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IN-SITU COMBUSTION PROCESS FOR THE RECOVERY OF OIL

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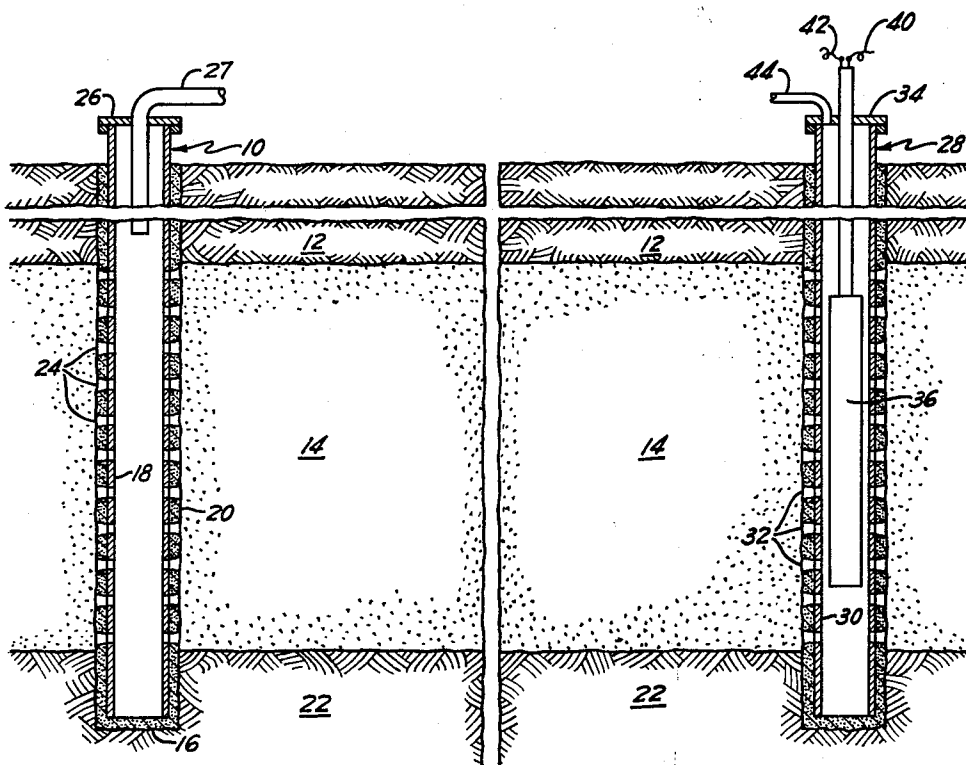


Fig. 1

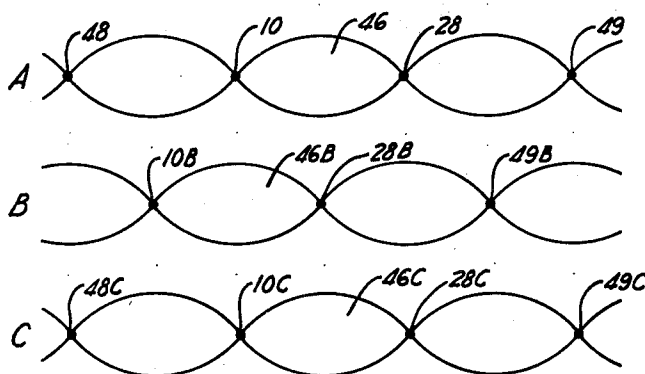


Fig. 2

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IN-SITU COMBUSTION PROCESS FOR THE RECOVERY OF OIL

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This invention relates to the production of oil and more particularly to a secondary recovery process for producing oil from unconsolidated formations.

One of the secondary recovery processes used to increase the amount of oil produced from oil-bearing formations is the in-situ combustion process. In the conventional in-situ combustion process, an oxygen-containing gas, usually air, is injected into the pay zone at an injection well, and oil in the formation is ignited at that well. A combustion front moves through the pay zone from the injection well to an adjacent production well. The heat and gases released by the burning of oil in the formation reduce the viscosity of the oil and the increased pressure resulting from the injection of gas into the formation drives the oil through the formation to the production well.

The conventional forward burning in-situ combustion process suffers disadvantages which in many instances prevent its use or the production of oil at rates sufficient to justify the continued production of oil from the field. The radial flow pattern from a well makes necessary high velocities through the formation immediately adjacent to the injection well if satisfactory production rates are to be obtained. At least during the early stages of the operation, the oil pushed ahead of the combustion front is cold and viscous. The resistance to flow, particularly at the high rates near the well is, consequently, very high. If the permeability of the formation is low, the oxygen-containing gas sometimes cannot be injected at a rate sufficient to maintain the combustion. Immediately ahead of the combustion front is a three-phase mixture of oil, water, and gas, which further increases resistance to flow through the formation.

It has been suggested that the formation be hydraulically fractured before the in-situ combustion process is performed. In this manner the permeability of the pay zone can be greatly increased and the resistance to flow during the initial stages of the in-situ combustion process can be greatly reduced. However, many unconsolidated formations, particularly those which are relatively young geologically, are extremely difficult to fracture, and are especially difficult to fracture at a desired depth and in a controlled direction. Upon release of the pressure on the fracturing fluid, the unconsolidated formations frequently embed the propping agent and close the fracture.

This invention resides in a process for the secondary recovery of oil from unconsolidated oil-bearing formations in which a zone of high permeability communicating with a well is formed through the unconsolidated formation by reverse combustion. Then a fluid is injected into the formation through the zone of high permeability to drive oil from the pay zone to a production well. In a preferred form of this invention, a second zone of high permeability communicating with a production well and spaced from the first zone is formed by reverse combustion to provide a path through which oil moves from the formation to the production well.

Referring to the drawings:

FIGURE 1 is a diagrammatic illustration of an injection and production well for forming a stratum of high permeability from one well to an adjacent well by a reverse combustion procedure.

FIGURE 2 is a plan view showing a series of rows of

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wells after formation of permeable zones connecting adjacent wells in a row for a linear drive process for the secondary recovery of oil from the pay zone after the highly permeable zones have been formed through the pay zone.

Referring to FIGURE 1 of the drawings, an injection well indicated generally by reference numeral 10, extends down through a cap rock 12 and an oil-bearing formation designated as a pay zone 14 to a total depth 16. Casing 18 is run into the well and is cemented in place by a cement sheath 20 in accordance with the usual practice. In the apparatus shown in the drawings, casing 18 extends into a bed rock formation 22 underlying the pay zone 14. Casing 18 and cement sheath 20 are perforated, as indicated by reference numeral 24, at intervals from the top to the bottom of the pay zone 14. The well 10 is closed at the well head by conventional equipment illustrated in the drawing as a cap 26. An air supply line 27 passes through the cap and extends down into the well for injection of air into the pay zone 14.

Referring to FIGURE 2, a field having a number of rows of wells is illustrated. The rows are designated by letters A, B, and C. The wells illustrated in FIGURE 1 are in row A. For convenience, wells and structures in rows B and C are identified by the reference numerals corresponding to the reference numerals of FIGURE 1, followed by the suffix B and C, respectively.

A second well, indicated generally by reference numeral 28, adjacent to well 10 in row A extends through pay zone 14 into the bed rock 22 in the manner described for well 10. Casing 30 in well 28 also is cemented through the pay zone. Perforations 32 extend through the casing and the surrounding cement sheath through the depth of pay zone 14. Well 28 is closed at the surface by a suitable cap 34.

For ignition of oil in the formation adjacent well 28, an electric heater 36 is suspended in the well at the level of the pay zone 14. Electric heater 36 is connected with a suitable source of current through lead lines 40 and 42. Although an electric heater 36 has been illustrated in well 28 for heating the pay zone 14 adjacent the well 28, other conventional heating means such as a burner for burning mixtures of a fuel with air can be used.

To form the permeable zone extending through the unconsolidated formation 14, an oxygen-containing gas, preferably air, is pumped into the well through line 27 and injected through perforations 24 into the pay zone 14. Even though the permeability of the pay zone 14 is such that oil cannot be moved through the formation at practical rates, the greater permeability of the formation to gas than oil allows the air to thread its way to well 28 and enter that well through perforations 32 without moving the oil in the pay zone. The pay zone surrounding well 28 is heated by means of electric heater 36 to a temperature at which ignition of oil in the pay zone takes place when the oxygen-containing gas injected through well 10 comes in contact with the hot pay zone. An observation of the products discharged from well 28 through outlet 44 will indicate when ignition in the formation adjacent well 28 has occurred. After oil in the formation has been ignited, the electric heater 36 can be withdrawn from well 28.

Burning of oil in the formation 14 by reverse combustion is accomplished by continuing injection of air into the formation 14 through well 10. The combustion front moves counter to the flow of air from the vicinity of well 28 toward injection well 10. Oil driven from the pay zone by the hot combustion products travels in a direction opposite the combustion front and is produced at well 28. After reverse combustion proceeds from the output well 28 to the well 10, continued injection of

oxygen-containing gas into the formation 14 will cause forward combustion from well 10 to well 28 to burn hydrocarbons remaining in the pay zone between the two wells and further increase the permeability.

The burning between wells 10 and 28, regardless of whether the burning is by reverse combustion along or by reverse combustion followed by forward combustion, forms a highly permeable zone, indicated by reference numeral 46 in FIGURE 2, extending between the wells. The process described above for wells 10 and 28 is repeated for wells in row B to form a permeable zone 46B between wells 10B and 28B. The procedure can similarly be repeated for wells in row C to form a permeable zone indicated by reference numeral 46C between wells 10C and 28C. The permeable zone extending from wells 10 to 28 can be made to extend in both directions from wells 10 and 28, for example to adjacent wells 48 and 49, to connect all of the wells in a single row, if desired.

After the formation of a permeable zone connecting adjacent wells in a row, an oxygen-containing gas is injected into the pay zone 14 through one or more and preferably all of the wells in a single row in the field. For purposes of illustration, the wells 10, 28, 48, and 49 in row A and the wells 10C, 28C, 48C, and 49C in row C are injection wells. Oil in the pay zone is then ignited and the continued injection of oxygen-containing gas, preferably air, through wells in rows A and C burns oil in the formation and supplies energy to move oil through the pay zone 14 to the permeable zone 46B in row B. The oil then flows readily through the permeable zone 46B into wells 10B and 28B from which it is lifted to the surface.

The combustion to move the oil from the formation 14 towards permeable zone 46B for delivery to the wells can be either forward or reverse combustion. Ordinarily because of the low permeability of the pay zones in which this invention is most useful, reverse combustion to produce the oil from the pay zone or to warm it prior to the initiation of a forward combustion phase is preferred. Ignition in permeable zone 46B can be accomplished by injecting a mixture of a combustible gas and air into permeable stratum 46B through wells in row B and igniting the mixture to heat the formation to a temperature at which ignition will occur upon contact with air or other oxygen-containing gas injected into the pay zone in row A or rows A and C. A preferred method of ignition is to inject a mixture of a combustible gas and air through the wells in row A and ignite that mixture as it enters the permeable zone 46B by means of an electric spark. After ignition, the injection of a combustible gas through the wells in row A is discontinued while the injection of the oxygen-containing gas is continued. In the arrangement shown in FIGURE 2, injection of oxygen-containing gas into the pay zone through wells in row C is continued simultaneously with the injection of oxygen-containing gas through the wells in row A.

The linear flow from permeable zones 46 and 46C to permeable zone 46B allows substantially complete removal of oil from the oil-bearing formation. Although resistance to flow through the oil-bearing formation between the permeable zones will interfere with the flow of oil in forward burning or gas repressuring secondary recovery procedures, the highly permeable zones extending to the wells greatly reduce the total resistance to flow. Oil can flow at high rates through the highly permeable zones directly into the wells.

In an example of this process, in an oil field in which the wells are arranged in a five spot pattern, three boreholes are drilled 660 feet apart in a line to a total depth of 1510, 1515, and 1522 feet through a pay zone 78 feet thick. Seven inch casing is set through the pay zone and cemented in the conventional manner. The strings of casing are perforated at the intervals 1445 to 1500 feet,

1450 to 1505 feet and 1455 to 1515 feet, respectively. A mixture of air and lease gas is injected into the middle well and ignited at the other wells by means of an electric spark. After ignition, injection of the lease gas is stopped and the injection of air is continued at a rate of one and one-half million standard cubic feet per day. Reverse combustion is continued for 300 days and then converted to forward combustion in the vicinity of the first well by increasing the rate of air injection to three million standard cubic feet per day, and continued for 30 days. The procedure is repeated in three directly offset wells in an adjacent line.

A mixture of lease gas and air in a ratio of 15 volumes of air per volume of lease gas is injected into three wells in the first line at a total rate of ten million standard cubic feet per day. When the gas mixture breaks through into adjacent line of wells, the mixture is ignited. Injection of the mixture of gases is continued for ten days, after which the injection of the lease gas is stopped. The injection of air is continued at the rate of ten million standard cubic feet per day while the oil is produced from the wells in the second line.

The initial reverse combustion steps are highly effective in increasing the permeability of the unconsolidated formations and reducing the resistance to flow of heavy oils present in the oil-bearing formation. In addition to heating oil throughout the permeable zone of the formation, any clays present in that zone tend to be irreversibly dehydrated thereby preventing their swelling upon contact with water. The heat from the reverse combustion process raises the temperature of the oil in the formation and decreases its viscosity. The reverse combustion procedure is particularly effective in fields containing very heavy oils. It is possible in many such fields to cause flow of gas from one well to an adjacent well without displacing oil from the formation, whereas displacement of the cold oil from the formation is not feasible. By forming substantially parallel zones of high permeability joining wells in adjacent lines, a second secondary recovery step using a linear flow pattern is made possible. The linear flow pattern and relatively short distance between the permeable zone allow low fluxes (vol./sq. ft./hr.) for the injected air and reduced oxygen absorption in subsequent reverse combustion steps. The process of this invention is particularly advantageous in producing oil from unconsolidated formations of low permeability in which the high resistance to flow makes the usual secondary recovery processes ineffective.

I claim:

1. A process for the production of oil from a sub-surface oil-bearing formation penetrated by a plurality of wells in a series of substantially parallel rows comprising injecting an oxygen-containing gas into the oil-bearing formation through a first well in a first row and withdrawing gas from a second well in the first row, igniting oil in the formation at said second well, continuing the injection of oxygen-containing gas at the first well to cause reverse combustion to proceed from the second well to the first well to form a first permeable zone through a portion of the oil-bearing formation communicating with said first and second wells in the first row, thereafter injecting an oxygen-containing gas into the oil-bearing formation through a first well in a second row of wells spaced from the first row of wells and withdrawing gas from a second well in said second row of wells, igniting oil in the formation at said second well in said second row, continuing the injection of oxygen-containing gas into the first well in the second row of wells to cause reverse combustion to proceed from the second well in said second row to the first well in said second row whereby a second permeable zone is formed spaced from and substantially parallel to the first permeable zone, then injecting a fluid into the first permeable zone and withdrawing fluids from a well penetrating the second permeable zone to displace oil through the oil-bearing forma-

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tion in a direction substantially perpendicular to the rows of wells toward the second permeable zone.

2. A process for the production of oil from a sub-surface oil-bearing formation penetrated by a plurality of wells in a series of substantially parallel rows comprising injecting an oxygen-containing gas into the oil-bearing formation through a first well in a first row and withdrawing gas from a second well in the first row, igniting oil in the formation at said second well, continuing the injection of oxygen-containing gas at the first well to cause reverse combustion to proceed from the second well to the first well to form a first permeable zone through a portion of the oil-bearing formation communicating with said first and second wells in the first row, thereafter injecting an oxygen-containing gas into the oil-bearing formation through a first well in a second row of wells spaced from the first row of wells and withdrawing gas from a second well in said second row of wells, igniting oil in the formation at said second well in said second row, continuing the injection of oxygen-containing gas into the first well in the second row of wells to cause reverse combustion to proceed from the second well in said second row to the first well in said second row whereby a second permeable zone is formed spaced from and substantially parallel to the first permeable zone, then injecting an oxygen-containing gas into the first permeable zone and withdrawing fluids through a well penetrating the second permeable zone to establish flow through the oil-bearing formation between the first and second permeable zone substantially perpendicular to the rows of wells, igniting oil in the formation adjacent the second permeable zone, continuing the injection of the oxygen-containing gas into the first permeable zone to cause reverse combustion to proceed from the second permeable zone to the first permeable zone, and lifting fluids to the surface through a well penetrating the second permeable zone.

3. A process for the production of oil from a sub-surface oil-bearing formation penetrated by a plurality of wells in a series of substantially parallel rows comprising injecting an oxygen-containing gas into the oil-bearing formation through the first well in a first row and withdrawing gas from a second well in the first row, igniting oil in the formation at said second well, continuing the injection of oxygen-containing gas at the first well to cause reverse combustion to proceed from the second well to the first well to form a first permeable zone through a portion of the oil-bearing formation communicating with said first and second wells in the first row, thereafter injecting an oxygen-containing gas into the oil-bearing formation through a first well in a second row of wells spaced from the first row of wells and withdrawing gas from a second well in said second row of wells, igniting oil in the formation at said second well in said second row, continuing the injection of oxygen-containing gas into the first well in the second row of wells to cause reverse combustion to proceed from the second well in said second row to the first well in said second row whereby a second permeable zone is formed spaced from and substantially parallel to the first permeable zone, then injecting an oxygen-containing gas into the first permeable zone and withdrawing fluids through a well penetrating the second permeable zone to establish flow through the oil-bearing formation perpendicular to the rows of wells, igniting oil in the formation between the first permeable zone and the second permeable zone, continuing injection of the oxygen-containing gas into the first permeable zone to cause combustion of the oil between the two permeable zones and drive oil through the formation to the second permeable zone and to a well penetrating the second permeable zone through which fluids are withdrawn.

4. A process for the production of oil from a sub-surface oil-bearing formation penetrated by a plurality of wells in a series of substantially parallel rows com-

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prising injecting an oxygen-containing gas into the oil-bearing formation through a first well in a first row and withdrawing gas from a second well in the first row, igniting oil in the formation at said second well, continuing the injection of oxygen-containing gas at the first well to cause reverse combustion to proceed from the second well to the first well to form a first permeable zone through a portion of the oil-bearing formation communicating with said first and second wells in the first row, thereafter injecting an oxygen-containing gas into the oil-bearing formation through a first well in a second row of wells spaced from the first row of wells and withdrawing gas from a second well in said second row of wells, igniting oil in the formation at said second well in said second row, continuing the injection of oxygen-containing gas into the first well in the second row of wells to cause reverse combustion to proceed from the second well in said second row to the first well in said second row whereby a second permeable zone is formed spaced from and substantially parallel to the first permeable zone, then injecting an oxygen-containing gas into the first permeable zone and withdrawing fluids through a well penetrating the second permeable zone to establish flow through the formation substantially perpendicular to the rows of wells, igniting oil in the formation adjacent the first permeable zone, and continuing the injection of the oxygen-containing gas into the first permeable zone to cause forward burning to proceed from the first permeable zone to the second permeable zone.

5. A process for the production of oil from a sub-surface oil-bearing formation penetrated by a plurality of wells in a series of substantially parallel rows comprising injecting an oxygen-containing gas into the oil-bearing formation through a first well in a first row and withdrawing gas from a second well in the first row, igniting oil in the formation at said second well, continuing the injection of oxygen-containing gas at the first well to cause reverse combustion to proceed from the second well to the first well to form a first permeable zone through a portion of the oil-bearing formation communicating with said first and second wells in the first row, thereafter injecting an oxygen-containing gas into the oil-bearing formation through a first well in a second row of wells spaced from the first row of wells and withdrawing gas from a second well in said second row of wells, igniting oil in the formation at said second well in said second row, continuing the injection of oxygen-containing gas into the first well in the second row of wells to cause reverse combustion to proceed from the second well in said second row to the first well in said second row whereby a second permeable zone is formed spaced from and substantially parallel to the first permeable zone, then injecting a mixture of an oxygen-containing gas and a gaseous fuel into the first permeable zone and withdrawing fluids through a well penetrating the second permeable zone to establish flow through the formation substantially perpendicular to the rows of wells, igniting the mixture of oxygen-containing gas and fuel gas in the second permeable zone to ignite oil in the formation adjacent the second permeable zone, discontinuing the injection of the fuel gas and continuing the injection of the oxygen-containing gas to cause reverse combustion from the second permeable zone to the first permeable zone and lifting fluids to the surface through a well in the second row of wells.

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