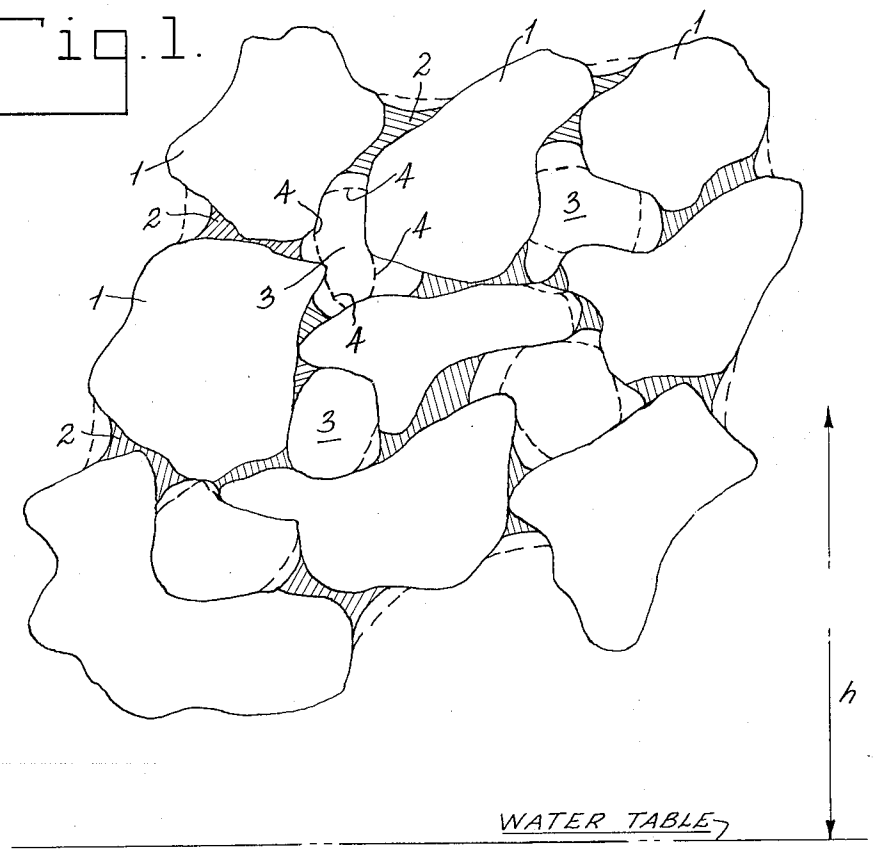
Jan. 17, 1956 R. W. JOHNSTON, JR 2,731,090

PETROLEUM PRODUCTION IN OIL BEARING FORMATIONS

Filed Feb. 28, 1951

Fig. 1.



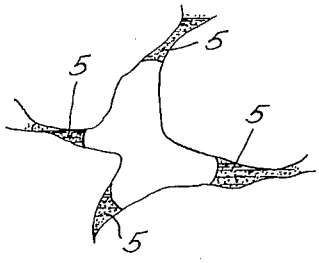


Fig. 2.

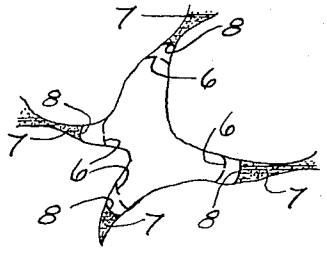


Fig. 3.

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PETROLEUM PRODUCTION IN OIL BEARING FORMATIONS

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The present invention relates to the production of petroleum hydrocarbons from subsurface formations by means of a producing well and is more specifically concerned with hydrocarbon production from a subsurface formation containing a non-wetting phase of liquid petroleum, and a wetting phase of connate formation water which rises by capillary action above the water table.

Broadly, the present invention contemplates excluding water production and simultaneously effecting a substantial increase in the rate of hydrocarbon production by injecting into the formation a fluent wetting phase which is readily miscible with formation water and which, after a predetermined time, sets up as a solid or relatively immobile phase. The settable wetting phase is caused to substitute itself for the wetting phase of connate formation water without blocking the passages or pores occupied by the non-wetting petroleum hydrocarbon. In short the settable material exclusively occupies the more minute capillaries previously occupied by the formation water and, upon setting, positively blocks the capillary flow of formation water in the region of the well bore.

It is particularly important to distinguish the present invention from prior proposals which have been advanced to inject into the formation a material which sets up as a solid to block the formation or a portion thereof. Such proposals usually look toward the creation of a solid dam or dike through some predetermined section of the formation for the purpose of preventing all flow in that region.

The present invention, on the other hand, contemplates sealing the minute water capillaries without blocking or impairing the free flow of oil through the relatively larger oil conducting pores. As a result oil flow is unimpaired by capillary water migrating into its path of flow and the substitute wetting phase is, in effect, immobilized in the capillary interstices so that it does not move into the path of oil flow to restrict oil permeability and to result in water production.

Therefore, blocking or damming of the formation as hitherto proposed would be fatal to the present invention and it is important that it be avoided.

To this end the substitute wetting phase capable of setting up in a condition of substantial immobility is injected through the well bore into the formation preferably as a readily fluent liquid and is caused to radially flow a substantial distance outwardly from the well bore. As a result a portion of the formation oil is displaced and the substitute wetting phase, being in excess of normal wetting phase saturation, tends to drain into the wetted capillaries normally occupied by the connate formation water.

After thus completing injection of the substitute immobilizable liquid into a predetermined section of the formation about the well bore and before setting has commenced, the excess of the immobilizable liquid over and above that which will be received by the water containing capillaries must be displaced and removed from the oil containing passages. A convenient way of accomplishing the result is to positively inject into the formation about the well bore a substantial volume of a non-wetting liquid, preferably oil. Oil injection is continued to force the substitute wetting phase into the capillary interstices normally occupied by the connate water of the formation, the excess moving ahead of the oil flow and progressively entering the portions of the formation radially

outwardly of that originally reached and being ultimately consumed in the capillaries thus encountered. Oil injection is, therefore, continued until the originally injected immobilizable, substitute wetting phase is completely dissipated in this manner so that essentially no settable phase remains in the normally oil containing passageways. Therefore permeability to oil is unimpaired. Stated in another way oil injection restores the oil saturation of the formation treated, at least, to the same value prevailing prior to treatment so that the oil passages remain free and open after setting has occurred. Therefore, it is manifestly important that the volume of oil injection be sufficient to restore the original and preferably the maximum oil saturation throughout the entire section of the formation which is subjected to treatment.

Another important feature of the present invention involves treating the interface between substitute wetting phase and the oil with a surface active agent effective to substantially reduce the interfacial tension between the oil and wetting phase and thereby materially reduce the water saturation of the formation under treatment. Manifestly, decreasing the water saturation increases the effective cross section of the passages available for flow of the non-wetting oil phase thus increasing oil saturation and materially improving permeability of the formation to oil.

The present invention therefore has the advantage not only of selectively and exclusively blocking water production, but of materially facilitating oil production, by increasing oil permeability of the formation. In short, the flow of oil into the well bore is substantially increased, either in the absence of or at a substantially decreased production of water.

The nature of the present invention may be better understood by reference to accompanying drawing of which Figure 1 represents, in diagrammatic or symbolic form, a cross section, highly magnified, taken through a typical oil bearing formation. The solid grains of the formation are represented by the numeral 1 and these, as indicated, leave between them minute pores of irregular cross sectional configuration. The wetting phase of connate water occupies the more restricted portions of the pores at 2, rising upwardly in these minute capillaries by capillary attraction from the water table, more or less diagrammatically represented by the line marked "Water table" a distance *h*. The non-wetting phase of oil accordingly occupies the larger passages of the pores as indicated by the reference numeral 3.

Under normal, static conditions, the pressure in the water at the interface between the oil and water is necessarily less than the pressure at the surface of the water table by an amount equal to the head of water above the water table. This is in turn dependent upon the height of the point of reference above the water table and the density of the formation water.

Likewise, at the oil-water interface, the oil pressure is less than the pressure at the water table by an amount equal to the head of oil above the water table. But, since the density of the water or wetting phase is substantially greater than the density of the oil phase, the oil pressure at any point of reference is substantially greater than the water pressure. This differential is the capillary pressure.

If the pressure in the well at the point where it meets the formation is lower than the normal formation oil pressure, then oil will tend to flow from the formation into the well. The difference in these two pressures is called "draw-down." If the draw-down is sufficient to bring the pressure in the well bore below the static water pressure, then both water and oil will tend to flow into the well.

Moreover, as draw-down is imposed upon the formation, both the oil and water pressures in the vicinity of

the well bore necessarily tend to approach the same pressure, namely that resulting from the draw-down.

In any event, however, as draw-down is imposed upon the well, the resultant release in pressure in the adjacent oil phase permits the capillary wetting phase to move outwardly into the oil-bearing passages, for example, to a point indicated by the dotted lines 4. This manifestly tends to restrict the cross sectional area of the oil passages and accordingly the flow of oil. Moreover, as the pressure on the liquid phases in the formation becomes further reduced due to an increase in draw-down, water moves further out into the oil passages and ultimately proceeds through the pores and is produced with the oil.

The results realized by the practice of the present invention are represented on a similar diagrammatic scale in Figure 2 of the present drawing wherein the capillary wetting phase of water which normally occupies the relatively restricted pores is substituted by an immobile wetting phase which, after introduction into the capillaries normally occupied by the water, sets up or immobilizes to form a selective water barrier. By virtue of its wetting character, the immobilizable liquid injected into the formation moves into the region previously occupied by the formation water to the position indicated diagrammatically by the reference numeral 5.

If the formation is subjected to treatment with oil under a pressure substantially in excess of normal formation oil pressure, and before the wetting phase sets up, the excess settable phase is not only forced out of the formation as indicated above but the wetting phase tends to be forced further into the minute capillary interstices. For example, if the dotted line 6 in Figure 3 represents the oil-water interface location in a typical formation under normal conditions, the application of a substantial oil pressure following injection of a substitute wetting phase may force the wetting phase back into the position indicated by the reference numeral 7 with an interface at the line 8. Manifestly, if this condition is maintained till the wetting phase sets up as an immobile solid then the available cross section of the oil passages and accordingly the permeability to oil is permanently increased. Moreover water is prevented from flowing into the well bore.

Essentially, the same effect, as the last mentioned, results from the inclusion of the surface active agent effective to materially lower the interfacial tension between the wetting and non-wetting phases. Inclusion of an effective portion of such an agent with the immobilizable wetting phase has the effect of lowering the capillary force tending to cause water to rise in the formation. This follows because of the fact that in any formation of fixed internal porosity the capillary force acting upon the water is dependent upon the interfacial tension between the wetting and non-wetting phases and the angle at which the wetting phase wets the solid surfaces of the formation. Therefore, reduction of the oil-water surface tension at this interface lowers the capillary lifting force and results in a tendency for decreased saturation of the formation by water as well as a correspondingly increased saturation by oil wtih resulting improvement in oil permeability.

As examples of a wetting phase miscible with formation water and capable of setting up to a condition of substantial immobility may be mentioned the known alkaline metal silicate-ammonium bicarbonate solutions which are of desirably low initial viscosity, and after a period of time, subject to reasonable control, set up as a sol or colloidal solution. Thus, a solution of sodium silicate and ammonium bicarbonate, after a few hours, forms a silicon hydroxide or silicic acid as a sol or colloidal solution with a water solution of sodium carbonate and ammonium hydroxide as the liquid phase. As the colloidal solution forms, the viscosity increases rapidly until it becomes a semi-solid. On further standing, it becomes an elastic gel of high molecular weight and subsequently becomes more rigid and increasingly inelastic.

Such cements are particularly advantageous in that they remain fluid for the period of time required to effect their injection into the subsurface formation, the selective replacement of the formation water by the injected fluid, and ultimate dissipation of the excess. They are also compatible with many of the typical oil-water surface active agents. Particularly important, however, is the fact that the resulting immobilized product is substantially insoluble to both oil and water and to any wetting or non-wetting phases which may be encountered in underground subsurface formations of the present character.

Many other settable compositions having these characteristics may be employed instead of the foregoing, in particular the class of inorganic gel-forming materials in general such, for example, as the alumina-silica gels, the iron, cobalt, nickel, tin and chromium gelatinous oxides, and the copper ferrocyanide gels.

The mechanism of gel formation per se forms no part of the present invention and accordingly will not be described in detail. In general, however, a dilute solution of the metal sol is hydrolyzed to effect a slow precipitation of the gel. Preferably, as in the case of the first illustrated example, hydrolysis takes place at a low rate by the use of some slowly dissociating salt such as the ammonium bicarbonate above mentioned.

In general, however, the immobilizable liquid may comprise any settable material which: (1) wets the oil bearing formation and is miscible with the formation water, (2) is preferably a relatively low viscosity liquid prior to setting, (3) sets up after a reasonable length of time to form a substantially immobile essentially oil insoluble and water insoluble material and, (4) is not miscible with the non-setting oil phase prior to setting. Therefore, any settable material or composition having these physical characteristics manifestly meets the requirements of the present system.

Examples of surface active agents which materially lower the interfacial tension between oil and water are polyoxyethylene sorbitan monolaurate, polyoxyethylene stearate and the well known class of alkyl-aryl sulfonates. However, as above intimated, these are merely illustrative of the vast field of known oil-water interfacial tension depressants which, in the formation, lower the capillary lifting force and result in substantial reduction of water saturation in the formation.

Small effective quantities of these agents may advantageously be dissolved in the settable phase prior to introduction into the formation. By small, effective quantities is meant that quantity of the selected surface active agent which is effective to cause a material decrease in the interfacial tension between the oil and water. This is obviously dependent upon the agent selected and is a characteristic thereof, which, per se, forms no part of the present invention. It is important to note, however, that the desired water desaturation takes place exclusively as the result of the change effected at the interface between the wetting and non-wetting phase. Therefore, it is only necessary to effect the disposition of the surface active agent at the interface and accordingly, instead of mixing the surface active agent with the settable phase, a small amount may be injected following injection of the settable phase. Alternatively, the surface active agent may be associated with the subsequently injected oil. Also a small injection of surface active agent may precede the injection of the settable phase. In each instance, the surface active agent is preferably employed in solution and in a quantity sufficient to thoroughly permeate the interface.

Following is an illustrative example of the application of the present invention to a producing oil well. The well in question extends into the Oligocene Reservoir in the Manvel Field, in Brazoria County, Texas. The well depth is about 5,000 ft. and the physical properties of the producing formation involve a porosity of about 25% and a permeability of about 1000 millidarcys. The well, prior

to treatment, produced about 60 barrels per day of oil and 40 barrels per day of water at a drawdown of about 10 p. s. i. in a production zone about 10 ft. thick.

In accordance with this practice of the present invention, a settable fluid is prepared by mixing about 50 parts of 18% sodium silicate and 15 parts of 12% ammonia bicarbonate solution and adding about 35 parts of water. Production from the well is stopped and about 150 barrels of this solution is forced through the well bore out into the formation. This injection is immediately followed by the injection of 450 barrels of oil containing about 5% of Atlas G–931 comprising a polyoxyethylene-cottonseed oil reaction product, a known surface-active agent which is radically effective in reducing the interfacial tension between oil and water.

The oil injection forces the aqueous, substitute setting phase into the smaller water bearing capillaries and simultaneously displaces any excess outwardly into the formation, opening the larger and normally oil bearing spaces for oil flow. The well is left shut in for approximately 24 hours to permit solidification or immobilization of the settable phase.

Thereafter production from the well is resumed at a substantially increased permeability. For example, at a drawdown of 10 p. s. i., the well now produces about 90 barrels per day of oil with no water production. At a drawdown of 15 p. s. i., the oil production rises to approximately 130 barrels per day with no water production.

From the foregoing, it is apparent that the present invention is effective for selective water exclusion by selectively sealing off the water bearing capillaries about the region of production. In addition the permeability of the formation to oil may be materially increased. This follows from the fact, intimated above, that the material water desaturation, resulting from the action of the surface active agent, and the pressuring of the formation with non-wetting phase, opens a much greater portion of the interior space to the flow of oil. Accordingly oil production becomes strikingly greater and the pumping of undesired water from the formation is obviated. As a result difficulties such as corrosion, inherent in the handling of ground waters, are obviated.

As above indicated, the shutting in of the well after clearing excess settable phase from the oil bearing passages is held for a period of time sufficient to permit immobilization of the setting phase. Manifestly this will vary with the setting time of the composition selected.

As also intimated, it is advantageous during the setting period to maintain upon the formation a pressure substantially in excess of normal formation pressure to positively force the wetting phase of settable material back into the minute water wet capillaries, thereby correspondingly increasing the effective cross sectional area of the oil-bearing passages and materially improving oil permeability.

The present invention contemplates resort to any suitable formation pressuring practice in accomplishing this result. Such technique forms, per se, no part of the invention. However, it may involve, for example, pumping of oil into the formation during the setting period at a rate sufficient to maintain the desired increment in pressure over that of the normal formation pressure.

It is important to note that the advantages of the present invention may be fully realized even though the formation is treated to only a relatively limited extent about the well bore. This follows from the fact that in a porous radial flow system the pressure drop at the central point of withdrawal in the well bore is reflected materially only a relatively short distance out into the formation. In other words the pressure drop is concentrated close to the well. Thus, for example, the pressure drop is greatest in regions close to the well bore and radically decreases in regions outwardly therefrom. As a result treatment for a distance greater than 50–100 radial feet is seldom justified. Actually treatment for as little as 10 radial feet is normally of considerable advantage although radial treatments to the extent of 25 radial feet are to be preferred.

Obviously many modifications and variations of the invention, as hereinbefore set forth, may be made without departing from the spirit and scope thereof and, therefore, only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. A method of producing petroleum from a well bore penetrating a porous subsurface petroleum-producing formation which formation immediately overlies a water table, the capillaries of said formation being occupied by a non-wetting liquid oil phase and a liquid phase of connate capillary formation water derived by capillary attraction from said water table, which formation water wets the surfaces of the capillaries of said formation, which comprises injecting from said well bore into the capillaries of said formation a fluent aqueous liquid capable of setting up, per se, to a solid, said aqueous liquid wetting the surfaces of the capillaries of said formation and being miscible with said capillary formation water and immiscible with said liquid oil phase contained in the capillaries of said formation, whereby said injected aqueous liquid displaces said capillary formation water from the capillaries of said formation and also some of the liquid oil phase from the normally oil-occupied portion of the capillaries for a substantial region surrounding said well bore, thereafter displacing said injected aqueous liquid out of the normally oil-occupied portion of the capillaries of said formation in said region surrounding said well bore by injecting into said formation from said well bore a second liquid which is non-wetting with respect to the surfaces of the capillaries of said formation in an amount sufficient at least to saturate the normally oil-occupied portion of the capillaries of said formation in said region undergoing treatment, said second liquid being immiscible with said aqueous liquid and miscible with said liquid oil phase contained in said capillaries, discontinuing the injection of said second liquid and permitting said injected aqueous liquid to set up to a solid within said capillaries and thereafter producing petroleum from said formation via said well bore.

2. A method in accordance with claim 1 wherein the amount of said second liquid injected into said formation is substantially in excess of the amount of said aqueous liquid injected into said formation.

3. A method in accordance with claim 1 wherein said second liquid is injected into said formation at a pressure sufficient to force said second liquid into the normally water-occupied portion of the capillaries in the region undergoing treatment thereby increasing the oil permeability of the thus-treated region of said formation.

4. A method according to claim 1 wherein the formation is treated for at least about 10 feet radially outwardly from the well bore.

5. A method according to claim 1 wherein said formation in said region undergoing treatment is treated with a surface active agent to materially lower in the interfacial tension at the interface between the aqueous liquid and said second liquid.

6. A method according to claim 1 wherein said second liquid is liquid oil.

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