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HEAT TRANSFER PETROLEUM RECOVERY PROCESS

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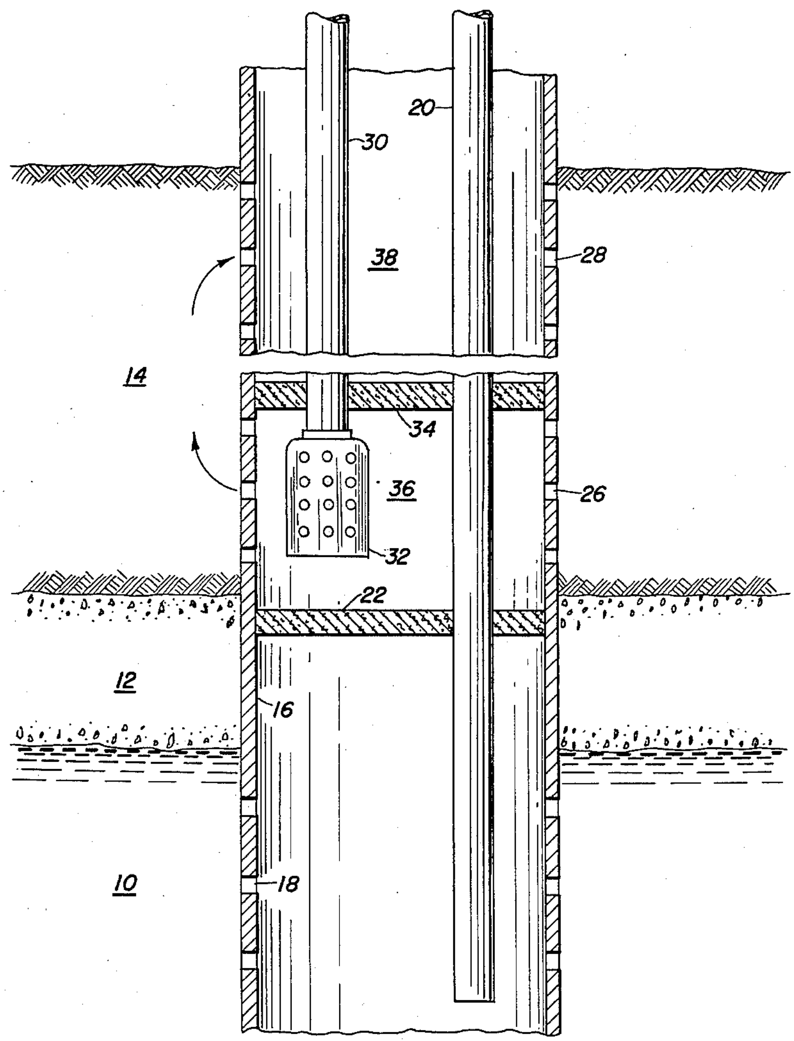

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HEAT TRANSFER PETROLEUM RECOVERY PROCESS

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This invention relates to a novel in-situ combustion process for increasing the rate of production from petroleum wells. The method of this invention is applicable to increasing the production of petroleum from formations subject to plugging by waxy, petroliferous deposits which form in the formation rock surrounding the well-bore.

In certain oil reservoirs, non-viscous crude oils are produced which contain large amounts of wax. Under virgin reservoir conditions the wax is contained in solution in the reservoir fluid. When the reservoir is produced through a well, wax deposits in the formation rock surrounding the well, and eventually plugs the formation. The flow capacity of such formations is reduced to a very low value. Fracturing the well through the region where the wax has formed temporarily alleviates the situation, but wax deposition continues in the rock surrounding the fractures, and plugging again occurs.

It has been proposed to clear such wells by disposing heaters in the well-bore adjacent to the plugged formation, the heaters being supplied with air and a gaseous fuel. Such methods have not been very satisfactory because of the inability of the heat produced to satisfactorily penetrate the formation countercurrent to the direction of petroleum flow and melt the waxy deposits. The amount of heat produced by the burners must be closely regulated or the temperature in the well-bore may rise to a point deleterious to the down-hole equipment. Over a period of time, even moderately high temperatures result in destruction of down-hole equipment. It has further been proposed to institute in-situ combustion in paraffin-plugged formations. The formation wall is heated to a high temperature by means of a down-hole well-bore heater, and then a free-oxygen-containing gas is injected into the formation to maintain combustion of the combustible formation constituents. While such methods are effective for the removal of wax deposits from the formation surrounding the well-bore, the flow of oil to the well-bore is necessarily seriously disrupted, and it is frequently difficult to restore the treated well to normal production. Moreover, after the well-bore is returned to production and the temperature drops by conductive heat transfer to about normal formation temperatures, wax again deposits and production must again be interrupted so that the well may be treated.

In some instances, where waxy oils are produced from a petroleum-containing stratum, it is found that a sub-adjacent or super-adjacent stratum exists which is permeable, but is separated from the petroleum-producing stratum by an impermeable layer of rock. Where the permeable super-adjacent or sub-adjacent formation contains quantities of non-commercial combustible materials, it has been proposed to initiate in-situ combustion in such strata, and propagate a flame-front through the stratum between injection and outlet wells. In this manner, heat may be transferred through the impermeable layers to the petroleum producing formation, so that the temperature of the petroleum is raised and the viscosity reduced. While such treatments have been helpful in some circumstances, they are not well adapted to preventing wax deposits adjacent to the producing well because the flame-front in the adjacent stratum remains in the zone of the petroleum-producing well-bore only for a short time, and

is propagated outward through the stratum so that heat transferred through the impermeable layer is for the most part not effective for melting waxy deposits adjacent to the producing well-bore. It is in the zone immediately surrounding the producing well that reduction of permeability due to wax deposits is critical, since it is here that the rate of flow of oil is necessarily the highest. Moreover, that petroleum which is effectively heated cools as it passes through the formation rock from the location at which the flame-front resides.

It is an object of this invention to provide an improved method of in-situ combustion by which heat can be liberated in a super-adjacent or sub-adjacent fuel-containing stratum and transferred through an impermeable rock layer to a producing formation surrounding an oil-producing well, whereby viscous petroleum deposits can be effectively melted and the rate of petroleum production increased.

This invention can best be described with reference to the drawing, which shows in section a petroleum reservoir which is penetrated by a well-bore. The reservoir comprises a petroleum-producing stratum 10, and impermeable layer 12, and a permeable stratum 14 which contains non-commercial, 600-B.t.u.-per-cubic-foot natural gas. To be susceptible to treatment in accordance with this invention, the reservoir must have an impermeable layer with a thickness within the range of about 5 to about 50 feet and a permeability which is preferably less than about 0.01 millidarcy. The porous, gas-containing stratum preferably has a thickness in the range of about 10 to 100 feet, and a permeability which is preferably in excess of about 5 millidarcies. The well casing 16 is perforated at 18 to communicate with the petroleum-producing zone 10. Oil-producing tubing string 20 extends through the well-bore to a point adjacent to perforations 18. A packer 22 is set at the impermeable layer 12 to isolate the portions of the well-bore lying above and below the impermeable layer. The casing is perforated at 26, adjacent to the lower extremity of the gas-containing stratum 14, and is also perforated at 28 adjacent to the upper extremity of the gas-containing stratum 14. In this manner, communication is established between the well-bore and the lower portion of the gas stratum through perforations 26, and between the well-bore and the upper portion of the gas stratum through perforations 28. A second tubing string 30 is also disposed within the well-bore. This tubing string terminates at burner 32, which is positioned adjacent to perforations 26. A second packer 34 is placed within the well-bore, between the perforations 26 and 28, to isolate a well-bore zone 36 which lies between packers 22 and 34, and an upper well-bore zone 38 which lies above packer 34.

Combustion in the gas-producing stratum 14 may be instituted in a conventional manner, by supplying a combustible mixture of gas and air to the burner 32 by way of tubing string 30. While the temperatures within the well-bore during the period in which in-situ combustion is initiated will be undesirably high, these temperatures need be maintained for only a relatively short period of time. After combustion has been initiated, by means of the burner 32 as described, or alternatively by other techniques well known in the in-situ-combustion art, the flow of gaseous fuel to tubing string 30 is terminated, and air, or other combustion-supporting gas, is pumped down tubing string 30, through burner 32, and into the lower portion of gas-containing stratum 14. Combustion products and unreacted nitrogen from the injected air are exhausted to well-bore zone 38 through the perforations 28, and then flow upward through the well-bore in heat-exchange relationship with tubing strings 20 and 30. Heat transfer from the partially cooled flue gases to the produced oil in tubing string 20 eliminates the waxy deposits within tubing string 20, and heat transfer to air pumped downward in tubing string 30 serves to preheat the air before injection into the gas-containing formation 14.

Natural gas in stratum 14 migrates towards the low-pressure zone at the well-bore, and would seek an outlet through the perforations 28 but for the injection of combustion-supporting air into the stratum through perforations 26. In this manner, a combustion flame-front can be maintained in the formation within a short radial distance outward from the well-bore, without causing the flame-front to be propagated through the formation. The flow of gaseous fuel is constantly towards the location of the flame-front, and the front itself is static. Outlet for the combustion products is provided as aforedescribed.

It is evident that by the method of this invention the zone of burning can be maintained within relatively close proximity of the well-bore, preferably within about 30 feet of the well-bore. Heat transferred downward through the impermeable layer 12 is applied to the producing formation at the zone of critical pressure-drop, where viscous petroleum deposits are a severe problem. The waxy deposits are melted and move along with the produced petroleum to the well-bore, and then flow to the surface of the earth through tubing string 20. It is evident that production of oil can be continued uninterrupted throughout the duration of the combustion process, which is preferably substantially coextensive with the productive life of the petroleum reservoir.

It also is evident that it is necessary to miantain the rate and pressure of oxygen-containing gas injection within reasonable limits. Excessive injection rate will result in an advance of the flame-front away from the well-bore, so that heat will be produced at a point undesirably remote from the well-bore, and the amount of heat then available to melt waxes deposited in the producing formation in the zone immediately around the well-bore will be reduced. On the other hand, too low an injection rate may result in back-burning to the well-bore, with the accompanying danger of explosion or injury to down-hole equipment by excessive well-bore temperatures. While the correct rate and pressure of injection will vary from reservoir to reservoir, depending upon the size of the natural-gas-containing stratum, the quantity, pressure, and calorific value of the gas contained within the reservoir, as well as the number of exhaust perforations 28 provided above the packer 34, it is possible to provide the correct injection rate from an analysis of the flue gases produced through the well-bore annulus. A large excess of unreacted oxygen in the flue gases indicate that excessive quantities of air are being injected, and the flame-front is progressing outward away from the well-bore. On the other hand, the production of unburned natural gas along with the flue gases indicates that insufficient air is being injected and that the fire in the formation is limited to the immediate vicinity of the perforations 26. The absence of large amounts of unreacted oxygen or unburned natural gas in the combustion products indicates a proper air injection rate. The injection pressure should be adjusted to maintain this rate throughout the life of the reservoir. In general, as the pressure of the natural gas declines, the injection pressure may be reduced.

As a specific example of the method of this invention, a petroleum-producing reservoir in which production has declined due to the accumulation of wax deposits in the formation adjacent to the well-bore is treated by in-situ combustion. Above the oil-producing stratum lays an impermeable layer having a thickness which varies from 10 to 25 feet. Above this impermeable layer lays a permeable stratum of Mississippian rock containing non-commercial 600-B.t.u.-per-cubic-foot natural gas. The initial gas pressure is 1000 pounds per square foot. A packer is set adjacent to the impermeable layer to separate and isolate the portions of the well-bore lying above and below this layer. A tubing string terminating in a gas burner is lowered to a point a short distance above the impermeable layer, and a packer is set above the burner to separate an injection well-bore zone around the burner, and an exhaust well-bore zone above the burner and second packer. A combustible mixture of gas and air is pumped down the tubing string to the burner and combustion in the burner is instituted. Combustion is maintained for a period of 15 hours, during which time the gas-containing formation rock surrounding the well-bore is heated to ignition temperatures; thereafter, the passage of gas to the burner is terminated, and air is injected through the tubing string leading to the burner at a pressure of 1275 p.s.i. and a rate of 500 cubic feet per hour. Combustion is maintained in the formation surrounding the well-bore, and combustion products re-enter the well-bore above the second packer. The combustion products flowing from the well-bore to the atmosphere are analyzed, and found to contain free oxygen in the amount of about 20% of the injected oxygen. The injection pressure is reduced to 1200 pounds per square inch, and the injection rate thereupon drops to 400 cubic feet per hour. After the lapse of two hours, the flue gases are again analyzed and found to have a free oxygen content of 3%. The injection pressure and rate are maintained, and petroleum is produced at gradually increasing rates from the underlying petroleum-containing stratum.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows.

We claim:

1. In the recovery of oil through a well-bore penetrating a subterranean reservoir, comprising an oil producing stratus, a combustible-gas-producing stratus vertically spaced therefrom, and a substantially impermeable stratum lying between said producing strata, wherein viscous deposits of petroliferous material form in and plug the oil-producing stratum around said well-bore, the improvement comprising isolating zones of said well-bore adjacent to said oil-producing and gas-producing strata from each other, initiating combustion of gas in said gas stratum, maintaining combustion in the gas stratum near to said well-bore by the injection of a free-oxygen-containing gas from said well-bore into a portion of said gas stratum near one vertical extremity thereof, venting combustion products to said well-bore from a portion of said gas stratum near the other vertical extremity thereof and producing oil from said oil producing stratum through said well-bore.

2. The method in accordance with claim 1 in which said oxygen-containing gas is air.

3. The method in accordance with claim 2 in which the quantity of air injected is adjusted to produce combustion products substantially free of excess unreacted oxygen and combustible gas.

4. The method in accordance with claim 1 including the steps of perforating the well casing adjacent to said portions of the gas-producing stratum, and placing a packer in the well-bore between the said portions to isolate two well-bore zones, one zone being adjacent to each of the said portions.

5. The method in accordance with claim 3 wherein the well-bore contains an oil-producing tubing string and air-injection tubing string, and combustion products are exhausted through the well-bore externally of the tubing strings in heat-exchange relationship therewith.

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