Oct. 14, 1941. **J. F. KENDRICK** **2,258,614**

METHOD OF TREATING AND PRODUCING OIL-WATER WELLS

Filed Feb. 28, 1938 2 Sheets-Sheet 1

Fig. 1.

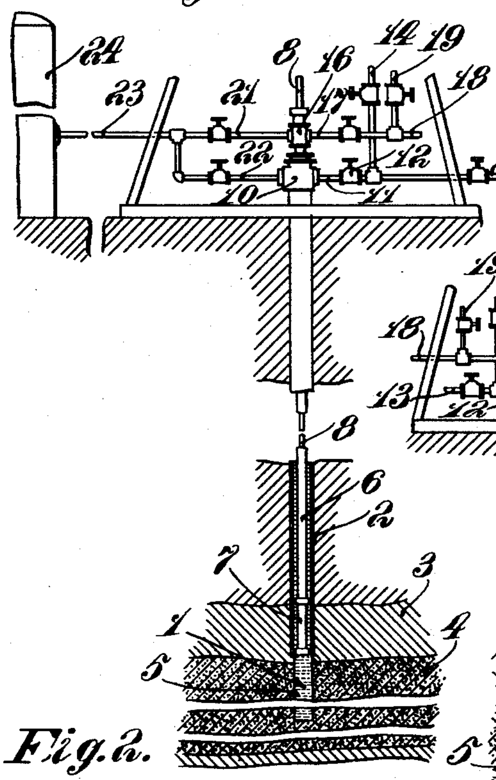


Fig. 3.

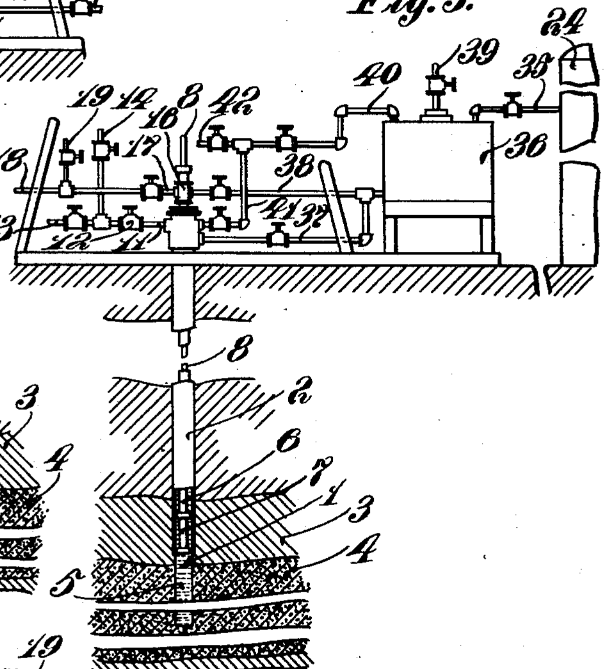
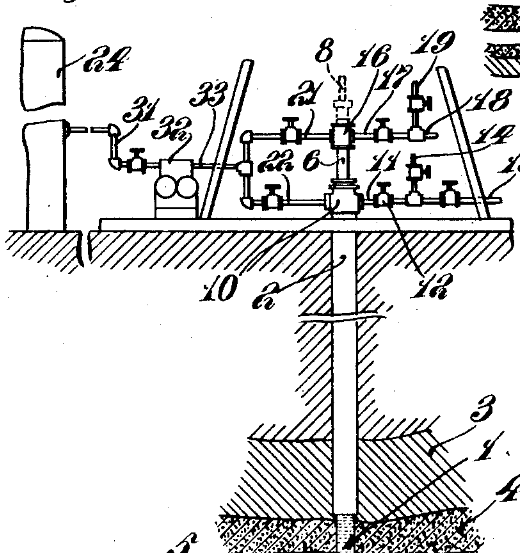


Fig. 2.



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METHOD OF TREATING AND PRODUCING OIL-WATER WELLS

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Fig. 4.

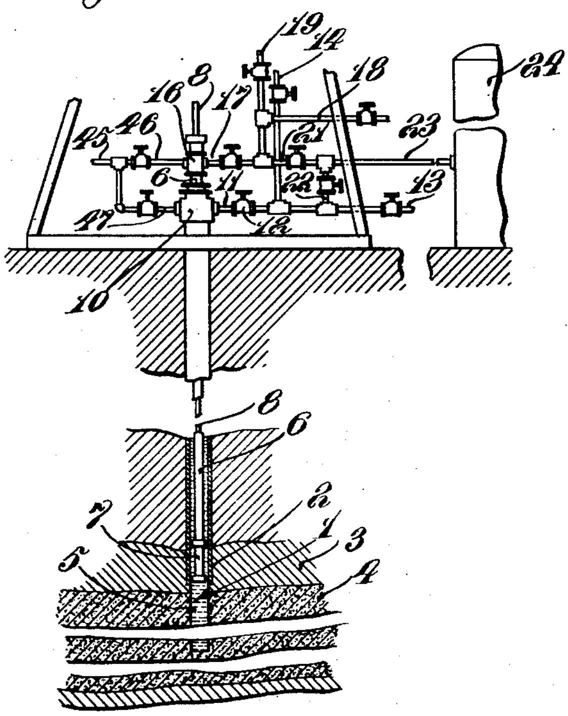
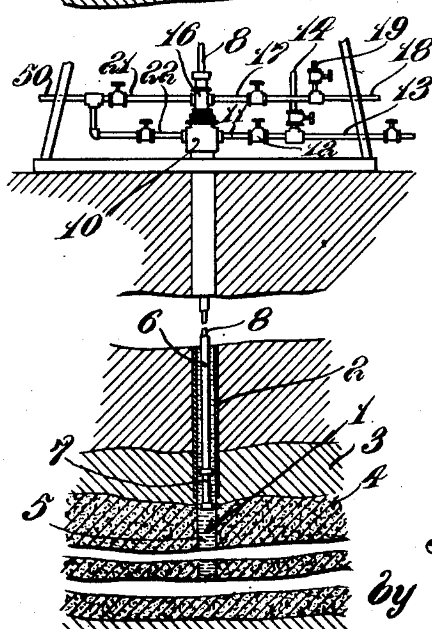


Fig. 5.



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UNITED STATES PATENT OFFICE

2,258,614

METHOD OF TREATING AND PRODUCING OIL-WATER WELLS

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Application February 28, 1938, Serial No. 193,160

32 Claims. (Cl. 166—21)

This invention relates to the treatment and producing of oil wells, and more particularly to improved methods for the treatment and producing of so-called oil-water wells for the purpose of increasing the proportion of oil in the liquid produced therefrom.

In many oil fields the producing formation is permeated, prior to commencement of production, in its lower portions by water which is under pressure. Under such conditions, water usually ultimately appears in the well discharge, and the quantity of water usually increases with continued production, until ultimately the wells may be producing large quantities of liquid of which but a small percentage may be oil. The total quantity of fluid produced is, most frequently, determined by the capacity of the available pumping equipment; and increases in rate of operation, or even in capacity, of pumping equipment commonly do not increase materially the ratio of oil to water. It is to such wells that the present invention has, it is believed, its maximum applicability, but it is to be understood that when an artificial water drive is applied to a gas-drive field, there may develop conditions so analogous to those above mentioned as to provide opportunity for a most beneficial application of this invention in one or another of its modifications.

It should be further borne in mind that there may be other conditions under which the disadvantages of having the oil produced attended by serious quantities of water may be overcome by the use of the present invention.

Many different modes of procedure, designed to shut off the water in an oil sand, or to retard or prevent its incursion into an oil well, have been proposed.

The industry is coming to regard the oil produced from a water drive field as being forced out by a liquid piston, and determined efforts are being made to maintain the drive at a uniform pressure. This is taking the form of trying to limit the rate of withdrawal, as nearly as possible, to the rate at which the water advances, and in this way keep the reservoir pressure as high as possible. The different characteristics of the oil sands in different parts of the field make it necessary to regulate the production from different wells so as to maintain as nearly as possible a uniform back pressure on the oil sands. This is attempted in various ways, such as "pinching" or "beaning" a flowing well; or slowing up the sucker rod pump, when one is used, by reducing the strokes per minute and/or length of strokes, or by using a smaller plunger; or lessening the capacity of the gas-lift, where one is used, by reducing the size of the tubing, "pinching" or "beaning" the discharge, or reducing the volume of the gas circulated for pumping. Could such measures succeed in maintaining the reservoir pressure equal to the ultimate pressure of the water drive, the seriousness of the water problem would be reduced greatly, but, among other factors, the lack of uniformity of the different wells makes it impracticable to achieve such an ideal in practice. A reduction of but 100 lbs. per sq. in. in the reservoir pressure or locally in the formation surrounding a well is roughly equivalent to a head of about 210 feet of the average oil field brine, which is enough to flood a great many wells. Therefore, while such methods may serve to retard the encroachment of water, in time a serious water problem nevertheless faces the operators in the field. And experience has shown that regulating the rate of withdrawal, by throttling, or pinching, or by lowered capacity of the mechanical pump, or by operating the gas lift under back pressure (which is essentially a throttling process) has little or no beneficial effect generally after the water has passed a relatively small percentage.

Thereafter, a variety of expedients designed to cope with the water problem are in use. Once the well is flooded, many operators increase the liquid production of the well, either by speeding up the pumping equipment as much as possible or by installing pumping equipment of larger capacity. Here the objective is the reverse of that practiced before water came in, as it is now desired to reduce the back pressure on the sand as much as possible. Generally, the oil-water ratio remains unchanged, as the production is increased, until the back-pressure is reduced materially, which may be indicated by a slight increase in the percentage of the oil produced. While this procedure increases the amount of oil produced, the production costs are likewise increased, and frequently the cost per barrel of oil is greater than before the production rate was speeded up.

On account of the higher costs of trying to pump down an oil-water well many operators prefer to try to plug off the water with cement. If injected into the formation, the cement follows the path of least resistance, and not infrequently an imperfect seal results, which may be soon washed out or channeled around. Also there is a possibility that considerable oil may be trapped and lost behind the cement plug, where it is successfully applied. In order to overcome the danger of cement's plugging the oil channels, certain substitute processes have been developed, using substances that are soluble in oil but not in water. These are used in much the same way as cement, are subject to much the same limitations, and should they plug the oil channels, their dissolution is apt to be slow on account of insufficient circulation of the solvent.

Other processes have been developed, using chemicals designed to render the sands less permeable to the flow of water, while maintaining or increasing the permeability to the flow of oil. Again the substance will follow the path of least resistance, upon injection into the formation, will have but slight effect on the larger channels, and will achieve but slight penetration in the small channels. Even when conditions are favorable to the process, the effects may be of short duration, due to the removal of the grain coating by erosion and other causes.

While all these expedients have been used with limited success under special conditions, the results to be expected are always speculative, the application involves risk of permanently impairing the productive capacity of the well, and production costs are generally decreased only temporarily. By contrast, the application of my invention hereinafter described and claimed, does not entail the risk of permanently impairing the productive capacity of the well, and the production of the well is automatically restricted so as to promote a relatively uniform advance of underlying water and approach the ideal of a liquid piston pushing the oil from the reservoir. As a result, the salt water disposal problem is kept within limits that can be handled economically relative to production costs and natural drainage pollution. At the same time the range of pump capacity required throughout the life of the field is narrowed, making it possible to do the entire pumping job with lighter pumping equipment, involving a smaller capital investment. As the pumping load more nearly follows the natural decline of the field, service and maintenance expense is reduced due to the slower pumping speeds and the better lubrication of the pump parts. The gas produced will more nearly equal, or will equal, the power requirements on account of the reduction in the total fluid pumped and the increase in the amount of oil pumped. In fields where the encroachment of water is very rapid, the application of the process will make it possible to recover any oil that may be trapped in the reservoir by the water, and which might otherwise be lost.

Whatever may be the cause of the increasing percentage of water which is so widely encountered, and which results in increased expense, legal difficulties, the loss of much oil, and the plugging or abandonment of many wells, certain observations seem to be sound, and these are advanced for what they may be worth, though it is to be understood that the theories herein advanced are tentative only, and that the invention is not dependent upon their soundness. It is believed to be generally regarded as true that a given sand will offer a greater resistance to the flow of oil than to the flow of water. It is believed that once a given body of sand is wet with water, it will not again be permeable freely to oil until the water has been displaced. It is believed that a well which, when shut in, has a column of water standing therein, in communication at its base—or elsewhere—with a relatively unlimited quantity of water under considerable pressure, will not generally, by mere gravitational restratification, within any reasonable period, reassume any condition such that a mere resumption of production will result in a permanently increased oil-water ratio. It is believed that when a well has so far gone to water that upon stratification of the liquid column which will stand therein when production is interrupted, there will be a water column in the well to a height above the top of the producing formation, improved oil production will rarely, if ever, result from shutting in the well, at least not within any commercially practicable time. On the other hand, if the water be driven by a fluid of lower specific gravity at least to a position below the top of the producing formation, conditions suited to a freeing of water-sealed oil-flow channels become available. Then subjection of the formation to a suitable back pressure, and production at a rate correlated to the back pressure needed, will enable a great improvement in the percentage of oil in the total quantity of liquid produced. Under some conditions, depending upon the nature of the formation and the nature and quantity of the lighter fluid used, resumption at a carefully controlled rate, of production under a carefully regulated back pressure may be possible soon after the completion of the driving down of the water. On the other hand, under other conditions, a definite period of shutting in of the well, followed by a substantial period of very low-rate production under correlated back pressure, may need to precede any approach to the former oil-production rate, in order to obtain best results.

According to the present invention, from a major aspect, a well is thus treated so as to restore, to availability for oil delivery, portions of the formation adjacent the well which have become water-sealed, as it were, and upon the renewal of production, conditions are established and maintained to preclude or at least delay renewed water ingress in objectionable quantities. This is not, however, to be understood to exclude the possibility of a deliberate reproduction of water ingress conditions, for the purpose of gauging quickly the conditions necessary to be maintained to provide maximum oil production with water suppression as herein described.

It is an object of my invention to provide an improved method of treating and producing oil-water wells. It is another object of my invention to provide an improved method of treating oil-producing formations. It is still another object of my invention to provide an improved method of treating the wells of a gas-drive field. It is a further object of my invention to provide an improved method of treating and producing oil-water wells, utilizing a fluid of lighter specific gravity than the water for forcing down the well the water in the latter, and thereafter producing the well under correlated conditions of back pressure and production rate. It is still a further object of my invention to provide an improved method of treating and producing oil-water wells according to which such wells are subjected to an improved treatment for promoting a restratification in the producing formation. It is yet another object of my invention to provide an improved method of treating and producing oil-water wells utilizing a liquid of lighter specific gravity than the water of the well for forcing down the well the water in the latter and thereafter effecting and maintaining a restratification of the fluids in the producing formation. It is another object of my invention to provide an improved method of treating and producing oil-water wells utilizing gaseous pressure and a suitable liquid cap for forcing down the well the water therein, and subsequently creating and maintaining a restratification of the fluids in the producing formation. Still another object of the invention is to provide an improved method of treating and producing oil-water wells utilizing a gaseous pressure to force down the well the water therein, and subsequently treating said well to effect and to maintain during subsequent production a restratification of the fluids in the producing formation. Another object of the invention is to provide an improved method of establishing a back pressure in an oil-water well, and producing the well under the back pressure so provided. It is, again, an object of my invention to provide an improved method of treating and producing oil-water wells where the quantity of water that must be handled with ordinary production methods is very large. It is another object of my invention to provide an improved method of treating oil-water wells having a relatively high formation pressure in relation to their depth, enabling them to resume production by natural flow. It is a still further object of my invention to provide an improved method of treating and producing oil-water wells including the step of forcing down the well, with a column of lighter liquid, the water in the well and comprising an improved method of effecting the introduction of the liquid column so utilized. Other objects and advantages of the invention will hereinafter more specifically appear. Improved apparatus for carrying into effect the foregoing objects and facilitating the performance of the methods herein disclosed and claimed is shown and described both in this present application and in my copending application Serial No. 193,161, filed of even date herewith; and is claimed in said other application.

Specific steps which may be effective in the broad procedure hereinabove mentioned may now be considered severally.

It will be apparent from what has already been described that an actual forcing of the water which may be standing in the well downwardly until its uppermost portion is at least below the top of the producing formation is necessary. This may be accomplished in divers ways. Liquids, gaseous fluids, or a liquid and a gaseous fluid jointly, may be used. A preferred method is to introduce a quantity of ordinary crude oil into the casing, selecting the quantity according to the circumstances, but where crude oil alone is utilized as the means for effecting the desired forcing, utilizing a quantity sufficient to insure a bringing of the lowermost end of the oil column in the well at least somewhat below the uppermost point of communication of the formation with the well bore. A quantity which, when confined in a column of a cross section equal to that of the casing, will exert a force equal to or somewhat in excess of the bottom hole pressure, will be a rational one to start with in a field where conditions are relatively unknown, though such an amount may be unnecessary if there is a substantial oil cap already at the top of the liquid in the casing, or inadequate, for example, if the water-producing conditions have been of long standing.

Again, it is possible to introduce only a cap of oil and to force it down with superimposed gaseous pressure.

The oil may be introduced when the well is not under material casing-head pressure, or forced by a suitable pump into the well while there is a substantial gaseous pressure in the latter. In like manner, oil in desired quantity may be introduced into a suitable vessel at the top of the well, and by equalizing the pressure in the top of such vessel with the pressure in the casing, the oil may be caused to enter the well by gravity flow and be forced down by the gaseous pressure in such a manner as is necessary. Gaseous pressures from within the formation which the well penetrates, or gaseous pressures from other higher-pressure oil or gas wells may be used for forcing down the liquid in the casing. Gaseous pressures, produced by compression of casing head gases or other suitable gaseous media, may also be employed. Mechanical pumping may be resorted to to force the liquid into the well when a column of crude oil equal in weight to the column of oil and water in the well would exceed in height the depth of the well or when required by the formation pressure. Other liquids than crude oil may be used, natural or artificial, and under special conditions, as when it is desired to clean the formation or change the characteristics of the water to assist in restoring the channels to oil delivery, suitable special fluids may be utilized, singly or in combination.

Under some conditions gaseous pressure alone may be introduced; as for example when the column in the well includes, as above suggested, a cap of oil of substantial volume, but generally, though not necessarily exclusively, it is believed that when it is thought that there is no (or an inadequate) cap of oil already in the well it will be best to introduce, prior to the application of gaseous pressure, oil or other suitable liquid sufficient in quantity at least to start the restratification hereinafter considered. It is believed, however, that under some conditions, by introducing a sufficient quantity of gaseous fluid completely to displace all the liquid above the top of the formation, and then very gradually lowering the gaseous pressure at a rate to keep step with the inflow of oil from the formation and maintain a cumulative back pressure only slightly below the formation pressure, it will be possible thereby to accumulate the necessary oil quantity for effective processing. It is also within the contemplation of my invention to proceed directly to the latter steps of the process, immediately after the completion of the displacement of the liquid by the gaseous pressure, when circumstances permit.

Introduction of the fluid for this first step of the general process through the casing, or through the tubing, or through both, is of course possible, and also introduction with the tubing withdrawn.

With reference to the selection of the agent or agents to be used in the step of forcing down the water, the decision will be affected very materially by the well conditions. For example, when the formation pressure is very high and the well is deep, the use of a liquid column will be a natural, though not an imperative, choice. So also, if the formation pressure is high enough to indicate, having in mind the depth of the well, a possibility of resumption of natural flow when the production is largely freed of water. When the formation pressure is low, a gaseous pressure, or a gaseous pressure with an extraneously introduced liquid cap, will in many cases be satisfactory. A gaseous pressure with an introduced liquid cap may of course be utilized under other conditions, provided there be economically available a gaseous pressure of the requisite height, or if there be introduced a cap of the needed vertical length. The particular choice may under some conditions be almost a matter of preference, and it will be found that virtually any conditions encountered will be met satisfactorily by at least one of the choices available.

After the water in the well has been forced down, it will be desirable, ordinarily, to apply a procedure which will promote a restratification of the liquids in the producing formation. For convenience we may employ the familiar term "cone" to simplify the discussion. If the present invention is applied to a well soon after it commences to make an objectionable amount of water, the "cone" may be relatively small, and the problem of effecting a restratification within the formation may be relatively simple. Indeed, in some cases, it may be unnecessary to provide, between the completion of the forcing down of the water and the commencement of production at a reduced rate, any distinct step for the purpose of promoting restratification. On the other hand, if the well has been pumped hard for a long time, the "cone" may be large and irregularly distributed throughout the area adjacent the well, and the restratification procedure may be more complex and require more extended application.

After the water has been forced from the well, and the fluid of lesser density has been brought into junction, so to speak, with at least the upper portion of the sands, restratification within the formation will start, but ordinarily resumption of production at a reduced rate will best be deferred for a time. One possible mode of procedure will be to keep the well shut in temporarily, and the minimum duration of this step will, in a field where the process is first being applied, be determined by the cut and try method. After the conditions of the field have been experimentally determined this step can of course be put upon a more definite basis. It will be unnecessary to keep the well shut in until restratification is complete, but ordinarily it will be sufficient, it is believed, if the well is shut in until some of the oil channels, particularly but not solely some of the upper ones, have been freed of water, thus increasing the flow area for the oil.

This shut-in condition will desirably be superseded by a period of pumping at a greatly reduced rate, in order that the oil passages may be freed the more readily of the water which blocks them to oil flow. It is believed that this pumping will aid the restratification, by causing the discharge into the well bore of the water in some of the oil passages, the gravity descent of at least the major part of this water in the bore to the level of the water in the well bore, and its return to the formation. Thus, the pumping rate will desirably be maintained at this time so low that at least the major part of the water displaced from the formation will not be discharged from the well, but will instead return to the sands. Leaving the fluids undisturbed by shutting in the well and then stimulating circulation by very slow pumping will effectively free the larger passages of water. The degree to which the smaller passages may be freed of water will depend on the pressure differential which is possible, or in some cases perhaps on the use of a liquid or gas that will mix with the water and reduce the capillary attraction so that a small difference in pressure will cause flow through the sands. This mode of effecting a circulation is of very great advantage when a liquid is introduced of such a character as to aid in the removal of water from structure whence the introduction of crude oil would not enable its material displacement. And it is to be understood that this mode of effecting such a slow circulation, especially when applied with a liquid of the character mentioned, constitutes as it were a sub-process capable of use advantageously, under some conditions, without the other steps herein described.

It will be evident that the quantity of fluid used in forcing down the liquid in the well, and the extent to which it is forced into the formation may exercise a marked effect on the later stages of the process. If a comparatively large quantity of fluid of lower specific gravity than the water be utilized, and this fluid be forced into the formation to such an extent that the, perhaps only slightly, water-permeated sands (in a case where the well is treated, for example, early) have their oil-flow channels largely cleared of water by the forcing down step described, the need for, or at least extended application of the second step, may be obviated. Such a possibility also exists in the case of a well making large quantities of liquid from a loose formation. Usually, it is believed, since the flow under pressures above the formation pressure will take the paths of least resistance, during the first step above described, the water in the well bore will be rather largely forced out, and threads of oil (or of the other fluid of lower specific gravity) will penetrate the water-filled portion of the sands as water is displaced from water-filled channels therein, but it should be mentioned that this hypothesis of the results of the process is not to be regarded as so related to the process that the later substantiation of a different theory, accounting for the end results obtained by the steps disclosed, would in any way derogate from the process itself. In conclusion, with respect to the present general disucssion of this second step, it should again be noted that there is as it were a correlation between it and the one designated the first step, and that the extent to which the first is carried markedly affects, or in some cases obviates, the second.

Following the at least initiated re-conditioning of the well, for a resumed production of oil, whether by the first, or by the successive use of both, of the steps which have been generally considered, the production of oil at a reduced rate and under conditions adapted to preclude a return of water in serious quantity to the well discharge is to be commenced. During the application of the previously described procedure it will be noted that the well may have been placed under a back pressure at first exceeding, and then substantially equal to, and then somewhat less than the formation pressure. During the forcing down of the liquid column initially in the well, the pressure imposed upon the formation will have been sufficient to effect a reverse flow relative to the face of the formation. When the well is shut in, the pressure upon the formation and the formation pressure will be approximately equal. During slow pumping, to effect circulation to promote restratification, the back pressure will be lower than the formation pressure. Upon resumption of production, the well is to be maintained under such a back pressure as will preclude a rapid return of water in serious quantity to the total liquid produced. When the well has been treated by the forcing into it of a substantial quantity of liquid lighter than the water therein, the liquid column, except as its height may be reduced by pumping, will stand high enough to counterbalance the formation pressure. The pumping will be maintained, both during any that may be done to promote restratification, and upon resumed production pumping, at such a rate as to prevent lowering the level in the well enough to permit serious water incursion. In other words, the pumping rate will be held so that the head on the well will act to limit or preclude renewed water ingress, and by correlating the rate of pumping to the rate of oil entrance to the well, the back pressure will be maintained at a value needed to hold the water in check.

When gaseous pressure has been utilized with a lighter-liquid cap in the first general step of the process, by maintaining the needed gaseous pressure the production of water from the well may be limited or precluded, and the pumping rate will be correlated to the potential rate of oil production, and to the cumulative gaseous and liquid back pressure, to hold back the water.

When, under special conditions, it is found possible to utilize gaseous pressure alone, and the gaseous pressure is employed to force all the liquid above the top of the formation back into the latter, then, by locating the pump with its inlet in oil and operating it at a rate substantially within the potential rate of oil production, the gaseous back pressure may be held such as to keep the water from returning seriously to the production of the well. Moreover, it will be evident that if gaseous pressure has been used as the means of effecting the forcing down of the water in the well, it will be possible, by gradual reduction (bleeding off) of the gaseous pressure at a rate not exceeding the rate at which oil can enter the well from the formation, when no oil is being produced from the well, or at a rate not exceeding the difference between the respective rates of entry of oil to the well and its production therefrom, during oil production, to cause a column of oil to rise in the well until a height adequate to maintain the necessary liquid-column back pressure on the formation is attained. In like manner where the forcing agency has been cumulatively gas and oil, a gradual reduction of the gaseous back pressure may cause a building up of a liquid column sufficient to provide per se the needed working back pressure. The rate of pumping, upon resumption of production pumping, will naturally be slow, and this will be gradually increased as this is found possible without causing water again to appear seriously. When the method is first applied in a given field, it may take some days, or even weeks, to attain to the maximum safe production rate. If desired, the rate may be increased more rapidly, with, of course, maintained rates of operation for material periods so that conditions may be fairly evaluated, until water again begins to appear, and the entire process may then be repeated, but with reestablishment of the maximum safe pumping rate found, as soon as possible, following upon the necessary degree of restratification in the formation. Under some circumstances, as where the conditions existing have been learned from experience with other nearby wells, resumption of production pumping at a slow rate and a gradual building up of the rate may be unnecessary, and production at a reasonably rapid rate may follow restratification promptly.

Throughout continued production, it will be evident that the rate of production and the maintained back pressure will be correlated to insure, ordinarily, a higher percentage of oil in the total fluid produced than prior to the processing of the well. Ordinarily the liquid produced will be largely, if not exclusively, oil, and the quantity of oil obtained may be the same, greater than, or possibly in some instances less than previously, but in any event the lowered production costs and the avoidance of or reduction in water disposition expense will, even in the last condition, make the employment of the process valuable.

It will be evident that in some cases, say when the formation pressure would be sufficient to effect the discharge of oil with a column mainly composed of oil in the well, but inadequate to effect liquid flow from the sands when a column of oil and water adequate to offset the formation pressure stands in the well, it may be possible wholly to dispense with pumping after the process is applied. And should the percentage of water become undesirably great after the well has been producing for an extended period after the conditions have once been rectified, a renewed reduction in the percentage of water through a repetition of such of the operations as may be required, will be possible.

With reference to the rates of pumping during the promotion of restratification, and the resumed production thereafter, it will be helpful to bear in mind that in a case where the well has been producing with a sucker rod pump, those changes in the pumping equipment necessary to meet the expected conditions will ordinarily be made before the application of the first step of the process is made. For example, if the well has been producing a very large quantity of liquid, with a relatively small percentage of oil, it may be desirable to install a smaller pump plunger, and at least arrangements will be made to shorten the strokes of the pump and to reduce its number of strokes so that when pumping to stimulate restratification is commenced, if this be needed, the pump discharge rate may be as low as a comparatively small percent of the prior production of oil alone, and when production pumping is resumed the pump discharge rate will in all probability for safety be for a time maintained materially less than the former delivery rate of oil alone. It will be obvious that changes directed to a reduction in the pumping rate will also be made when other types of pumping equipment are initially used, and are to be used further in producing the well.

When my invention is applied in conjunction with the application of an artificial water drive to a gas drive field, there may be produced, depending upon the mode of application of the artificial water drive, at least two different types of wells adapted for and needing the application of my invention thereto. The artificial water drive may produce water flooding of one of the wells utilized for oil production, as distinguished from introduction of the driving water, and that well will be a subject for the invention. Again, where the water is obtained from a lower formation by drilling some of the wells deeper, those wells may be caused, by the application of my invention, to play the dual function of producing wells and of flooding wells, respectively in their portions adjacent the uppermost and the lowermost parts of the producing formation. Thus, as is made clear by these illustrations, the term "oil-water well," which I am utilizing for purposes of simplicity, is to be understood not to be limited to oil wells in a natural water drive field which have "gone to water," but instead to include all wells to which my invention shall be applicable in dealing with the water problem; and this term is therefore not to be given a limited interpretation.

In the accompanying drawings, in which, to facilitate understanding, there are presented certain diagrammatic showings of arrangements which may be employed in different practices of my invention,

Fig. 1 is a diagrammatic view of equipment utilizable in the practice of my invention when a liquid is the forcing-down agent and the hydrostatic head of the liquid provides the required pressure.

Fig. 2 is a similar view showing diagrammatically equipment utilizable when a liquid is the forcing-down agent and a portion at least of such liquid must be forced into the well to drive down the water in the latter.

Fig. 3 is a view showing diagrammatically a system by means of which a liquid may be introduced by gravity flow, and cumulatively acting gaseous and hydrostatic pressures effect the forcing-down operation.

Fig. 4 is a diagrammatic view showing illustrative means by which modifications of my invention may be practiced which involve superimposing gaseous pressures on liquid caps introduced into the well.

Fig. 5 is a diagrammatic view designed to facilitate explanation of a gaseous-pressure-agent modification of my invention.

Referring to Fig. 1, a well 1 is shown having a casing 2 terminating in an impervious stratum 3 overlying the producing formation 4. The bore 5 of the well is shown extending for a substantial distance into the formation. Within the casing is a tubing 6 carrying at its lower end a pump 7 which may be of any suitable type and which is herein shown, for purposes of illustration, as of the sucker-rod-actuated type; and the sucker-rod line 8 extends upwardly through the tubing to a point at the surface, where it may be actuated by any suitable means, not shown. The casing head 10 is shown provided with a line 11 controlled by a valve 12 and having valve-controlled branches 13 and 14, respectively adapted to deliver the casing head gases to any desired point and to permit convenient venting of the casing head pressure if desired. The tubing 6, as shown, carries at its top a fitting 16 from which a valve-controlled line 17 leads off. The line 17 is shown branched, and the branch 18 may lead to a suitable treating system or any other desired point, while the branch 19 is valve-controlled and serves to permit venting of the tubing if desired.

Additional equipment to be used in the practice of my invention is provided, and this may be installed when the well is completed, when the ultimate application of my improved method of treating and producing a well is foreseen, or may be installed at old wells at the time the method is to be applied.

For the purpose of permitting the introduction of a fluid medium for driving down the liquid column in the casing, there is shown means by which such a liquid agent may be introduced into the tubing, into the casing, or into both. Introduction through the tubing presupposes a temporary removal of the pump, or some other arrangement to enable the discharge of the liquid agent through the tubing into the well. A valve-controlled line 21 leads to the top of the tubing. A valve-controlled line 22 leads to the casing head. A line 23 constitutes a common supply line for delivering the liquid agent to the connections 21 and 22. Herein, since in the specific practice of my invention which I propose now to describe, the fluid treating agent may advantageously be crude oil, I have shown the supply line 23 leading to a tank 24, which may represent any suitable source of crude oil.

It will be evident that the piping connections and controls shown are wholly diagrammatic, and that they in no wise affect or limit my invention, and that, for example, single connections with the casing head and the top of the tubing might be made to serve both supply and discharge functions merely by rearranging the piping and its fittings.

In other figures, treating-agent delivery lines and lines for handling the gaseous and liquid discharge of the well are also shown diagrammatically, and throughout the drawings wherever similar parts are disclosed like reference numerals will be applied.

During the operation of the well prior to the application thereto of the practice of my invention which will now be described, the sucker-rod line 8 operates the pump 7 and effects discharge from the well, through the line 17, of crude oil and water. As above indicated, these liquids may be delivered to any desired point; and the casing head pressure may be maintained high or low, as desired, for example, by adjustment of the valve 12.

This well may be regarded, for purposes of illustration, as a rather deep one, having a considerable formation pressure but not one sufficient to offer any possibility of production without pumping. Prior to the application of the invention to this well, the production of the latter may be assumed to have comprised rather serious quantities of water with some oil, and the pumping equipment, under such circumstances, will have been pressed, perhaps, to near the limit of its capacity to secure enough oil to warrant continued pumping, in view of the high percentage of water in the well discharge. When such a well is shut down, preliminary to the application of the process thereto, a column of oil and water will stand comparatively high in the casing, the water component extending from the bottom of the well to a point materially above the top of the producing sands 4. Accordingly, a mere shutting in of the well would not, in any commercially practicable time, result in any change taking place which would cause an improved production of oil upon resumed pumping.

As we have assumed the characteristics of the well 1, it will require pumping to effect production, both after the treatment thereof, as well as before. Therefore, prior to the initiation of the forcing-down step, the pump 7 and the operating means for the sucker-rod line 8 will desirably be modified and adjusted, as by reducing the size of the pump plunger and providing for a less rapid reciprocation of the sucker-rod line 8 and shorter strokes of the latter, so that upon the resumption of pumping a much slower discharge rate will be possible.

To effect the introduction of a column of liquid of lower specific gravity than the water in the well, according to the present practice of my invention, the casing head pressure is reduced to the necessary degree, as by opening the valve-controlled discharge line 14; and then a quantity of crude oil, for example, a quantity which when confined in a column of a cross section equal to that of the casing will exert a force equal to or slightly in excess of the bottom-hole pressure, will be flowed from the source 24 through the line 23 and through the line 22 into the casing to act upon the liquid column standing in the latter. As the crude oil is added to the top of the liquid column in the well, the bottom of the original liquid column will be forced back into the formation, and as more and more oil enters the casing the lower end of the column of oil which stands above the top of the water column will approach and finally pass below the top of the oil sands and commence to enter the latter and to displace the water from the well bore within the sands and from some, at least, of the uppermost water-sealed oil-delivery passage in the sands. The oil column in the casing will not have its upper end move in the casing down to a point below the limit fixed by the formation pressure; and it is possible that a considerable time may be required to effect the introduction of the desired total quantity of oil and the attainment of a balance between the formation pressure and the pressure exerted by the oil column in the well.

After the oil has been introduced, and preferably also after the end of the forcing-down action has been reached, the well may desirably be shut in for a time, this period varying with the quantity of oil introduced and with the severity and duration of the previous water-producing condition. A shut-down of all pumping until the day following the completion of the introduction of the oil may be selected as a convenient, though by no means a fixed, minimum, when this step is regarded as advisable. This will provide an opportunity for the more definite establishment of restratification.

Following the period of complete inactivity, so far as production is concerned—when such a period is provided—a very slow production may be initiated. The pump will be positioned preferably with its intake above the top of the oil sands; and pumping at a slow rate compared to that which would be sufficient to effect the discharge of the oil component only of the prior delivery, may be started and maintained for a time to insure still more definitely the effecting of a restratification of the fluids within the producing formation.

Thereafter, the pumping speed may be increased, and by stages it may be carefully brought up towards a rate equal to the former rate of oil delivery, as passages previously sealed by water become cleared; and the ultimate rate of oil delivery may be expected to equal, and perhaps materially to exceed, that which preceded the initiation of application of my invention thereto. In increasing the rate of production, the pumping speed should be increased only at intervals, and each new rate should be maintained long enough for sub-surface conditions to become stabilized.

If desired, the rate of production may be deliberately increased until water again begins to appear in substantial quantity. This will enable the experimental determination of the limit beyond which pumping cannot be advantageously pushed. The whole process may then be repeated and the production rate set, with the information so obtained, so that the maximum practicable quantity of oil may be secured.

It will be understood that correlation of the rate of production and of the back pressure, in this instance determined at least largely by the height of the column of oil in the casing (which will vary with the pumping rate and the relation of the latter to the rate of liquid discharge into the well from the formation) will maintain the production at least mainly oil.

The quantity of crude oil employed in the first step of the process may vary widely from the amount hereinabove tentatively suggested, but ordinarily the quantity mentioned will prove adequate, and experience and knowledge gained at similar wells in the same field will afford guidance as to possible modification in the volume to be employed.

Other practices of my invention also may employ a liquid forcing agent, and this, instead of being introduced by gravity flow after a lowering of the casing head pressure, may be forced into the well by imposing upon it a pressure of the necessary height. Such a procedure will be found advantageous where the formation pressure is high enough, with respect to the depth of the well, to permit production by natural flow to be resumed upon the substantial elimination of water from the well discharge. The application of a modification of my invention suited to those conditions may be explained by reference to Fig. 2, disregarding the dotted disclosure of the sucker rod and its gland or stuffing box in that figure.

It will be noted that the well and its equipment in Fig. 2 in the main follow the disclosure of Fig. 1. Provision is made for liquid discharge from the tubing 6 and for gas discharge from the casing head 10; for the shutting in of the casing head and for the closing off of the usual discharge for liquid from the tubing; and for the introduction of a treating agent into either the tubing or the casing or both. Instead of provision for the gravity flow of crude oil to the connection 21 or 22 in Fig. 2, I have shown diagrammatically means for drawing crude oil from a storage receptacle 24, through a line 31, means for placing it under pressure, as by a pump 32, and means for discharging it, the line 33, which may supply fluid either through the line 21 to the tubing 6 or through the line 22 to the casing 2.

Where it is to be expected, from the knowledge possessed of the formation pressure and the depth of the well, that production by natural flow can be reestablished when the water discharge is substantially eliminated, the pump 7 and its actuating devices may be removed, a condition which is suggested by the dotted showing of the sucker-rod line and its gland in Fig. 2; and prior to the initiation of the application of the invention to the well, the bottom of the tubing 6 will advantageously be positioned above the top of the producing formation 4. With this explanation, the mode of application of this modification of the invention may be readily understood. The various connections for liquid and gas discharge from the well will be closed, and the pressure applying means, represented by the pump 32, will be caused to force the liquid treating-agent, for example, crude oil, through the connections

21 and 22 into the well, and to drive down in the tubing and in the casing the liquid columns standing therein. It will evidently be necessary to provide a forcing means of suitable capacity to impose the necessary pressure on the introduced liquid to force it into the well. The pressure necessary will be a matter of simple calculation, knowing, for example, the formation pressure or the depth of the well, the mean specific gravity of the liquid column and the height at which the latter stands when the casing head pressure is vented. The top of the tubing will, of course, be capped prior to the forcing in of the treating liquid if production without pumping is to be effected.

As the column of oil is forced into the well, it will progressively displace into the formation the liquid which previously stood in the well. When all of that liquid or, if it is stratified, the lower, water, portion thereof, has been forced below the top of the producing formation, there will be a continuous column of oil from the top of the casing down to and into the formation; and the oil in the casing will effect a junction with the oil in the sands and will displace the water from at least some of the water-sealed passages and produce a condition where restratification of the fluids in the formation can take place. The well may then, if desired, be shut in and allowed to stand for a period in order to promote the initiation of restratification, as hereinabove explained. Thereafter, if a period of very slow production of oil for the purpose of effecting circulation within the formation and the displacement from the oil channels of the water seals therein be desired, it will be possible by throttling the rate of production through the line 17 to maintain the necessary back pressure and to hold in check the rate of production to accomplish the desired result. Subsequent production at higher rates will be possible, when this is indicated, merely by increasing the rate of oil delivery permitted through the line 17. Should the rate of production be allowed inadvertently to become too high, or be deliberately allowed to proceed to such a degree as to initiate the return of water to the well discharge, for the purpose of determining the maximum safe rate of production, a reapplication of the process will restore the well to a substantially exclusive oil production.

It will be evident that the crude oil or other liquid agent may be forced into the well either when the latter has a column of liquid of considerable height standing therein (a condition which follows protracted reduction of the casing head pressure), or at a time when the gaseous casing head pressure is high, through the well's having been shut in for some time. Under the latter conditions, the gaseous pressure in the casing will force the treating liquid, as the latter is introduced by the forcing instrumentality into the well, downwards, and thereby displace the lower liquid column originally standing within the well. When this has been completed to the necessary degree, it will be evident that, upon resumed production, the well must rely rather largely upon a gaseous back pressure unless steps are adopted to effect a replacement of the gaseous back pressure, or the combined gaseous and liquid back pressure, by a primarily, at least, liquid back pressure. This can be done readily by allowing, as will be more fully explained in connection with a later modification of the invention, the gaseous casing head pressure to be bled off at a rate so restricted that oil ingress into the well from the formation will cause a column of oil to build up in the well as the gaseous pressure is reduced and thereby maintain the desired back pressure upon the formation.

When the depth of the well and the depletion of the formation pressure are such that production by natural flow will be impracticable, and the modification of the invention described with the aid of Fig. 2 is to be applied, the pumping equipment, whose presence is indicated by the dotted sucker-rod line and stuffing box, will, before the liquid agent is introduced into the well, be modified and readjusted to enable, upon resumed production, slow enough rates of pump operation to bring about the needed restratification and to maintain the rate of liquid production within the rate of oil influx into the well. Here it will be understood that the quantity of liquid, e. g. tank oil, will not be sufficient wholly to fill the casing, even when a column of sufficient height to drive down the water, by its weight, is introduced; and the quantity of the liquid agent may be varied, as more fully explained in connection with later modifications, depending upon the relative reliance it is desired to place upon hydrostatic and gaseous pressures for the forcing-down action.

Fig. 3 will provide further aid in understanding the various modifications of the invention. Here it will be observed the discharge lines for the liquid production of the well and for casing head gases are shown leading to the left from the top of the well; and at the right of the well is shown equipment which can be used for enabling the introduction, by gravity flow, of a liquid to act upon the top of the liquid column in the well, though the well may be under pressure; and this without the need for means for imposing mechanically upon the liquid a pressure to overcome the pressure against which it is to be introduced. A valve-controlled line 35 is provided to permit delivery of the liquid to be introduced from any suitable source, herein represented by the oil tank 24, to a receptacle or vessel 36 so positioned as to permit gravity flow from it into the casing, or tubing, or both, respectively through the valve-controlled line 37, the valve-controlled line 38, or both. A vent, suitably valve-controlled, is shown at 39, and means for introducing a pressure to enable gravity flow of the liquid within the vessel 36 into the well, or to exert, if desired, a superior pressure upon it, is provided in the form of the valve-controlled line 40, to which casing head pressure may be admitted through the valve-controlled line 41 leading to the casing head, or to which any suitable gaseous pressure may be delivered from any available source by way of the valve-controlled supply line 42, when a somewhat different modification of the invention is desired to be employed. While but one vessel 36 is illustrated, it will be evident that use of a number, aggregating the necessary capacity, or use of a single vessel large enough to hold the entire needed quantity of treating liquid, or use of a small vessel repeatedly, are all within the scope of my invention.

Before application of this modification of my invention to the well through the equipment illustrated in Fig. 3, provision will be made to enable slower displacement of liquid by the pumping equipment. These details need not be described again.

The lines 11 and 17 being closed, there will exist a pressure within the top of the well (i. e. in the casing head) which will depend upon the formation pressure and the height of the liquid column standing in the well. With each of the valve-controlled lines 37, 38 and 40 closed, the vent line 39 from the vessel 36 will be opened, and the desired quantity of liquid of lighter specific gravity than the water in the well will be flowed through line 35 into the vessel 36. Lines 35 and 39 will then be closed, and line 40 opened, and casing head pressure admitted through line 41 to the top of the vessel 36. As previously indicated, a suitable pressure could be supplied, if preferred, through line 42. Lines 37 and/or 38 will be opened, following, or concurrently with, the application of the needed gaseous pressure on the top of the liquid in the vessel 36, and the liquid will then flow by gravity through the open delivery line or lines into the well, and will force down the previous liquid column in the well and move the water in the well to a position below the top of the formation 4. It will of course be understood that where liquid introduction to the well through line 38 is to be effected, removal of the pump will have been necessary, unless some arrangement be made to enable liquid to pass the pump valves.

Following the introduction of the necessary quantity of liquid and the completion of the downward displacement of the water within the well, the well may be shut in for a time; slow pumping to effect a circulation which will clear the water-sealed oil passages carried on for a time; and the well thereafter produced at an appropriate rate and under the necessary back pressure, to confine the production to oil as may be desired. Detailed rediscussion of these steps is unnecessary. It should be noted, however, that the quantity of liquid—e. g. crude oil—introduced may be either sufficient per se wholly to displace the entire previous liquid column in the well, or as more fully considered in connection with another modification, a lesser quantity, to provide a cap of the necessary depth, as may be determined.

Fig. 4 is intended to show, in the simplest possible manner, equipment for the practice of the invention in aspects thereof in which caps of a liquid of lower specific gravity than the water of the well are introduced into the latter and then subjected to gaseous pressure to force them downwardly. Obviously the gaseous pressure may be provided by a compressor—in which event maintenance of a gaseous back pressure by suitable control of the compressor is possible—by a well having a higher casing head pressure than the well being treated, by a gas main containing gas at the requisite pressure, such as the residue line from a gasoline plant or a booster station line, or even, under some conditions, by simply shutting in the well and allowing the pressure which will thereupon build up in the casing head to provide the needed pressure. Other potential sources of gaseous pressure will be evident to those skilled in this art.

As in earlier figures, the usual liquid discharge line from the well is indicated at 17, and the provisions for conducting away the casing head gases to a point of use or storage, at 13, and for venting the casing head, at 14, respectively. A pump, actuated in any suitable manner, is shown at 7. A line 45 constitutes a means for delivering gaseous pressure from any suitable source to either or both of the valve-controlled lines 46 and 47 leading to the top of the tubing and to the casing head respectively. The source of supply 24 for the desired quantity of liquid treating-agent is connectible herein through the line 23 and its valve-controlled branches 21 and 22 to the lines 17 and 11 respectively, these latter serving as well for liquid ingress lines as for liquid and gas discharge lines respectively. Obviously many variations of these connections, which are shown for illustration only, are possible.

The modifications of the invention now being described are not limited to, but will be found very desirable under conditions where the bottom hole pressure is comparatively low. Of course, however, provided higher gaseous pressures be economically available, and the casing and other equipment be able to withstand such pressures, these modifications may be applied as well to wells having higher bottom hole pressures.

As in the other cases described, it will be desirable to reduce the displacement of the pump plunger, to shorten the stroke of the latter, and to arrange for a slower rate of pump operation; and also to alter the location of the pump intake, if necessary, to insure the latter's being in liquid and not in gas when the process is applied. Desirably, the necessary changes will be made before the gaseous pressure is applied.

While, as herein later explained, the introduction of gaseous pressure from an extraneous source with the other steps of my process may be applied effectively, under suitable conditions, even when no natural cap of oil surmounts the column of water in the well, a natural oil cap, augmented by an extraneously introduced cap of liquid of lower specific gravity than the water in the well, will ordinarily greatly improve the results of the process; and whenever it is believed that the cap of crude oil upon the column standing in the well prior to the application of my process thereto is likely to be inadequate or its quantity is problematical, or when the use of a lower gaseous pressure is desirable for any reason, or when operation under maintenance of a substantial casing head pressure is important for any collateral reason, or when it is desired to make use of gaseous pressure accumulating from and within the particular well to be treated as at least in part the pressure agency, the extraneous introduction of a cap of liquid will be desirable, though it may not be imperative.

When, if this is to be done, the liquid cap has been introduced into the well, as through the lines 23, 22 and 11, one or the other of the lines 46, 47—usually the line leading to the casing head—will be opened, and gaseous pressure will be delivered into the well to act upon the liquid cap which has been introduced into the latter. By continuing the supply of gaseous pressure so that the casing head pressure will increase, it will be evident that the cap of lighter liquid will be forced down the well and brought into contact with the upper portion, at least, of the formation, and drive the water down into the latter. When shutting in the casing head and building up the pressure from within the well is relied upon, added time must usually be counted on, and when the casing head pressure reaches the magnitude computed, as described below, it will be evident that the liquid cap will have been forced down as necessary.

The other steps heretofore described may then be applied, and after a period of shutting in the well, the pump may be started as hereinabove described in connection with other practices of the invention, while the gaseous pressure is maintained in balance with the apparent pumping head, and subsequent operations will then be similar to those described in the case of such other practices.

Where it is desired to replace the gaseous pressure with a back pressure imposed by oil from the formation, after the maintenance for the desired period of the undisturbed state, during which the gaseous pressure is maintained and initial restratification advanced, the gaseous pressure can be slowly reduced at a rate that at least will not exceed the effect of the initial pumping speed which is to be used, and in this way a flow of oil from the formation into the well will be induced. The oil will rise in the well and take the place of the gaseous pressure until all the back pressure is supplied by the column of oil. Thereafter, the reinitiation of slow pumping, etc. as hereinbefore described may be applied. Generally, the type of back pressure maintenance employed will depend upon the desirability, for collateral reasons, of having a high casing head pressure. If desired, after an oil column has been built up in the well, this may be forced down to insure a more certain reconditioning, and the shutting in, slow producing, and more rapid producing steps applied.

Not infrequently the normal operation of a well makes the use of some casing head pressure desirable, and under such circumstances the combined liquid and gaseous pressure methods are especially advantageous. Where combination liquid and gaseous pressure is used to force the water from the well, it will be possible to bring the gaseous pressure below any desired maximum limit by increasing the height of the column of liquid used. Conversely, by increasing the gaseous pressure, the liquid required can be reduced to a minimum. Before using the combined liquid and gaseous pressure methods, it will be best to compute the relative proportions of liquid and gaseous pressure which will equal the bottom hole pressure. In applying the process, it will then be possible to build up the gaseous pressure to a value slightly in excess of that computed, to be sure the treating liquid has been brought into contact with the oil sands. Thereafter, the steps of the process will be effected in a manner which will be obvious from the descriptions given with the aid of other figures.

Fig. 5 illustrates in a diagrammatic way arrangements by which a modification of the invention according to which no liquid treating or forcing agent at all is introduced into the well, may be employed.

The well 1 has its casing head 10 connectible through a line 13 to any point to which it may be desired to deliver casing head gases. A line 14 may be used to vent the casing head pressure if desired. A line 50 conducts a gaseous fluid, say casing head gases, under pressure, from any suitable source, to the lines 21 and 22 respectively leading to the tubing and to the casing head. The well is equipped with a sucker-rod-operated pump 7 and before the application of the forcing-down step of this modification of my invention to the well the pump will desirably have its plunger size-reduced, and its actuating means, of whatever type, adjusted to reduce the number and length of the strokes. And in this case, desirably, the pump may be positioned with its intake slightly, at least, below the top of the oil-producing formation.

The gaseous pressure, obtained from any suitable available source, may be delivered to the well, say through the line 22, and the casing head pressure will increase, indicating that the water is being forced down and out of the well. When the pressure ceases to increase, this will indicate that the water has been lowered sufficiently so that the gaseous fluid is flowing into the oil sands. The flow of gaseous fluid will then be reduced, or, preferably, stopped entirely, and the pressure conditions will be maintained, as by closing in the well, to permit natural restratification to proceed. Because of the less favorable conditions, the shut-in period will be longer than when crude oil is introduced. Following this period, depending upon the mode of back-pressure maintenance desired, either of two procedures may be adopted. The pump may be started up as has been described in connection with earlier-explained practices, while the gaseous pressure is maintained in balance with the apparent pumping head, and subsequent operations will be similar to those that I have heretofore disclosed. When it is desired to replace the gaseous pressure with a back pressure imposed by oil from the formation, in a manner similar to that described in connection with Fig. 4, after the undisturbed state, during which the gaseous pressure will be maintained and initial stratification advanced, the gaseous pressure can be reduced slowly, at a rate that would not exceed the effect upon the producing formation of the indicated initial pumping speed. This will induce a flow of oil into the well, and the oil will rise in a column in the well and take the place of the gaseous pressure, as the latter is reduced, until all, or any desired part, of the back pressure is supplied by the column of oil. The subsequent steps will be apparent from the practices hereinabove described. This modification of my invention, according to which gaseous fluid pressure alone is the forcing agent, will probably be of the greatest utility at wells of small capacity with relatively low bottom hole pressure.

Ordinarily the use of at least a liquid cap, and rather generally, when conditions permit, the use of liquid pressure to force the water down the well, will be desirable in the application of my improved well treating and producing method. There will, however, be conditions where combining liquid with gaseous pressure will be very definitely advantageous and even preferable, for instance where it is desired to clean the oil sands adjacent the well bore, or to treat the water in the oil sands to make it flow through the sands more freely and thus make it possible to remove the water from the smaller oil flow channels. Liquids that are usually used for such purposes are generally more expensive than crude oil, so frequently reducing the quantity required by the use of gaseous pressure will be an advantage. Ordinarily, it will be possible to bleed off the casing head pressure, so that the treating liquids can be flowed into the well by gravity, as above described. Occasionally, however, it will be necessary to maintain the casing head pressure, in which case the treating liquid can be forced into the well by means of any suitable pump, or it can, as above described, be placed in a tank at the surface, capable of withstanding the required pressure. Through suitable simple connections, it will be possible to introduce the casing head pressure to the portion of the tank above the liquid, whereupon the treating liquid will drain into the well through another suitable connection. If the natural cap of crude oil is undesirable, it can be removed in any convenient way, such as with a bailer.

In connection with the use of certain of the steps of my process, for the purpose of treating oil-producing formations to assist in the removal of water from capillary passages, or to render sands which may have been wet by water more permeable to oil by wetting them with a solution of a compound having a preferential wetting characteristic, it is to be noted that a very slow producing of oil from the formation, while maintaining the latter under an appropriate back pressure, fixing the rate of production so that at least the major part of the water displaced from the formation will enter the well bore and descend by gravity through the latter and then return to the lower portion of the sands, may be highly beneficial. In the application of this procedure, the treating fluid may sometimes be mixed with the water before it is forced from the well. Again the treating fluid, where it is not miscible with and is heavier than the substance that may have been used to force the water from the well (when this preliminary step is employed), may be introduced by running it down the inner surface of the casing. Or, where the characteristics of the treating substance make this necessary, it may be introduced through a small pipe placed along the side of the tubing but not necessarily connected to the latter, and leading down into the formation. Whether the introduction of these special treating agents (which may include gases as well as liquids and solutions as well as natural fluids) and the promotion of circulation as above described, are followed by the later steps of my process, or by one or another of the methods of producing which commonly follow the introduction of special treating fluids, the successive steps of displacing the water by a lighter liquid and treating the formation by effecting a recirculation, or the latter step alone, will be definitely valuable. It may be noted that the water in the formation, when caused, by maintaining a proper low oil-production rate, as it were, to be recirculated, passes out of the sands into the well bore, down the latter, outwardly at a lower level, and then, while the treating process creates conditions effecting its relatively permanent dislodgement from increasing volumes of the formation, passes again more or less upwardly and inwardly through the formation and back to the well bore, with, if the addition of treating solution be maintained at the requisite rate, increased concentration of the latter in the circulating liquid. This sub-process, comprising what has been called a setting up of a recirculation of the water to and from the well bore, either with or without the use of a treating agent, is a definite aspect of my invention which may be practiced apart from the remaining aspects thereof, and is specifically claimed hereafter. It will also be understood that this same sub-process may be utilized to effect a cleaning of the formation adjacent the well by the introduction of suitable solvents and their circulation in the formation.

While the application of my invention has heretofore been considered previously in regard to the problems of water-drive fields, the same methods can be applied to a gas-drive field, which has been converted to a water-drive field by the application of an artificial water-drive.

The artificial water-drive is an efficient way to obtain secondary oil recovery from a gas-drive field. It normally achieves its greatest usefulness in relatively shallow fields where the oil sands are reasonably homogeneous, and do not erode too easily. The method of secondary recovery soon becomes uneconomical when the lift exceeds that at which the oil and water can be pumped together economically. Also, a loose sand or one which erodes and channels easily, may defeat the object of the artificial drive by permitting the water to by-pass the oil. Still another difficulty is not uncommon, in that the supply of surface or shallow well water may be insufficient, or be contaminated to an extent to require special handling or treatment, particularly if part of it is produced with the oil which is forced out.

My invention will afford a means for overcoming the difficulties mentioned by limiting the water that must be pumped, by overcoming channeling by enabling the wells to be operated under back pressure, and by making it practical to utilize other sources of water supply to a greater extent than heretofore realized, because water disposition problems may be avoided.

While my invention can be combined with the usual practice of injecting the flood water through key wells, it will achieve its greatest usefulness in the water-drive field when combined with the less common practice of drilling certain of the wells deeper into underlying water, or perforating the casing where an overlying water stratum is known to exist. Such water is generally available in adequate quantities, under desirable pressure, and would not require exposure to the surface, the atmosphere or metal pipes: the more frequent sources of impurities which hinder the injection of the water into the oil sands, due to the depositing of material that clogs the pores of the oil sands. Where the water is obtained from an overlying stratum, by perforating the casing of certain wells, such wells will have to be reserved for injection wells. Where, however, water is obtained by drilling certain wells deeper, these same wells can be used for production wells by the application of my invention. However the artificial water flood be introduced into the producing formation, the voids in the oil sands will fill with water, until a back pressure is built up sufficiently to offset the pressure of the water. Before this occurs the water will usually rise high enough in the wells from which production is proposed, to flood them. With my invention, however, the water can be forced down these wells by means of a column of liquid, gaseous pressure, or a combination of both, as already described, restratification effected where required, and an almost wholly oil delivery restored with regulated production under back pressure, thus securing to any gas drive field the same economical more complete recovery of oil that will be characteristic of the water drive field, after my invention has been applied.

Obviously my process can also be used early in the arising of the water problem to check it at its inception.

From the descriptions of various modifications of the invention that have been given, it will be apparent that the forcing-down of the liquid column in the well until conditions are produced permitting restratification to be effected, the effecting of restratification, and the production of liquid from the well under correlated conditions of back pressure and pumping rate, which together result in a much improved percentage of oil in the well discharge, are, as it were, major factors in the attainment of the desired results. It will also be evident, however, that there may be merging of different steps into each other; for example, the extent to which the forcing-down step may be carried may markedly affect the succeeding step or steps; and, when there is a restratification step, the boundary between it and the resumption of production under controlled conditions may, in some cases, be by no means sharply defined. When, for example, a large amount of crude oil or other suitable liquid is displaced into the formation, any distinct step of restratification may under some conditions practically disappear, since of the two illustrative procedures designed to promote restratification, to wit: shutting in the well, and pumping under a back pressure at a very low rate to effect a circulation in the formation, the pumping for restratification may merge into the first stages of production pumping and shutting in the well may be made almost, if not in some instances, indeed, wholly unnecessary by the extent to which the liquid-forcing step is carried. Further, it will be clear since the second procedure for promoting restratification—production at a very slow rate so that a clearing of the oil channels of water may be promoted by a circulation, as it were, in the formation—involves a difference in rate only from the early stages of the return to production, that there is not ordinarily an at all sharp line of demarcation between these steps. However, throughout the procedures there will be observed to be present the initial step of forcing down the casing at least one fluid of lower specific gravity than the mean specific gravity of the original liquid column in the well, the ultimate step of production under a back pressure and at a rate adopted to confine the production usually at least to a much improved percentage of oil, and, intermediate the first attainment of a fluid of lower specific gravity to the top of the formation and the operation of the well at what may be called a working production rate, there is the change within the formation which I have described, for want of a better term, as restratification.

The use of liquids, cumulatively acting liquids and gases, and gases for the forcing-down step have been described. The maintaining of back pressure with liquids, liquids and gases acting cumulatively, or gases has been disclosed. Ultimate controlled production by natural flow under back pressure and by pumping under back pressure have been explained. And it will be understood that rotary or reciprocating pumps, beam or motor actuated pumps, all may be used when desired. The steps—not the instrumentalities—are the important items in this present invention in its manifold applications and modifications.

This is a continuation-in-part of my applications Serial No. 96,236, filed August 15, 1936, and Serial No. 131,203, filed March 16, 1937.

While there have been specifically described in this application several different practices and a sub-aspect, as it were, of this invention, it will be understood that these have been disclosed for purposes of illustration, and that the invention may be further modified and practiced in other forms without departing from its spirit or the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent is:

1. The method of treating and producing an oil-water well containing a liquid column consisting at least in part of water, which method comprises establishing conditions for the production of an increased proportion of oil from the well through a treatment of the latter including delivering into the well to act upon the liquid column therein, and thereby forcing down the water, a fluid of lower specific gravity than said water, and thereafter producing the well while maintaining by the fluid contents thereof a back pressure upon the formation, the rate of production and the back pressure being correlated to maintain the desired restraint upon the water in the formation.

2. The method of treating and producing an oil-water well which contains a liquid column consisting at least in part of water, which method includes the steps of introducing into the well a fluid of lower specific gravity than the water until by the pressure so produced at least the water portion of the column is forced to a position wherein improved oil entry to the well is possible, shutting in the well for a period, and then producing the well while maintaining by the fluid contents thereof a back pressure upon the formation, the rate of production and the back pressure being correlated to hold in check the water in the formation.

3. The method of treating an oil-water well which includes the step of introducing into the well, upon the top of any liquid column therein, a column of oil of such length that said oil when superposed on the oil cap, if any, standing upon the water in the well will force from the well bore substantially all the water therein to a point at least below the top of the producing sands.

4. The method of treating an oil-water well which includes the step of forcing the water in the well down the latter by introducing into the well, upon the top of any liquid column therein, a quantity of oil sufficient when confined in a column of the cross section of said liquid column to exert a pressure at the bottom of the well exceeding the bottom hole pressure.

5. The method of treating and producing an oil-water well, which contains a liquid column comprising water at least in its lower portion and including an overlying oil cap, which method includes the steps of introducing into the well a column of oil of such a height as when superimposed upon the liquid in the well to establish a column of oil above the water of a height sufficient to overbalance the formation pressure, effecting a disposition of the water in the formation such that there will be a reduced interference with the entry of oil to the well, and producing the well under a back pressure with the rate of production and the back pressure correlated to preclude the building up of a water component in the well discharge in excess of a predetermined percent.

6. The method of treating and producing an oil-water well which includes introducing into the well a quantity of a liquid of lower specific gravity than the water therein sufficient when introduced into the casing to exert a hydrostatic pressure at least equal to the formation pressure, forcing down the well the liquid previously in the latter, and then producing the well under a back pressure provided by the fluid contents of the well and at a rate correlated to such back pressure to preclude a proportion of water in the well discharge in excess of a predetermined percent.

7. The method of claim 6 in which the well is

shut in for a period intermediate the forcing down of the liquid and the resumption of production.

8. The method of claim 6 in which a restratification within the producing formation is promoted between the forcing down of the liquid and the resumption of production at a comparatively high rate, by the subjection of the formation to a back pressure and the production of oil at a low rate controlled to confine the production substantially to oil.

9. The method of treating and producing an oil-water well which includes effecting a reconditioning of the well and the contiguous producing formation by a procedure which includes forcing into the well a quantity of crude oil sufficient to fill the well completely full from the casing head to a point below the top of the producing formation, forcing thereby the liquid previously in the well below the top of the formation, and subsequently producing the well by natural flow while controlling the discharge rate of the well to maintain a back pressure and hold the percentage of water in the liquid produced from the well below a predetermined maximum.

10. The method of treating an oil-water well which includes the production within the well of a cumulative pressure of oil, and of gas upon the oil, sufficient to force down and to expel the water from the well to a point in the latter below the top of the producing sands.

11. The method of treating and producing an oil-water well which includes effecting the establishment within the well of a substantial gaseous pressure and then introducing into said well a cap of a liquid of a lower specific gravity than the water in the well of such height that the hydrostatic pressure of the cap and the gaseous pressure within the well are effective to force down the liquid previously standing in the well and displace the water in the well into the producing formation, and thereafter producing said well under a back pressure and at a rate correlated to preclude the building up of the water component of the well discharge above a predetermined percentage.

12. The method of treating and producing an oil-water well which includes effecting the establishment within the well of a substantial gaseous pressure and then introducing into said well a cap of a liquid of a lower specific gravity than the water in said well of such height that the hydrostatic pressure of the cap and the gaseous pressure within the well are effective to force down the liquid previously standing in the well and displace the water in the well into the producing formation, shutting in said well for a period to provide opportunity for a repositioning of the liquids within the formation, and thereafter producing the well under correlated conditions of back pressure and rate of production to preclude excessive discharge of water with the oil.

13. The method of treating and producing an oil-water well which includes effecting the establishment within the well of a substantial gaseous pressure and then introducing into said well a cap of a liquid of a lower specific gravity than the water in said well such height that the hydrostatic pressure of the cap and the gaseous pressure within the well are effective to force down the liquid previously standing in the well and displace the water in the well into the producing formation, thereafter producing oil from said well for a material time at a rate substantially below the prior rate of oil production alone and while maintaining the well under a back pressure differing from the formation pressure sufficiently only to effect discharge of oil from the formation into the well bore, and thereafter producing the well under a back pressure and at a rate correlated to confine the liquid production from the well to at least a high percentage of oil.

14. The method of treating and producing an oil-water well which includes the steps of introducing into the well a cap of a liquid of lower specific gravity than the water in the well and then building up a gaseous pressure within the well to act upon the introduced cap and with the latter to produce a pressure sufficient to force the water in the well to a position below the uppermost limits of the producing formation, and thereafter producing said well under a back pressure and at a rate correlated to retard the serious return of water to the liquid produced from the well.

15. The method of treating and producing an oil-water well which includes the steps of introducing into a well a cap of a liquid of lower specific gravity than the water in the well and then building up a gaseous pressure within the well to act upon the introduced cap and with the latter to produce a pressure driving the water in the well to a position below the uppermost limits of the producing formation, then shutting in said well for a period to provide opportunity for a relative repositioning of the liquids in the formation under static pressure conditions, and thereafter producing the well under correlated conditions of back pressure and rate of production to preclude excessive discharge of water with the oil.

16. The method of treating and producing an oil-water well which includes the steps of introducing into the well a cap of a liquid of lower specific gravity than the water in said well and then building up a gaseous pressure within the well to act upon the introduced cap and with the latter force the water in the well to a position below the uppermost limits of the producing formation, thereafter producing oil from the well for a material time at a rate substantially below the prior rate of oil production alone while maintaining a back pressure on the well, and then producing the well at a faster rate, also under a maintained back pressure, said back pressure and production rate correlated to confine the liquid production from the well at least largely to oil.

17. The method of treating and producing an oil-water well, which includes the steps of subjecting the liquid standing in the well to the combined depressing action of a gaseous pressure and of a cap of liquid of lower specific gravity than the liquid in the well together exerting a pressure at least equal to the formation pressure, and thereby forcing the liquid down the well and displacing the water in the latter to a position below the top of the producing formation, thereafter closing in the well for a period and maintaining the liquids therein free from external disturbance, and then successively producing the well at different rates at least the first of which is materially below the previous rate of production of oil alone from said well, while maintaining the well under a back pressure sufficient to preclude excessive discharge of water.

18. The method of treating and producing an oil-water well, which includes introducing into the well a lighter fluid to act upon the liquid therein, thereby forcing the water in said well down the well and causing the same to assume a position where its discharge can be kept under control, and thereafter producing the well under

a back pressure provided by a liquid column of lower specific gravity than the water and maintained of a height sufficient to exert a hydrostatic pressure on the formation adequate to hold water in the formation in check.

19. The method of treating and producing an oil-water well, which includes introducing into the well a fluid of lower specific gravity than the liquid therein, thereby forcing the water in said well down the well and causing the same to assume a position where its discharge can be kept under control, and thereafter producing the well under a back pressure furnished by a cumulatively acting liquid and a gaseous pressure together exerting on the formation a pressure sufficient to preclude water in the well discharge in excess of a predetermined percentage.

20. The method of treating and producing an oil-water well, which includes the steps of introducing into the well a cap of a liquid of lower specific gravity than the water in said well, to act upon the top of the liquid column in the latter, then closing in the well until the gaseous pressure building up therein from the formation, cumulated with the hydrostatic pressure of said cap, forces the liquid originally in the well down and there occurs within the formation such a rearrangement of the fluids therein that by correlating back pressure and rate of production a mainly-oil production will be possible, and thereafter producing the well under a back pressure while restricting the rate of production to preclude water in the well discharge beyond a predetermined proportion.

21. The method of treating and producing an oil-water well, which includes introducing into the well a quantity of a gaseous fluid sufficient in volume and pressure to force down the liquid in the well and displace the water in the latter to a position below the uppermost limits of the producing formation, thereafter slowly bleeding down the gaseous pressure at a rate not exceeding the rate at which the oil can enter the well from the formation, to build up an oil column in the well, and then, under the back pressure furnished by the oil column, producing said well at a rate not materially exceeding the potential rate of oil ingress to the well under the back pressure maintained by the oil column.

22. The method of treating an oil-producing formation to reduce the occupany thereof by water, which includes the steps of introducing into the formation a substance miscible with the water to reduce the capacity of the latter to wet the sands, and repeatedly causing the circulation of the resulting solution through the sands by effecting a production of oil from the well at a rate and under a back pressure such as to preclude excessive discharge of the water from the well with the oil.

23. The method of treating an oil-producing formation to alter the permeability to oil of the portion thereof surrounding a well bore, which includes the steps of introducing into the well bore a suitable treating substance and causing repeated circulation thereof through the sands by effecting a production of oil from the well at a rate and under a back pressure effective to preclude excessive discharge from the well of fluids of greater specific gravity than the oil.

24. The method of treating an oil-producing formation, which includes driving down the well any liquid column standing therein, to a point below the top of the producing formation, introducing a selected treating substance, and bringing the same into intimate contact with the producing formation surrounding the well bore by effecting, through the maintaining of an adequate back pressure and a low production rate, a relatively slow discharge of oil from the well, but mainly a recirculation of heavier liquids including the passage thereof downward through the well bore.

25. The method of cleaning the portions of an oil-producing formation surrounding the bore of a well, which includes the steps of introducing into the formation a solvent for formation-sealing substances and causing a recirculation of such substances through the sands by effecting a production of oil from the well at a rate and under a back pressure such as to preclude material water discharge.

26. The method of producing oil from a well in a gas drive field which overlies a stratum containing water under pressure, which includes the steps of deepening the well bore to effect a communication with the subjacent water stratum, and, upon the flooding of the well by the water from the subjacent water stratum, forcing the water down the well, maintaining the well under a back pressure sufficient to preclude renewed rise of the water therein, and producing the well at a rate correlated to the back pressure maintained to effect production of oil from the well as the oil is displaced by the water entering the formation from the subjacent stratum.

27. Method of treating an oil well where the oil produced is attended by water in such quantity as to present a substantial complication and where with the method of production in use the well contains a liquid column consisting at least in part of water and where there is a substantial natural gas pressure available in the formation; said method comprising delivering into the well to act upon the liquid column therein a liquid of less specific gravity than the water, causing the action upon the top of the resulting column of a gaseous pressure delivered from the formation sufficient to force said resultant column to such a position that oil can enter the well in greater percentage of the total entering fluid, and producing the well while maintaining a back pressure upon the formation, the rate of production and the back pressure being correlated to maintain oil inflow to the well at a rate, compared with the total fluid produced, greater than that which prevailed prior to the application of said method.

28. Method of treating an oil well where the oil produced is attended by water in such quantity as to present a substantial complication and where with the method of production in use the well contains a liquid column consisting at least in part of water and where there is a substantial natural gas pressure available in the formation: said method comprising precluding escape of gaseous formation pressure, thereby to cause the building up of a substantial gaseous pressure in the well, delivering into said well, while escape of said gaseous pressure is precluded and against the resistance imposed thereby, a quantity of liquid of less specific gravity than that of the water in said well, thereby to cause the introduced liquid to displace the original liquid column to a position at which oil can enter the well in greater percentage of the total entering fluid, and producing the well while maintaining a back pressure upon the formation, the rate of production and the back pressure being correlated to maintain oil inflow to the well at a rate, compared with the total fluid produced, greater than that which

prevailed prior to the application of said method.

29. Method of treating an oil well according to claim 27, in which, prior to the delivery into the well of the liquid of less specific gravity than the water, the gaseous pressure in the well is vented to facilitate the introduction of such liquid, and subsequent to the introduction of such liquid the escape of gaseous pressure from the well is interrupted to effect a building up of the gaseous pressure to act upon the top of the resulting column.

30. Method of treating an oil well where the oil produced is attended by water in such quantity as to warrant its elimination and where with the method of production in use the well contains a liquid column consisting at least in part of water and where there is a substantial natural gas pressure available in the formation: which includes the steps of restraining the discharge of gas from said well to effect the building up of a substantial gaseous pressure therein, providing at a suitable height relative to said well for gravity delivery into the latter a substantial quantity of liquid of lighter specific gravity than that of the water in said well, establishing a flow connection for said liquid to said well, and equalizing the pressures in said well and upon said liquid sufficiently to cause said liquid to enter the well and by the pressure so produced force the lower portion of the column in said well to a position in which oil can enter the well in greater percentage of the total entering fluid, and producing the well while maintaining a back pressure upon the formation, the rate of production and the back pressure being correlated to maintain oil inflow to the well at a rate, compared with the total fluid produced, greater than that which prevailed prior to the application of said method.

31. Method of treating an oil well where the oil produced is attended by water in such quantity as to present a substantial complication and where with the method of production in use the well contains a column of liquid consisting at least in part of water, said method comprising delivering into the well to act upon the liquid column therein a liquid of less specific gravity than the water, subjecting the introduced liquid to a gaseous pressure, higher than the formation pressure, from another well to force the resultant liquid column to such a position that oil can enter the well in greater percentage of the total entering fluid, and producing the well while maintaining a back pressure upon the formation, the rate of production and the back pressure being correlated to maintain oil inflow to the well at a rate, compared with the total fluid produced, greater than that which prevailed prior to the application of said method.

32. Method of treating an oil well according to claim 31 in which prior to the delivery into the well of the liquid of less specific gravity than the water any gaseous pressure in the well is vented to facilitate the introduction of such liquid and subsequent to the introduction of such liquid the connection with the gaseous discharge from another well is established.

JOHN F. KENDRICK.

CERTIFICATE OF CORRECTION.

Patent No. 2,258,614.

October 14, 1941.

JOHN F. KENDRICK.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 7, first column, line 27, for "passage" read --passages--; page 13, first column, line 67, claim 13, after "well" insert --of--; and page 14, first column, line 51, claim 22, for "occupany" read --occupancy--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 23rd day of December, A. D. 1941.

Henry Van Arsdale,
Acting Commissioner of Patents.

(Seal)