Feb. 1, 1938. W. E. LANG 2,107,007

METHOD OF INCREASING RECOVERY FROM OIL SANDS

Filed Dec. 15, 1936

Fig. 1.

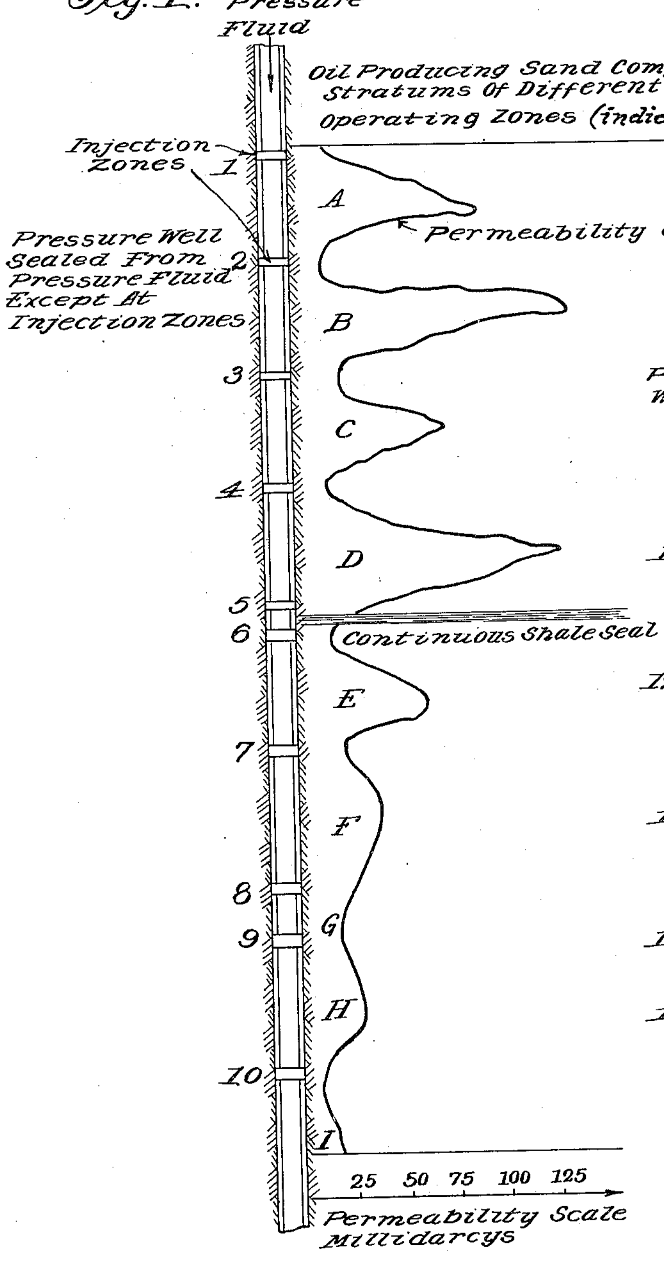
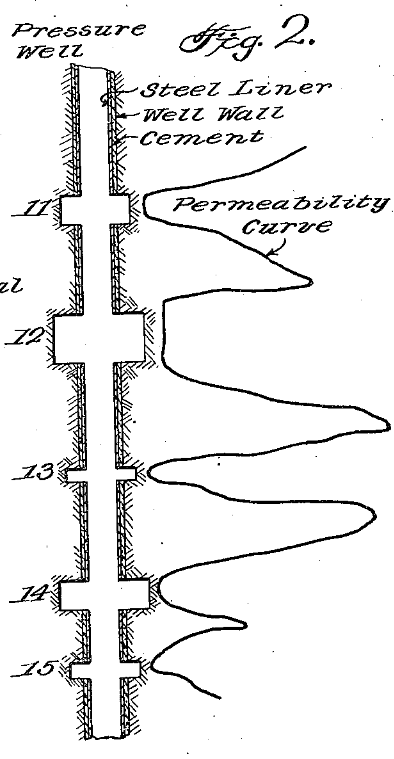


Fig. 2.



Inventor

William E. Lang

By Emery, Booth, Holcombe & Miller

Attorneys

Patented Feb. 1, 1938 2,107,007

UNITED STATES PATENT OFFICE

2,107,007

METHOD OF INCREASING RECOVERY FROM OIL SANDS

William E. Lang, Lexington, Ky.

Application December 15, 1936, Serial No. 115,996

12 Claims. (Cl. 166—21)

This invention relates to a method of efficiently pressuring or repressuring an oil-bearing sand or horizon with the aim of securing the greatest possible recovery of oil from the entire thickness thereof throughout the area treated.

My present invention represents an improvement upon the method described and claimed in my Patent No. 2,019,418, issued October 9, 1935; and the present application constitutes a continuation in part of my copending application Serial No. 77,413, filed May 1, 1936.

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 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 or 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.

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. And 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%.

In an attempt to secure a greater recovery, but without an adequate understanding of the factors involved, it has become the practice in certain of the Pennsylvania fields and elsewhere to supply pressure into the sands from an external source, this practice being known as repressuring. This is accomplished by utilizing an existing well, or preferably one drilled expressly for the purpose, which is near to one or more producing wells and passes through the same sand, and which is known as a pressure well. Air, natural gas, or water is forced under pressure into the pressure well and flows under pressure into the sand, and thereby causes or increases the flow of oil from the sand into the producing wells, thus increasing the recovery of oil. But by this method the entire thickness of the sand exposed in the pressure well is subjected to the same pressure (or if divided into zones exposed to different pressures, each zone is subjected to the same pressure for its entire thickness), with the result that the highly permeable stratums or units will absorb much more energy than is required to move the oil therein, causing a fast rate of depletion and approach to an oil saturation value at which by-passing presents further recovery; while during the same period the stratums of low permeability (which requires a greater amount of energy) will have received less energy and only a small amount of oil will have been recovered therefrom by the time this artificial pressuring is lost due to nearly complete by-passing of all the pressure fluid through the highly permeable stratums.

This undesirable result can be lessened, to secure a greater total recovery from the sand, by selectively introducing the pressure fluid into the various stratums, or groups of associated stratums, in accordance with their effective permeabilities so as to make the recovery from the various stratums more nearly uniform. This method is described in my aforesaid Patent No. 2,019,418.

According to the present improved method, a pressure fluid (for example a gas such as air, natural gas, and mixtures of gases and liquids, or a liquid such as water) is injected into the stratums of low permeability only, there being no injection into the stratums of relatively high permeability.

This is illustrated by the accompanying diagrammatic drawing, wherein Figs. 1 and 2 show a vertical section through a representative oil sand and pressure well.

As shown in Fig. 1 of the drawing, the oil sand does not have a uniform permeability, the permeability varying from less than 10 to more than 100 millidarcys at different vertical points, indicated by the changing contour of the permeability curve, the magnitudes being indicated by the permeability scale at the bottom of the diagram.

Instead of allowing the pressure fluid to enter directly from the pressure well into the various stratums of the sand, the well wall is sealed from the fluid except at zones where stratums of relatively low permeability are exposed, so that direct injection will occur at these places only. The upper portion of Fig. 2 indicates a typical situation in which the permeability curve presents a series of high peaks, there being alternating sections varying greatly in permeability. Injection zones 1, 2, 3, 4, and 5, located in the regions of relatively low permeability, include between them what are termed operating zones, within which lie the stratums of relatively high permeability. As designated, operating zone A lies between the injection zones 1 and 2, B lies between 2 and 3, C lies between 3 and 4, and D lies between 4 and 5.

Assuming a gas being used as the pressure fluid and the pressure well to be in operation, and thus constituting a common supply zone for gas under pressure for the various injection zones, the dense high pressure gas will enter the stratums of low permeability only, which require a high pressuring, and as this gas advances through and parallel with said stratums a part will diffuse vertically into the stratums of relatively high permeability. In this way, for example, operating zone B will be supplied with gas under pressure from injection zones 2 and 3. By the time pressuring gas has entered the stratums of high permeability, it will have expanded and become less dense and of lower pressure than if it had been directly injected into these stratums at the pressure well. Thus the condition of the sand itself is made use of to cause distribution of the pressuring gas between the various stratums in the most desirable way that is known to me.

The pressuring gas in passing toward the more highly permeable stratums forces oil into these stratums from the stratums of low permeability, thereby not only facilitating recovery from the latter but helping to secure a uniform degree of oil saturation of the various stratums. And the recovery work which is done by the more highly compressed gas in passing through the stratums of low permeability tends to equal the work done by the expanded gas which has diffused into and passes through the stratums of high permeability by the time the gas in each case has expanded to the pressure pervailing at the recovery well. The result is that my method provides a way of keeping uniform the oil saturation percentages in the various stratums of an operating zone during the process of oil recovery, to the end of securing the maximum production of oil from all and not merely from the stratums of relatively high permeability. Even if a stratum of high permeability becomes depleted to the extent that no further recovery is obtained therefrom, in advance of the stratums of lower permeability, the by-passing and wastage of pressuring gas will obviously be minimized by my method of controlled injection and the stratums of lower permeability will not be deprived of pressuring to the extent that would follow if said stratum of high permeability were exposed to direct injection from the pressure well.

Referring to the middle portion of Fig. 1, a condition is illustrated in which a continuous and substantially unbroken shale lamination passes through a region of low permeability, acting as a seal to prevent vertical diffusion of gas from one side to the other. To meet this condition, injection zones may be provided immediately above and below the shale lamination (as shown) in order to service both of the adjacent operating zones. Thus injection zone 5 services operating zone D, which is above the shale, while injection zone 6 services operating zone E, which is below the shale.

The lower portion of Fig. 1 illustrates a condition where a relatively thick zone composed of a number of stratums of low permeability exists, requiring not only an injection zone 9 at a point of lowest permeability, but an additional injection zone 8 located nearby. In this case the interposed operating zone G includes stratums which are all of relatively low permeability.

Not only does my method provide for obtaining uniform recovery from the various stratums in each operating zone bounded by stratums of relatively low permeability, 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.

In accordance with my invention, the volume of pressure fluid injected into the sand at each injection zone is regulated to suit conditions by adjusting the area of well wall exposed to the pressure fluid with the object of proportioning the fluid injected at the various injection zones in relation to the needs of the different operating zones. Thus an injection zone situated in a relatively thin region of low permeability should not be supplied with as great a volume of fluid as is supplied where contrary conditions prevail. As indicated in the drawing, 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 fluid is to be injected into an exceptionally thick layer of low permeability sand, particularly if the layer is found to be divided into stratums separated by shale partings.

The foregoing relates to the regulation of the relative volumes of pressure fluid injected at the various injection zones. The total volume per unit of time is regulated not only by the area of exposed rock but also by the pressure maintained in the pressure well, the greater the pressure the greater the rate of injection and the greater the work done in each stratum, other conditions being unchanged. The pressure in the pressure well should be made sufficiently high to cause adequate oil recovery from the lowest permeability unit available for commercial production. In the case of an oil-containing stratum of extremely low permeability, it may not be economical or even possible to secure an adequate oil recovery rate therefrom and it should not be considered in determining the desired recovery rate from the various other stratums.

The use of a gas as the pressure fluid will ordinarily be preferable in dealing with dense formations, but in the case of formations which have a high average permeability, water may be found preferable and may make possible a greater oil recovery owing to its ability to displace a higher percentage of oil in the sand before serious by-passing occurs.

The sealing of the pressure well wall from the pressure fluid except at injection zones, as heretofore described, may be accomplished by means of a pressure packer or series of packers supplied with fluid by means of a pipe extending down the bore of the well from the surface, and so constructed and arranged that the wall surface of the well adjacent zones of injection are sealed to prevent exposure of the surface to the pressure fluid. A form of packer having positive mechanical means for providing the necessary sealing is described in my aforesaid copending application Serial No. 77,413.

Sealing to permit of controlled injection may be accomplished without the use of a pressure packer in the following manner, illustrated in Fig. 2. The face of the pressure 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 to fluid 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 to permit passage of pressure fluid from the well into the stratums of relatively low permeability so as to control the injection of pressure fluid as heretofore indicated. 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 injection 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 injection desired. The result of this procedure is that the well wall is sealed with lengths of cemented liners which are separated at the injection zones to permit of the desired controlled injection of pressure fluid.

In order to further control the injections of pressure fluid, the sand or rock formation exposed at one or more of the injection 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 11 to 15 shown in Fig. 2. The result is that the effective radius of the pressure well may be adjusted as desired at each of the injection zones to influence the effect of injection. When pressure fluid is injected into the formation at each injection zone under pressure, the horizontal flow is controlled by the laws of radial flow, so that the volume which can be injected under any given pressure, and the radial pressure distribution and effect of the injected fluid, is fundamentally influenced by the radius of the exposed rock at the place of injection as well as by the spacing and character of the surrounding recovery wells and velocity of flow. Thus the radial flow formula contains the factor: $\log_e R_a/R_w$ (logarithm to the base e of the ratio of R_a to R_w, where R_a is the radius of the reservoir or the distance from the pressure well to the recovery well in question or the distance at which the drop in pressure or rate of flow is to be determined, and R_w is the radius of the well). Hence by increasing the effective radius of the well at an injection zone, the flow of pressure fluid may be controlled and greatly facilitated. It is evident that this expedient makes possible a greater spacing between pressure wells and recovery wells, since the $\log_e$ factor will be the same when R_a and R_w are both doubled, for example. The volume distribution of injected fluid as between different injection zones can be adjusted by varying the relative radii, thus providing an additional way of effecting such control.

The reaming out of the rock or sand at an injection zone will expose surfaces to direct vertical injection of pressure fluid, thus increasing flow of fluid to adjacent stratums. This can be modified by partially or entirely sealing such exposed surfaces.

Thus the reaming out of the formation, taken in combination with variations which can be obtained in the vertical width of the injection zones, makes it possible to provide for controlled injection of pressure fluid in any given situation to the end of securing maximum results under the formation conditions encountered.

The openings in the well lining of the cemented liner type previously 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.

The rate at which pressure fluid can be introduced into stratums of low permeability 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 the desired fluid injection zones by use of a packer (such as described in my said copending application). Preferably one zone at a time is treated, the amount of acid or other fluid used being regulated to suit the permeability desired. When the well is sealed by use of a cemented liner cut away to provide injection 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. Such treatment makes for an enlarged radial injection zone, by honeycombing and disintegrating the stratum formation adjacent the well so as to provide larger passageways. Owing to the laws of radial flow, the greatest part of the total resistance between pressure well and recovery well is offered adjacent the pressure well, so that the treatment will substantially increase the volume of fluid which can be injected at any given pressure, and the radius of action of the injected fluid. However, treatment may not be desirable with respect to a relatively thin stratum of low permeability, which is next to stratums of high permeability, since the injected treatment fluid will in part flow vertically and affect the formation so that pressure fluid will pass too directly into the stratums of high permeability and thus undesirably affect the pressuring of the low permeability stratum.

The pressure maintained in the pressure well need not be kept constant. My invention contemplates the use of fluctuating pressure, whereby when the pressure has been built up to the desired maximum, the introduction of pressure fluid into the well will be discontinued in whole or in part to cause the pressure in the well to gradually drop to a substantially lower value, after which fluid will be introduced to build up the pressure again, and this cycle can be repeated as long and as often as desired. By this procedure a variation of injection pressure at each injection zone results, which will tend to cause a change of oil saturation in the sand from small saturated capillaries to larger depleted capillaries, making for a more complete recovery of oil.

Owing to the varying conditions, largely unknown in detail, which usually exist between a pressure well and associated recovery wells, it is impossible to calculate in advance the exact pressure and volume requirements for each injection zone in order to obtain the greatest possible uniformity of recovery, as stratum thicknesses and permeabilities determined at any of the wells afford definite information only as to very localized regions. Such information, however, provides a starting point, and particularly, it enables the most important aspect of the method to be controlled, namely, the injection of pressure fluid into stratums of relatively low permeability only and the sealing off at the pressure well of stratums of relatively high permeability, so as to divide the thickness of the sand into producing zones containing highly permeable stratums which are repressured efficiently to prevent excessively rapid depletion and bypassing of gas or water before substantial recovery has been obtained from stratums of relatively lower permeability.

While conditions in the sand may prevent obtaining the theoretically maximum recovery which might be secured under ideal conditions, the method of pressuring which I have described clearly provides a way of definitely increasing the total recovery from the sand over what is otherwise possible.

In addition, a feature of my method is that it permits of using a lower pressure in the pressure well, for a given spacing of recovery wells and rate of recovery. Of more importance, my method permits of using higher pressure and of spacing the pressure well farther apart from the most distant recovery wells to be serviced so as to affect a greater area, owing to the efficient utilization of the energy of the pressure fluid.

No claim is made herein to the treatment of the recovery well, that being the subject-matter of my companion application Ser. No. 115,997, filed simultaneously herewith, for a method of controlling recovery from oil sands.

What I claim is as follows:

1. A method of pressuring an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a pressure well, comprising injecting a pressure fluid under pressure directly from the well into one or more stratums of relatively low permeability without making an injection into the stratums of relatively high permeability, so that pressure fluid can enter the latter stratums only after diffusion through and from sand of lower permeability, whereby oil from the stratums of low permeability is forced into the stratums of high permeability and increases the percentage of saturation thereof, promoting uniformity of recovery and maximum production from the entire sand.

2. A method of pressuring one or more adjacent productive stratums of relatively high permeability bounded above and below by productive stratums of substantially lower permeability, exposed in a pressure well, comprising introducing a pressure fluid under pressure into the well and injecting it only into said stratums of lower permeability so that pressure fluid must pass therethrough to reach said stratums of relatively high permeability, whereby oil from the stratums of low permeability is forced into the stratums of high permeability and increases the percentage of saturation thereof, promoting uniformity of recovery and maximum production from the entire sand.

3. The method of controlling the recovery of oil from a plurality of associated productive stratums in the same sand, some of the stratums being of relatively high permeability and others of substantially lower permeability, which comprises injecting a pressure fluid under pressure from a common supply zone into stratums of lower permeability only so as to tend to equalize the saturation percentages of the various stratums during the progress of oil recovery, and promote uniformity in the work done by the pressure fluid throughout the sand, thereby obtaining maximum production of oil for the amount of pressure fluid injected.

4. A method of pressuring an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a pressure well, comprising sealing the well wall throughout said sand except at zones where stratums of relatively low permeability are exposed, so as to prevent direct entry of fluid from the well into stratums of relatively high permeability, and introducing a pressure fluid under pressure into the well to cause the injection thereof into stratums of relatively low permeability.

5. A method of pressuring a series of associated

oil-containing stratums of different permeabilities exposed in a pressure well and constituting a plurality of operating zones bounded by stratums of low permeability and each including stratums of high permeability located therebetween, comprising sealing the well wall throughout said sand except at injection zones where said stratums of low permeability are exposed, and injecting a pressure fluid under pressure into the stratums at said injection zones only, to cause a controlled distribution of pressure fluid within and between the stratums of different permeability.

6. The method of pressuring an oil sand having a plurality of contiguous oil-containing stratums of different permeabilities exposed in a pressure well, comprising injecting a pressure fluid under pressure only into the stratums of relatively low permeability and proportioning the fluid entering the various stratums to meet the energy requirements thereof, and of adjacent stratums of higher permeability, thereby increasing the effectiveness of the pressuring treatment in recovering the oil from the sand as a whole.

7. A method of pressuring an oil sand having a plurality of associated productive stratums of different permeabilities exposed in a pressure 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 in relation to the relative volumes of pressure fluid required to be injected at each of said zones to minimize differences in rates of oil depletion as between the various groups of stratums located between said zones, and introducing a pressure fluid under suitable pressure into the pressure well to service said zones.

8. The method of controlling the recovery of oil from a plurality of associated productive stratums having different permeabilities, comprising injecting a pressure fluid under pressure from an external source and through a common supply zone into the stratums of relatively low permeability only so that pressure fluid must pass therethrough to reach stratums of relatively high permeability, and periodically decreasing and increasing the pressure.

9. A method of selectively pressuring an oil sand exposed in a pressure well and having a plurality of contiguous oil-containing stratums of different permeabilities, comprising treating only the exposed oil-containing stratums of lower permeability to increase permeability adjacent the pressure well, and selectively pressuring the oil-containing stratums with a pressure fluid to minimize differences in rates of depletion of the various stratums.

10. A method of selectively pressuring an oil sand exposed in a pressure well and having a plurality of oil-containing stratums of different permeabilities, comprising injecting a treating agent into and only into stratums of relatively low permeability to increase permeability adjacent the well, and thereafter injecting a pressure fluid under pressure into the stratums of lower permeability only and regulating the injection into each of said stratums.

11. A method of selectively pressuring 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 directly injecting pressure fluid under pressure from the well into stratums of lower permeability only.

12. A method of selectively pressuring 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 injection zones where stratums of low permeability are exposed, removing portions of the well wall at one or more unsealed injection zones to increase the effective radius of the well thereat, and injecting a pressure fluid under pressure directly into the oil sand at said injection zones, to cause a controlled distribution of pressure fluid within and between the stratums of different permeability so as to secure a more nearly uniform depletion of the various stratums.

WILLIAM E. LANG.