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REVERSE COMBUSTION METHOD OF RECOVERING OIL FROM STEEPLY DIPPING RESERVOIR INTERVAL

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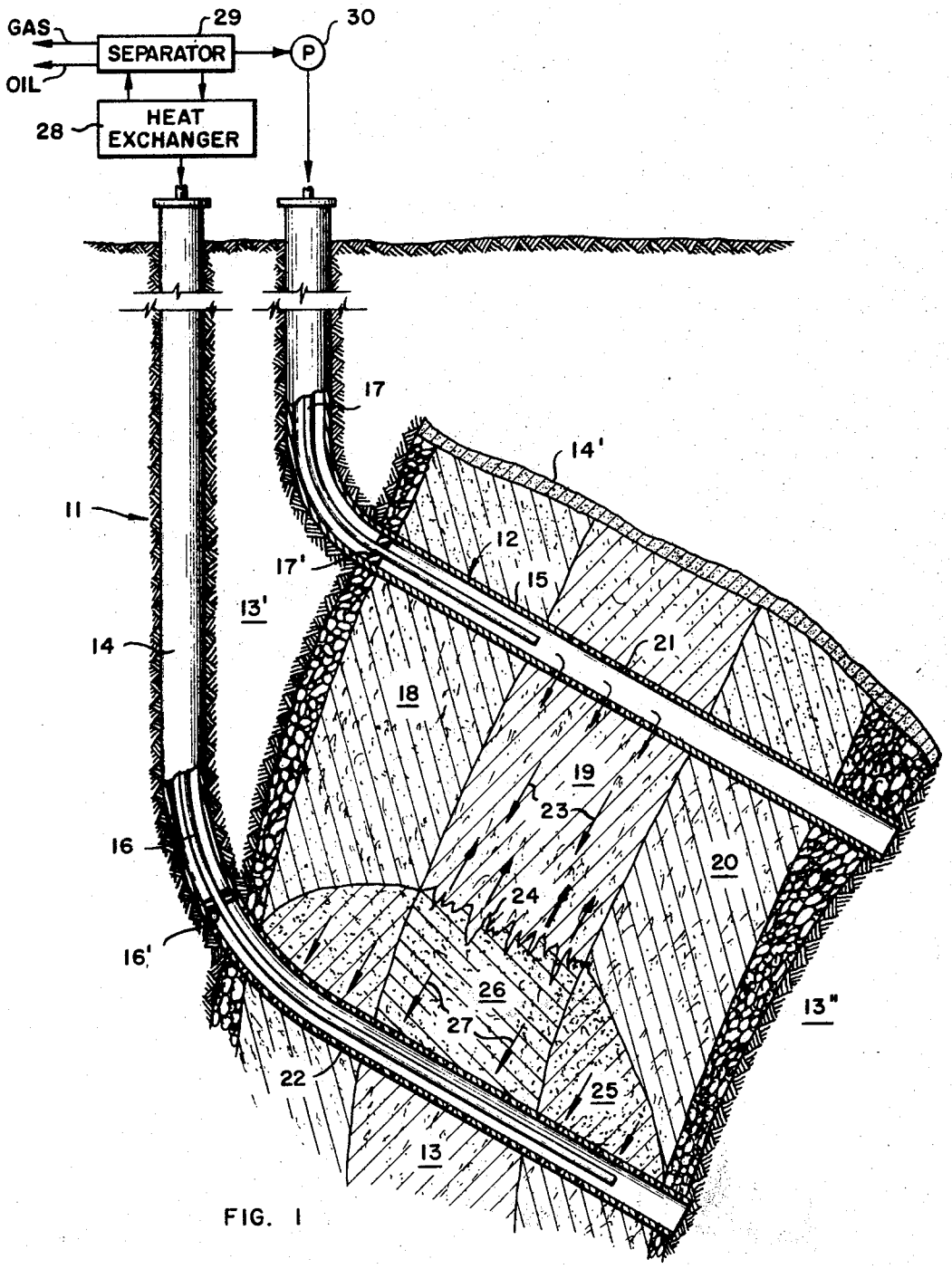


FIG. 1

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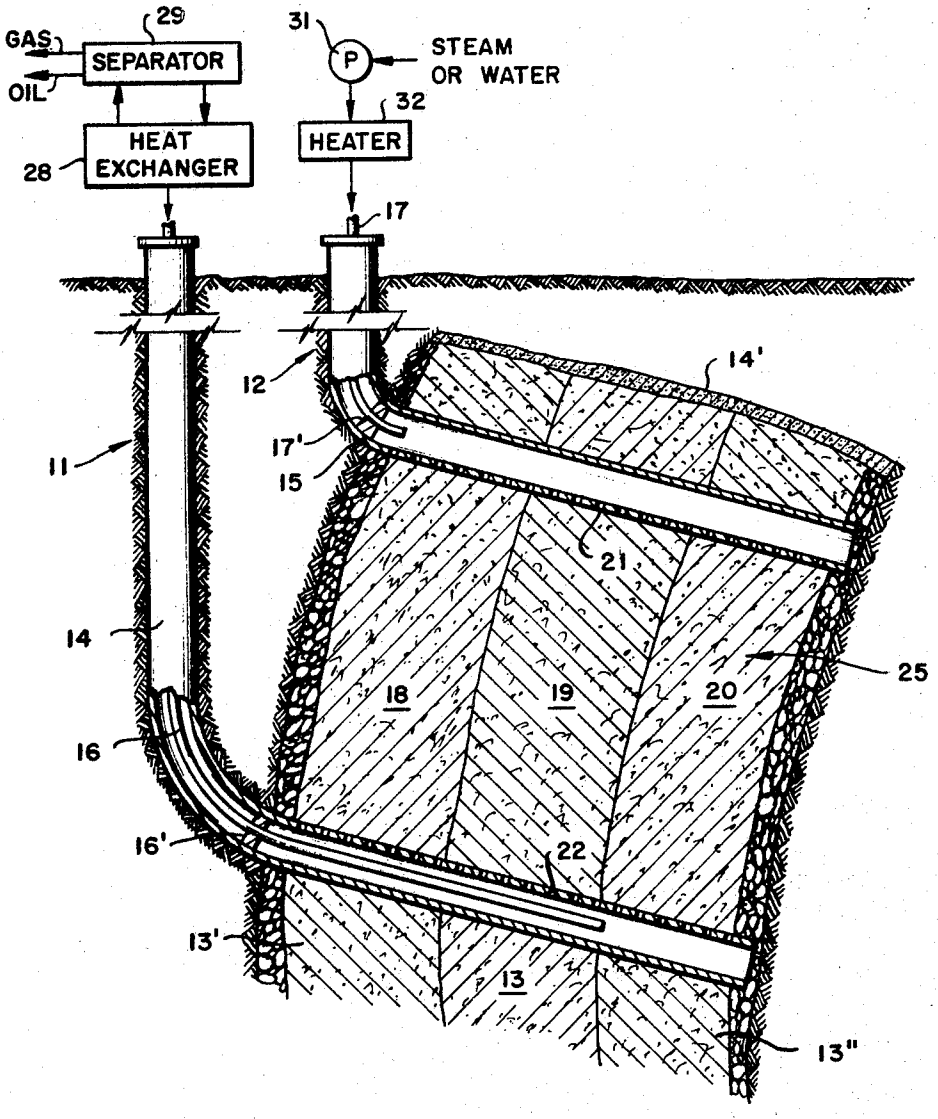


FIG. 2

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REVERSE COMBUSTION METHOD OF RECOVERING OIL FROM STEEPLY DIPPING RESERVOIR INTERVAL

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U.S. Cl. 166—258 6 Claims

ABSTRACT OF THE DISCLOSURE

A method of recovering oil from a steeply dipping reservoir interval within an underground hydrocarbon-bearing formation by providing a downdip opening into the interval by completing at least one well so that at least one path of fluid communication extends substantially through the thickness of the interval along a substantially horizontal line substantially normal to the bedding planes of the interval. An updip opening is then provided into the same interval by completing at least one well at a depth above that of the downdip opening into the interval substantially normal to the bedding planes of the interval. Communication between the two wells is provided by a layer or fracture within the interval that is more permeable than the remainder of the interval and more or less parallel to the bedding planes. The hydrocarbons within or near the permeable layer are heated adjacent the encounter of the layer with the downdip opening. A combustion supporting fluid is injected through the updip opening into the interval so as to initiate a reverse combustion of the heated hydrocarbons within the permeable layer or adjacent to the fracture.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a method of recovering oil from underground formations, and more particularly, to an oil recovery method which utilizes combustion within a steeply dipping reservoir interval within an underground hydrocarbon-bearing formation to aid in the displacement and recovery of the oil or in the recovery of oil from the kerogen in the oil shales.

Description of the prior art

Various techniques have been tried in an attempt to recover oil, particularly from bituminous or solid oil-beairng deposits, tar sands and oil shales. Examples of such hydrocarbon-bearing formations are the Athabasca tar sands and the like, and the large deposits of oil shale found in various sections of the United States, particularly in Colorado and surrounding states. The recovery of viscous crude hydrocarbon material is important in those areas where such hydrocarbons are, or may soon be, the principal indigenous source of petroleum liquid hydrocarbons or where the cost of finding and producing crude petroleum has risen so that the viscous oils and other non-flowable hydrocarbons can be recovered and refined on an economically competitive basis. The formation which contains the non-flowable hydrocarbons may be one of a number of types. For example, shale is a fine-grained, compact sedimentary rock having splintery uneven laminae, which may contain about 10 to 65 or more gallons of oil per ton in the form of a solidified, resinous organic material such as kerogen which clings to the siliceous shale particles. In other formations, the basic structure may comprise porous rock clogged with non-flowable hydrocarbons, or sand particles having hydrocarbons at the interstices. Such sand formations may

be unconsolidated, that is, crumbly in the absence of hydrocarbons or consolidated.

Various underground combustion operations have been suggested for the recovery of oil from such oil-bearing formations. However, these operations have been found to be generally unsuccessful where the hydrocarbons are present in steeply dipping reservoirs containing the viscous oils. These reservoirs dip at angles greater than about 45 degrees and raise especial problems in the recovery of oil therefrom. Such reservoirs comprise a significant proportion of proven oil reserves.

SUMMARY OF THE INVENTION

It is an object of this invention to provide a method for recovering hydrocarbons from steeply dipping reservoirs containing viscous oils or kerogen.

It is a further object of this invention to provide a preheating process for heating the central portion of a reservoir interval prior to the initiation of heated fluid drive wherein the heated fluid is injected into an updip opening and thus into the reservoir interval.

The objects of this invention are carried out by providing a downdip opening into a steeply dipping reservoir interval within an underground hydrocarbon-bearing formation by completing at least one well so that at least one path of fluid communication extends substantially through the thickness of the interval along a substantially horizontal line substantially normal to the bedding planes of the interval. An updip opening is then provided into the same interval by completing at least one well at a depth above that of the downdip opening into the interval substantially normal to the bedding planes of the interval. Communication between the two wells is provided by a layer or fracture within the interval that is more permeable than the remainder of the interval and more or less parallel to the bedding planes. The hydrocarbons within or near to the permeable layer are heated adjacent the encounter of the layer with the downdip opening and a combustion supporting fluid is injected through the updip opening into the interval so as to initiate a reverse combustion of the heated hydrocarbons within the permeable layer or adjacent to the fracture.

The above combination of steps may be used as a preheating process for heating the central portion of a reservoir interval prior to the injection of heated fluid drive into an updip opening preferably extending across the entire reservoir interval.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a schematic embodiment of the preferred method of carrying out the concept of this invention; and

FIGURE 2 is a schematic embodiment of a further step in the carrying out of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The oil recovery method of the present invention contemplates the use of at least a pair of wells extending down into communication with an oil-bearing formation and preferably additional wells whereby in situ combustion or a fluid drive may be carried out.

Referring to FIGURE 1 of the drawing, a pair of wells **11** and **12** are shown as having been drilled down into a steeply dipping oil-bearing oil sand formation **13** located between stratas of overburdens **13'** and **13''** substantially normal to the bedding planes of the reservoir interval and aligned with casings **14** and **15**, respectively. The formation **13** contains heavy viscous crude or tar and is preferably sealed at the top by a sealing fault **14'** as is well known in the art. Although the method of this invention will be described hereinbelow with reference to an

"updip" or injection well drilled into formation 13, it is to be understood that such a well may be one of a series of pre-existing substantially vertical wells that encounter only the central layer of low oil saturation or fracture within a steeply dipping reservoir interval or one or a series of pre-existing wells that encounter the central layer and only one of the richer layers of such a reservoir interval. Such wells may be completed in substantially any manner that provides openings into the indicated portions of the reservoir interval.

Thus, casings 14 and 15 are preferably closed at the top, depending upon the operation being carried out, with smaller diameter tubing strings 16 and 17 extending through the closed upper ends of the casing 14 and 15, respectively. The smaller diameter strings 16 and 17 may be used for various operations, depending on how they are equipped or to what they are connected. Well 12, which may be referred to as an injection well providing an updip opening into the formation 13, is drilled close to the upper limit of the reservoir interval, packed at 17', and perforated in a zone of high effective permeability to gas. Formation 13, illustrated in FIGURE 1, is divided into three layers or zones, 18, 19 and 20, wherein layers 18 and 20 are zones of lower effective permeability to gas. Accordingly, well 12 is perforated at 21 in the vicinity of zone 19. Although zone 19 is formed naturally in formation 13 as illustrated in FIGURE 1, this zone of high permeability may be a fracture formed by conventional fracturing techniques as is well known in the underground oil recovery art. One of the tubing strings 16 and 17 may be used for this purpose, such as for introducing a source of pressure fluid to fracture area 19 of formation 13, with the fractures extending substantially vertically between the two wells 11 and 12.

Thus, the portions of well casings 14 and 15 within formation 13 are provided with a series of perforations 22 and 21, respectively, whereby the interior of each of the well casings 14 and 15 is brought into communication with the hydrocarbon-bearing zone 19 whereby fluids can be either forced into the zone 19 or extracted therefrom.

Well 11, which may be referred to as a production well providing a downdip opening into the steeply dipping formation 13, is drilled lower in the sand formation 13 than well 12 as illustrated in FIGURE 1 and along a substantially horizontal line extending through the thickness of formation 13. Perforations 22 also extend over the entire sand interval, i.e., zones 18 through 20, for reasons to be discussed further hereinbelow. Well 11 is packed at 16' as is well known in the art.

In operation, assuming an oil-bearing formation 13, the combustion is initiated along the permeable zone 19 by pumping air through tubing string 17, through perforations 21 and into zone 19 in the direction of the arrows 23 as illustrated in FIGURE 1. Oil contacted by the air is then heated to a temperature at which the oil is ignited. This can be facilitated by use of down-hole heaters and any suitable chemical and/or mechanical means for increasing the speed or ease of igniting the oil in a subsurface formation.

By heating the interval surrounding well 11 in zone 19 through which the gas is flowing to ignition temperature in production well 11, a reverse combustion front 24 can be made to travel vertically upward from production well 11 to the injection well 12, heating the adjacent zones 18 and 20 as indicated by heated zone 25. Thus, a hot burned formation 26 is formed between front 24 and well 11 in zone 19. Hot exhaust gases are removed from zone 19 through perforations 22 and up tubing string 16 in well 11 as indicated by the arrows 27 in FIGURE 1. During this combustion drive step, the pumping pressures for the injected air are preferably, but not necessarily, held below the over-burden pressure of zone 19.

In this type of process, the injected air is guided by the impermeable formations or zones 18 and 20 bounding permeable zone 19 and conveyed to the continuously expanding formation 26 in which the heat is most efficiently utilized.

As a result of the increased temperature of zone 19, the oil viscosity within formation 26 is lowered thus greatly improving the production rates resulting from gravity drainage. In addition, fluid expansion and the flashing to steam of any connate water present in formation 13 further contributes to the effectiveness of the production mechanism. Thus, in the hot zone 26, hot gases exhausted therefrom contain a certain percentage of cracked hydrocarbon products resulting from the combustion process which mix with the hydrocarbon-bearing fluid produced by gravity drainage and increase the gravity of the produced crude thus increasing the value. Accordingly, the exhaust gas and the produced fluid are removed from zone 26 through perforations 22 and up tubing string 16 of production well 11. Oil and gas components are then recovered from the produced fluid by means well known in the petroleum art.

For example, the produced fluid is passed from tubing string 16 into a conventional heat exchanger 28 and conventional separator 29 where the oil and gas components are separated as is well kown in the art. The recovered air may be recirculated from separator 29 through pump 30 and into zone 19 as again is well known in the art.

Conventional channeled underground combustion techniques, such as those described in Patent No. 3,149,670 to Grant which discloses downhole heating means, may be suitable for the downhole heating of zone 19 and the forming of the reverse combustion front of the present process. The application of Prats, Serial No. 349,923, filed March 6, 1964, discloses a preferred method for forming a reverse combustion front which also may be applied to the teachings of this invention.

In the hot zone 26, downstream from the combustion front 24, the oil-bearing fluids in the formation are concurrently heated and displaced so as to leave a heated zone 25 that is hot, permeable and continually expanding as indicated by upwardly directed arrows in FIGURE 1. Thus, hot produced oil-bearing fluids may be removed from substantially the entire reservoir interval through perforations 22 in production well 11. The method disclosed hereinabove causes all of the natural drive forces, especially gravity drainage, and the induced drive forces and inevitable heat losses to the formations (i.e., zones 18 and 20) adjacent to the combustion front 24, to operate concurrently in inducing the reservoir fluids to flow relatively freely into production well 11 because of the lowered oil viscosity and parallel direction of gradients.

The present process may also be used as a preheating process for heating the central portion of a reservoir interval (for example, zone 19 of formation 13) prior to the initiation of a steam and/or hot water drive or hot or cold solvents in which the fluid is injected into an updip opening or injection well, which opening or well preferably extends across the entire reservoir interval.

Accordingly, once the reverse combustion front 24 reaches the injection well 12 as illustrated in FIGURE 2, the entire reservoir interval (i.e., along zones 18 through 20) is perforated also as illustrated in FIGURE 2. The remaining recoverable oil in the now completely heated formation 13 may be produced by either forward combustion, steam injection, solvent or water injection over the entire reservoir interval as is well known in the underground oil recovery art. The previously recited patent to Grant and the application of Prats discuss such well-known prior art techniques. Preferably, water injection is the most economical; however, the preferred technique depends somewhat on the relative thickness of each zone and the average reservoir temperature at the end of the reverse burning phase.

Thus, in FIGURE 2, water preferably is pumped from pump 31 through heater 32 and into tubing string 17 whereby the heated fluid passes through perforation 21 into heated zone 25. In this matter, the remaining recoverable oil in formation 13 is produced therefrom by

gravity drainage of the produced fluid through perforations **22** and up string **16** of well **11** where the oil is recovered therefrom as discussed hereinabove with reference to FIGURE 1.

I claim as my invention:

1. A method of recovering oil from a steeply dipping reservoir interval within an underground hydrocarbon-bearing formation, said interval having substantially vertical bedding planes and a portion thereof that is more permeable than theremainder of said interval, said method comprising the steps of:

providing a downdip opening into said reservoir interval by completing at least one well so that at least one path of fluid communication extends substantially through the thickness of the reservoir interval along a substantially horizontal line substantially normal to the bedding planes of the interval;

providing an updip opening into the same reservoir interval by completing at least one well at a depth above that of the downdip opening into the reservoir interval substantially normal to the bedding planes of the interval;

providing communication between said wells by an opening within said more permeable portion of said reservoir interval and generally parallel to the bedding planes of the interval;

heating any hydrocarbons within and adjacent said permeable opening adjacent the encounter of said opening with said downdip opening; and

injecting a combustion supporting fluid through the updip opening into the reservoir interior so as to initiate a reverse combustion of the heated hydrocarbons within and adjacent to the permeable opening.

2. The method of claim **1** including the step of advancing a reverse combustion front through the permeable opening within the reservoir interval and recovering oil therefrom.

3. The method of claim **2** wherein the step of advancing said reverse combustion front and recovering hydrocarbons is carried out by injecting the combustion supporting fluid through the updip opening into the reservoir interval, producing hydrocarbon-bearing fluid from the downdip opening into the reservoir interval, and recovering oil from the produced fluid.

4. The method of claim **3** including the step of injecting a driving-oil-displacement fluid across substantially the entire extent of said updip opening through said reservoir interval so as to produce any recoverable hydrocarbons remaining in the reservoir interval after the reverse combustion front reaches the updip opening.

5. The method of claim **3** including the step of producing any recoverable hydrocarbons remaining in the reservoir interval after the reverse combustion front reaches the updip opening by forcing said recoverable hydrocarbons in said reservoir interval towards the downdip opening by initiating combustion in said interval between the updip and downdip openings.

6. A method of recovering shale oil from a steeply dipping reservoir interval within an underground oil shale formation, said interval having substantially vertical bedding planes and a portion thereof that is more permeable than the remainder of said interval, said method comprising the steps of:

providing a downdip opening into said reservoir interval by completing at least one well so that at least one path of fluid communication extends substantially through the thickness of the reservoir interval along a substantially horizontal line substantially normal to the bedding planes of the interval;

providing an updip opening into the same reservoir interval by completing at least one well at a depth above that of the downdip opening into the reservoir interval substantially normal to the bedding planes of the interval;

providing communication between said wells by an opening within said more permeable portion of said reservoir interval and generally parallel to the bedding planes of the interval;

heating any hydrocarbons within and adjacent said permeable opening adjacent the encounter of said openings with said downdip openings; and

injecting a combustion supporting fluid through the updip opening into the reservoir interior so as to initiate a reverse combustion of the heated hydrocarbons within and adjacent to the permeable opening.

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166—272