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THERMAL OIL STIMULATION PROCESS

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ABSTRACT OF THE DISCLOSURE

An oil stratum around a well is opened up to increase oil flow and oil is produced therefrom by driving a combustion zone from adjacent the well radially into the stratum, followed by injection of water and injection of inert gas, sequentially, and thereafter opening up the well to flow of fluids, including oil.

This invention relates to a process for producing oil from an oil-stratum penetrated by a well and opening up the stratum around the well to improve flow of oil at temperatures which are not deleterious to the downhole equipment, including casing and tubing.

The exposure of casing and tubing in production wells to temperatures in the range of 400 to 550° F. and higher has resulted in cracking, parting, and other detrimental effects on the steel casing as well as cement damage. This condition has been encountered in the so called "huff-puff" steam injection technique, causing shutdown and the need for removing and replacing the casing. Under such conditions, the increases in production costs are obvious. In a "huff-puff" fire flood operation, the in situ burning produces temperatures of the order of 1000° F. Such a process is disclosed in the copending application of J. C. Trantham, S.N. 408,157, filed Nov. 2, 1964, now Patent 3,332,482, issued July 25, 1967. It has been found that the produced oil flowing into the injection and production well following the burning phase of the operation raises the temperature of the casing and tubing to substantially higher temperatures than 400° F., is detrimental to the casing and tubing, and results in severe coking.

This invention is concerned with an improved method of operation, using in situ combustion and flow back into the injection well which avoids overheating the casing and downhole equipment and minimizes coking.

Accordingly, it is an object of the invention to provide an improved "huff-puff" in situ combustion or fire flood process for producing oil and/or opening up the stratum around a production well in a reservoir under substantial original pressure. Another object is to provide a process for producing oil from an oil stratum by in situ "huff-puff" which avoids overheating of the downhole casing and tubing and minimize coking of oil in the stratum. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises initiating in situ combustion in an oil stratum around a well therein, driving the resulting combustion zone radially away from the well a substantial distance such as 5 to 30 feet, preferably 10 to 25 feet, by air injection, thereafter terminating air injection, injecting a substantial slug of water thru the well into the burned out zone so as to effect partial cooling thereof, thereafter injecting behind the water a substantial slug of a cool inert gas such as flue gas, and thereafter opening the well to flow so that the pressure within the stratum produces the more fluid oil resulting from the heating operation. Permeability of the stratum around the well is substantially increased due to complete burnout of carbonaceous material and to fracturing induced by the high temperatures (900° F.+). By injecting a substantial slug of water into the hot stratum in the burned out zone, this zone is cooled substantially and resulting steam is forced deeper into the stratum from the well, this hot zone being further extended by the injection of cool combustion or flue gas which also adds to the cooling effect of the operation and reduces water saturation around the wellbore. Sufficient water and cooling gas are injected to reduce the temperature of the backflowing fluids, including oil, to not substantially more than 400° F.

In addition to reducing temperatures to a level relatively safe for producing equipment and less conducive to coking in the burned out zone, the injected fluids provide a number of additional benefits. Heat displaced into the unburned reservoir lowers the viscosity of the reservoir oil, thereby facilitating its flow to the production well. Carbon dioxide present in the injected gas and formed in the burning operation is dissolved in the reservoir oil, further reducing this viscosity as well as inducing swelling of the oil. Nitrogen present in the gas from both the injected air and the injected combustion gas is not absorbed but fills available pore space farther back in the reservoir thereby providing additional expulsive energy for the reduced viscosity oil closer to the production well when backflow is initiated.

The process is particularly advantageous when applied in thin, heavy oil reservoirs where injected water and exhaust gas volumes required for heat transfer are not prohibitively large, and viscosity reduction benefits are the most pronounced.

A preferred method of igniting the oil stratum around the injection-production well comprises injecting a substantial slug of an autoignitible liquid fuel, preferably containing an oxidation catalyst, into the stratum thru the well and contacting the slug within the stratum with air or other O_2-containing, combustion-supporting gas (diluted or enriched air). The use of autoignitible fuels in initiating in situ combustion in an oil stratum is disclosed in the copending application of F. A. Klein and M. R. Dean, S.N. 559,804, filed June 23, 1966, now Patent 3,400,763, issued Sept. 10, 1968. Such autoignitible fuels include tung oil, linseed oil, red oil, castor oil, turpentine, tall oil, tall oil fatty acids, oleic acid, linseed oil fatty acids, and mixtures thereof. It is preferred to incorporate in the fuel a concentration of oxidation catalyst in the range of 0.025 to 1.0 weight percent of the fuel. Liquid oxidation catalysts are preferred and a representative member of this class is cobalt naphthenate.

The amount of igniter oil to be injected depends upon the thickness of the stratum being ignited and is usually in the range of about 10 to 50 gallons of the fuel per foot of stratum thickness. To minimize the possibility of wellbore fires and to safeguard against high wellbore

temperatures during ignition, it is preferred to follow the igniter oil with a small slug (on the order of 1 bbl.) of a liquid hydrocarbon (preferably diesel fuel) miscible with the igniter oil and to displace it into the stratum surrounding the well by injecting a slug of inert gas prior to initiating combustion in the stratum.

After a combustion zone has been initiated and propagated the desired distance into a stratum by direct-drive air injection, a volume of water is injected sufficient only to reduce the temperature of the burned zone to a temperature close to, but still above that of saturated steam at the pressure existing within the stratum. The amount of water to be injected is so minimized in order to avoid creating an excessive water saturation around the wellbore, and will vary both with stratum pressure and the burned zone volume and temperature as estimated from known reservoir fuel availability and the amount of injected air. For a combustion zone driven a radial distance in the range of about 10 to 25 feet from the well, the amount of water injected is in the range of 5 to 50 barrels per foot of stratum thickness. Following injection of the water slug, a volume of cool combustion gas is injected sufficient to displace the resultant steam from the burned-out zone and disperse it as condensate deeper in the stratum, and, if necessary, to further reduce burned zone temperature from saturated steam temperature to a safe backflow level (400° F. or less). Dispersion of steam from the burned zone both reduces water saturation around the wellbore, and has the advantageous effect of fluidizing more of the oil deeper in the stratum for production during backflow. The amount of combustion gas to be injected will also vary with the temperature of saturated steam at stratum pressure and with the burned zone volume. The minimum amount to be injected will be the equivalent of one burned zone pore volume (measured under stratum conditions of pressure and temperature) in cases where the saturated steam temperature is 400° F. or less. In cases where the saturated steam temperature is substantially above 400° F. (stratum pressures substantially greater than 250 p.s.i.a.), sufficient gas is injected so that the amount of heat removed from the burned zone by convection coupled with conductive heat losses during its injection will result in a burned zone temperature of 400° F. or less.

In reservoirs in which substantial pressure exists such as 500 to 1500 p.s.i., only one burning and backflow phase of the operation may be necessary. Under such circumstances the opening up of the reservoir or stratum in the burned-out annulus extending 5 to 30 feet from the well provides sufficiently increased flow rates of oil from the natural reservoir pressure to effect good continuous production from the surrounding stratum. In reservoirs in which the pressure is insufficient to produce oil at a satisfactory rate even with the opening up of the stratum immediately surrounding the well, the in situ combustion and backflowing steps are repeated as many times as the operation warrants based upon the oil produced during the backflow step. By operation in this manner (repeated cycles of burning and backflow) around different wells in a pattern, it is advantageous eventually to drive a direct-drive combustion front or zone from one well to another or to a plurality of wells. To illustrate, when operating in a pattern including a central well and a ring of wells, after repetition of the process around each of the wells a direct combustion drive from either the center well to the ring wells or from the ring wells to the central well produces most of the remaining oil in the pattern. Similar procedure is effective between parallel lines of wells.

It is significant that the cooling steps (water and inert gas injection) following the in situ combustion has considerable advantage in addition to the lowering of the temperature of the backflowing fluids. In conventional "huff-puff" fire flood, the backflowing oil from beyond the combustion zone passes thru the hot burned-out area which is at a temperature of above 900° F. and up to 1100° F. so that substantial coking of the produced oil takes place. This results in less oil production and also has the effect of materially decreasing the permeability of the stratum thru which the combustion zone passed.

The following example is presented to illustrate the invention without unduly limiting the same.

In applying the "huff-puff" in situ combustion operation of the invention to an oil reservoir at a depth of about 2400 feet and having a thickness varying from about 12 to 20 feet and an oil gravity of 16 to 18° API, a formation temperature of 111° F., and a reservoir pressure of 750 p.s.i.g., 6.7 barrels (280 gallons) of catalyzed ignitor oil (nine volumes of tung oil to one volume of tall oil fatty acids containing cobalt naphthenate) is injected thru a well penetrating the stratum followed by 0.5 barrel (21 gallons) of diesel fuel and displaced into the stratum with combustion gas. Air is injected for 24 hours (150,000 standard cubic feet) and the well is closed in for determining bottom hole temperature to be sure that ignition has been effected. Air is then injected into the ignited stratum to burn out to a 10-foot radius from the well. The air injection rate during the burnout is about 150 M s.c.f. per day and the total air required is approximately 700 M s.c.f. Preparation for backflow at the end of the burning phase of the operation comprises injecting approximately 60 barrels of water followed by injection of flue gas (88% N_2 and 12% CO_2 by volume). After a 5-day period of inert gas injection at a rate of about 150 M s.c.f./d., backflow is initiated, the backflowing fluids are produced at a temperature of about 400° F. This operation greatly increases the permeability of the stratum in the 10-foot radius around the production well.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

I claim:

1. A process for producing oil from an oil stratum penetrated by a well, opening up the stratum around the well to improved flow, and avoiding overheating of casing and downhole equipment in said well, which comprises the steps of:

(a) igniting said stratum adjacent said well;

(b) injecting an O_2-containing, combustion-supporting gas thru said well into the ignited area to drive a combustion zone radially into said stratum a substantial distance at a pressure substantially above normal stratum pressure;

(c) thereofter, injecting a substantial slug of water thru said well into the hot burned out zone to substantially reduce the temperature in said zone, form a substantial steam slug, and drive a resulting hot zone more remote from said well;

(d) thereafter, injecting a slug of cool inert gas thru said well into said stratum so as to drive said steam slug more remote from said well and extend said hot zone further into said stratum, reduce the water saturation around said well, and further cool said zone; and

(e) thereafter, opening said well to production so as to allow stratum pressure to force fluids from said stratum into said well.

2. The process of claim 1 wherein cooling in steps (c) and (d) is regulated so as to produce fluids in step (e) at a temperature not substantially above 400° F.

3. The process of claim 1 wherein step (a) comprises injecting a slug of an autoignitible liquid fuel containing an oxidation catalyst into said stratum thru said well and contacting said slug within said stratum with an O_2-containing, combustion-supporting gas.

4. The process of claim 1 wherein the slug of inert gas is combustion gas.

5. The process of claim 1 wherein the volume of water introduced in step (c) is sufficient only to reduce the temperature of the burned zone resulting from step (b)

to a temperature close to but above that of saturated steam at the pressure existing within said stratum.

6. The process of claim 5 wherein the amount of said inert gas introduced in step (d) is at least the equivalent of one burned zone pore volume.

7. The process of claim 5 wherein the amount of said inert gas introduced in step (d) is sufficient to reduce the temperature of said burned zone to a value not greater than about 400° F.

8. The process of claim 5 wherein said combustion zone is driven out from said well in step (b) a distance within the range of about 10 to about 25 feet, and the amount of water injected in step (c) is in the range of about 5 to about 50 barrels per foot of stratum thickness.

References Cited

UNITED STATES PATENTS

2,863,510	12/1958	Tadema et al.	166—38
3,171,482	3/1965	Simm	166—39
3,180,412	4/1965	Bednarski et al.	166—11
3,332,482	7/1967	Trantham	166—2
3,363,687	1/1968	Dean	166—38 X
3,376,929	4/1968	Hagedorn	166—2 X

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