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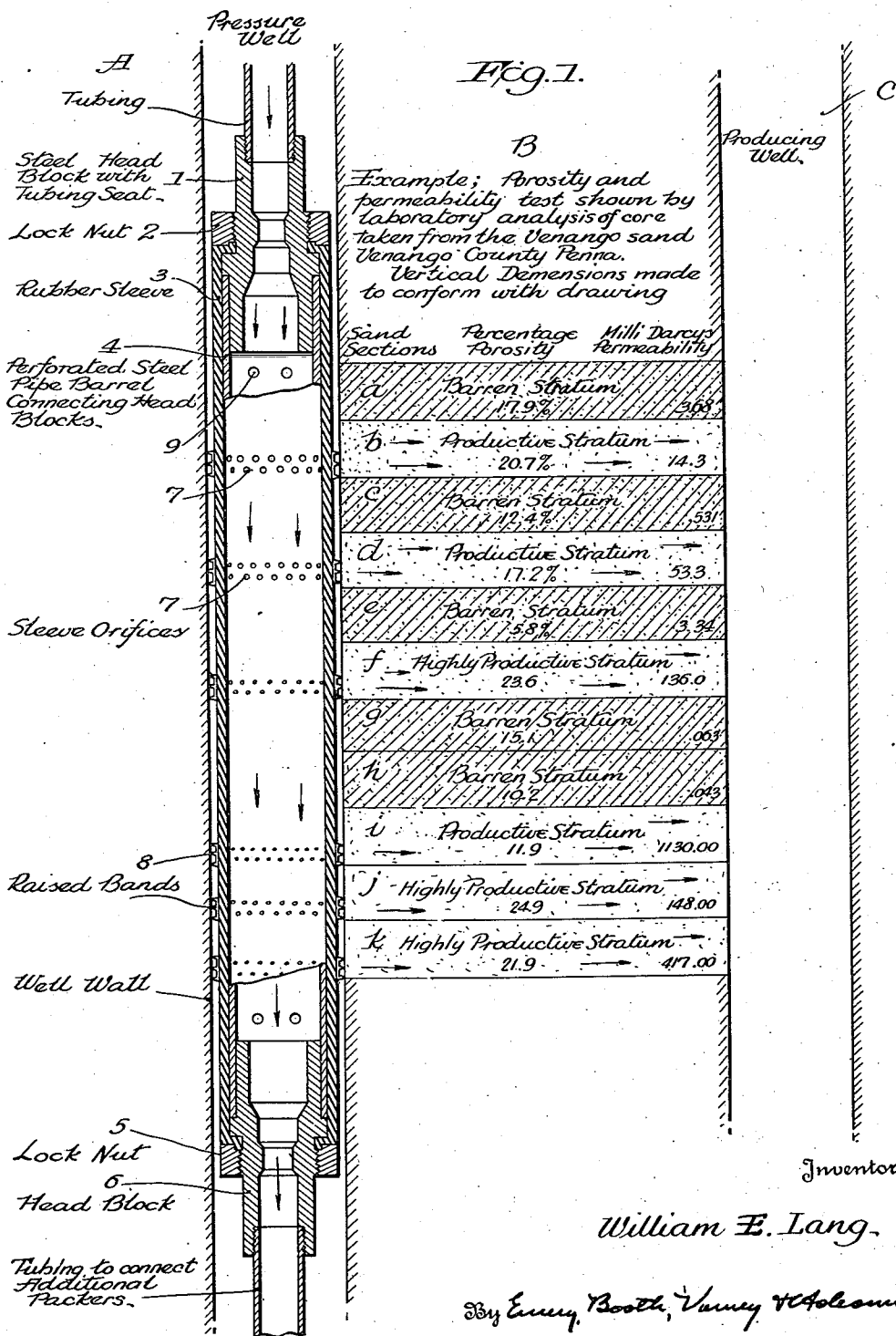
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METHOD AND APPARATUS FOR INCREASING RECOVERY FROM OIL SANDS

Filed April 24, 1935

2 Sheets-Sheet 1



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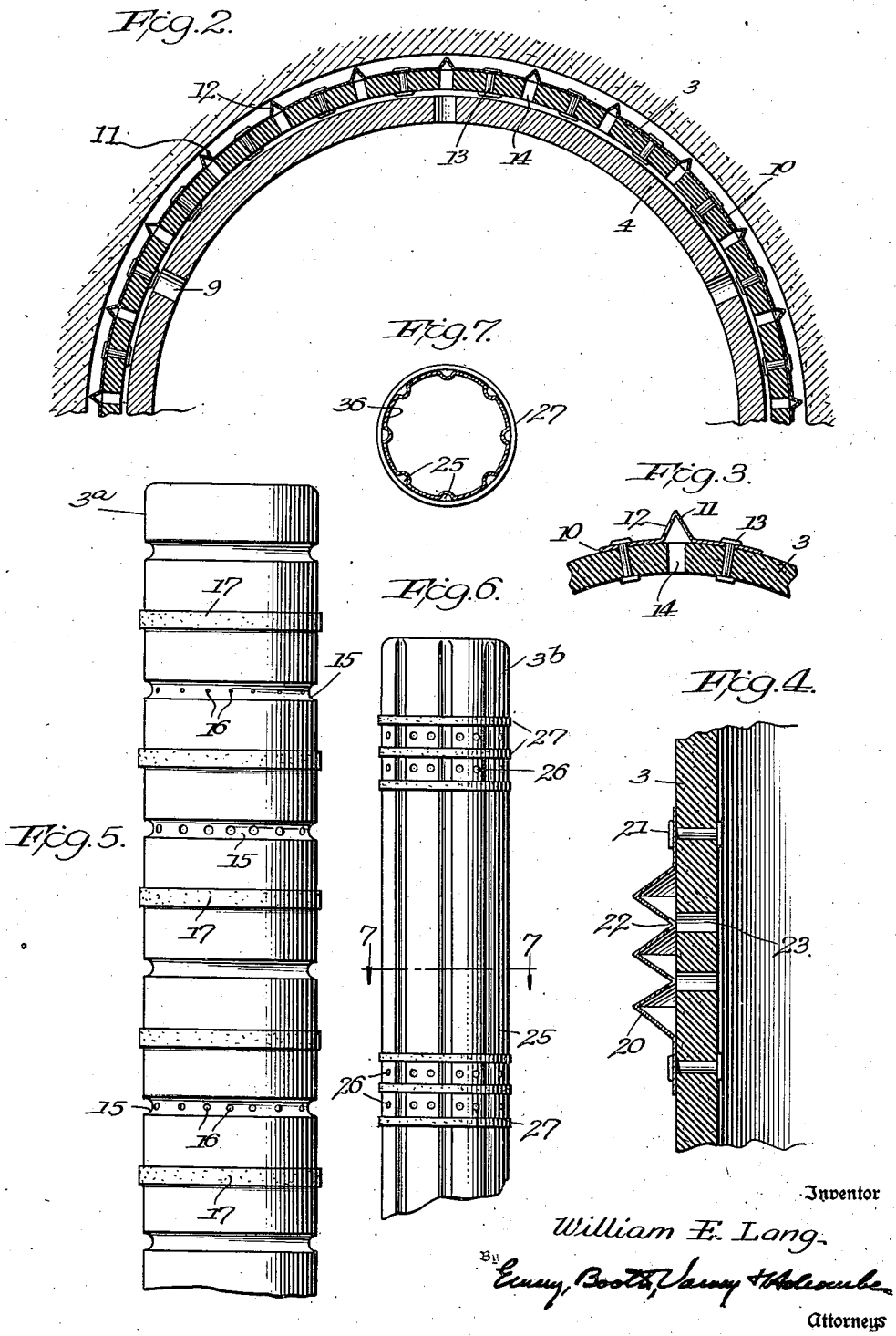
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## UNITED STATES PATENT OFFICE

2,019,418

## METHOD AND APPARATUS FOR INCREASING RECOVERY FROM OIL SANDS

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14 Claims. (Cl. 166—21)

My invention aims to provide a method and apparatus for more efficiently operating pressure wells to secure a greater recovery of oil from virgin and partially depleted sands than has been possible with previous methods.

As is now well known in the art, oil wells which have partly or wholly ceased producing, due to decline in the reservoir or rock pressure within the oil bearing strata, may be revived by repressuring the strata. This is accomplished by utilizing a nearby well, or one drilled expressly for the purpose, and which passes through the same strata, as a pressure well into which air, gas, or water is forced under pressure and thence into the oil bearing strata. The pressure of the fluid forced into the strata causes or increases a flow of oil from the strata to the producing wells and thus increases the recovery of oil from the sands.

The oil which can be recovered without repressuring is estimated as being only about 10-40% of the oil originally stored in the oil bearing sands, and hence the value of repressuring is quite evident. However, repressuring as heretofore practiced does not and cannot result in either a complete or uniform recovery from the various oil bearing strata which go to make up a given sand or horizon, due to the lack of uniformity of resistance to flow offered by the different strata in the same sand or horizon and to the fact that all are subjected to repressuring indiscriminately.

An object of the present invention is to provide for selectively repressuring the several productive strata comprising a sand or horizon so as to obtain the maximum recovery of oil from each and hence from all, and thus to increase the total recovery.

My invention is also of great value for use in effecting a proper control of oil recovery from virgin or newly opened oil fields, so as to avoid depletion of highly permeable strata, and often the flooding of wells due to passage of water through such depleted strata into the wells, prior to depletion of oil in the less permeable strata from which the oil normally flows more slowly. In this connection, the initial employment of repressuring by use of air or gas will lower the viscosity and decrease the density of the oil as a result of becoming dissolved therein, thereby increasing its flowability under pressure and thus for this reason will still further facilitate the recovery of the oil from the less permeable strata.

My invention also contemplates a method and apparatus for determining the relative effective permeability or resistance to flow of the individual strata of a sand and thus securing valuable

information for use in regulating the repressuring of the several strata.

Other objects and features of the invention will be made evident as the description progresses.

In the accompanying drawings,

Fig. 1 is a partly diagrammatic representation of an oil bearing structure; the portion designated A illustrates a pressure well containing a packer, shown in vertical section partly broken away, adapted to permit of selectively repressuring the several productive strata of a sand or horizon; the portion designated B illustrates in diagrammatic manner a vertical section through a representative sand, showing the various strata and properties thereof, to indicate the mode of operation of the packer; and the portion designated C similarly illustrates a producing well into which the oil is caused to flow from the sand;

Fig. 2 is a transverse section, broken away, of a rubber packer sleeve provided with a modified spacing and orifice arrangement;

Fig. 3 is an enlarged view of a portion of the sleeve arrangement shown in Fig. 2;

Fig. 4 is a longitudinal cross-section of a portion of a rubber packer sleeve provided with still another spacing and orifice arrangement;

Fig. 5 is a vertical elevation view of a metal packer sleeve;

Fig. 6 is a vertical elevation of a modified form of metal packer sleeve; and

Fig. 7 is a transverse section of the sleeve shown in Fig. 6, taken on the line 7-7.

Referring to Fig. 1, B, which shows the results of a core analysis of the Venango sand, Venango County, Pennsylvania, and indicates the percentage porosity and the permeability in millidarcys of the various barren and productive strata which make up the sand, it is evident that there is a very great variation in properties between strata in the same oil bearing formation. There are a number of productive strata (b, d, f, i, j, k), and a number of barren strata (a, c, e, g, h), some of which are interposed between the productive strata. The productive strata which are adjacent each other (i, j, k) are separated by shale laminations and hence may be treated as independent of each other. As indicated, some of the productive strata are more highly productive than others, and the permeability of one productive stratum (i) is about eighty times that of another (b).

My invention depends upon the observed fact that the greater the permeability of a stratum the less the resistance to flow of oil or other fluid offered by the stratum. Since air, gas or water

introduced under pressure into the strata without control will, because of its nature, follow the lines of least resistance, a high rate of recovery of oil is effected from the highly permeable strata while a low percentage of recovery results from the less permeable regions. This occurs when repressuring is indiscriminate, as when the air, gas or water is forced into a formation from a pressure well without regulation of the pressure, volume and velocity as between strata. This has been the practice heretofore, except as perhaps modified by the sealing off of a highly permeable and depleted stratum from which no further substantial recovery can be expected. The result is that a property may be repressured for several years with the recovery of oil from only the more highly permeable strata and with little recovery from the strata of low permeability, notwithstanding that the latter may be highly saturated with oil.

Furthermore, in fields having hydraulic control, the edge wells are flooded out before any substantial recovery of oil has been secured from the strata of low permeability, due to the ready flow of water into the wells through the depleted strata of high permeability. For example, it is known that the water-flooding method practiced in the Bradford, Pennsylvania, fields, has produced only 35-40% of the oil remaining after the first recovery. This I believe is due to the fact that the water passes rapidly through the highly permeable strata, resulting in a low percentage of recovery from the less permeable strata prior to the flooding of the producing wells.

In accordance with the present invention, the energy supplied by repressuring is directed selectively into each of the various productive strata making up a sand or horizon so as to deplete the oil in each at a more nearly uniform rate. I have discovered that by regulating the pressure, volume and velocity of the repressuring fluid introduced into the several strata, so as to exert a greater force on oil in the less permeable strata than on oil in the more highly permeable strata, a more nearly complete recovery of the oil in all of the strata can be secured in any given period and no stratum need become exhausted before having obtained effective recovery from all.

Another great advantage of my method is that less repressuring fluid will be required per barrel of oil recovered due to the more efficient use of the repressuring fluid, and hence recovery cost will be greatly lowered.

According to my invention, I prefer to inject the repressuring fluid into the lower portion only of each productive stratum. This is the most highly saturated portion and the result is to move the oil most effectively with the least wastage of the repressuring fluid and to secure a maximum recovery of oil.

Illustrative apparatus for carrying out the invention is shown in Fig. 1A, and comprises a packer unit adapted to permit of controlling the repressuring of each of several associated strata independently of each other. The packer unit is made to have an external diameter substantially filling the bore of the well in which it is to be used, leaving about  $\frac{1}{8}$  inch clearance from the well wall when not under pressure, and may be made in any reasonable and practical length to conform to the thickness of the pay sand.

If necessary, several units may be connected directly in series.

In the form of the invention illustrated in Fig. 1A, at each end of a unit there are cylindrical steel head blocks 1 and 6, provided with internally threaded tubing seats to receive the threaded ends of the well tubing in which the unit is interposed in series. The end blocks are connected by a perforated steel pipe barrel 4, having openings 9, which may be welded to inner shoulders thereof. A rubber sleeve 3 concentrically surrounds pipe barrel 4 and is secured and sealed at each end by being clamped against external shoulders of each head block by lock nuts 2 and 5, respectively, which engage externally threaded portions of the head blocks.

Rubber sleeve 3 is provided with sets of circumferential orifices or openings 7 so spaced along its length that a set of orifices will communicate with the lower portion of each of the productive strata in the sand for which the packer unit is designed, the sleeve being otherwise air tight. Raised bands 8 are secured around the sleeve to space the latter away from the well wall in proximity to the orifices.

When air, gas, water or other fluid is pumped under pressure into the well tubing, the packer unit being in operative position in the pressure well, the fluid will pass through perforations 9 in pipe barrel 4 and will force the flexible sleeve 3 against the well wall so as to effect a seal at all portions except where the orifices are exposed to the sand strata. A portion of the fluid will be forced into each productive stratum through the corresponding orifices, and once having passed through such orifices will be sealed off from all other exposed strata by the intervening sleeve pressed against the well wall. The fluid will thus be forced into the lower portions only of each stratum, assuming the orifices to be opposite such lower portions and no orifices opposite the upper portions, due to the sealing action of the sleeve.

By suitable variation in the size, number and arrangement of orifices as between the sets of orifices, each set corresponding to one stratum, it will be evident that the repressuring of each stratum can be controlled independently of the others and thus the desired results can be obtained in accordance with my invention.

Obviously many variations of the above described apparatus are possible. Thus, instead of perforated pipe barrel 4, rods may be used to secure and space apart end blocks 1 and 6 and permit access of the pressure fluid to the sleeve. Sleeve 3 need not be made of rubber or even of a highly elastic material. A strong fabric, such as canvas, impregnated with rubber, may be used; or any suitable pressure resistant flexible material. The raised spacing bands 8 may be dispensed with, and the orifices may be provided with eyelets so contrived as to serve as spacing members.

Figs. 2 and 3 show a modified arrangement for providing orifices in rubber sleeve 3. A stiff metal strip 10, which may encircle the sleeve, is fastened with rivets 13 circumferentially of the sleeve at portions where orifices are desired. These strips are provided with corrugations 11, which run longitudinally with respect to the sleeve, so as to space the sleeve from the well wall thereat, and holes or other openings 12 in the sides of the corrugations permit the fluid to pass through underlying openings 14 in the sleeve to the strata outside. Openings may also

be provided in portions of the strips lying between the corrugations.

In Fig. 4 an optional arrangement is shown in which the sleeve 3 is provided at appropriate places with a stiff metal band or ring 20, fastened to the sleeve by means of rivets 21. This band is internally corrugated, the corrugations encircling the sleeve and having holes or other openings 22 in the depressions to permit of the desired fluid flow. The sleeve is provided with openings 23 to expose the openings in the band to fluid within the sleeve.

In the form of packer sleeve 3a illustrated in Fig. 5, which may be used in place of the rubber sleeve 3 shown in Fig. 1 and secured and positioned in the same manner, the sleeve is made of seamless drawn copper or other suitable metal having some capacity for stretching or expanding under pressure before breaking or splitting open. At distances of every few inches, this metal sleeve is provided with interiorly projecting corrugations 15 which provide circumferential encircling grooves in the outer surface. Some or all of these corrugations are drilled, in accordance with the nature and arrangement of the strata, to provide openings or orifices 16 to permit air or other fluid under pressure to pass through the sleeve and fill the annular spaces surrounding and adjacent to the corrugations in which such openings are located.

When the sleeve is under pressure, as when strata are being repressured, the fluid pressure within the sleeve will force it against the well wall to provide longitudinal sealing. In addition, sealing bands 17 of rubber or other suitable material may be placed in some or all of the unperforated corrugation grooves to provide additional sealing action, such sealing bands being disposed with relation to the perforated corrugations so as to seal the various strata from each other as previously described.

Still another form of packer sleeve is shown in Figs. 6 and 7. Sleeve 3b is made of metal and is provided with a multiplicity of longitudinal corrugations 25 which permit and facilitate the expansion of the sleeve under internal pressure independently of the stretchability of the metal itself. Holes 26 are drilled in the sleeve at suitable places to serve as orifices and provide the desired selective injection of fluid into the strata as heretofore described. Sealing bands or rings 27, of rubber or other suitable material, are disposed about the sleeve on either side of the various portions containing orifices so as to space them from the well wall, provide annular discharge zones, and seal the discharge zones apart. These sealing bands are made of resilient material and penetrate into the corrugations of the sleeve when compressed between the well wall and the sleeve, the latter expanding under internal pressure so as to exert the necessary pressure on the sealing bands.

From the foregoing description it will be evident that there are many possible embodiments of my apparatus invention and this description thereof is intended to illustrate my invention and not to limit the same.

The considerations affecting the actual design of a particular packer unit are of course many, and one form may be found more suitable under one set of circumstances and others under different circumstances. Thus the pressure of the fluid employed for repressuring may vary in practice from 60 to 2500 pounds per square inch depending on the particular fluid, the nature of the

strata, and the spacing of the pressure well from the producing wells, and a more readily expandible form of packer sleeve will be required the lower the pressure.

The oil present in the pressure well to which the packer is exposed, the pressure fluid itself, and the chemicals which may be contained therein to facilitate repressuring, will also impose design restrictions, due to the necessity of avoiding excessive corrosion or deterioration. Thus a copper packer sleeve, or one of special alloy steel, may be most suitable because of its resistance to certain types of corrosion, for example, where rubber cannot be efficiently used; or vice versa.

Several packer units may be connected in a single string of well tubing for serving different separated sands, or by the use of concentric strings of well tubing they may be supplied separately with repressuring fluid or fluids under different pressures.

No simple rule or formula can be given for determining the relative size and number of orifices corresponding to each producing stratum of a sand. It will be apparent that the pressure, volume and velocity of the repressuring fluid entering each stratum will be dependent upon a number of variables, including the permeability and degree of saturation of the stratum, and its thickness, the character and number of orifices, the supply pressure within the packer barrel, the nature of fluid used for repressuring, the well spacing pattern, and the oil content to be recovered.

However, knowing the relative permeabilities of the different strata, as determined by a core analysis, a rough initial estimate can be made which will result in greatly improving the repressuring of the sand, bearing in mind that the lower the relative permeability of a stratum the greater the energy that must be supplied in comparison with strata of high permeability, other factors being equal. This is indicated in Figs. 1A and 1B, where the size of the orifices corresponding to stratum b, which has a very low permeability, is much greater than that of the orifice corresponding to stratum i, which has a very high permeability. After repressuring for some time the effects can be changed, as operating experience indicates, in order to secure even better uniformity of depletion as between strata.

Permeabilities as determined by laboratory core analyses are useful, but due to the fact that core samples represent only small portions of the strata from which they are taken, the results obtained may not represent the effective permeability of the strata with sufficient accuracy when considered in relation to the reservoir as a whole.

A more direct measurement of the effective permeabilities of different strata can be obtained by use of the packer unit previously described, and the results so obtained may advantageously be used in determining the relation of orifices for repressuring. For this purpose the packer unit may be constructed in the manner set forth, but the outer flexible sleeve 3 should be provided with orifices in one region only, so as to provide orifices for only a short distance longitudinally, for example 6-10 inches. This packer unit, plugged at the bottom, is lowered on tubing into the desired position for testing, beginning at the bottom of the pay sands so that the orifices or perforations in the sleeve will be opposite the lower part of the stratum. Pressure is then applied, the desired repressuring fluid,

whether air, gas or water being introduced in sufficient quantity to hold the pressure constant in the packer supply line. The sealing action of the sleeve when under pressure will cause the fluid to be injected directly into the sand opposite the orifices. The amount of fluid which must be forced into the well pipe to maintain the pressure during a certain period of time measures the permeability of the stratum, the greater the amount of fluid needed, the greater the permeability at the particular region under test.

The pressure is then released and the packer unit raised for a test of the next adjacent region in the same manner, and similarly each foot or fraction of the sand can be tested.

From the results so obtained, the effective permeabilities of the different strata making up the particular sand or horizon may be estimated and their relation to the reservoir as a whole ascertained. Thus the efficient pressure and volume that the formation will take in its various strata can be determined, and from this information the size, number and arrangement of orifices in the packer unit for repressuring can be estimated.

I claim the following as my invention:

1. The method of selectively controlling the recovery of oil from a sand having a plurality of associated productive strata offering different resistances to flow of oil contained therein, which comprises injecting a fluid under pressure into each productive stratum of the sand, and independently regulating the injection into each stratum so as to more nearly equalize the rate of depletion of oil in the several strata within a given period of time.

2. The method of selectively controlling the recovery of oil from a plurality of associated productive strata in the same sand which normally become depleted at different rates, which comprises simultaneously injecting a fluid under pressure into each productive stratum of the sand, and controlling the fluid energy thereby introduced into the different strata of the sand according to the different resistances to flow of oil offered by each stratum.

3. The method of repressuring an oil sand having a plurality of oil containing strata, which comprises repressuring each productive stratum of the sand independently of the others and controlling the relative repressuring of the several strata.

4. The method of controlling the recovery of oil from a plurality of associated productive strata in the same sand, which comprises injecting a fluid under pressure into the lower portion only of each stratum of the sand and controlling the relative injection into the several strata.

5. The method of controlling the recovery of oil from a sand having a plurality of associated productive strata of different permeabilities, which comprises simultaneously introducing a fluid under pressure from a common supply zone to exposed portions of each stratum at a place distant from a recovery well, and regulating the pressure, volume and velocity of the fluid introduced into each stratum of the sand to increase the comparative rate of recovery at the recovery well from the strata of lower permeability.

6. The method of selectively supplying fluid under pressure to several associated productive strata in the same sand to increase the recovery therefrom, which comprises first introducing a fluid under pressure to each stratum individually

to determine the relative permeabilities of the several strata, and thereafter simultaneously injecting fluid under pressure into the several strata and controlling the relative injections in accordance with the relative permeabilities previously determined so as to increase the comparative uniformity of recovery from the different strata of the sand.

7. Apparatus for introducing fluid under pressure to several associated productive strata in the same sand, which comprises means for simultaneously supplying fluid to the several strata in the sand from a common supply zone adapted to be located within the sand, and means for selectively controlling the fluid supply to the several individual strata of the sand independently of each other.

8. Apparatus for simultaneously and selectively introducing fluid under pressure to a plurality of neighboring productive strata of a sand exposed in a pressure well, which comprises a fluid supply chamber of length coextensive with the several exposed productive strata and means for connecting the same to a well pipe for supplying fluid under pressure thereto, said chamber having openings communicating with the exterior, concentric means external of the chamber for sealing the strata from the fluid, and a plurality of passages through the sealing means for conducting fluid from the supply chamber to the several productive strata simultaneously but independently of each other.

9. A pressure packer for use in a pressure well for repressuring a plurality of neighboring oil strata, comprising a fluid supply chamber and means for connecting the same to a well pipe, an expansible tubular sleeve surrounding the chamber and secured at the ends to prevent outflow of fluid therebetween, said sleeve being adapted to press against the well wall when under pressure, and openings in the sleeve spaced apart to correspond to the various strata to be repressured.

10. A pressure packer for use in a pressure well for determining the permeability of individual oil strata in a sand having several associated strata, comprising a fluid supply chamber and means for connecting the same to a well pipe, an expansible sleeve concentrically surrounding the chamber and secured at the ends to prevent outflow of fluid therebetween, said sleeve being adapted to press against the well wall when under internal pressure exerted by fluid in the supply chamber, and openings in the sleeve to permit flow of fluid to a localized region of a single sand only when the sleeve is pressed against the well wall.

11. A pressure packer for use in a pressure well for supplying fluid under pressure to a plurality of neighboring exposed productive strata, comprising a tubular sleeve and means associated therewith adapted to expand against a well wall to seal exposed productive strata apart while providing a space between each exposed productive stratum and the sleeve, means for supplying fluid under pressure to the interior of the sleeve, and spaced passages for conducting and individually controlling the flow of the fluid from the interior of the sleeve to the several productive strata.

12. A pressure packer for use in a pressure well for supplying fluid under pressure to a plurality of neighboring productive strata, comprising an expansible tubular sleeve having a length coextensive with several productive strata and having openings to control passage of fluid from the interior of the sleeve to said strata, sealing rings

encircling the sleeve at intervals to provide separated annular fluid supply zones for the several strata externally of the sleeve, and means for supplying fluid to the interior of the sleeve.

- 5 13. A pressure packer for use in a pressure well for supplying fluid under pressure to a plurality of neighboring productive strata, comprising a tubular sleeve having a length coextensive with several productive strata and provided with longitudinal corrugations to facilitate expansion of  
10 the sleeve under internal pressure, and exterior sealing means dividing the outer surface of the sleeve into annular zones.

14. An oil field repressuring system embodying means for simultaneously supplying a pressure medium to each productive stratum of an oil sand containing a plurality of productive strata, and means for controlling the volume and pressure of said medium supplied to each stratum to suit the resistance to flow therein, whereby rapid over-depletion of the more permeable strata of the sand is prevented and a more complete recovery from the sand is secured. 10

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