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METHOD OF PRODUCING AN OIL BEARING FORMATION

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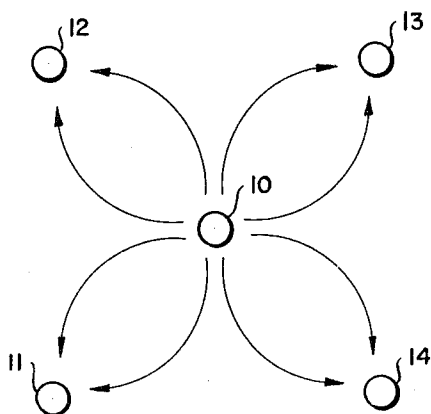


FIG. 1

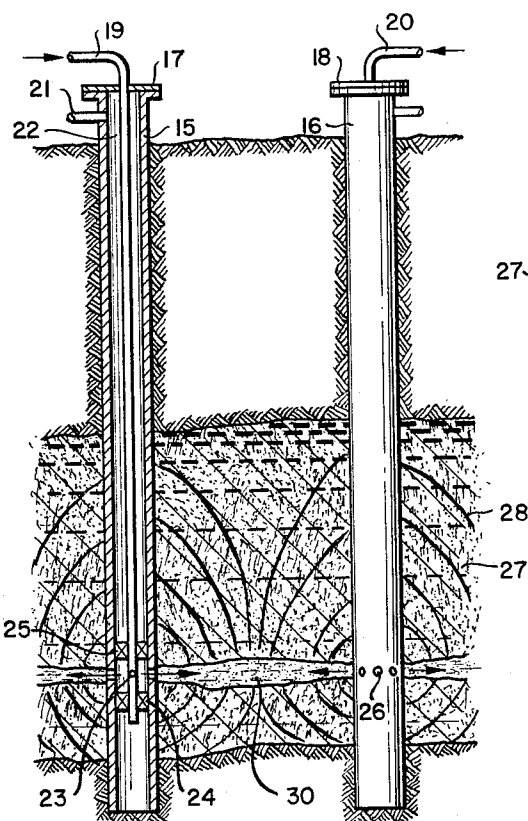


FIG. 2

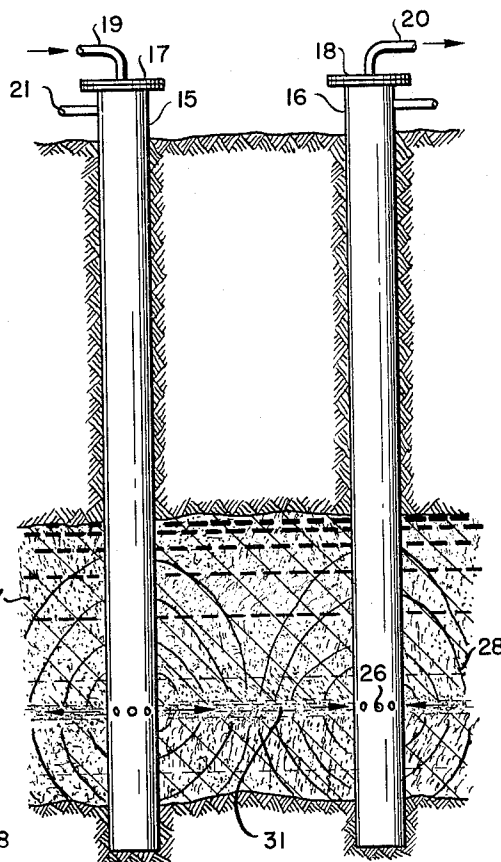


FIG. 3

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METHOD OF PRODUCING AN OIL BEARING FORMATION

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This invention relates to a method for producing oil from underground formations and pertains more particularly to a method of preheating and flooding a formation in order to recover oil therefrom which, because of the characteristics of the oil or the state that it is in, could not be produced by normal oil-producing methods. The method of the present invention is especially applicable to hydrocarbon reservoirs where the injectivity is relatively low, such for example, as in tar sands.

In some regions oil-bearing formations contain an oil whose viscosity or state of existence is such that the oil does not flow from the formation. Attempts have been made to heat these formations with varying degrees of success. The use of heaters in a well is not very satisfactory since the heat cannot penetrate a great distance from the well bore. It is often difficult to create a steam flood or a drive since the steam condenses and cools in the formation to interfere with the further injection of steam therinto. The injection of hot fluid into an injection well so as to force oil to an adjacent production well is well known but this operation may take a prohibitively long time to accomplish the heating desired of the formation between the two wells. For example, in order to double the radius of the steam heated zone during steam injection into an injection well, an injection period of 16 times as long is required.

It is, therefore, an object of the present invention to provide an oil field with a series of injection and production wells and to preheat a substantial zone of the oil-bearing formation between any pair of injection and production wells, or adjacent each of the wells, in order to reduce the viscosity of the oil subsequently to be moved out of the intermediate zone between the two wells by a driving fluid being forced down one well while the drive fluid and oil is extracted or produced from an adjacent well.

An additional disadvantage of injecting a hot drive fluid into only the normal injection wells in communication with fractures in a formation is that, in the cases of very viscous tars, the heated tar in the formation may actually flow into the fracture path and be forced therealong to a relatively cooler part of the formation, thus effectively limiting further injection of the hot drive fluid into the formation.

It is therefore another object of the present invention to provide a method of preheating substantially the entire formation between an injection and production well to prevent heated tars from solidifying or forming in a non-flowable state in the path of communication through the oil-bearing formation between the two wells.

A further object of the invention is to provide an oil recovery method wherein interconnecting fractures are formed adjacent and/or between wells in an oil-producing formation prior to heating the formation with steam so that an area is formed outside the direct line between an injection and production well into which steam conden-

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sate may flow rather than block the channel or that portion of the fracture communicating between the two wells.

These and other objects of this invention will be understood from the following description taken with reference to the drawing, wherein:

FIGURE 1 is a diagrammatic plan view of a five-point well injection system showing schematic flowlines along which the oil may move during the production period of the method of the present invention;

FIGURE 2 is a longitudinal view taken in cross section of a pair of wells in communication with a common oil-bearing zone or formation while being in communication through the formation with each other through a horizontal fracture that is maintained open; and

FIGURE 3 is a longitudinal view taken in partial cross section illustrating the two wells of FIGURE 2 after a substantial permeable path has been formed between the two wells and the fracture has been allowed to close.

The oil recovery method of the present invention contemplates the use of a plurality of alternately-disposed input or injection wells arranged in any suitable pattern in the vicinity of production output wells which penetrate the same oil-bearing formation so that oil can be produced from the formation by a drive, that is, by injecting a drive fluid, either a gas or a liquid, through the injection well and forcing it to one or more of the production wells. In the most simple form, the arrangement of wells would be merely a pair of wells, one well being an injection well and the other a production well, as shown in FIGURES 2 and 3. Another simple arrangement of wells is the five-spot arrangement of production wells and injection wells as is well known to the art. Thus, as shown in FIGURE 1, the central well 10 during the producing stage may serve as the injection well for a hot or a cold drive fluid while the surrounding wells 11, 12, 13 and 14 serve as production wells from which the drive fluid and oil is extracted from the formation. Alternatively, in reversing the production pattern, the drive fluid may be injected through the surrounding wells 11, 12, 13 and 14 with the production fluid being produced up well 10. It is to be realized that the five-spot pattern of wells as shown in FIGURE 1 is merely one illustrative unit or arrangement of wells which may be surrounded by dozens of other alternately spaced wells.

As mentioned hereinabove, a most important aspect of any oil production method is the preheating of the formation between an injection and a production well so that the oil and drive fluid may flow readily between them. Thus, the present invention relates to an improved process for producing petroleum from an underground reservoir by injecting hot fluid to displace the petroleum from the reservoir. The method of the present invention comprises completing at least two wells into an oil-bearing formation, one to serve as an injection well and the other as a production well, and then horizontally fracturing the formation between the fluid injection well and the adjacent oil-production well in a manner such that the wells are in fluid flow communication with each other through the oil-bearing formation. Hot preheat fluid, preferably steam, is injected down both the fluid injection well and the oil production well and through the communicating fracture between the wells and into the oil-bearing formation. Preferably, the hot preheat fluid is injected simultaneously or substantially simultaneously down both the fluid injection and oil production wells in order to reduce greatly the time required to preheat the oil-bearing formation

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prior to production of it. However, in some cases the oil-bearing formation may be preheated by injecting steam into one well, say the injection well, while closing or greatly restricting any flow from the production well in order to maintain pressure on the injected fluid within the oil-bearing formation. Subsequently, the process may be reversed with steam being injected into the production well and flow from the injection well being closed or greatly restricted until the desired area adjacent both the injection and production wells has been heated.

The injection of hot preheat fluid into both the fluid-injection and oil-production wells is maintained for a time and at a temperature sufficient to preheat at least that portion of the oil-bearing formation adjacent the communicating fracture to a condition where the oil in the formation flows in response to a pressure less than overburden pressure. Overburden pressure may be defined as the minimum pressure necessary to cause fracturing of the formation. After calculations have indicated that a substantial zone of the formation around each of the injection and production wells, and between the two wells, has been heated to the desired temperature to cause oil flow, a drive or oil-displacement fluid, either hot or cold, is injected into the fluid injection well while oil from the formation together with the oil-displacement or driving fluid is produced from the oil-production well.

The fractured formation between the fluid-injection well and the oil-production well may be maintained open, that is with the fractures open, during the original preheat period by forcing the hot preheat injection fluid simultaneously into the fracture from both of the wells at a pressure greater than overburden pressure. It is generally necessary to reduce the pressure of the hot preheat injected fluid to less than the overburden pressure prior to the oil at the vertical extremities of the oil-bearing formation reaching a viscosity at which it may be readily displaced. By this reduction in pressure precautions are taken against forcing the oil from the oil-bearing formation into an adjacent formation where it might be lost. Additionally, the danger of the hot preheat injected fluid blowing out around the well casing to the surface is minimized. In some cases, it may be desirable to inject an oil removal fluid down the injection well and through the fractured oil-bearing formation to the oil production well to clean oil from the walls of the fracture prior to injecting the hot preheat fluid down both of the fluid injection and oil production wells to preheat the formation.

To aid in preventing hot injection fluids from heating only the oil near the well and escaping up along the casing, it is often desirable to cool the formation adjacent the well and above the fracture into which the hot fluid is being injected by insulating the pipe down which hot injection fluid is being pumped or by circulating cooling water in an annular space inside the well casing or evacuating it, thus preventing heat transfer from the injection fluid pipe to the well casing. One such apparatus is described in copending patent application Serial No. 43,463, filed July 18, 1960, now Patent No. 3,142,336 and entitled "Method and Apparatus for Injecting Steam into Sub-surface Formations."

In FIGURES 2 and 3, two wells are shown having well casings 15 and 16 closed at the top by plates 17 and 18 with concentric small diameter pipes 19 and 20 extending through the closure plates 17 and 18. If desired, as shown in FIGURE 2, the well casing 15 may be provided with an outlet 21 so that the annulus 22 between the pipe 19 and the casing 15 can be evacuated. The lower end of the injection pipe 19 is closed with a discharge port 23 being preferably positioned between a pair of tubing packers 24 and 25 of any suitable type well known to the art. It is to be understood that casing 16 of FIGURE 2 and casings 15 and 16 of FIGURE 3 may be provided with identical equipment and are provided with discharge ports or perforations 26 whereby fluids may be discharged into or withdrawn from the oil-bearing formation 27.

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The curved lines 28 surrounding each well casing indicates the spread of heat through the formation to heat the oil therein.

In FIGURE 2 an interconnecting fracture is illustrated as extending between the two wells and outwardly from both wells. It is through this fracture that heating liquids may be injected through both pipes 19 and 20, preferably substantially simultaneously, to preheat the formation in the shortest time possible prior to producing oil therefrom.

After calculating that a substantial portion of the formation has been heated and that tar or heavy oil has been removed from the walls of the fractures so as to form a lateral flow passage through the formation between the two wells, as shown in FIGURE 3, the injection pressure is reduced so that the fracture is allowed to close with further flow into the formation being through the passageway of mobile oil or displaced oil as represented at numeral 31. In FIGURE 3, the preheat period of the present method has been carried out and thereafter hot or cold drive fluids such as a gas or liquid is forced through the injection pipe 19 and while oil and drive fluid is discharged through the pipe 20 from the production well. It is to be understood that at this time the pressure of the injection fluid has been reduced to less than that of the overburden pressure.

This invention is uniquely suited for producing petroleum from formations that become mechanically incompetent when the oil or tar they contain is heated to a temperature at which its viscosity is significantly reduced. As used herein in reference to petroleum-bearing formations, the term incompetent refers to formations that may be competent at the reservoir temperatures but tend to slump or cave into any voids created therein when they are heated to a temperature at which the petroleum in the formation can flow or be forced therefrom to a production well. In such formations, fracture propping agents become ineffective when the fracture walls have been heated in accordance with the present invention. Such mechanically incompetent formations are typified by Athabasca tar sands in Canada, Edna sands in the United States, Bolivar tar sands in Venezuela, etc.

Horizontally fracturing the formation in accordance with the present invention insures that the injected hot fluids used for preheating will be distributed over a relatively large area between any pair of wells.

In many areas, it is essential to thermally isolate the hot fluid used for preheating while conveying it to the vicinity of the fracture and injecting the hot fluid into the fracture at a pressure exceeding the overburden pressure. It presently seems unlikely that it would be economically attractive to heat the Athabasca tar sands, for example, by using a hot liquid free of steam. The thermal isolation of the preheat fluid as it is pumped out down the injection well or wells prevents or substantially minimizes the heating of the formations that are located adjacent the injection well casing and above the fracture. When such formations are sufficiently heated during a steam injection, they are apt to permit a blowout as has been encountered in the Athabasca field. Even if no blowout to the surface occurs, the heating of such formations materially increases the likelihood that the injected fluid will bypass the cemented casings and enter permeable formations above or outside the oil-bearing reservoir formation.

Example I

Oil was produced in accordance with the method of the present invention by completing a pattern of injection and production wells into an oil-bearing sand located between the depth of 150 and 210 feet. This particular reservoir formation contained a viscous oil, was mechanically competent and exhibited a low fluid permeability. The wells were arranged in a five-spot pattern with a center well surrounded by four corner wells, as

shown in FIGURE 1, with the spacing of the wells being 120 feet from each other. The reservoir formation was hydraulically fractured at a depth of 200 feet and treated to provide an open horizontal fracture that communicated with all five wells. Steam was injected into the fracture through all five wells so that steam radiated from all of the wells to the surrounding formation. The steam was injected at a pressure of about 140 p.s.i.g. at a rate of about 20 tons per day for about 20 days. The injected steam relatively rapidly extended a heated zone between each pair of wells in the manner shown in FIGURE 2. When the reservoir oil in the immediate vicinity of the fracture has been heated to a temperature that materially reduces the viscosity, the steam injection through the center well was terminated. The center well was placed on production and reservoir oil was produced by continuing to inject steam through the corner wells to steam drive the oil from a volume of the reservoir which continued to expand as additional oil was heated to a temperature at which it flows in response to the pressure gradient.

Example II

Oil was produced in accordance with the method of the present invention from wells arranged in the pattern of FIGURE 1 which had been completed in an Athabasca tar sand located between a depth of 150 and 219 feet. This reservoir formation contained a viscous tar, was mechanically incompetent, and exhibited a low fluid permeability. In this reservoir formation the fracture was initially held open and tar immediately adjacent to the fracture was initially heated by injecting steam and hot aqueous fluids through the central well at a pressure of about 180 p.s.i.g., which exceeded the overburden pressure. In conveying this relatively high pressure steam to the depth of the fracture, the preheat injection fluid was thermally insulated by circulating between the steam line and the earth formation a cooling fluid to prevent the heating of the formation next to the well casing above the fracture.

During this initial stage of injecting fluids through the central well 10 (FIGURE 1) a flow restriction was maintained on the corner wells to maintain the pressure of the injected fluids so that the fracture stayed open. After preheating the oil-bearing formations around the central injection well, the injection pattern was altered so that the preheat injection was pumped down the corner wells while a flow restriction was maintained on the central well. Heating in this manner took about 30 days until the heated zone extended between pairs of wells as shown in FIGURE 2.

After the tar in the immediate vicinity of the fracture had been heated to a temperature which its viscosity was materially reduced, and prior to the transfer of heat over a vertical distance sufficient to permit steam to break through to the surface, the further injection of fluid in the form of an oil-displacement fluid was confined to injection through the corner wells at a pressure less than that of the overburden pressure. By preheating and producing the wells in this manner, a high degree of displacement efficiency was obtained relatively quickly throughout the swept zone which continued to expand as the drive continued.

Example III

The method described in Example II was carried out with the fracture being initially held open and the tar immediately adjacent the fracture being initially heated and removed by injecting a hot liquid comprising a liquid fraction of hydrocarbons distilled from the tar. This hot liquid was injected at a pressure greater than overburden pressure until the viscosity of the tar immediately adjacent the fracture had been reduced to permit the flow of steam through the formation at a pressure less than overburden pressure, at which time the steam was injected at this lower pressure.

Example IV

In a modification of the present method for utilizing a non-viscous liquid solvent for the viscous oil or tar in such a reservoir, the fracture was initially held open by injecting an unheated liquid fraction of the tar hydrocarbon. During the initial stages such a liquid solvent was injected at a pressure exceeding the overburden pressure. If desired, the injection production pattern may be alternately reversed between the central wells and corner wells. After the extraction of a tar from the fracture walls had proceeded to an extent resulting in permeability to a hot fluid injected at less than the overburden pressure, such a hot preheat fluid was injected through all of the wells simultaneously to rapidly extend heated zones between pairs of wells as described in the preceding examples. The liquid solvent which is so utilized can comprise substantially any liquid which is non-viscous and is significantly miscible with the reservoir oil, for example, liquid such as hydrocarbons, alcohols, ketones, aldehydes, esters, amines, imines, etc.

It is to be understood that after the preheat portion of the present method has been carried out production of oil from the oil-bearing formation may be done by alternately using one set of wells for injection wells and subsequently for production wells until the reservoir has been swept clean.

We claim as our invention:

1. A method of recovering oil from an underground oil-bearing formation which is penetrated by a plurality of wells, at least one of said wells being normally a fluid-injection well and at least one well adjacent said injection well being normally an oil-production well, said method comprising

establishing communication between all of said wells and the oil-bearing formation surrounding said wells, horizontally fracturing the formation between a fluid-injection well and at least one adjacent oil-production well in a manner such that the wells are in fluid-flow communication with each other through the oil-bearing formation,

injecting hot preheat fluid down both the fluid-injection and oil-production wells and through said communicating fracture and into said oil-bearing formation, maintaining said injection of hot preheat fluid into both said fluid-injection and oil-production wells for a time and at a temperature sufficient to preheat at least that portion of the oil-bearing formation adjacent the communicating fracture to a condition where the oil in said formation flows in response to a pressure less than overburden pressure,

reducing the injection pressure that is applied to said hot preheat injected fluid to less than overburden pressure prior to the oil at the vertical extremities of said oil-bearing formation reaching a viscosity at which it may be readily displaced, subsequently stopping the injection of hot fluid into said oil-production well while injecting an oil-displacement fluid into said fluid-injection well, and producing oil and oil-displacement fluid from said oil-production well.

2. The method of claim 1 wherein the fractured formation between the fluid-injection well and the oil-production well is maintained open during the original preheat period by forcing hot injection preheat fluid simultaneously into said fracture from both wells at a pressure greater than overburden pressure.

3. The method of claim 1 including the subsequent step of reversing the flow of oil in the oil-bearing formation by stopping the injection of oil-displacement fluid into said injection well and converting it to a production well while at the same time converting the original production well to an injection well and injecting oil-displacement fluid therethrough into said oil-bearing formation.

4. The method of claim 1 including the step of thermally isolating said hot fluid as it flows down a well to substan-

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tially the point at which it is forced from said well into the fractured oil-bearing formation.

5. The method of claim 4 including the step of cooling the formation adjacent the well and above the fracture into which hot fluid is being injected.

6. The method of claim 1 including the step of injecting an oil-removal fluid down said injection well and through said fractured oil-bearing formation to said oil-production well to clean oil from the walls of the fracture prior to injecting hot preheat fluid down both said fluid-injection and oil-production wells to preheat the formation.

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