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SECONDARY RECOVERY PROCESS

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The present invention relates to an improved process for the recovery of viscous hydrocarbons from underground formations. More particularly, the invention is directed to a thermal recovery process wherein a hot aqueous fluid is injected into an underground formation to reduce the viscosity of hydrocarbons therein and the hydrocarbons so reduced in viscosity are produced through the same well used for the injection of fluid into the formation.

Typically, thermal recovery processes using steam drives include injection and production wells extending into an underground earth formation containing viscous hydrocarbons that are to be produced. In application of the processes, steam is initially injected into one of the wells and production is attempted from another of the wells. The temperature of the steam functions to both reduce the viscosity of the hydrocarbons within the formation and to drive these hydrocarbons towards the producing well. However, upon initial injection, the hydrocarbons around the production well and in other areas remote from the injection well remain at original formation temperature and, therefore, remain relatively immobile. As a consequence, when using economically feasible injection pressures, increased production of viscous hydrocarbons is not significant during the early stages of the steam drive process. A significant increase in the production is not attained until sufficient steam has been injected into the injection well to heat substantially all of the portion of the formation that is located between the injection and production wells.

It is, therefore, an object of the present invention to provide a steam-type thermal recovery process wherein production may be initiated without the necessity of heating extended areas of the formation before production can be obtained from the formation.

Another object of the invention is to provide a steam-type thermal recovery process wherein compression costs for injected steam, including the cost of supporting equipment, are minimized.

Yet another object of the invention is to provide a steam-type thermal recovery process wherein maximum hydrocarbon yields are reached at an accelerated rate and, as a result, the yield per unit time is also maximized.

A further object of the invention is to provide a thermal recovery process of the steam-type wherein both ambient formation pressure and artificially induced pressure are used to most effectively produce hydrocarbons from the formation.

Yet another and more specific object of the invention is to provide a thermal recovery process of the steam-type wherein viscous hydrocarbons are reduced in viscosity by heat absorption and wherein the effluent produced from a formation is primarily in a liquid form.

As was set forth previously, the present invention is basically directed to a method of recovering liquid hydrocarbons from a hydrocarbon bearing earth formation. The method includes completing a well into the formation and injecting hot aqueous fluid, such as steam, into the formation through the well at a pressure that is less than the overburden pressure of the formation and a temperature that is sufficient to vaporize some, but not all, of the liquid hydrocarbons in the formation. After the aqueous fluid is injected into the formation, it is permitted to cool by absorption of heat into the formation to condense at least some of the vaporized hydrocarbons, said absorption of heat functioning to reduce the viscosity of liquid hydrocarbons within the formation. After permitting the aqueous fluid to cool or "soak," condensed liquids and liquids that have been reduced in viscosity are produced through the same well used for the injection.

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The above described steps of injecting, "soaking," and producing can be repeated successive times from a single well at such intervals of time as prove to be economically desirable. Furthermore, the method may be concurrently carried out from more than one injection well opened into the formation. In this case, where a single steam generation plant is being used, or where there is a pressure response from one well to another, it is desirable to inject from one well while producing from another and vice versa. It is to be understood, however, that in the latter circumstance the method is not functioning as a conventional forward or direct steam drive process. Specifically, when two or more wells are being used in the method of the present invention, each well is functioning independently of the other in the sense that the fluid injected through one well is not advanced to the vicinity of the other well and steam is not being utilized to drive hydrocarbons from an injection well to a production well spaced laterally therefrom. This is not to say, however, that the method of the present invention cannot be converted to a conventional forward steam drive process after two or more wells have been recycled a number of times. On the contrary, after recycling of two or more wells for a number of times the temperature of a substantial proportion of the formation interval between a pair of wells may have risen to such an extent that it is economically desirable to treat the formation with a forward steam drive process, using one well as an injection well and another well as producing well. In the latter case, it is merely necessary to continuously inject steam into one well while continuously producing from another well.

The detailed operation of the method of the present invention and the above enumerated and other objects will become apparent when viewed in light of the following complete description.

In the application of the present invention, a formation containing viscous hydrocarbons is placed in communication with at least one well facilitated for both introducing fluids into the formation and producing fluids from the formation. This well may take the form of a relatively conventional production well having a casing string, a production string and valve means at the upper end thereof to control flow into and out of the well. In addition to the well, the equipment needed for carrying out the method according to the invention comprises a steam generator and valved conduits for connecting the outlet of the generator to the well or wells. The conduits, as well as the tubing present in the wells or wells for passing steam into the formation may, if desired, be provided with a suitable heat insulating layer to minimize the cooling of the steam. The tubing through which hydrocarbons flow upward through the well is placed in communication, via a valve, with a conduit leading to a reservoir for storing the hydrocarbons. If desired, a heat exchanger for condensing any steam produced with the hydrocarbons may be located in the latter conduit. In this case, the feed water for the steam generator may be used as a coolant in the heat exchanger.

It is noted that the tubing used for producing hydrocarbons from the formation may also be used for passing steam into the formation. In this case, the conduits leading from the steam generator to the well and from the well to the hydrocarbon storage reservoir are provided with shut-off valves and are connected to the upper end of the tubing. By closing the valve in the latter conduit and opening the valve in the steam conduit, steam is injected into the formation. When a sufficient quantity of steam has been injected into the formation, the valve is closed and, after a suitable soaking period, the valve in the conduit leading to the hydrocarbon storage reservoir is opened. In many cases this reduces the pressure within the well and the production tubing enough so that hydrocarbons produced from the formation are lifted via the tubing and are subsequently passed, preferably via a heat exchanger, to the hydrocarbon storage reservoir.

Returning now to the operation of the method of the present invention, after a well has been formed and equipped as above-described, a hot aqueous fluid, such as steam, is injected into the formation through the well. This fluid is injected into the formation at a pressure that exceeds the reservoir fluid pressure, but is less than the overburden pressure of the formation being treated. The latter limitation is necessary in order to avoid fracturing of the overburden and resultant blowouts. This limitation is particularly critical in shallow formations (i.e., those located at depths of less than 500 ft.), since blowouts in such formations are prevalent when high injection pressures are used. It is noted that as a rule of thumb, overburden pressure can be calculated in pounds per square inch to be equal to about 0.7 times the depth of the formation in feet. Therefore, the pressure of the hot aqueous fluid should exceed reservoir fluid pressure, but be less in pounds per square inch than about 0.7 times the depth of the reservoir in feet. The temperature of the hot aqueous fluid exceeds the reservoir temperature, and is sufficient to vaporize at least some but less than all of the hydrocarbons within the formation.

It is noted that the temperature and pressure of the hot aqueous fluid injected in accordance with the process of the present invention is intentionally maintained so as to vaporize only fractionally the hydrocarbons within the formation being treated. This relationship is maintained since fractional vaporization has been found to be no problem. In fact, it has been found that, because of the present procedure, which involves only fractional vaporization of the hydrocarbons, the high temperature fluids most effectively reduce the viscosity of hydrocarbons and thus facilitate their production. In actual application of the invention, after being vaporized, at least some, and preferably most of the hydrocarbons condense prior to their production. In addition to the condensation of the hydrocarbons prior to production, a similar proportion of vaporized water (i.e., steam) is also condensed, and thus the efficiency of production from the well is maximized by that release of the heat of condensation.

The hot aqueous fluid is injected into the formation in a quantity sufficient to traverse a significant portion of the formation adjacent to the well. Upon being so traversed, that portion is heated to a temperature sufficient to reduce the viscosity of hydrocarbons therein to a point where they may be produced through the well that was used for injection. The viscosity of hydrocarbons within the formation is lowered primarily by their absorption of heat. As the heat is so absorbed, the formation is heated, the hot aqueous fluid is lowered in temperature, vaporized water and hydrocarbons are condensed to liquids at the temperature of the heated formation, and, when the well pressure is lowered below the pressure of the fluids in the formation, aqueous and hydrocarbon fluids are produced into the well.

Upon forcing the hot aqueous fluid into a substantial portion of the formation surrounding the well, the injection is terminated, the pressure within the well is reduced, and fluid is produced from the same well used for the injection. The pressure reducing and fluid producing steps may be effected in a relatively conventional manner. Generally, the term of injection may extend from several months up to nearly a year. After termination of injection, production of fluids from the formation may be commenced either immediately or after a period of "soaking." In the latter case, the injected fluid is allowed to further cool within the formation, thus heating hydrocarbons and condensing vaporized water and hydrocarbons. It is noted, however, that in either the case where production is commenced immediately after the termination of injection, or in the case where there is a delay between injection and production, the formation is in essence subjected to a "soak," since the hot aqueous fluid is always in the formation for a considerable time during the injection and the turn around to production.

In the production of the well after the injection and soak period, primarily liquid hydrocarbons and water are produced from the well. In general, of the fluids in the formation a major proportion, e.g., about 80%, of the vaporized hydrocarbons condense prior to entering the well and most of the vaporized water condenses prior to entering the well. Upon entering the well some of the condensed vapors may revaporize due to a pressure drop across the face of the formation. Furthermore, due to heat losses in the production string and flow lines, even greater condensation may take place prior to the time fluids are communicated to a storage reservoir from the well.

The steps of injecting, soaking and producing a formation may be repeated periodically in any manner that proves desirable from an economical standpoint. The time interval between applications will depend upon the rate at which the formation cools during production, which will in turn be reflected upon the production rate.

The above-described production method of the present invention is preferably carried out in a number of wells in one field. In so executing the invention, the period during which hot aqueous fluid is injected into one of said wells should substantially coincide with the period during which hydrocarbons are produced from an alternative well, while the period during which hydrocarbons are produced from the former well should substantially coincide with the period which hot aqueous fluid is injected into the latter well. This arrangement is particularly advantageous where steam production facilities are limited, since a single steam generator can be alternatively connected to the wells. When using the above-described method on a number of wells within a single field, the amount of viscous hydrocarbons in the formation between the wells decreases and at the same time the temperature of the depleted areas of the formation increases. As a result, the resistance to flow encountered by hydrocarbons in the formation is materially decreased. After a number of cycles, each comprising a period of fluid injection and a period of hydrocarbon production, the amount of hydrocarbons left in the formation will be diminished to such an extent, and at the same time the temperature of the formation will have so risen, that the steam injected into one of the wells will be capable of driving the remaining quantity of hydrocarbons to one or more of the other wells from which it may be produced. At this point, production will be commenced in what is essentially a direct drive process. It can be seen that at this point no hot aqueous fluid is injected into the wells being used as production wells.

If the production and injection periods for wells penetrating into the same formation substantially coincide, the time at which continuous hot aqueous fluid injection should be applied to effect the direct drive process will manifest itself automatically. Specifically, at that point, the production rate from a well or wells being produced will materially rise due to a driving effect of the injection wells. It is to be understood that the method of the present invention is not restricted to a particular well pattern, but can be employed in oil fields in which the wells are arranged according to previously existing patterns. If, for instance, the wells are arranged in a rectangular pattern, the injection and production periods for two equivalent sets of wells may coincide. In an oil field where wells are arranged in a triangular pattern, the injection periods, the close-in periods (i.e., the soaking periods subsequent to injection and prior to production), and the production periods may coincide for three equivalent sets of wells.

Example

A production well was completed into a producing formation located at a depth of 460 ft. and having a reservoir pressure of 60 p.s.i. and a reservoir temperature of 85° F. The well was equipped with apparatus to facilitate both the introduction of fluids thereinto and the removal of effluent therefrom. In this reservoir, overburden pressure was estimated at 322 lbs. per square inch (i.e., 0.7×460=322).

In this case, injection of steam was commenced at a pressure of about 94 lbs. per sq. inch and was continued for a period of 84 days. The average steam injected was estimated as having a pressure of 94 lbs. per sq. inch and a temperature of 334° F. At the end of the 84 day injection period, injection was terminated and the injected steam was allowed to soak for 12 days. Backflow from the injection well was then begun and it took place at a production rate of about 306 barrels per day of oil during the first week. By the end of this first production cycle, 9 months later, this well was producing about 66 barrels per day of oil, significantly more than its initial production rate of 24 barrels per day prior to the steam soak treatment. At the end of the first production cycle the injection of steam is resumed. In this manner, the steps of injection and production are repeated until the reservoir being treated is depleted to a point where further production is no longer economically feasible or until the reservoir has been heated to an extent making it attractive to steam-drive the oil from one well to another.

It is to be understood that the above example is intended for the purpose of illustration only. Under formation conditions corresponding to those of the example the application of the invention could be changed in any of the manners described previously. For example, if desired, more than one well could have been completed into the formation and these wells could have been concurrently treated with one well having steam injected thereinto while the next adjacent well was being produced. In this case, the method could include a direct steam drive after the formation between adjacent wells was substantially heated. Furthermore, the example could be altered to exclude the "soaking period" after injection and prior to production. In the latter case, either a single well or a plurality of wells could be used.

In operating the present process by injecting steam at a pressure that is less than the overburden pressure of the reservoir formation, the overburden cannot be ruptured to open passageways through which the steam can escape from the reservoir. The importance of this is exemplified by an instance in which steam was injected at pressures ranging from 500–570 p.s.i.g. into a reservoir having an overburden pressure slightly less than the average injection pressure. That injection pressure was selected to obtain an injection rate of about 70 tons per day. The selected rate of injection was sustained for about 21 days. However, the steam then erupted to the surface and flowed out of the ground for about 9 hours after the cessation of the injection. By adopting the present process of injecting steam for a limited time at a pressure less than the overburden pressure and then backflowing to produce oil from the well through which the hot fluid was injected, oil was economically produced from several wells, including the above mentioned well of the example, that were completed into the reservoir formation of the example.

From the foregoing description it is believed apparent that the present invention provides an improved method of thermally recovering viscous hydrocarbons from hydrocarbon bearing formations. The invention avoids the necessity of high pressures and production delays encountered in conventional direct steam drive processes. Furthermore, the method of the invention is practiced at such pressures that fractional vaporization does, in fact, occur within the hydrocarbon bearing formation. This vaporization does not, however, lead to the build up of heavy residues within the formation, as might be expected. As a result, steam compression expenses are maintained at a minimum and the danger of fracturing the overburden is eliminated. The latter characteristic is of particular importance in shallow formations where it is contemplated the present invention will find a great part of its application.

To conclude, the present invention provides a method whereby viscous hydrocarbons may be efficiently and economically produced. In particular, the invention provides a method whereby a hot aqueous fluid, such as a steam, may be used for the thermal recovery of hydrocarbons in relatively shallow formations which were previously difficult, if not impossible, to treat with steam recovery processes. It is noted that the practice of previous fluid injection secondary recovery processes such as that disclosed in my Trinidad Patent No. 23/62 has demonstrated that blowouts frequently occur in shallow formations where fluid injection pressures are not limited according to the instant invention.

The foregoing description of the invention is, however, merely intended to be explanatory thereof. Various changes in the details of the described method may be made, within the scope of the appended claims, without departing from the spirit of the invention.

I claim as my invention:

1. A method of recovering hydrocarbons from hydrocarbon-bearing, earthen formations comprising:

(a) penetrating a hydrocarbon-bearing formation with a plurality of boreholes spaced from one another;

(b) injecting hot aqueous fluids into a significant portion of said formation through said boreholes at a pressure which is less than overburden pressure at the injection levels, said hot aqueous fluids having a temperature sufficient to vaporize only some of the hydrocarbons in said reservoir;

(c) retaining said hot aqueous fluids injected into said formation within said formation for a period permitting adsorption of heat by said formation from said aqueous fluids and condensation of some of the vaporized hydrocarbons within said formation;

(d) backflowing effluents in said formation to said boreholes through the same portion of said formation which was injected with said hot aqueous fluid by reducing the pressures in said boreholes to less than said hot aqueous fluid injection pressures;

(e) recovering hydrocarbons entering said boreholes; and

(f) subsequently injecting additional hot aqueous fluids into some of said boreholes and recovering hydrocarbons from adjacent boreholes driven thereinto by said subsequent injection.

2. A method according to claim 1 wherein steps (b), (c), (d) and (e) are repeated prior to carrying out step (f).

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