This invention relates, as indicated, to an improved in-situ combustion process. More particularly, the present invention relates to a method of recovering oil from a subsurface formation by a low temperature in-situ combustion process.

As it is well known in the producing division of the oil industry, a substantial amount of time and effort is being expended in perfecting the recovery of oil from partially depleted reservoirs by processes involving burning of a portion of the hydrocarbons in the reservoir. Several in-situ combustion processes have been proposed and tried. Results to date indicate that this type of process has substantial merit if certain difficulties can be overcome.

In substantially all previous in-situ combustion processes, an injection well is surrounded by a plurality of recovery wells, with all of the wells traversing the formation to be treated. The initial step in the process is to force air or some other gas through the formation from the injection well to the recovery wells to determine that gas can be forced through the formation. The second step in the process is the ignition of a portion of the hydrocarbons in the formation around the injection well to form a flame front which is sustained by injection of air through the injection well, such that the flame front proceeds radially from the injection well toward the recovery wells. One of the major problems in the process is the ignition of hydrocarbons in the formation in an economical manner without damage to the equipment in the injection well.

Perhaps the most popular method of ignition is locating a suitable heater in the injection well bore adjacent to the formation to be treated, such that the air injected into the formation from the injection well is heated by the heater to a temperature sufficient to ignite the hydrocarbons on the face of the formation formed at the injection well. This method has two serious objections. First, the high temperatures reached in the injection well bore (sometimes as high as 1200 degrees F.) seriously damage the well casing and cement and the heater has a short service life at these temperatures. Secondly, the rather sudden heating of the formation at the injection well frequently causes permeability blocking which is primarily caused by vaporization of water in the formation and subsequent cooling or condensation of the water in the colder formation ahead of the flame front. When permeability blocking occurs, air cannot be forced through the formation to sustain the flame front.

Another ignition method involves preheating an inert gas (such as nitrogen) at the surface and then injecting the heated inert gas down through the well bore into the formation to heat the formation to an ignition temperature; whereupon air is substituted for the inert gas to ignite hydrocarbons in the formation and form a flame front. This method is also disadvantageous since inert gas is expensive and not readily obtainable; large heat losses occur in forcing the heated gas through the length of the injection well bore, and excessive temperatures are created in the well bore with results similar to those described above. As a variation of this method, it has also been proposed to deion the injection well cool off to, say 400 degrees F., from an initial temperature of from 650° F. to 900 degrees F., prior to injection of air in order

to provide ignition in the formation at some distance from the injection well. This is undoubtedly an improvement since it reduces the maximum temperatures attained in the injection well, but the high temperature of the inert gas injected in the formation provides permeability blocking and a coking of the oil in the formation around the injection well which requires an appreciable temperature for the ignition of the coke. Also, of course, the high heat losses in forcing the heated inert gas through the length of the injection well remain.

The present invention contemplates a novel process of in-situ combustion utilizing low temperature oxidation of oil in a formation around an injection well. As a preliminary step, a gas (such as air) is forced through the formation from the injection well to one or more recovery wells to establish that gas can be forced through the formation. The air being injected is then slowly heated in the injection well to a temperature greater than the vaporization temperature of the formation water, but less than the coking temperature of the oil in the formation. As a result, permeability blocking is prevented and residual oil will remain in the formation around the injection well. Continued injection of the heated air slowly oxidizes the residual oil around the injection well, and the ignition temperature of the oil is reached at some distance from the injection well. It will thus be apparent that the flame front is formed away from the injection well to prevent excessive temperatures in the injection well which would cause damage to equipment in the injection well. The flame front is directed on through the formation by continued injection of air through the injection well. As used herein, the term “flame front” means the high temperature combustion front which occurs after the ignition temperature of the oil is reached.

More specifically, the present invention contemplates a method of recovering oil from a subsurface formation containing oil and water and traveled by an injection well and at least one recovery well, comprising the steps of:

(a) forcing air through the formation from the injection well to the recovery well,

(b) slowly increasing the temperature of the air to a temperature sufficiently high to oxidize oil in the formation, but to a temperature less than a coking temperature of the oil,

(c) moving the flame front provided by said oxidation toward the recovery well, and

(d) recovering the gases and liquids flowing from the formation into the recovery well.

An important object of this invention is to efficiently and economically recover oil from a subsurface formation.

Another object of this invention is to recover oil from a subsurface formation by in-situ combustion without damage to any of the equipment installed in the injection well.

Another object of this invention is to minimize the possibility of permeability blocking in an in-situ combustion process.

A further object of this invention is to provide a maximum service life for a heater used in an injection well in an in-situ combustion process.

A further object of this invention is to initially ignite hydrocarbons in a formation subjected to in-situ combustion at a minimum temperature and in spaced relation from the injection well.

A still further object of this invention is to provide an in-situ combustion process having minimum energy requirements.

Other objects and advantages of the invention will be evident from the following detailed description, when
read in conjunction with the accompanying drawings which illustrate this invention.

In the drawings:

FIG. 1 is a plan view of a typical injection and recovery well pattern used in an in-situ combustion process.

FIG. 2 is a vertical sectional view through the injection well and one of the recovery wells, as taken along line 2-2 of FIG. 1.

FIG. 3 is a set of typical heat curves obtained in a process according to this invention.

Referring to the drawings in detail, and particularly FIG. 1, reference character 10 designates an injection well and reference character 12 designates each of a plurality of recovery wells arranged in circumferentially spaced relation around the injection well. In a typical arrangement, five of the recovery wells 12 are drilled around the injection well 10 to provide adequate drainage points for fluids forced radially outward from the injection well 10, as will be explained below.

As shown in FIG. 2, the injection well 10 and each of the recovery wells 12 are drilled to such a depth as to traverse the formation 14 to be treated. It will be understood, of course, that the wells 10 and 12 may have all been producing wells utilized in recovering oil from the formation 14 by artificial lifting means, such as pumps, until the flow from the formation 14 was reduced to such an extent that the use of pumps became uneconomical. On the other hand, a portion of the wells 10 and 12 may be drilled specifically for utilization of the in-situ combustion process of this invention.

The injection well 10 may be completed "open hole," but is normally provided with suitable casing 16 cemented in place and having perforations 18 therein extending through the zone of the injection well traversing the formation 14. The recovery wells 12 may be completed in any desired fashion, as long as the fluids from the formation 14 may easily enter the recovery wells and be removed from the recovery wells. The recovery well 12 shown in FIG. 2 is shown as being completed "open hole" and no equipment is shown therein, to simplify the illustration.

In accordance with the present invention, suitable packers 20 and 22 are placed in the injection well 10 at the upper and lower ends of the formation 14 to isolate the zone 24 of the injection well which traverses the formation 14. It will be understood by those skilled in the art that the lower packer 22 may be eliminated if the injection well terminates approximately at the bottom of the formation 14, and if no perforations are provided below the formation 14. A suitable tubing string 26 is extended downwardly through the injection well 10, through the upper packer 20 and into the upper portion of the zone 24. A suitable heater 28 is supported on the lower end of the tubing string 26 within the upper portion of the zone 24. The heater 28 may be of any desired construction, such as electric or gas-fired, and is so constructed that gas forced downwardly through the tubing string 26 will be heated by the heater 28 before flowing into the zone 24.

With the heat equipment installed in the injection well 10 as illustrated in FIG. 2, air or any other suitable gas is forced through the tubing string 26 and through the heater 28 into the zone 24. The gas flows from the zone 24 through the perforations 18 and into and through the formation 14 toward the recovery wells 12. The pressure required to force the gas through the formation 14 will depend upon the characteristics of the formation 14, but is typically about 600 p.s.i. When the gas begins discharging into the recovery wells 12, showing that gas can be pumped through the formation 14, the heater 28 is placed in operation to start heating the gas being forced through the formation 14.

The heater 28 is fired in such a manner as to slowly or gradually heat the gas being forced through the formation 14, and hence to slowly or gradually heat the formation. We have found it particularly useful to operate the heater 28 in such a manner as to heat the gas being injected in a stepwise or temperature retarded manner. For example, in one field test of the present process, the gas (air) was heated and forced through the formation at 200 degrees F. for five days; then 300 degrees F. for three days; then 400 degrees F. for two days; then 600 degrees F. for five days. With this gradual heating, no permeability blocking was encountered. It may also be noted that at each step, from 200,000 to 800,000 cubic feet of air per day were forced through the formation being treated.

In a preferred embodiment of this invention, the gas forced or pumped through the formation 14 in all stages of the process is air, since this is the most economic gas to use and, as shown, has highly useful results. It is to be understood, however, that the gas used for determining that gas can be forced through the formation 14 and for initially heating the formation 14 may be an inert gas, such as nitrogen, if desired. In this latter event, oxygen must be supplied to the formation 14 through the injection well 10 to oxidize hydrocarbons in the formation and initiate combustion, as is described below, when the necessary temperature of the formation is reached.

The temperature curves shown in FIG. 3 were obtained from a laboratory test conducted in accordance with the process set forth herein, and are believed to be representative of the increase in temperature of any oil bearing formation treated in accordance with our invention. It will be observed in FIG. 3 that the temperature of the air being injected was gradually raised from about 300 degrees F. to approximately 475 degrees F. and retained at this latter temperature. This test data clearly shows that the particular oil being used began to oxidize at a temperature of approximately 425 degrees. As the temperature of the injection air increased on up to 450 and 475 degrees, oxidation of the oil increased in such a manner that the temperature of the expanded air stream of the injection point began to increase and continued to increase until the ignition temperature of approximately 875 degrees F. was reached. Thus, when air is injected into a formation from an injection well and is slowly heated as described above, the oil in the formation 14 around the injection well 10 will begin to oxidize, yet ignition will take place radially outward from the injection well 10 to protect the injection well 10 from excessive temperatures.

In the past, it has been the practice to heat a formation around an injection well to temperatures substantially above the coking temperature of the oil in the formation (from 550° F. to 700° F.). Under these conditions, the coke at the face of the walls of the injection well or the coke immediately adjacent the injection well was ignited. This procedure is desirable in the sense that all of the valuable hydrocarbons should be recovered and only the low value coke would be burned. We have found, however, that coke has a high ignition temperature, compared with residual oil. In our process, the formation around the injection well 10 is gradually heated to drive off the lighter hydrocarbons, but the temperature of the formation adjacent the injection well is not raised into the coking temperature range of the oil until a flame front has been formed away from the well bore. As a result, the initial ignition of the hydrocarbons in the formation 14 around the injection well is established with much lower well bore temperatures than have been used in the past. It will be understood by those skilled in the art that the flame front is maintained until the oil temperature in the oil zone reaches the ignition temperature.
ability block as is frequently encountered with prior processes, as indicated above. The injection of air through the injection well 10 is continued after establishment of the flame front in order to sustain the flame front and drive the flame front radially toward the recovery wells 12. It is preferred that the heater 28 be continued in operation after ignition is established to continually preheat the air being fed to the formation. This sustains the flame front to prevent the possibility of excessive heat loss behind the flame front and extinguishment of the flame.

The gases and liquids driven from the formation 14 into the recovery wells 12 may be recovered in any desired manner which will preserve the valuable hydrocarbons. The recovery of these hydrocarbons from the wells 12 is not, in itself, a part of our invention, and may be performed by well known procedures.

From the foregoing it will be apparent that the present invention provides a convenient and economical process of recovering oil from a subsurface formation. The temperature of the injection well is retained sufficiently low as not to damage any of the equipment in the injection well, and the heater used in the injection well will have a long service life. The flame front is formed radially outward from the injection well and is formed without permeability blocking. It will also be apparent that the present process will have a minimum of energy requirements.

Changes may be made in the combination and arrangement of steps or procedures as hereinafter set forth in this specification and shown in the drawings, it being understood that changes may be made without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A method of recovering oil from a subsurface formation containing oil and water and traversed by an injection well and at least one recovery well, comprising the steps of:

(a) forcing gas through the formation from the injection well to the recovery well;
(b) slowly, over a period of days, increasing the temperature of said gas within the injection well and while the resulting heated gas is being injected into the formation from the injection well to a temperature greater than the vaporization temperature of the formation water, but less than the temperature of the oil in the formation, to retain residual oil in the formation around the injection well;
(c) injecting air into the formation from the injection well at a temperature sufficiently high to oxidize the residual oil for initiating combustion of the residual oil and forming a flame front around the injection well;
(d) continuing the injection of air into the formation from the injection well until the flame front formed by combustion of the oil in the formation has advanced into proximity with the recovery well, and
(e) recovering the gases and liquids flowing into the recovery well from the formation.

2. A method of recovering oil from a subsurface formation containing oil and water and traversed by an injection well and at least one recovery well, comprising the steps of:

(a) forcing air through the formation from the injection well to the recovery well;
(b) slowly over a period of days, increasing the temperature of said air within the injection well and while the resulting heated air is being injected into the formation from the injection well to a temperature less than the coking temperature of the oil in the formation, but sufficiently high to oxidize residual oil in the formation around the injection well to form a flame front in the formation;
(c) continuing the injection of air into the formation through the injection well for moving the flame front formed by said oxidation toward the recovery well, and
(d) recovering the gases and liquids flowing into the recovery well from the formation.

3. The method defined in claim 2 wherein the temperature of the air injected through the injection well is increased stepwise.

4. The method defined in claim 2 wherein said air is heated within the injection well in the zone of the well traversing the formation.

5. The method defined in claim 2 wherein the air injected into the formation through the injection well for moving the flame front toward the recovery well is heated to a temperature sufficiently high to oxidize residual oil in the formation.

6. The method defined in claim 2 wherein the temperature of the air is between about 300° F. and about 700° F.

7. The method defined in claim 6 wherein the temperature of said air in step (a) is greater than the vaporization temperature of the formation water.

8. The method defined in claim 2 wherein the temperature of the air is between about 300° F. and about 550° F.

9. The method defined in claim 2 wherein the temperature of the air is between about 300° F. and about 475° F.

10. A method of recovering oil from a subsurface formation containing oil and water, comprising the steps of:

(a) providing an injection well from the surface through the formation;
(b) providing a plurality of recovery wells in circumferentially spaced relation around the injection well, with each of said recovery wells being drilled through the formation;
(c) isolating the zone of the injection well traversing the formation;
(d) forcing gas through the formation from the injection well to the recovery wells,
(e) placing a heater in said zone,
(f) activating said heater,
(g) pumping air through said heater and said zone into the formation;
(h) controlling the temperature of said heater to slowly increase the temperature of the air being forced into the formation from said zone, over a period of days, until the temperature of the air exceeds the vaporization temperature of the water in the formation but is less than the coking temperature of the oil in the formation, for forcing formation water and lighter hydrocarbons through the formation toward the recovery well and initiating combustion of residual oil in the formation around the injection well, and
(i) recovering the gases and liquids flowing from the formation into the recovery wells.

11. A method of recovering oil from a subsurface formation containing oil and water and traversed by an injection well and at least one recovery well, comprising the steps of:

(a) gradually, over a period of days, heating the formation from the injection well towards the recovery well with a gas heated within the injection well and while the resulting heated gas is being injected into the formation from the injection well to a temperature less than the coking temperature of the oil to drive the water and lighter hydrocarbons components of the oil toward the recovery well;
(b) igniting the residual oil in the formation around the injection well with air heated to a temperature less than the coking temperature of the oil in the formation to form a flame front;
(c) injecting air into the formation from the injection well to drive the flame front toward the recovery well; and
(d) recovering the liquid and gaseous hydrocarbons from the recovery well.
12. The method defined in claim 11 wherein the temperature of said gas is between about 300° F. and about 700° F.

13. A method of recovering oil from a subsurface formation containing oil and water and traversed by an injection well and at least one recovery well, comprising the steps of:

(a) introducing heated air into the formation from the injection well;
(b) slowly, over a period of days, increasing the temperature of said heated air while in said injection well to a temperature less than the coking temperature of the oil in the formation but sufficiently high to oxidize residual oil in the formation around the injection well simultaneously while the heated air is being injected into said formation from the injection well to form a flame front in the formation;

(c) continuing injecting air into the formation from the injection well to drive the flame front toward the recovery well; and

(d) recovering liquid and gaseous hydrocarbons from the recovery well.

14. The method defined in claim 13 wherein the temperature of said air is between about 300° F. and about 700° F.

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