where the stratums of relatively low permeability are exposed, which zones are termed recovery zones and are situated between the operating zones. As indicated in the drawing, operating zone A lies between recovery zones 1 and 2, B lies between 2 and 3, C lies between 3 and 4, D lies between 4 and 5, E lies between 5 and 6, and F lies below 6.

Assuming the recovery well to have been sealed as described, so that oil and other fluids can enter the well from the sand only at the injection zones, it is evident that recovery from the exposed stratums of low permeability will take place most readily; while recovery from the stratums of high permeability located between the recovery zones will be restricted and take place less readily than if the latter stratums were exposed, since fluid contained therein must first pass through stratums of lower permeability in order to reach the recovery zones. The result is to bring about a greater uniformity in the rate of recovery as between adjacent stratums of different permeability and thus minimize the inequalities which occur when recovery is uncontrolled.

Not only does my method provide for obtaining uniform recovery from the various stratums in each operating zone, but also for securing more uniform recovery as between the various operating zones making up the entire producing sand, so that they will not interfere with each other and so that they will become as nearly as possible depleted at the same time. The flow of oil into the well at each recovery zone is regulated to suit conditions by adjusting the area of exposed well wall so as to properly proportion the flow as between the different zones. The area of exposed well surface forming each injection zone can be made larger or smaller by adjusting the vertical width of the unsealed wall at such points, the exposed surface constituting a cylindrical surface having an area proportional to vertical width. In some cases it may be preferable not to provide a cylindrical exposed surface, but to seal off part of the area and provide an exposed area in the form of a vertical strip which will thus extend for a greater vertical distance for the same exposed area. This may be desirable when the recovery zone is located where there is an exceptionally thick layer of low or medium permeability sand, particularly if the layer is found to be divided into stratums separated by shale partings.

Sealing to permit of controlled recovery may be accomplished in the following manner, illustrated by the drawing. The face of the recovery well wall is entirely sealed by cementing in a liner or casing of steel or other suitable material so that none of the producing sand is exposed in the well. This may be readily accomplished even though high pressure values exist in the formation. After the cement has set and properly hardened, openings are provided through the liner and cement at the desired recovery zones to permit passage of fluid into the well from exposed stratums of relatively low permeability. Such openings may be made in any desired way, but I prefer to make them by milling out annular portions of the liner and cement to provide annular passageways at the desired recovery zones. The vertical width of each annular passageway will of course affect the area of exposed well surface and is adjusted to suit the rate of recovery desired. The result of this procedure is that the well wall is sealed with lengths of cemented liners which are separated at the recovery zones to permit of the desired controlled recovery of oil.

In order to further control the recovery, the sand or rock formation exposed at one or more of the recovery zones may be cut or reamed out to provide an annular chamber having a radius greater than that of the well. This is illustrated by injection zones 1 to 6, shown in the drawing. The result is that the effective radius of the recovery well may be adjusted as desired at each of the recovery zones to influence the rate of recovery.

Owing to the laws of radial flow, the rate of flow of oil into a recovery well, under any given reservoir pressure, is profoundly influenced by the radius of the well, the rate of flow increasing rapidly with an increase in the well radius, since the greater part of the resistance to flow occurs immediately adjacent the well and is smaller the larger the radius. Therefore the reaming out or other removal of sand from the formation at a recovery zone serves to influence the effective radius of the well thereat and produce an increased rate of flow, and this effect can be made different in the various recovery zones by adjusting the relative effective radii to obtain a proper proportioning of flow as between the recovery zones.

The reaming out of the rock will expose surfaces to direct vertical flow into the well from adjacent stratums. This can be modified when desired by partially or entirely sealing such exposed surfaces.

The openings in the well lining of the cemented liner type, just described, need not be in the form of annular passageways. Holes may be provided, or the liner and cement can be cut out to provide vertical slots.

Thus the reaming out of the formation, taken in combination with variations which can be obtained in the vertical width and extent of the recovery zones, makes it possible to provide for controlled recovery in any given situation to the end of securing maximum results under the formation conditions encountered. Variations to meet conditions and minimize differences in rates of depletion are illustrated in the drawing.

The flow of oil from the rock formation at the recovery zones may be increased and controlled in various other alternative or supplemental ways. Thus the rate of flow from stratums of low permeability exposed at injection zones may also be increased by acid treatment, the acid, or solutions designed to interact to form the acid, or other suitable fluid, being injected under pressure into the sand at one or more recovery zones by use of a packer (such as described in my copending application Ser. No. 77,143, filed May 1, 1936). One zone at a time may be treated, the amount of acid or other fluid used and the injection pressure being regulated to suit the desired change of permeability and radial distance of treatment. When the well has been sealed by use of a cemented liner cut away to provide recovery zones, the treating agent can be introduced through the well simultaneously into the formation at each zone, or into the zones one at a time by use of a packer. Hydrofluoric acid may be used in treating sandstone and hydrochloric acid for treating calcareous formations.

Beneficial results follow not only from the direct restriction in flow imposed on fluid from the stratums of high permeability, but also from the fact that the formation or reservoir pressure is conserved and directed so as to function most efficiently. As previously pointed out, as the degree of saturation of an oil containing stratum diminishes, a greater and greater volume of pressure fluid is required and becomes vented into the well per barrel of oil recovered, and hence during the progress of the primary recovery period there is a progressive decrease in the efficiency of utilization of the available energy for driving the oil and an increasing wastage. My method of controlled recovery maintains the percentage liquid saturation of the various stratums more nearly uniform and at higher values, thereby increasing the efficiency of the energy available for recovering the oil, and causes the available pressure-volume reservoir energy of the pressure fluid to be utilized in driving oil contained in the low permeability stratums to the recovery wells in increased amounts to secure substantial recovery before serious by-passing and wastage begins. Hence a more rapid depletion of low permeability stratums and a more complete final recovery from the whole sand is obtained, as well as a more uniform rate of depletion as between component stratums and a more efficient utilization of the energy available.

Where a sand is subjected to hydraulic pressure from edge water, not only is the driving energy utilized to best advantage when my method is employed, but the early flooding out of recovery wells is prevented—a situation which occurs with uncontrolled recovery methods owing to the ready passage of the water through stratums of high permeability as these become depleted. The problem of excessive water entry arises long before recovery of oil from low permeability stratums has terminated. As recovery progresses after opening the well, the amount of water per barrel of oil, while small at first, progressively increases, thus progressively increasing the pumping and water-separation costs per barrel of oil. This undesirable effect is minimized by my method, since the encroaching water approaches the well at substantially the same rate in all stratums and the well will not be flooded until substantial oil depletion has occurred in all stratums.

What has been said as to the value of my controlled recovery method obviously applies to primary and secondary recovery periods when the natural reservoir energy is supplemented by the pressure-volume energy of pressure fluids injected into the sand by means of pressure wells, the pressure fluid (whether a gas or water) being utilized more efficiently, for the reasons mentioned.

A feature in this connection is that a wider spacing between pressure wells and recovery wells is made possible, owing to the more efficient utilization of the injected pressure fluid energy and to the increased utilization of the energy for driving oil into the recovery wells from stratums of lower permeability. This is true even though the exposed stratums are not treated; but an even greater spacing can be used when the effective radii of the recovery wells are increased by reaming at the recovery zones, and when the low permeability stratums adjacent the well are acid treated, as heretofore described.

My method embraces and provides for a much more effective and efficient "back-pressuring" of recovery wells. Back-pressuring in a recovery well is produced by increasing the pressure exerted by the fluid in the well against the oil sand. Where the formation pressure is sufficiently high to produce flow from the well without pumping, the hydrostatic pressure exerted by the column of oil in the well may be supplemented by restricting the rate of outflow of oil (and gas) from the top of the well to cause an increase of pressure. Where pumping is resorted to, the height of the oil column in the well is regulated to produce the desired hydrostatic pressure, and this pressure may be supplemented by superposed gas pressure.

The purpose of back-pressuring a well is to control the rate of oil recovery and this may be desirable for various reasons. When a well is first brought in and starts producing, it is desirable to prevent excessive gas wastage and maintain a more complete liquid saturated flow system operative in recovering the oil and prevent increase in viscosity of oil in the sand resulting from the sudden release of pressure in the formation adjacent the well. Also, where there are a plurality of irregularly spaced wells, back-pressuring is employed in an effort to balance the rate of oil recovery. The present practice of back-pressuring does not tend to equalize the relative rates of oil recovery from the various component stratums of different permeability making up the producing formation, since all stratums are subjected to the same back-pressure regardless of permeability, and hence the relative rates remain uncontrolled and only the total rate of oil recovery for each well is controlled.

When a recovery well is operated in accordance with my method, as heretofore described, so that there is uniform recovery based on controlled oil flow from the various stratums of the producing sand, back-pressuring will proportionately affect the recovery from the various stratums to reduce recovery from each to substantially the same percentage extent. The effect is to reduce the total rate of oil recovery without substantially disturbing uniformity of recovery.

I particularly contemplate the use of back-pressuring where a plurality of recovery wells are being operated in a field provided with one or more pressure wells, for the purpose of balancing the recovery from the different recovery wells and thus overcoming the lack of balance which would otherwise exist due to irregular spacing and variable conditions in the sand. A relatively small back-pressure will have a considerable effect on the comparative rate of recovery, owing to the laws of radial flow in accordance with which the pressure exerted by a fluid injected into the sand at a pressure well is mostly utilized in overcoming resistance to flow immediately adjacent said well. Hence a few pounds per square inch of back-pressure applied in a recovery well located near an injection or pressure well will result in oil recovery balanced or equalized with that of a recovery well located twice as far away. In other words, back-pressuring is utilized to control directional flow of oil within the stratums of the oil sand. Since the desired result can be obtained fairly easily by trial, this expedient may be readily employed even in complex situations where there are a number of irregularly spaced pressure wells and recovery wells in the same sand, back-pressures of different magnitudes being used in various recovery wells to produce equality of oil recovery or to minimize differences to the extent deemed desirable.

Back-pressuring of recovery wells may also be utilized to produce improvement in the oil saturation of the sand and maintain a more complete liquid saturated flow system operative between the injection and recovery wells. By intermittently imposing a back-pressure or increased back-pressure the rate of oil flow through each stratum will be intermittently lowered and greater opportunity given for oil to pass from small saturated capillaries or pores to larger depleted capillaries, making for a more complete recovery of oil. Such intermittent back-pressure may be made so great as to cause flow of oil from the well into the sand; and in some cases it will prove beneficial to go a step farther and inject another fluid (such as air, natural gas or water) into the sand from time to time through the recovery well.

My method of controlling the flow of oil into recovery wells from a sand provided with one or more pressure wells, in its various aspects, may be employed irrespective of the way in which the injection or pressure wells are operated and controlled. The latter may be operated without imposing control over the injection of fluid energy into the various stratums, in accordance with present practice, in which case the oil recovery from the different stratums will only be controlled at the recovery wells. Preferably, however, the pressure wells should be operated so as to inject pressure fluid into the various stratums in relation to the different energy requirements thereof, as described and claimed in my Patent No. 2,019,418, issued October 9, 1935, and in my copending applications, Ser. No. 77,413, filed May 1, 1936, and Ser. No. 115,996, filed of even date herewith, so that the operation of both the pressure wells and recovery wells will contribute in direct and positive fashion toward securing uniform oil recovery from the different stratums and maximum recovery from the entire thickness of the sand.

Referring particularly to the method described in detail in the latter application, the walls of the pressure wells are sealed where they penetrate the oil sand so as to permit direct injection solely into the stratums of lower permeability, pressure fluid reaching the stratums of higher permeability only after first diffusing vertically through and from the adjacent stratums of lower permeability. The system of sealing therein described is the same as is described in the present application, the pressure fluid being injected into the sand at injection zones corresponding to the recovery zones referred to herein and shown in the accompanying drawing. The volume of injected fluid is proportioned between the injection zones to meet the pressure-volume energy requirements of the stratums of the corresponding operating zones serviced thereby, to the end of securing as uniform depletion of the entire thickness of the sand as possible.

In the claims the word "horizon" is used to mean a continuous producing sand usually designated by a distinctive name in the technical literature.

What I claim is as follows:

1. A method of controlling the recovery of oil from an oil sand having a plurality of associated productive stratums of different permeabilities exposed in the same horizon in a recovery well, comprising selectively restricting the flow of oil into the well from the various stratums commensurately with their respective permeabilities to minimize lack of uniformity in the oil depletion thereof during the progress of oil recovery.

2. A method of controlling the recovery of oil from an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a recovery well, comprising selectively sealing off the stratums of relatively high permeability to prevent direct entry of oil therefrom into the well and cause the oil to flow into the well only after first passing through sand of lower permeability so as to minimize lack of uniformity in the oil depletion of the various stratums during the progress of oil recovery.

3. A method of controlling the recovery of oil from a series of associated oil-containing stratums exposed in a recovery well and constituting a plurality of operating zones bounded by stratums of low permeability and each including stratums of high permeability located therebetween, comprising selectively sealing the well wall except at recovery zones located where said stratums of low permeability are exposed, to cause a controlled direct and indirect flow of oil into the well from the various stratums so as to minimize lack of uniformity in depletion of the various operating zones and the various stratums in each of said zones.

4. A method of controlling the recovery of oil from an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a recovery well, comprising sealing the well wall except at zones where stratums of relatively low permeability are exposed, and adjusting the wall areas exposed at said zones to control the relative oil recovery therefrom and thereby minimize differences in oil depletion of the various productive stratums.

5. A method of controlling the recovery of oil from an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a recovery well, comprising treating only the exposed oil-containing stratums of lower permeability to increase permeability adjacent the recovery well, and thereby selectively controlling the flow of oil into the well from the various productive stratums so as to minimize differences in the oil depletion of the various stratums during the progress of oil recovery.

6. A method of controlling the recovery of oil from an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a recovery well, comprising injecting a treating agent into and only into stratums of relatively low permeability to increase permeability adjacent the well, and thereby se-

lectively controlling the flow of oil into the well from the various productive stratums so as to minimize differences in the oil depletion of the various stratums during the progress of oil recovery.

7. A method of controlling the recovery of oil from an oil sand exposed in a pressure well and having a plurality of oil-containing stratums of different permeabilities, comprising mechanically removing portions of the sand from one or more exposed stratums of lower permeability to increase the effective radius of the well thereat, and thereby selectively controlling the flow of oil into the well from the various stratums so as to minimize differences in the oil depletion of the various stratums during the progress of oil recovery.

8. A method of controlling the recovery of oil from an oil sand exposed in a pressure well and having a plurality of oil-containing stratums of different permeabilities, comprising sealing the well wall except at recovery zones where stratums of low permeability are exposed and removing portions of the well wall at one or more unsealed recovery zones to increase the effective radius of the well thereat, thereby to effect a comparatively constant control over the flow of oil into the well from the various stratums tending to equalize the depletion of the stratums during the progress of oil recovery.

9. A method of controlling the recovery of oil from an oil sand having a plurality of associated oil-containing stratums of different permeabilities exposed in the same horizon in a plurality of wells, comprising introducing a pressure fluid under pressure into the stratums through one or more of the wells and introducing means into one or more of the remaining wells for exerting continuous selective control of the flow of oil from the various oil-containing stratums of the sand so as to minimize lack of uniformity in the oil depletion of the various stratums during the progress of oil recovery from the sand.

10. A method of controlling the recovery of oil from an oil sand having a plurality of associated oil-containing stratums of different permeabilities exposed in the same horizon in a plurality of wells, comprising injecting a pressure fluid under pressure from one or more pressure wells into the stratums of relatively low permeability without making direct injection into stratums of high permeability, to cause a controlled distribution of pressure fluid within and between the various stratums, and introducing means into one or more recovery wells for maintaining constant selective control of the flow of oil from the various oil-containing stratums of the sand, so as to minimize lack of uniformity in the oil depletion of the various stratums during the progress of oil recovery from the sand.

11. A method of controlling the recovery of oil from an oil sand having a plurality of associated oil-containing stratums of different permeabilities exposed in one or more pressure wells and in a plurality of recovery wells, comprising injecting a pressure fluid under pressure into the stratums from the pressure wells, introducing means into each recovery well for maintaining constant selective control of the flow of oil from the various stratums in the same horizon to minimize differences in oil depletion of the various stratums of the sand adjacent thereto, and selectively back-pressuring one or more of the recovery wells to balance the oil recovery from the various recovery wells.

12. A method of controlling the recovery of oil from an oil sand having a plurality of associated oil-containing stratums of different permeabilities exposed in a recovery well, comprising introducing means into the well for selectively restricting the flow of oil into the well from the various stratums in the same horizon commensurately with their respective permeabilities so as to minimize differences in depletion of the various stratums, and back-pressuring the well to control the total rate of oil recovery therefrom.

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