

May 20, 1952

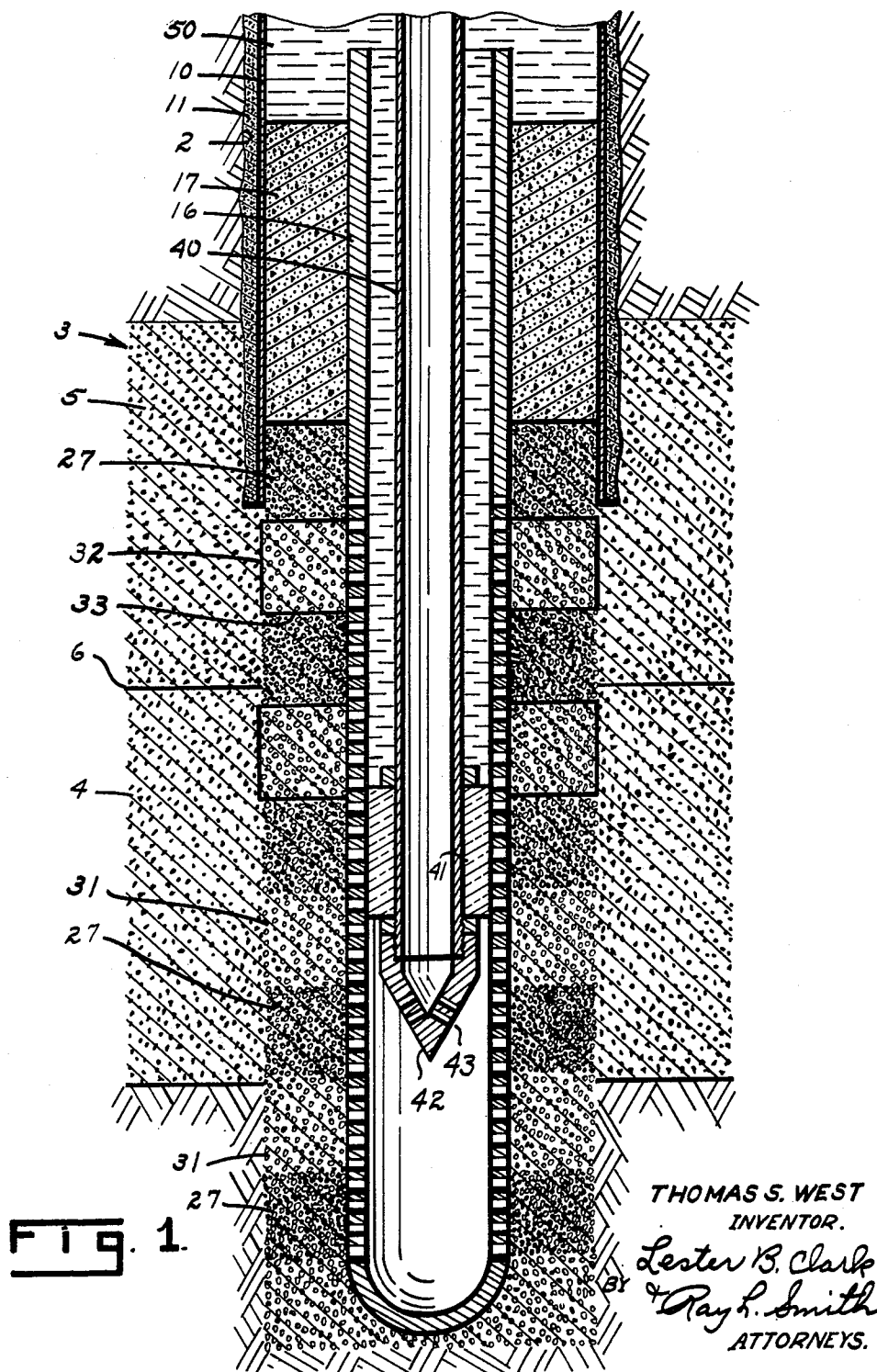
T. S. WEST

2,597,554

GRAVEL PACK COMPLETION METHOD

Filed May 15, 1947

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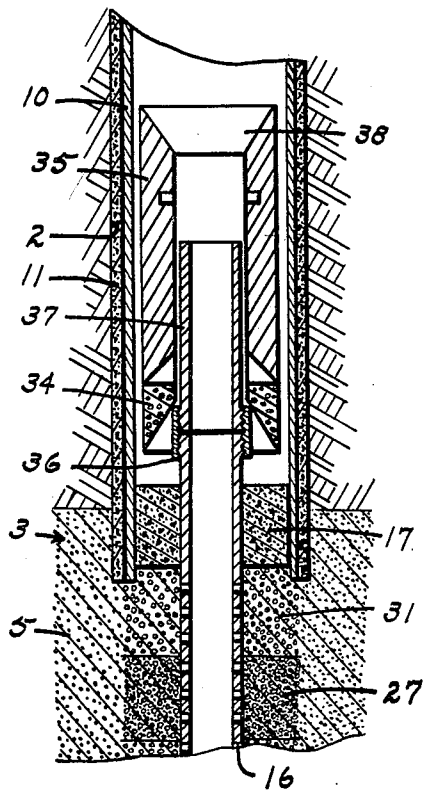


Fig. 3.

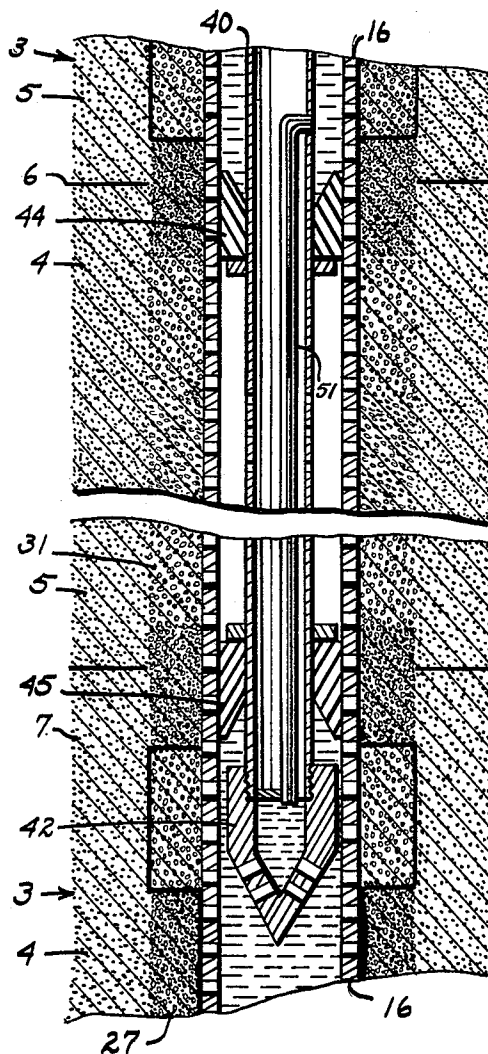


Fig. 2.

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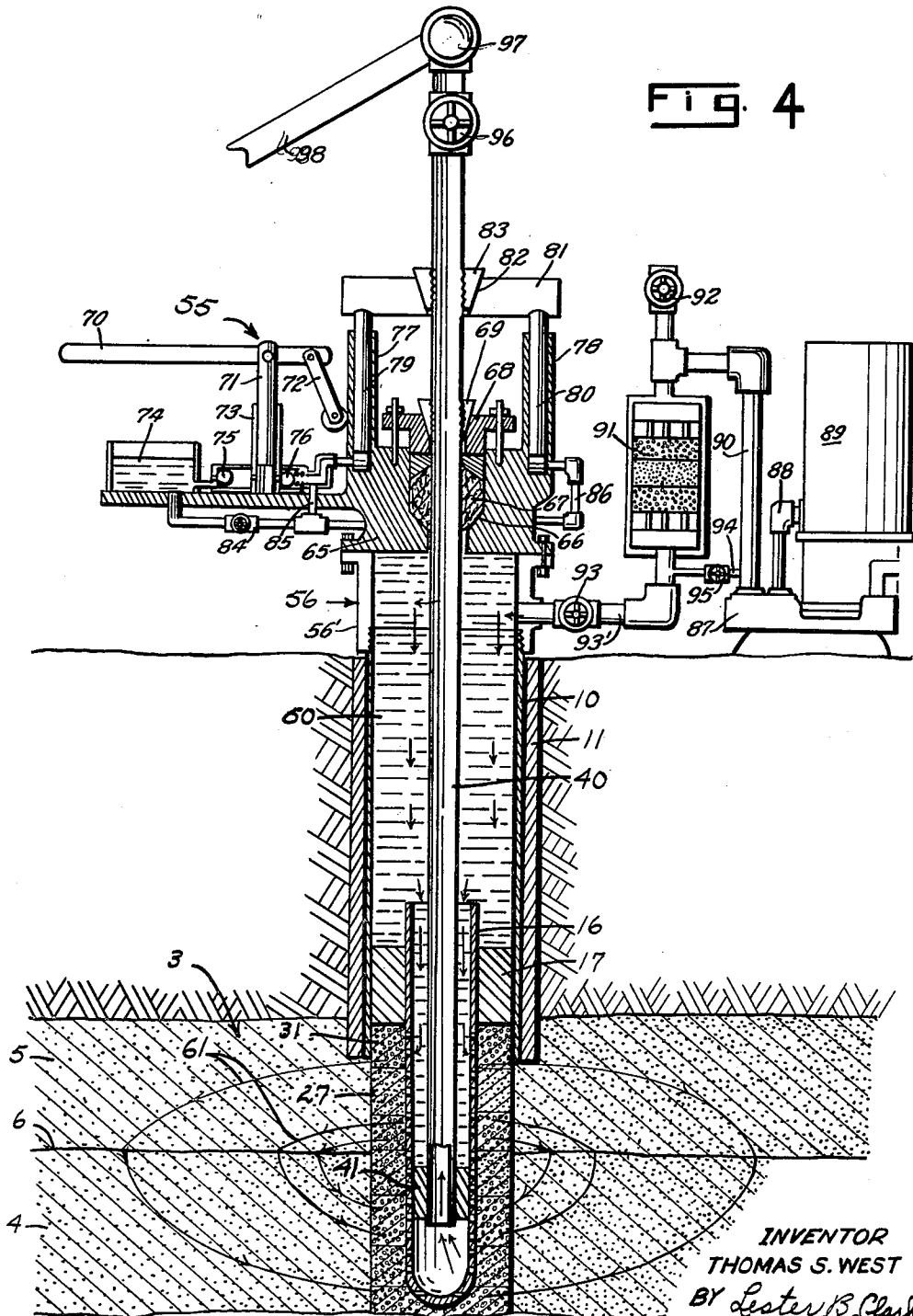
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Fig. 4



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UNITED STATES PATENT OFFICE

2,597,554

GRAVEL PACK COMPLETION METHOD

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Application May 15, 1947, Serial No. 748,217

9 Claims. (Cl. 166—26)

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This invention relates to means and method for segregating and selectively flowing the oil productive portion of a sand from other fluid productive zones encountered in a well and this application presenting such invention comprises a continuation-in-part of my prior copending application, Serial Number 623,989, filed October 23, 1945, for Well Completion.

Frequently the condition is encountered in oil wells in which gas occurs in the top portion of a given permeable formation penetrated by a well bore, this gas zone being immediately underlaid by an oil productive formation which is in turn underlaid by a water productive formation. In such cases an excessive amount of gas, water or both may be produced with the oil.

Rigid cementing materials such as Portland cement or plastics are ordinarily employed in an effort to effectively seal the space between the usual casing and the wall of the well. Effort is then made to selectively expose the oil producing formation to the interior of the casing to obtain a flow of oil without gas or water by gun perforating, by setting the casing below the gas-oil contact, by various plug back procedures and the like.

Many cases are encountered in which a completion, resulting in low gas-oil or oil-water ratio, is obtained only after considerable expense, this expense in some cases exceeding the initial cost of the well. In other cases, a completion of a well having low gas-oil or low water-oil ratio has been found to be impossible by any method now known even though a substantial thickness of oil productive formation exists. Under such conditions only a very small fraction of the possibly recoverable oil is produced. Furthermore, this oil production is frequently accompanied by the waste of large volumes of gas. Increase in the cost of producing oil also results due to the abnormal reservoir pressure decline resulting from excessive gas or water production.

The exclusion of gas or water becomes increasingly difficult as the thickness of the oil saturated zone within the producing formation is decreased with the result that an oil zone which would be highly profitable if segregated from an adjacent water or gas productive zone may not be commercially productive because of the proximity of gas or water. A minimum critical distance from the gas-oil or oil-water contact, at which commercially profitable completion may be made, therefore exists. Since oil production is in most cases accompanied by a rising of the

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oil-water contact or a lowering of the gas-oil contact, the distance from the gas-oil or oil-water contact at which completion may be made determines the economic limit of oil production in most cases regardless of the initial thickness of the oil saturated zone.

Furthermore as depletion progresses in an initially thick oil zone it may be necessary to change the producing level from time to time as gas or water encroachment progresses. This procedure is usually expensive, several attempts at plug back or gas shut off frequently being required before an acceptable completion results.

The difficulty in excluding gas and water in the above type of completion is shown, by experience and various experimental studies, to be due almost entirely to one or more of the conditions now briefly outlined.

The mud filter, which is usually present on permeable formations between the cementing material and the wall of the well, and which results from the filtering out of solids contained in the drilling mud, may fail, as when the pressure gradient along the outer face of the cementing material exceeds some critical value the filter cake layer flows out leaving a channel for flow of gas or water to the oil zone from a higher or lower level or both.

Due to the eroding force of fluid, flow cavities or channels in the producing formation may result which may ultimately extend to the gas-oil or water-oil contact. This erosion may be considerably aggravated in the case of unconsolidated sands or if a relatively large difference in pressure is caused to exist between the gas or water zone and the oil zone by fluid production from the latter.

Failure of cementing materials such as that resulting from mud contamination of cement or plastic from agitation while cement is setting, etc.

Vertical coning may occur when the producing formation has effective vertical permeability. If the pressure in the oil zone is reduced sufficiently because of the rate of oil withdrawal, gas may flow downward or water upward through the producing formation regardless of the effectiveness of the segregation of the oil zone in the well space.

Consequently it is an object of this invention to provide means and method whereby the difficulties above indicated are avoided more effectively and more economically than possible with present practices.

Still another object of the invention is to make

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it unnecessary to have advance knowledge of the exact level of the gas-oil, oil-water, or gas-water contact. This eliminates the necessity of precise measurement of depth and of expensive coring and testing operations for accurately determining gas-oil and oil-water contacts.

As another object this invention further provides for easily and economically changing the level from which oil or gas production is secured at any desired time.

Still another object of this invention is to provide an inexpensive method for changing the level from which production is secured thereby greatly reducing the cost of completion and workover operations during the life of a well. The optimum producing level changes as depletion progresses due to water or gas encroachment and hence the invention contemplates means for maintaining the optimum producing level at all times during such depletion.

A further object of the invention is the provision of means for alternately producing individual oil or gas productive strata within a given zone. Oil or gas producing zones are frequently segregated into a series of approximately horizontal layers between which there is restricted fluid flow within the formation. Some of the layers may also have much higher horizontal permeability than others. This may result in a much more rapid gas or water invasion along some layers than others. Some of these layers may therefore be commercially oil productive long after the producing formation as a whole has reached the economic limit because of excessive water or, in some cases, gas production from the water or gas invaded layers within the zone. This invention provides a means for selectively producing oil productive layers occurring within a partially gas or water invaded zone. Likewise, either gas or water may be selectively produced if these fluids are desired.

As yet a further object the invention takes advantage of the finding that when water or gas invasion first reaches a well the boundary between the oil and water or gas has the form of a cusp or cone which has its point or vertex at the well. Excessive water or gas production at a given well therefore occurs long before the average position of the advancing water or gas front reaches the well. Tests which I have conducted on oil wells, after water or gas invasion has occurred, prove that discontinuing fluid production from the producing formation for a period of time results in material reduction of gas-oil or water-oil ratio when production of the well is resumed. This reduction in water or gas production presumably occurs because of the flattening out of the cone or cusp formed by the gas-oil or oil-water contact in the vicinity of the well resulting in an increase in distance from the well to such contacts. This flattening out of a cone is believed to result from the action of gravity because of the difference in density of gas, oil and water and because of the usual dip of the producing strata.

Also, as a further object this invention provides a means for alternately producing from different layers within a producing zone thereby permitting oil production from one zone while the water or gas cone is receding in a previously produced zone which has been water or gas invaded. Continuous oil production from a well is thereby secured, while at the same time fluid withdrawal is temporarily discontinued from some strata within the producing zone to allow

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recession of water or gas cones. Heretofore the shutting in of a well for a sufficient time to allow the recession of water or gas cones has not ordinarily been economically feasible since in that case no oil production would be secured from the well during the shut-in period.

The invention has as another object the utilization of alternate layers of material having different permeabilities or different filtering characteristics with reference to fluids having fine solid particles in suspension. These alternate layers are placed opposite the producing zone and surrounding a liner having openings which permit an inflow of fluid but which do not permit the entry of the material comprising the alternate layers.

As another object, this invention provides an embodiment which utilizes these alternate layers in combination with a producing string or tubing carrying a packer assembly which is seated inside of the liner and fluid as drilling mud containing fine solid particles in suspension for sealing off desired zones of the producing formation while producing from another portion of this formation. By use of a mixture of fluid constituents and solid particles as a fluid as mud having fine particles in suspension, of the proper size range in relation to the size of the pore spaces of the alternate layers, such a particle laden fluid may be obtained which will flow into the layers having the larger pore space but which will not flow into the layers having the smaller pore space or into the producing formation. If the pressure of this mud or fluid at the face of the producing formation exceeds that of the fluid contained in this formation, the entry into the well of water, oil or gas from the producing formation is positively prevented in the zones exposed to the mud as fluid containing solid particles. Furthermore, the fluid containing solid particles will not flow into the tubing because of the sealing action of the packer or packers and because it cannot flow through the producing formation nor the alternate layers having the smaller pore space.

As yet another object this invention provides an embodiment which comprehends plugging the surfaces of the alternate layers having the smaller pore spaces by fine solids filtered from the fluid containing solid particles, or the use of a relatively impermeable layer, whereby a flow of viscous fluid through the producing formation from one portion of the producing zone to the zone from which fluid is being withdrawn, is induced. This circulation of viscous fluid may be used for the control of vertical coning in the producing formation in addition to maintaining an effective seal in the bore hole space.

This invention also has as an object the provision of a number of means for forming the required alternate layers. For example, these layers may comprise alternate layers of porous cement or plastic having different effective pore space sizes or filtration characteristics. The preferred embodiment is however that in which the alternate layers are composed of granular material, the permeability or filtration characteristics of the layers being regulated by varying the particle size, or particle size range, of the granular material. Because of their relatively low cost and resistance to corrosion and chemical action, siliceous materials such as gravel, sand, silt, including particles in the colloidal range, have been found to be a preferable granular material. The use of layers of granular material has the ad-

vantage over rigid cementing material in that such layers are fluid in nature and therefore avoid the formation of open channels or cracks. Granular material also has the important advantage of permitting the selection of a particle size range which will effectively screen unconsolidated sand.

Other and further objects of the invention will be readily apparent when the following description is considered in connection with accompanying drawings, wherein—

Fig. 1 is a vertical sectional view of a portion of an earth formation, well bore and production equipment illustrating the arrangement of material about the perforate liner.

Fig. 2 is a vertical sectional view of the layers of material around the perforate liner, illustrating an adjustable tubing inside of the liner through which a flow from the formation may be had from a segregated portion of the producing formation while effectively sealing the bore hole space above or below the level being produced.

Fig. 3 is a vertical sectional view showing the layer materials surrounding the liner which illustrates the guide arrangement used for facilitating the entry of the packer assembly into the liner.

Fig. 4 is a vertical sectional view illustrating the embodiment whereby a viscous fluid circulation is induced through the producing formation for control of vertical coning. This figure also illustrates a mechanism for manually raising or lowering the tubing for altering the position of packers attached thereto.

In Fig. 1 a well bore 2 has been drilled into a producing formation such as 3. Formations of this nature frequently contain both gas and oil. In this case the lower portion 4 contains oil while the upper portion 5 contains gas.

The casing 10 has been set and cemented in the top of the producing formation 3, the cement being shown at 11. For the purposes of my invention the exact point at which casing has been set is not critical since the illustrated completion procedure may be applied to uncased wells. Likewise, the cementing of casing is not essential. It is usually preferable, however, to set and cement casing proximate the producing formation. It is also to be noted that the line 6—6 indicates the demarcation between the sands 4 and 5, although such line usually comprises a zone of limited thickness rather than a sharp line, as shown.

Before placing the illustrated alternate layers in the well in the manner hereinafter described, any mud filter cake present on the face of the producing formation is preferably removed provided this filter cake has not been formed of a substance which will flow through the alternate layers or which can be removed by subsequent treatment. The perforated liner or screen 16 is then lowered to the desired level opposite the producing formation 3. Relatively thin layers of granular material such as those shown at 31 and 27, are then deposited around the liner 16. These layers may be of any thickness but are usually from six inches to one foot thick.

This gravel may be deposited by any of various procedures, for instance, by means of a dump bailer in the manner shown in my prior copending application to which reference has above been made. With this procedure the top of the liner 16 is closed by a removable cap while placing the gravel to avoid entry of gravel, cement or other material, into the liner. The gravel is thus

dumped at the top of the casing and settles through the well fluid to the point of deposition around the liner. After placing the various layers of granular material, the seal 17 is provided to seal the well space surrounding liner 16 and above the uppermost layer. This seal may be any form of packer or other sealing agent but is preferably a mixture of a quick set cement and sand, the function of the sand being to bridge the pore spaces of the gravel to prevent the entry of cement.

In case of unconsolidated sands in the producing formation 3, the particle size of the gravel must be such as to prevent the infiltration of sand from the formation and into the gravel layers. The proper gravel size for screening a given sand may be determined experimentally. The selection of gravel on the basis of a screen analysis of the sand is also well known in the art, having been discussed in numerous publications such as AIME Technical Publication No. 2904 by Thomas S. West. After selection of gravel, the liner 16 is slotted with slots of such width as to prevent the entry of gravel of the selected particle size. Gravel of this size is used for the alternate layers such as 31 which have the greater permeability.

For providing layers of the lesser permeability or effective pore size such as 27, a mixture of sand and gravel is usually employed. The quantity of sand mixed with the gravel is preferably just sufficient to fill the pore spaces of the gravel. With this quantity of sand the possibility of settling of the mixed sand and gravel layers due to the flowing out of the sand is minimized. The purpose of this mixture is to provide a layer on which mud laden fluid will form a filter cake of lower permeability but which will not flow through the slots of liner 16. Such a layer of filter cake is illustrated by the heavy lines shown at 23 on the faces of the mixed sand and gravel layers.

The gravel content of the mixed layers such as 27 forms a bridge around the slots of the liner preventing the entry of sand content of the mixture. The sand content of this layer results the formation of a filter cake by any fluid containing solid particles of the proper size range. Mixed layers such as 27 may be adjusted to a permeability approximating that of the producing sand with the result that the rate of fluid production from the formation opposite this layer is reduced only slightly. If desired, however, the permeability of mixed layers may be reduced to any desired extent by use of a properly graded particle size material. For example, mixtures of gravel, sand, silt, bentonite and cup grease have been prepared which approximate zero permeability.

To prevent the separation of the particles comprising mixed layers such as 27 during the process of deposition because of the coarser particles settling at a greater rate than the fine ones, it is necessary to mix some kind of binding material with the gravel, sand, or other material. This binding material is preferably one which can be removed if desired after deposition. Bentonite, starches, gums, sugars and other gummy substances and greases have been satisfactorily used for this purpose. Pellets coated with a soluble material have also proved satisfactory. However, the preferable binder thus far employed has been found to be a lime soap base cup grease. This grease not only effectively prevents separation of sand and gravel when deposited in water, aqueous solutions, or water base mud but will also

flow out of the mixture under relatively low pressure gradient leaving a permeable layer. When used in low pressure wells it is preferable to use additional means for removal of grease or other binder. The various methods of removing paraffin from oil wells have been found satisfactory for this purpose. A preferred method of removal of grease is the dumping of the clean gravel layer such as 31 with the pore space of this gravel filled with carbon tetrachloride, or trichloroethylene. Since such a grease solvent has a greater density than water or usual drilling mud, it settles to bottom and is therefore more effective than light solvents which would rise.

After depositing the various alternate layers 27 and 31 and the material of the sealing layer 17, a centralizer 34 is lowered to move about and centralize the screen 16 before the material 17 sets. This centralizer is of a frangible material and is of a size to lodge and rest upon the collar 36 which interconnects the screen 16 and the upstanding pipe 37. After the cementing material 17 sets the frangible centralizer 34 may be broken by impact with dump bailer or other suitable tool readily and accurately determined. The guide 35 is then lowered about the pipe 37 and has a tapered surface 38 to cooperate with the tapered nose 42 to facilitate the entry of the pipe string or tubing 40 into the screen 16. The nose 42 has openings 43 to admit fluids to the interior of the string 40.

Packer assembly 41 is attached to the lower end of tubing 40, this packer being of a type suitable for sealing the space between tubing 40 and liner 16. The length of the packer 41 is preferably greater than the height of the thickest of the clean gravel layers 31, otherwise a seal will not result if the packer 41 is positioned opposite of the layers 31. A series of cup or lip type packers have been found satisfactory for packer assembly 41.

The packer 41 is next positioned above the liner 16 by the raising of the tubing 40 by a lifting means at the top of the well and the well is filled with a drilling mud type of fluid 50. Packer 41 is then placed at the desired level inside of the liner 16. The drilling mud contained in the tubing 40 is then removed such as by swabbing to permit flow of formation fluid from sand 3. By the use of drilling mud of the proper density a hydrostatic head at the level of the sand exceeding the formation pressure may be secured. The mud fluid employed contains a range of solid particles of such size as to flow into clean gravel layers 31, but which form a relatively thin filter cake 32 and 33 of low permeability on the face of sand 3 and on the surfaces of the mixed sand and gravel layers 27, respectively, at all levels above the packer 41. Obviously, fluid flow from the sand 3 is physically impossible at points above the level of the mixed layer 27 opposite the packer 41. Perfect sealing action is therefore secured in the well space, a result which cannot be accomplished in many cases with present completion practices. No portion of sand 3 is, however, permanently sealed off by this procedure since by the simple expedient of raising the tubing 40, sealing by the packer 41 occurs opposite another mixed layer 27 resulting in fluid production and flowing out of the filter cake on the face of the sand in the clean gravel layers previously above packer 41. A simple means of regulating the producing level is thus secured. By raising or lowering the tubing to which packer 41 is attached such as by

an appropriate hand operated jack 55 in combination with a suitable well head 56 as shown by Fig. 4, the producing level may be changed quite easily with the result that fluid production may be secured from the optimum level at all times.

Such a well head 56 may have supported above the head 56' the tubing block 65 which has the opening 66 therein through which passes the tubing 40, the packing 67 being provided within the opening 66 to be held down and around the tubing by the gland 68. The slips 69, within the gland, grasp the tubing but permit it to move vertically therethrough.

The jack 55 comprises the handle 70 pivotal on the piston 71 and connected by the link 72 to the block 65. The vertical movement of the piston 71 in the cylinder 73 transfers fluid from the reservoir 74, through the valves 75 and 76 to the lower portions of the cylinders 77 and 78 which extend upwardly from the block 65. The pistons 79 and 80 within the cylinders 77 and 78 respectively, support the frame 81 thereabove which has the opening 82 therein to receive the tubing 40 therethrough and to receive and support the slips 83 which grasp the tubing to lift it as the frame is moved upwardly by the operation of the jack 55. To lower the tubing the valve 84 is opened to permit the fluid to pass back from beneath the pistons 79 and 80, through the lines 85 and 86, to the reservoir 74.

If excessive gas or water is found to be produced with the oil, or other undesired production occurs, because of vertical coning in the producing formation surrounding the well, it becomes desirable to use a sealing or flow retarding substance which actually flows into the pore spaces of the sand. Because of the difficulty of controlling fluid flow outside of the well bore it is also desirable that permanent plugging of the formation does not result.

The control of vertical coning by inducing a flow of viscous fluid through sand 3 may be secured by replacing mud fluid 50 (Fig. 1) by oil, oil-water emulsion, or other viscous fluid 60 more related to the formation fluid than to the drilling or circulating mud (Fig. 4), the general direction of flow of such viscous fluid being the path generally shown at 61. By first raising packer 41 to produce fluid from the entire producing section the filter cake on the face of the producing formation may be removed without removing the filter cake 33 on the horizontal surface of layers 27. Vertical flow does not therefore result through layers 27. Oil or other viscous fluid is supplied to sand 3 through the clean layers 31, above the point of shut off of the packer 41. A viscous fluid saturation may thus be maintained in the portion of the sand section in which vertical coning would normally occur, namely, the gas sand 5 or the water sand 7, where it exists, as shown in Fig. 2.

The induction of the viscous fluid may be accomplished as shown in Fig. 4. The pump 87 takes suction at 88 from the viscous fluid reservoir 89 and discharges it at 90 to the filter 91 below the starting valve 92. The opening of the valve 93 in the line 93' permits the viscous fluid to enter the head 56' and the well bore. The bypass line 94, when the valve 95 is opened, permits direct discharge of the viscous fluid therethrough to the line 93'.

The return of the viscous fluid follows the path of the tubing past the open valve 96 and

through the swivel 97 and hose 98 to a convenient basin, or directly to the reservoir 89.

Because a fluid having a viscosity many hundreds of times greater than that of gas or water may be used, the volume of viscous fluid which would be circulated through the sand above the packer 41 to the space below this packer is very much less than the volume of gas or water which would enter by coning or which would normally be produced from these zones. Obviously, of course, the viscous fluid saturation may be provided to prevent coning of undesired fluids in a gas well.

In cases in which it is desired to exclude water production from the lower portion 7 of sand 3, the procedure of Fig. 2 is employed.

Fig. 2 shows a modified arrangement for shutting off water which may be produced from the lower portion 7 of sand 3 or for simultaneously shutting off both water and gas. Tubing 40 carries two spaced apart packers 44 and 45, so constructed as to isolate and secure fluid production from the space between them while at the same time maintaining a seal against flow from the producing formation above and below this space. By-pass 51 is provided for permitting the flow of drilling mud or viscous fluid from the space above the upper packer 44 to the space below lower packer 45. Obviously the drilling mud will flow out into the clean gravel layers and form a filter cake on the face of the producing formation and on the outer surfaces of the mixed sand and gravel layers 27 as described in connection with Fig. 1.

Since the hydrostatic head of the mud at this level may be regulated by varying the density of the mud, a pressure exceeding that of the fluid contained in the sand may be obtained. Under such condition the entry of water or any other fluid from the producing formation into the well space in this zone is physically impossible. By raising or lowering the tubing 40, the zone produced may be altered, thus providing a means of selectively producing from any desired level in the producing formation. Also by altering the spacing between packers 44 and 45 any desired thickness of producing formation may be included in the segregated zone, the minimum possible thickness being determined by the thickness of the alternate layers. As in the case of gas exclusion it is desirable to use a mud or other fluid containing solid particles of such size range as to produce a very thin filter cake 32, 33 of low permeability which will readily flow out of clean gravel layers 31, under low pressure gradient if it is subsequently desired to produce fluid from this zone.

By replacing the drilling mud with a viscous fluid, and back flowing to remove the filter cake 32 from the face of the producing formation, a circulation of viscous fluid may be induced to prevent vertical coning of water or water and gas in a manner similar to that shown by Fig. 4 for the prevention of gas coning.

Obviously in some cases satisfactory results may be obtained with the procedure shown by Figs. 1 and 2 without the use of either a viscous fluid or a fluid containing solid particles. This will be particularly true if mixed layers 27 are of low permeability. In this case fluid flow into the space between the casing 10 and tubing 40 would occur from the producing zone above the packer 41 in Fig. 1 or from the space above packer 44 and packer 45 in Fig. 2 only until this space is filled. After the space between 10 and

40 is filled, all fluid produced will enter the tubing 40. The level from which production is secured can also be regulated by raising and lowering the tubing so as to change the position of the packer or packers in liner 16.

Most broadly, this invention considers a well completion method in which a perforated pipe is positioned in a well bore at the level of a producing formation, and alternate horizontal layers of granular materials having paths of fluid flow of different sizes in the alternate layers are deposited around the perforated pipe in superimposed relation.

This invention also broadly considers inserting a production string of pipe into the perforated tubing adapted to segregate a desired vertical interval of the perforated pipe, and introducing into the non-segregated portion of the perforated pipe a mixture of liquid constituents and solid particles which will flow through one of the alternate layers and not through the other and form a filter cake upon the borders of the mixture externally of the pipe interior, thereby diverting the flow of formation fluid into the segregated interval and into the production string.

Also, this invention broadly considers injecting a viscous fluid into the well bore and through the layers to circulate into the formation adjacent the perforated pipe and back through the segregated interval to the production string, thereby eliminating coning from the area of such formation circulation, while producing formation fluids.

The invention claimed is:

1. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and an adjacent perforate screening section of a screen member for screening said producing formation, the improvement which comprises arranging said filter pack in the form of alternate, superimposed and substantially horizontally disposed layers of granular material extending between the bore wall of the producing formation and the perforate screening section, each layer having a multiplicity of inter-granular flow passages of an effective size determined by the size and shape of the component granules, the flow passages of one of the alternate layers of granular material being effectively larger than the flow passages of the next adjacent layer and larger than the effective flow passages of the adjacent producing formation.

2. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and the perforate screening section of a screen member for screening said producing formation, the improvement which comprises arranging said filter pack in the form of alternate, superimposed and substantially horizontally disposed layers of granular material extending between the bore wall of the producing formation and the perforate screening section, each layer having a multiplicity of inter-granular flow passages, the flow passages of one of the alternate layers of granular material being effectively larger than the flow passages of the next adjacent layer and of the effective flow passages of the adjacent producing formation by an amount such that a drilling mud having a particle size range permitting it to flow through said layer having the larger flow passages will not substantially penetrate said next adjacent

layer or flow into said adjacent producing formation.

3. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and the perforate screening section of a screen member for screening said producing formation, the improvement which consists in providing first and second pack-forming layer means of granular material of sizes and shapes as to provide desired formation-screening action and to form a multiplicity of inter-granular flow passages therethrough, the effective size of the flow passages of the first layer means when arranged in layer formation in the well being greater than that of the second layer-forming means when similarly arranged in layer formation in the well and of the effective flow passages of the adjacent producing formation whereby a suspension of solid particles in fluid having a particle size range as to be flowable through the first layer means will not substantially penetrate into the second layer means or into the adjacent producing formation, and depositing said layer means alternately in the bore so as to form superimposed, substantially horizontally disposed layers extending between the bore wall of the producing section and the perforate screening section.

4. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and the perforate screening section of an adjacent screen member for screening said producing formation and which is associated with a production string of tubing extending into said perforate screening section for conducting the fluid to the surface from the interior of the screen member, the improvement which comprises the steps of arranging said filter pack in the form of alternate, superimposed and substantially horizontally disposed layers of granular material extending between the bore wall of the producing formation and the perforate screening section, each layer having a multiplicity of inter-granular flow passages of a size determined by the size and shape of the component granules, the flow passages of one of the alternate layers of granular material being effectively larger than the flow passages of the adjacent layers of granular material and of the effective flow passages of the adjacent producing formation, providing in the well annulus exterior to the tubing string a mixture of fluid with solid particles of a size range which permits said mixture when subjected to fluid pressure to flow through an alternate layer having the larger flow passages but which precludes said mixture from flowing into the layer next adjacent thereto or into the adjacent producing formation, and providing seal means between the perforated screening section of the screen member and the tubing string effective to close off a predetermined vertical interval of said screen section from at least one other vertical interval thereof in fluid communication with said annulus, while maintaining fluid communication between the interior of said closed-off interval and said tubing string.

5. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and the perforate screening section of an adjacent screen member for screening said producing formation and which is associated

with a producing string of tubing extending into said perforate screening section for conducting the fluid to the surface from the interior of the screen member, the improvement which comprises the steps of arranging said filter pack in the form of alternate, superimposed and substantially horizontally disposed layers of granular material extending between the bore wall of the producing formation and the perforate screening section, each layer having a multiplicity of inter-granular flow passages of a size determined by the size and shape of the component granules, the flow passages of one of the alternate layers of granular material being effectively larger than the flow passages of the adjacent layers of granular material and of the effective flow passages of the adjacent producing formation, providing in the well annulus exterior to the tubing string a mixture of fluid with solid particles of a size range which permits said mixture when subjected to fluid pressure to flow through an alternate layer having the larger flow passages but which precludes said mixture from flowing into the layer next adjacent thereto or into the adjacent producing formation, and providing seal means between the perforate screening section of the screen member and the tubing string at a level of the screening section intermediate the vertical length of said screening section, while maintaining fluid communication between the interior of the screen member below said seal means and said tubing string.

6. In a method of well completion employing a filter pack of granular material disposed in the annular space between the producing formation and the perforate screening section of an adjacent screen member for screening said producing formation and which is associated with a producing string of tubing extending into said perforate screening section for conducting the fluid to the surface from the interior of the screen member, the improvement which comprises the steps of arranging said filter pack in the form of alternate, superimposed and substantially horizontally disposed layers of granular material extending between the bore wall of the producing formation and the perforate screening section, each layer having a multiplicity of inter-granular flow passages of a size determined by the size and shape of the component granules, the flow passages of one of the alternate layers of granular material being effectively larger than the flow passages of the adjacent layers of granular material and of the effective flow passages of the adjacent producing formation, providing in the well annulus exterior to the tubing string a mixture of fluid with solid particles of a size range which permits said mixture when subjected to fluid pressure to flow through an alternate layer having the larger flow passages but which precludes said mixture from flowing into the layer next adjacent thereto or into the adjacent producing formation, providing a plurality of spaced seal means between the screen member and the tubing string effective to seal off a predetermined vertical interval of the perforate screening section of said screen member from said annulus, while maintaining fluid communication between the interior of said sealed-off interval and said tubing string, and providing a fluid passage through said sealed-off vertical interval for permitting flow of said mixture of fluid with solid particles between said annulus and the interior of the screen member below said sealed-off vertical interval.

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7. The method of well completion as set forth in claim 4, and the further step of subjecting said mixture of fluid with solid particles to a pressure exceeding the fluid pressure in the producing formation, thereby causing said mixture to invade such of the layers having the larger flow passages as are disposed immediately adjacent said other interval of the perforate screening section.

8. The method of well completion as set forth in claim 5, and the further step of subjecting said mixture of fluid with solid particles to a pressure exceeding the fluid pressure in the producing formation, thereby causing said mixture to invade such of the layers having the larger flow passages as are disposed immediately adjacent said screening section above the level of the seal means.

9. The method of well completion as set forth in claim 6, and the further step of subjecting said mixtures of fluid with solid particles to a pressure exceeding the fluid pressure in the pro-

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ducing formation, thereby causing said mixture to invade such of the layers having the larger flow passages as are disposed immediately adjacent said screening section and at levels other than those included in said sealed-off vertical interval of said screening section.

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