FIG. 1.

- WATER WET CASE
- OIL WET CASE

\[ \frac{u_0}{u_w} = 1 \]

FIG. 2.

- WATER WET CASE
- OIL WET CASE

\[ \frac{u_0}{u_w} = 10 \]
INCREASING PRODUCTION OF HYDROCARBONS

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The present invention is directed to a method for increasing the production of hydrocarbons such as oil and

gas. More particularly, the invention is concerned with increasing production of oil and gas from subsurface

earth formations. In its more specific aspects, the invention relates to a method for treating a well to increase the

permeability to oil of a sand packed fracture or barrier such that increased production of oil is obtained from the

well.

This application is a division of U.S. Serial No. 805,231 entitled "Increasing Production of Hydrocarbons" filed April 9, 1959, for John W. Graham, Joseph S. Osoba, and Patrick H. Monaghan.

The present invention may be briefly described as a method for fracturing a subsurface earth formation with oil containing a sand propping agent in which the sand propping agent is lodged in the resulting fractures to maintain them open. The feature of the present invention is rendering the sand propping agent water-wet whereby the permeability of the sand propping agent to oil is increased and increased production of oil is obtained.

The present invention is also directed to a method for forming a barrier of sand or finely divided particulate material around a well casing lining the wells of a borehole or around a screen and liner arranged in an unconsolidated horizon or zone from which formation sand is produced with the hydrocarbons. The barrier may suitably be formed in the well bore and the casing in a cavity formed by removal of sand with the produced well fluids or in a cavity produced by washing out the formation with fluid introduced into the well. The feature of the present invention is rendering the sand or finely divided particulate material water-wet prior to its being or after it has been formed into a barrier.

The sand propping agent or finely divided particulate material is rendered water-wet either prior to being lodged in the fractures or after it is lodged in the fractures.

There are various ways of practicing the present invention. In one mode of the present invention, the sand is wet with water by spraying it with water or immersing it in water such that each sand grain will have a coat of water which remains with it. The water-wet sand is then suspended in the oil which is to be used to form a barrier in the well or to fracture the subsurface earth formation and then the suspension of water-set sand and oil is pumped into a well which penetrates subsurface earth formations and is introduced or forced into the formation under a sufficient pressure when it is desired to fracture or crack the formation. As a result, the water-wet sand particles lodge in the formation or in the resulting fractures and serve to maintain them open such that oil may be produced from the formation through the open fractures. By virtue of the sand being water-wet, its relative permeability to oil is increased, thereby resulting in increased production of oil from the formation.

Another mode of practicing the invention involves wetting the sand with an aqueous solution of an anionic surface active or wetting agent which may contain sodium chloride. The water-wet sand is then suspended in an oil carrier vehicle and thereafter the suspension is pumped into a well penetrating the subsurface earth formation which is to be fractured under a sufficient pressure to lift the overburden and fracture or crack the particular subsurface earth formation which it is desired to fracture. As a result, the water-wet sand lodges and packs in the fractures to maintain them open and the water-wet sand is rendered more permeable to oil, allowing subsequent increased production of oil from the fractured formation.

In a still further mode of practicing the invention, a subsurface formation may be fractured with a suspension of sand propping agent in oil to fracture the formation and to lodge the sand propping agent in the resulting fracture. Thereafter, the fractures are treated with an aqueous or oily solution containing an anionic surface active or wetting agent to render the sand propping agent preferentially wettable by water. Thereafter, the treated sand propping agent is contacted with water which may be formation or produced water or may be water introduced through the well bore into the formation. As a result, the sand propping agent is water-wet and its relative permeability to oil is increased, allowing subsequent increased production of oil from the fractured formation.

In another and preferred method of practicing the present invention, a solution of water, anionic surface active agent, and sodium chloride is made up by agitation of water, surface active agent, and sodium chloride. Thereafter, sand in an amount of at least 0.1 pound per gallon of solution is added and the mixture is agitated and then allowed to stand for a period ranging from about one to about ten hours. The excess water is then removed from the sand and the water-wet sand is then dispersed into an oil carrier vehicle such as kerosene in an amount of at least one pound of wet sand per gallon of the oil carrier vehicle. The resulting suspension is then pumped under high pressure into a well against a formation to be fractured which causes the fractures of the formation and lodges the water-wet sand in the fractured formation. As a result, the relative permeability of the sand to oil is increased, allowing increased production of oil from the fractured formation.

As a modification of the preferred mode, a suspension of oil, sand, and anionic wetting agent may be formed and employed to fracture a selected earth formation penetrated by a well bore by pumping the suspension of oil and sand containing the anionic wetting agent into a well bore penetrating the selected formation under a pressure to cause fracturing of the formation and to cause the sand to lodge in the fractures and maintain them open. Thereafter, the sand is contacted with water which may either be produced water or water introduced from the borehole to contact the sand, thereby increasing the relative permeability of the sand in the fractures to oil such that subsequent production of oil increased amounts thereof are obtained.

As a still further modification of the present invention, the finely divided particulate material or sand is pumped or otherwise introduced into a well after being wet with water as a suspension in an oily vehicle. The suspension is introduced into a zone from which hydrocarbons are producible but which also is of such nature that substantial quantities of sand are also produced with the hydrocarbons such as oil or gas. The suspension of water-wet sand may be pumped down a casing well and out through perforations therein for lodgment back of the casing to form a barrier of water-wet sand around the casing to prevent production of sand from the production well. Under this mode of operation, pump pressures may be controlled to avoid imposing a fracturing pressure on the formation although both fracturing and formation of a barrier to prevent sand production may be performed simultaneously. Alternatively, the water-wet sand may be flowed as a suspension down the annulus between the...
borehole wall and the casing for deposition of the water-wet sand in sand and hydrocarbon productive zone. The water-wet sand may be dropped or dumped into the well for deposition into a barrier and thereafter the screen and liner may be washed down and arranged in the barrier.

The sand, when used for formation of a barrier in a well bore, may also be introduced down a tubing string or other pipe string either before or after being wet with water as described herein.

In the present invention where a barrier is deliberately formed to prevent sand being produced, it is now possible to remove the barrier without recourse to drilling operations since circulation of fluid, such as oil as a suspending medium, down the well and through the barrier may allow removal of the barrier.

This aspect of the present invention where a barrier is formed with the water-wet sand is quite important and useful in that many oil wells produce from unconsolidated or loosely consolidated sand formations or zones such that a considerable quantity of sand is produced or entrained in the well fluids such as oil and water. This entrained sand moving with the well fluids at the velocity thereof erodes pipes, connections, chokes, and pumps and deposits in tankage requiring frequent cleaning thereof with consequent removal from service.

In practicing the present invention, the sand or particulate material employed is usually round Ottawa sand having a mesh size (U.S. Sieve Series) in the range from about 10 to about 40 mesh. Equivalent sand to the round Ottawa may be used and different mesh size may be employed. For example, angular sand grains may be used and either angular or round sand having mesh sizes from about 10 to about 80 may be used. The sand may be between 20-40 mesh, 40-60 mesh, or 60-80 mesh or may be distributed over the range of mesh sizes. The 20 to 40 mesh will be preferred.

An amount of sand employed should be at least about 0.1 pound per gallon of the oil used as a suspending medium and/or as a fracturing liquid. Amounts of sand up to about 5 pounds per gallon oil may be used. For example, about 10,000 to 15,000 pounds of sand may be used for each 10,000 gallons of the fracturing oil.

The fracturing oil or the suspending vehicle for the sand may be a refined petroleum fraction such as gasoline or kerosene or may be gas oil or crude oil such as that found on the lease or a different crude oil. Under some situations, a reduced or topped crude may be used. It will be preferred, however, to use a refined oil.

The surface active or wetting agent is one of the anionic type, examples of which are the reaction product of tall oil and methyl taurine, a commercial product which is an anionic amine neutralized surfactant, alkyl aryl sulfonate such as marketed under the trade names of Tide, Chiffon detergent, and other anionic surfactant agents of a similar type. As examples of other anionic surfactant agents may be mentioned the salts of alkyl aryl sulfonates such as sodium xylene sulfonate, keryl benzene sulfonate, monobutyl biphenyl sulfonate, these sodium salts being commonly known as Naxionate G, Kreacon 64D, and Arscap 300, respectively. Alkyl sulfates such as Tergitol 08, which is the sodium sulfonate of 2 ethyl hexanol-1, may be used.

Other useful anionic surface active agents include the alkyl sulfonates such as Tergitol EH which is sodium sulfonate of 2 ethyl hexanol, Petrowet R and Duponol 199, both aromatic hydrocarbon sodium sulfonates, sulfonated amides, and amines as illustrated by Igepon TK-42, potassium N-methyl octyl taurate, Dianol N, and Sulframil DHL, both fatty amide sulfonates, sulfated, and sulfonated esters known to the trade as Nekal NS, triethyl sulfo-carbomate, and Triox X-200, an alkyl aryl sulfonate ester sulfonate. Where the metallic ion of the salt is not given, it is to be understood that the sodium salt is used. The amount of surface active agent employed may range from about 0.2 to about 5 percent by weight based on the water. A preferred amount may range from about 0.5 percent to about 2 percent by weight.

Inasmuch as introduction of water into a formation may cause formation damage due to swelling of interstitial clay, it is contemplated that sodium chloride may be included in the water used to treat the sand either before or after it is lodged in place. It is contemplated, therefore, that sodium chloride in an amount in the range from about 0.05 to about 5 pounds per gallon of water may be used. A preferred amount may range from about 0.1 to about 2 pounds per gallon of water.

The invention will be further illustrated by reference to FIGS. 1 to 4, which are graphs showing the relationship between the amount of oil in the produced fluid and the relative permeability to oil for water-wet and oil-wet sand columns.

The degree to which wettability influences oil permeability is seen more clearly if the relative permeability to oil is expressed as a function of the percent of oil in the flowing stream. The following relation makes the transformation:

\[ F = \frac{\mu_k}{K_w} \]

where

\[ F = \text{fraction of oil in the flowing stream} \]
\[ \mu_k = \text{relative permeability to oil} \]
\[ K_w = \text{relative permeability to water} \]

This was done for the two wettability conditions, water-wet sand and oil-wet sand, and for viscosity ratios of 1, 10, and 100. FIGS. 1 to 4 illustrate the results.

The dependence of oil permeability upon wettability at an oil-water viscosity ratio of 1 is shown in FIG. 1. The plot illustrates that:

1. The relative permeability to oil is greater when water is the wetting phase than when oil is the wetting phase if the oil in the produced fluid exceeds 50 percent. For example, if water is the wetting phase and the flowing stream contains 3 percent water (97 percent oil in produced fluids), the permeability to oil is 33 percent of the single-fluid value. On the other hand, if oil is the wetting phase, the permeability to oil is only 14 percent of the single-fluid value. Thus, at 3 percent water in the produced fluid, the water-wet condition gives an oil permeability 2.4 times greater than the oil-wet condition.

2. If the flowing stream contains less than 50 percent oil, both wettability conditions give about the same oil permeability.

FIGS. 2 and 3 show the effect of wettability on oil permeability when the oil-water viscosity ratios are 10 and 60. From these figures, it can be seen that an increase in the viscosity ratio sharply increases the range of flowing stream compositions over which the water-wet condition is desirable, i.e., gives a higher oil permeability than the oil-wet condition.

In many oil fields, the oil-water viscosity ratio is close to 1. However, there are other fields in which the ratio is much greater than 1. For example, one field in Texas has an oil-water viscosity ratio of about 60. If the oil production formation is fractured and contains sand which is oil wet, oil production for any stream composition and hence for the entire life of the field would be reduced.

In order to illustrate the invention further, a copper tube 153 cm. long and having a 1.11 cm. inside diameter was packed with 20 to 40 mesh round Ottawa sand. The column of sand was then saturated with distilled water and then two constant rate pumps, one delivering water and the other delivering oil, were used to conduct the steady state drainage and imbibition relative permeability data. After these data were obtained, they were interpreted as shown in FIG. 4, from which may be observed that the
oil permeability is always greater when water is the wetting phase. The invention will be further illustrated by reference to the following examples in which oil wells were hydraulically fractured employing the present invention. In these operations, wells in West Texas were fractured. In the first operation, 350 gallons of fresh water, 30 pounds of Tide, and 35 pounds of sodium chloride were agitated for ten minutes to form a solution. Thereafter, 10,000 pounds of 20 to 40 mesh round Ottawa sand was added to the solution and agitated for 30 minutes, following which the mixture was allowed to stand overnight. After standing overnight, excess water was drained from the water-wet sand and then the water-wet sand was dispersed in 10,000 gallons of refined oil and employed to fracture a selected formation. Following which the fractured formation was washed with brake crude.

Another similar fracturing operation was employed with water-wet sand excepting that 15,000 pounds of 20 to 40 mesh water-wet sand were used.

Another well in West Texas was treated in accordance with the present invention employing the following procedure. Ninety gallons of fresh water had eight pounds of Tide and eight pounds of sodium chloride added to it, which were agitated for fifteen minutes to form a solution. Twenty-five hundred pounds of 20 to 40 mesh sand were added to the solution and the mixture agitated for 30 minutes and allowed to stand overnight. The following morning, excess water was drained from the water-wet sand and the water-wet sand was then dispersed in 2,000 gallons of refined oil and pumped into the well to fracture a selected formation. The water-wet sand lodged in the fractures and the fractured formation was flushed with brake crude. As a result of this treatment, increased production was obtained.

An attempt was made in a well in the Gulf Coast of Texas to fracture the well and pack it with sand simultaneously using sand which had not been wet with water. This attempt was unsuccessful since flow of sand into the water-wet sand was flushed with brake crude. As a result of this treatment, increased production was obtained.

The water-wet sand was then employed to fracture the formation and form a barrier with the screen and liner in place.

The 10,000 pounds of water-wet sand as described supra in 9,820 gallons of 30° API gravity lease crude oil were used in the operation. After running in and placing sucker rods and pump, the well produced 105 barrels per day of oil with 6% salt water over an extended period of time which indicated high productivity for this successful operation in accordance with the present invention.

As stated previously, the sand may be wetted with the water prior to dispersal in the suspending or fracturing liquid. In this manner, each sand grain is coated with a film of water that protects the sand surface from becoming oil wet. However, wet sand is difficult to disperse in oil in that the sand grains become bonded together by water. Therefore, it is desirable to add an anionic interfacial tension-reducing agent to the water used to wet the sand and to cause preferential wetting of the sand with water.

In treating fractured formations which contain oil-wet sand, the fractured formation may be subjected to a treatment as follows:

1. Inject water containing about 10,000 p.p.m. of sodium chloride;
2. Inject lease crude containing about 2% of an anionic surface active agent; and
3. About thirty minutes after the treatment with the water contains an anionic surface active agent.

This method insures that water of suitably low salinity contacts the now water-wet sand.

The pressures employed to inject the water, the lease crude, and the second batch of water should be sufficiently low that new fractures are not created and existing fractures are not disturbed.

In such treatment, 1,000 gallons of water may be used followed by 2,000 gallons of the crude containing the anionic surface active agent and then followed by 2,000 gallons of the water.

As illustrations of the increased permeability of the sand to oil possible in the practice of the present invention, oil permeabilities caused by restoration of water wetness of 90%, 112%, 34%, and 78% have been obtained in other instances, increased permeabilities of as great or greater than the values reported were also obtained.

From the foregoing description and several examples, it will be clear that the present invention is quite advantageous and useful in that by the practice of the present invention increased and maximum recoveries of hydrocarbons such as oil and gas and the like may be obtained from fractured formations by insuring that the sand propping agent in the fractures is water-wet and therefore is provided with increased permeability to oil. Also, it is clear that the present invention prevents or suppresses sand flow from an unconsolidated zone into a well.

The invention is also advantageous in that the water-wet sand is pumpable and does not form packs or bridges across the well which resist removal from the well. In short, wetting of the sand renders it fluid which may increase the ease of fracturing and particularly the spotting of a body of sand into a selected zone where sand production is a problem. In one operation, it became necessary to stop the pumps while sand was being introduced. After about 45 minutes, it was found that the sand had not packed into an immobile mass and formed a bridge but had retained mobility, thus avoiding a sand removal job.

The nature and objects of the present invention having been completely described and illustrated, what we wish to claim as new and useful and secure by Letters Patent is:

1. A method for treating a well piercing an unconsolidated hydrocarbon-bearing formation with oil containing sand in which the sand is deposited in said well to form a barrier in said well adjacent said unconsolidated formation and wherein oil is produced through said barrier, the improvement which comprises wetting the sand with water whereby the permeability of the sand to hydrocarbon is increased and increased production of hydrocarbon from the unconsolidated formation through said barrier is obtained.

2. A method for increasing the production of hydrocarbon from an unconsolidated hydrocarbon-bearing subsurface earth formation pierced by a well which comprises wetting the sand, with water, admixing the water-wet sand with an oil carrier vehicle to form a suspension of water-wet sand in said vehicle and then introducing said suspension into said well and depositing said water-wet sand in said well to form a barrier in said well adjacent the unconsolidated subsurface earth formation and then producing hydrocarbon in increased amounts through said barrier.

3. A method in accordance with claim 2 in which the water contains an anionic surface active agent.

4. A method in accordance with claim 2 in which the water contains an anionic surface active agent and sodium chloride.

5. A method for increasing the production of oil from a subsurface earth formation pierced by a well in which
the well is lined with a casing perforated adjacent the subsurface earth formation which comprises introducing a suspension of oil and water-wet sand into said casing, flowing said suspension through the perforations in said casing to form a barrier around the perforated casing and then producing oil in increased amounts through the barrier into the perforated casing.

6. A method for increasing the production of oil from a subsurface earth formation pierced by a well in which the well is lined with a casing perforated adjacent the subsurface earth formation which comprises introducing a suspension of oil and sand into said casing, flowing said suspension through the perforations in said casing to form a barrier around the perforated casing, treating the barrier with an anionic surface active agent to render the sand in the barrier preferentially wettable by water, contacting the treated sand with water, and then producing oil in increased amounts through the treated barrier into the perforated casing.

7. A method for treating a well which comprises running in and setting a screen and liner in the well, introducing a suspension of oil and water-wet sand into said well, forming a barrier of water-wet sand from said suspension around said screen and liner and then producing oil through said barrier into said screen and liner.

8. A method in accordance with claim 1 in which the sand is wet with water prior to formation of said barrier.

9. A method in accordance with claim 1 in which the sand is wet with water after formation of said barrier.

10. A method in accordance with claim 2 in which a screen and liner is washed down and arranged in the barrier.

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