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COMBINATION IN SITU COMBUSTION-WATERFLOODING PROCESS

Philip H. Scott, Tulsa, Okla., assignor to Pan American Petroleum Corporation, Tulsa, Okla., a corporation of Delaware

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6 Claims. (Cl. 166—11)

The present invention relates to an improved method for conducting a waterflooding operation to recover oil from petroleum reservoirs. More particularly, it is concerned with a waterflooding procedure which takes advantage of the favorable oil recovery conditions produced by conducting a limited combustion process in the reservoir prior to the flooding step.

Specifically, my invention involves first injecting an oxygen-containing gas into one or several of a number of wells extending into a petroleum reservoir suitable for waterflooding operations. The remainder of the wells in which no air or oxygen-containing gas is injected are shut in. The injection step may be continued until pressures typically in the range of 500 to 3000 p.s.i. exist in the reservoir. Thereafter, the oil-containing formation is ignited in each of the air injection wells that is to be used as a water injection well. After ignition, the injection wells are opened to the extent required to establish a suitable flux resulting from the back flow of air through the formation and toward the injection well or wells. This results in the establishment of a combustion zone in the vicinity of the injection wells. The combustion front travels away from the injection well and out into the formation. When the air supply that has been packed into the reservoir is reduced to an extent such that it can no longer produce the required flux, the producing wells are opened and the flooding operation is begun. As far as operating conditions, e.g., water injection rates, etc., from this point on are concerned, they can be considered substantially equivalent to the procedures used in ordinary waterflooding methods.

As used in the present description and claims, the expression "petroleum reservoir" is to be construed as a reservoir in which a normal waterflooding operation can be carried out without prior treatment. In other words, the reservoirs contemplated by the process of my invention should have a minimum permeability of from about 5 to about 10 millidarcies. A further limitation in this regard concerns the reservoir temperature. Thus, such temperature should be sufficiently low to permit very little, if any, oxidation during the air injection step. In other words, in order to carry out the process of my invention, forward combustion during air injection should not occur. The maximum temperature that can be tolerated without the occurrence of forward combustion to an objectionable degree will vary with the type of hydrocarbons present. In general, however, reservoir temperatures of the order of 75° to about 100° F. can be tolerated without appreciable adverse effects.

I regard the nature of the reservoir subjected to the process of my invention to be a rather critical factor in the successful operation thereof. To secure the benefits of this invention, reservoir temperatures of the order of 800° to 1000° F., or higher, should be produced during the reverse burning phase. Such temperature, of course, cannot be reached by reverse combustion without the permeability and pressures required to produce a relatively high flux, typically 100 to 150 s.c.f.h. per square foot.

One of the outstanding advantages of the process of my invention is the increase in displacement and sweep efficiencies it provides. The steam generated by contacting the flood water with hot reservoir rock penetrates the pores

of the rock much more thoroughly than does liquid water, and also tends to flow over a greater area. The steam bank thus formed not only heats the oil to reduce its viscosity, thereby rendering it more readily recoverable, but also volatilizes the lighter hydrocarbons in the oil carrying them on ahead and ultimately redepositing them in reservoir oil which, in turn, is substantially reduced in viscosity. As a result of the increase in sweep and displacement efficiencies, increased oil recoveries can be realized. Thus, oil recoveries obtained by ordinary waterflooding after the reservoir has been depleted by primary methods, generally are of the order of 20 to 25 percent, based on the oil originally in place. By the substitution of my invention for conventional waterflooding, however, I am able to secure on the same basis recoveries of from about 40 to about 75 percent, representing an increase in recovery of from about 100 to about 125 percent over that obtainable by former flooding methods.

The rate of travel of the steam bank through the reservoir, and the duration of its existence therein depend upon a number of factors. For example, the speed at which such a bank passes through the reservoir is a function of permeability which, in turn, controls the water injection rate. These factors also have a direct effect on the rate of attrition of the steam bank, as such. Thus, while heat losses, for the most part, in operations of this kind may be considered relatively insignificant, the steam will eventually dissipate its heat to the overburden and condense. It is important, however, to maintain this bank intact as long as possible during its travel toward the producing well. This object can ordinarily be accomplished if the reservoir has a sufficiently high permeability to permit the steam bank to travel at a relatively rapid average rate, for example, 1 to 10 feet per day. A factor generally favoring the maintenance of the steam bank is that the reservoir pressure decreases as the producing well is approached, thus permitting steam to exist even at the lower temperatures encountered near said well. In fact, sufficient heat is contained in the reservoir around the producing well that the water is removed from the formation substantially at its boiling point. A still further advantage of the process of my invention concerns its application in reservoirs containing high API gravity oil, e.g., above 30 gravity. Thus, if forward combustion were attempted in such reservoirs it would not be successful because the boiling points of the majority of the hydrocarbons are so low that the reservoir rock cannot be raised to a temperature level sufficient to sustain combustion. In other words, the low boiling points of such materials prevent the accumulation of the necessary heat to maintain burning. On the other hand, since reverse combustion can proceed at much lower temperatures than forward combustion requires, these lighter hydrocarbons can be swept out of that portion of the reservoir affected by reverse burning and into the well into which air was originally injected.

The procurement of high watre injection rates is made possible by the fact that the reverse combustion step carried out prior to flooding renders the formation extremely permeable throughout the burned area. It should be pointed out that the length of the burned area obtained prior to waterflooding corresponds to from about 10 to 25 percent of the distance betwen injection and production wells. These values are based on the observation that, for a given volume of reservoir rock at about the peak temperature produced during reverse combustion, such volume of rock can convert into steam from about 4 to about 10 volumes of water. It should also be pointed out that by heating the reservoir via reverse combustion before waterflooding instead of using forward combustion methods for this purpose, there is no tendency for combustion products to condense between the combustion

zone and the producing well, causing a reduction in formation flow capacity, as is true in the case of forward combustion.

The well pattern used in carrying out the process of my invention may, if desired, be similar to that frequently employed in conventional waterflooding operations such as, for example, 5-spot or 9-spot patterns. The distance between wells, in general, varies with the depth of the reservoir, the spacing being closer where the zone to be flooded is shallow, i.e., under about 3000 feet. Air injection is effected preferably via the central well with the perimeter wells shut in. After the reverse burning step, as previously outlined, the perimeter wells are opened and waterflooding is commenced.

I have found that the duration of the reverse burning step at a flux sufficiently high, e.g., 100 s.c.f.h. per square foot, to produce reservoir temperatures in excess of about 700° F. depends upon a number of factors such as reservoir permeability, ultimate reservoir pressure, i.e., prior to burning but after air injection, injection time, etc. The influence of these conditions on reverse combustion performance is illustrated in the table below:

Table

Permeability (md.)	Number Hours Burned After Ignition [1]	Initial Reservoir Pressure, P.s.i.a.	Injection Time (hours) at 1.8 M M s.c.f.d./ft.	Reservoir Pressure After Air Injection, p.s.i.a.
25	26	200	100	470
25	35	316	100	565
25	72	707	100	840
50	46	316	100	460
50	52	316	500	545
50	56	316	900	575
50	117	707	100	775

[1] At a flux of s.c.f.d./ft.

From an inspection of the above table, it will be seen that permeability and initial reservoir pressure are two of the most important conditions required to obtain long reverse combustion periods. At a given permeability the number of hours burned at a constant flux, the burning time is practically a linear function of the initial reservoir pressure. It will also be seen that, while the period of injection has some favorable effect on the time reverse burning can be carried out at a given flux and reservoir permeability, the length of such period is probably the least important of the conditions listed.

While in the foregoing discussion I have stressed the applicability of water in obtaining the advantages of my invention, there are other variations contemplated to be within the scope thereof. For example, instead of performing a conventional waterflood after reverse combustion I may inject only enough water so that it will be present in slight excess over that required to form a steam bank of suitable size. Thereafter, the unvaporized water can be driven by a gas, preferably one that contains little or no oxygen such as natural gas. In this manner the steam bank is moved through the reservoir by a bank or band of water which is, in turn, driven by gas.

I claim:

1. In a process for the recovery of petroleum from a reservoir by driving said petroleum with water, said reservoir being penetrated by an injection well and a production well, the improvement which comprises:

first shutting in said production well,

injecting an oxygen-containing gas into said reservoir via said injection well until the pressure of said gas in said reservoir is at least about 500 p.s.i.; but less than that required to cause uncontrolled fracturing thereof,

thereafter igniting the petroleum in said reservoir at the face thereof in said injection well to form a combustion front,

next allowing said gas to backflow through said reservoir and into said injection well causing said front to move away from said injection well and countercurrently to said backflow, said backflow being at a flux sufficient to produce a reservoir temperature of at least about 700° F.,

opening said production well when said backflow falls below said flux,

flooding said reservoir by adding water thereto via said injection well whereby a portion thereof is converted into steam resulting in driving petroleum through said reservoir toward said production well, and recovering oil from said production well, the heat in said reservoir resulting from the above-mentioned combustion step being sufficient around said producing well so that water flows into said producing well substantially at its boiling point.

2. The process of claim 1 in which the oxygen-containing gas is air.

3. In a process for the recovery of petroleum from a reservoir by driving said petroleum with water, said reservoir being penetrated by an injection well and a production well, the improvement which comprises:

first shutting in said production well,

injecting an oxygen-containing gas into said reservoir via said injection well until the pressure of said gas in said reservoir is at least about 500 p.s.i.; but less than that required to cause uncontrolled fracturing thereof,

thereafter igniting the petroleum in said reservoir at the face thereof in said injection well to form a combustion front,

next allowing said gas to bacflkow through said reservoir and into said injection well causing said front to move away from said injection well and countercurrently to said backflow, said backflow being at a flux sufficient to produce a reservoir temperature of at least about 700° F.,

opening said production well when said backflow falls below said flux,

adding water to said reservoir via said injection well, said water being added in slight excess over that required to form a steam bank whereby a major portion of the injected water is converted into steam, thereafter injecting a substantially oxygen-free gas into said reservoir via said injection well to drive said steam bank toward said production well, and recovering oil from said production well.

4. The process of claim 3 in which the oxygen-containing gas is air.

5. The process of claim 4 in which the oxygen-free gas is natural gas.

6. The process of claim 4 in which the oxygen-free gas is a substantially inert gas.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,131,761 May 5, 1964

Philip H. Scott

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 56, for "watre" read -- water --; column 3, line 36, the footnote to the Table, for " [1]At a flux of s.c.f.d./ft." read -- [1]At a flux of 100 s.c.f.d./ft.[2]. --.

Signed and sealed this 8th day of September 1964.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents