(54) Title: FULLY CONTROLLED COMBUSTION ASSISTED GRAVITY DRAINAGE PROCESS

(57) Abstract: A method for extracting hydrocarbons from a hydrocarbon bearing reservoir, the reservoir being in fluid communication with at least one injection well, at least one production well, and at least one ventilation well, the method comprising, injecting an oxidizing gas into the reservoir through the at least one injection well to support in situ combustion in the reservoir to mobilize the hydrocarbons; using the at least one ventilation well to control the ventilation in the in situ combustion area; and recovering the mobilized hydrocarbons by way of the at least one production well.

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FULLY CONTROLLED COMBUSTION ASSISTED GRAVITY DRAINAGE PROCESS

RELATED APPLICATION


FIELD OF THE INVENTION

[0002] The invention relates to the recovery, extraction, and production of hydrocarbons, including bitumen and heavy oil.

BACKGROUND

[0003] With the world’s reliance on fossil fuels and hydrocarbon based energy sources, many different processes have been investigated and developed to recover viscous hydrocarbons from underground deposits, such as the deposits found in the tar sands of Alberta, Canada, Venezuela, and the United States.

[0004] Methods that have been developed include natural pressure depletion, water flooding or gas injection, steam based processes such as cyclic steam stimulation and steam assisted gravity drainage, polymer flooding, and in situ combustion.

[0005] The natural pressure depletion method may have low recovery factor and low production rate. The water flooding or gas injection method may consume a large amount of water with low recovery rates. Polymer flooding also has low recovery and production rates with a high consumption of water.

[0006] While steam assisted gravity drainage has better production rates, the method consumes a large amount of water and requires significant investment in capital cost. There is also significant carbon dioxide emission due to the need of generating a significant amount of steam by burning natural gas or other fuels for the steam production process.

[0007] Companies have tested the in situ combustion method in recovery of hydrocarbons. While the in situ combustion method has the advantage of not requiring the production of a large amount of steam, the current methods have potential problems with process control. For instance, the implemented methods cannot address the rates of oxidizing gas injection, hydrocarbon production, and flue gas ventilation properly. In addition, current methods of in situ combustion make it difficult to achieve sustainable and controllable in situ combustion within the reservoir. Furthermore, existing methods of in situ combustion may utilize the production well for removal
of combustion gases generated from the combustion, causing the production rate of such production well to decrease in view of the dual-use of the production well.

[0008] Other known methods are described in patents and published patent applications such as Canadian Patent No. 2096034 to Kisman et al., Canadian Patent No. 2176639 to Greaves and Turta, Canadian Patent No. 2594414 to Chhina and Nzekwu, and 2678347 to Bailey and Canadian Patent Application No. 2692885 by Sarathi et al., all of which are incorporated herein by reference.

[0009] A need therefore exists for an improved method of extracting hydrocarbons.

SUMMARY OF THE INVENTION

[0010] The invention relates to a method of extracting hydrocarbons using an in situ combustion method utilizing at least one injection well, at least one ventilation well, and at least one production well.

[0011] According to one embodiment of the invention, there is provided a method for extracting hydrocarbons from a hydrocarbon bearing reservoir, the reservoir being in fluid communication with at least one injection well, at least one production well, and at least one ventilation well, the method comprising, injecting an oxidizing gas into the reservoir through the at least one injection well to support in situ combustion in the reservoir to mobilize the hydrocarbons; using the at least one ventilation well to control the ventilation in the in situ combustion area; and recovering the mobilized hydrocarbons by way of the at least one production well.

[0012] According to one aspect of the invention, there is provided a method for extracting hydrocarbons from a hydrocarbon bearing reservoir wherein the at least one production well has a generally horizontal segment that is vertically spaced below the at least one injection well.

[0013] According to another aspect of the invention, there is provided a method for extracting hydrocarbons from a hydrocarbon bearing reservoir wherein the hydrocarbon is at a viscosity greater than 10,000 mPa.s.

[0014] According to another embodiment of the invention, there is provided a method of extracting hydrocarbons comprising selecting a hydrocarbon bearing reservoir, the reservoir being in fluid communication with at least one injection well, at least one production well having a generally horizontal segment and vertically spaced below the at least one injection well, and, at least one ventilation well; injecting an oxidizing gas into the at least one injection well to support in situ combustion in an area of the reservoir in proximity to the at least one injection well to
mobilize the hydrocarbons; increasing, maintaining, or decreasing ventilation of the in situ combustion area using the at least one ventilation well; and recovering the mobilized hydrocarbons by way of the at least one production well.

[0015] According to one aspect of the invention, there is provided a method of extracting hydrocarbons wherein the hydrocarbon is heavy oil.

[0016] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well has a horizontal segment in the reservoir that is generally parallel to a horizontal segment of the at least one production well.

[0017] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well is at an angle from about 0 to about 180 degrees relative to the at least one production well.

[0018] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one ventilation well intersects the at least one injection well within the hydrocarbon bearing reservoir.

[0019] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well and/or the at least one production well and/or the at least one ventilation well contain at least one sensor.

[0020] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well and/or the at least one production well and/or the at least one ventilation well contain at least one temperature sensor.

[0021] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well and/or the at least one production well and/or the at least one ventilation well contains at least one pressure sensor.

[0022] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the in situ combustion area contains at least one sensor.

[0023] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one sensor is a temperature, pressure, or oxygen sensor.
[0024] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one production well is at an angle from about 0 to about 30 degrees relative to the horizontal direction.

[0025] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the oxidizing gas contains additives such as low ignition point hydrocarbons and/or water mist.

[0026] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well contains circulation tubing to toe.

[0027] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one production well contains circulation tubing to toe.

[0028] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one injection well is open hole or cased.

[0029] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one production well is open hole or cased.

[0030] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the in situ combustion is initiated by steam circulation, oxidants, electrical heating, electrical-magnetic heating, or other physical/chemical heating methods.

[0031] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein more than one ventilation wells are installed.

[0032] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one ventilation well has a segment that is substantially perpendicular to the horizontal segment of the at least one injection well.

[0033] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one ventilation well is at an angle from about 0 to about 180 degrees relative to the at least one production well.

[0034] According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the oxidizing gas has an oxygen concentration from about 0% to about 100%.
According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the at least one ventilation well is used to remove combustion gases generated by the in situ combustion in the reservoir.

According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the combustion gases are redirected into the at least one injection well and/or the at least one production well through the at least one ventilation well.

According to another aspect of the invention, there is provided a method of extracting hydrocarbons wherein the in situ combustion occurs along the at least one injection well.

According to another embodiment of the invention, there is provided a method for sustaining a continuous in situ combustion in a hydrocarbon bearing reservoir comprising controlling ventilation in the in situ combustion using the at least one ventilation well.

According to another embodiment of the invention, there is provided a use of at least one ventilation well to sustain a continuous in situ combustion in a hydrocarbon bearing reservoir.

According to another embodiment of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion, comprising: at least one injection well; at least one production well; and at least one ventilation well.

According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the hydrocarbon bearing reservoir is in fluid communication with the at least one injection well and the at least one production well.

According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one production well has a generally horizontal segment that is vertically spaced below the at least one injection well.

According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one ventilation well intersects or communicates with the at least one injection well.

According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least
one injection well and/or the at least one production well and/or the at least one ventilation well contains at least one sensor.

[0045] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one sensor is a temperature sensor.

[0046] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one sensor is a pressure sensor.

[0047] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one sensor is an oxygen sensor.

[0048] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the production well is at an angle from about 0 to about 30 degrees relative to the horizontal direction.

[0049] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one injection well contains circulation tubing to toe.

[0050] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one production well contains circulation tubing to toe.

[0051] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one injection well is open hole or cased.

[0052] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one production well is open hole or cased.

[0053] According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein more than one ventilation wells are installed in the reservoir.
According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the at least one ventilation well is substantially perpendicular to the horizontal segment of the at least one production well.

According to another aspect of the invention, there is provided a system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion wherein the in situ combustion occurs along the at least one injection well.

Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples while indicating preferred embodiments of the invention are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Features and advantages of the embodiments of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

FIG. 1 is a front view illustrating the method of and system for extracting hydrocarbons according to an embodiment of the invention; and

FIG. 2 is a side view illustrating the method of and system for extracting hydrocarbons according to an embodiment of the invention.

FIG. 3 illustrates the effect of oxidizing circulation through the injection well in the hydrocarbon containing reservoir according to an embodiment of the invention.

FIG. 4 illustrates the temperature profile of a hydrocarbon containing reservoir after one year of air injection and using the method of and system for extracting hydrocarbons according to an embodiment of the invention.

FIG. 5 illustrates the temperature profile of a hydrocarbon containing reservoir after two years of air injection and using the method of and system for extracting hydrocarbons according to an embodiment of the invention.
[0063] FIG. 6 illustrates the temperature profile of a hydrocarbon containing reservoir after four and a half years of air injection and using the method of and system for extracting hydrocarbons according to an embodiment of the invention.

[0064] FIG. 7 is a graph illustrating the production rate from the hydrocarbon containing reservoir using the method of and system for extracting hydrocarbons according to an embodiment of the invention with a well pattern comprising two ventilation wells.

[0065] FIG. 8 is a graph illustrating the cumulative production of oil and gas from a hydrocarbon containing reservoir using the method of and system for extracting hydrocarbons according to an embodiment of the invention with a well pattern comprising two ventilation wells.

[0066] In the description which follows, like parts are marked throughout the specification and the drawings with the same respective reference numerals.

**DETAILED DESCRIPTION OF THE EMBODIMENTS**

[0067] The description which follows and the embodiments described therein are provided by way of illustration of an example or examples of particular embodiments of the principles of the present invention. These examples are provided for the purposes of explanation and not limitation of those principles and of the invention. In some instances, certain structures and techniques have not been described or shown in detail in order not to obscure the invention.

[0068] As part of this patent application, a number of terms are being used in accordance with what is understood to be the ordinary meetings of these terms. For instance, "fluid" includes both liquids and gases.

[0069] "Heavy oil" is defined as petroleum having an American Petroleum Institute gravity below 22.3°API (920 kg/m³ to 1000 kg/m³). "Bitumen" is defined as petroleum existing in semi-solid and solid phases with a density of greater than 1000kg/m³. While these terms are commonly used and are general categories, references to these terms in this application include the continuum of such substances and do not suggest some specific boundaries between the two substances. The term "heavy oil" includes within its scope "bitumen" of all forms.

[0070] "Petroleum" means mixtures consisting primarily of hydrocarbons in different phases, including, liquid, gas, or solid phase. "Hydrocarbon" is an organic compound consisting entirely of hydrogen and carbon and includes heavy oil and bitumen. In the context of this patent application, the words "petroleum" and "hydrocarbon" refer to mixtures with significant variations in composition.
A reservoir is a formation underneath the surface that contains natural accumulation of hydrocarbons.

Figure 1 is a front view illustrating a method of and a system for extracting hydrocarbons such as heavy oil according to an embodiment of the invention. An injection well 10 is present in a reservoir 60 along with a production well 20. The production well 20 is spaced vertically apart below the injection well 10. The injection well 10 and the production well 20 are also situated in a hydrocarbon bearing area 70 of the reservoir 60. In addition, the reservoir 60 contains a ventilation well 30 that is inserted into an area near the injection well 10. A combustion area 40 represents the area in the reservoir 60 that would be subject to heating by the in situ combustion inside the reservoir 60. The injection well 10, the production well 20, and the ventilation well 30 are all in fluid communication with the hydrocarbon bearing area 70 of the reservoir 60.

In one embodiment, in situ combustion may be started by injecting low ignition point material (such as oxidant) through the injection well 10 to create the combustion area 40 in the reservoir 60. Oxidizing gas 100 can be fed into the combustion area 40 through the injection well 10. In other embodiments, the in situ combustion process may be initiated by ignition naturally, steam circulation, electrical heating, electro-magnetic heating, or other physical/chemical heating methods.

In one embodiment, the oxidizing gas 100 is a mixture of oxygen and nitrogen. In other embodiments, the oxidizing gas 100 is oxygen enriched air.

The in situ combustion within the combustion area 40 will continue by burning a small portion of the hydrocarbons present in the hydrocarbon bearing area 70 of the reservoir 60 and the majority of the hydrocarbons in the hydrocarbon bearing area 70 will be mobilized upon being heated by the in situ combustion and drain to the production well 20 by gravity. The in situ combustion process within the combustion area 40 can be fully controlled using the injection well 10, the production well 20, and the ventilation well 30. This process does not rely on formation energy. In some embodiments, water or steam injection through the injection well 10 or the production well 20 may be applied to encourage circulation of fluids within the injection well 10 or the production well 20 to control the in situ combustion.

Figure 2 is a side view illustrating a method of and a system for extracting hydrocarbons according to an embodiment of the invention. The injection well 10 has a horizontal segment 12 in the hydrocarbon bearing area 70 of the reservoir 60. The production
well 20 also has a horizontal segment 22 in the hydrocarbon bearing area 70 of the reservoir 60. The horizontal segment 22 is spaced vertically below the horizontal segment 12 of the injection well 10. Multiple ventilation wells 30 are placed vertically into the hydrocarbon bearing area 70 of the reservoir 60 and spaced apart along the horizontal segment 12 of the production well. As such, the ventilation wells 30 are perpendicular to the horizontal segments 12 and 22 of the injection well 10 and the production well 20, respectively.

[0077] Upon commencement of the in situ combustion in the injection well 10 and through the horizontal segment 12 in the hydrocarbon bearing area 70 of the reservoir 60, the combustion area 40 is generated in the hydrocarbon bearing area 70 around the injection well 10. As a result of the in situ combustion, which can occur across the hydrocarbon bearing area 70 along the injection well 10, the heavy oil in the hydrocarbon bearing area 70 mobilizes to become mobilized heavy oil 120 which moves via gravity into the production well 20. In addition, combustion gases 110 are formed in the combustion area 40 as a result of the in situ combustion. The combustion gases 110 may include nitrogen, steam, carbon dioxide, trace amount of light hydrocarbons, and oxygen. Because of the presence of the ventilation wells 30 in the hydrocarbon bearing area 70 that are in fluid communication with such area, the combustion gases 110 can leave the combustion area 40 through the ventilation wells 30. In one embodiment, the ventilation wells 30 are open and the combustion gases 110 are released into the atmosphere. In another embodiment, the ventilation wells 30 are connected to a gas treatment facility where the combustion gases 110 are treated prior to their release into the atmosphere. In a further embodiment, the ventilation wells 30 may be connected to the injection well 10 whereby the combustion gases 110 can be recycled into the combustion area 40 through the injection well 10 as part of regulating the in situ combustion within the combustion area 40. In other embodiments, the ventilation wells 30 may be connected to the production well 20 whereby the combustion gases 110 can be recycled back into the production well 20.

[0078] By opening, choking back, or shutting each, some, or all of the ventilation wells 30, the ventilation of the combustion area 40 can be increased or decreased, such that the in situ combustion within the combustion area 40 can be regulated. For instance, if the in situ combustion is occurring too rapidly and the temperature within the injection well 10, the production well 20, and/or the combustion area 40 is becoming too high, then the ventilation wells can be completely or partially closed to reduce the amount of oxygen available to sustain the in situ combustion within the combustion area 40. Where the in situ combustion is unable to sustain across the horizontal segment 12 of the injection well 10 to allow for sustained combustion within the combustion area 40, the ventilation wells 30 can be completely opened or
partially opened to allow oxygen to enter into the combustion area 40 to encourage further combustion. As such, temperature, pressure and oxygen levels can be controlled to desired limits within the system 1, within the in situ combustion area 40 and/or within each injection well 10, production well 20, and/or ventilation well 30. The control of temperature, pressure, and/or oxygen levels also enables one to control combustion and/or rate of flow of the mobilized heavy oil 120 within the production well 20.

[0079] In one embodiment, temperature sensors, pressure sensors, oxygen sensors, and other sensors known to persons skilled in the art are installed to monitor conditions in the injection well 10, the production well 20, the ventilation wells 30, and/or the combustion area 40 such as temperature, pressure, hydrocarbon production rate, and oxygen levels. In other embodiments, a computerized system is used to regulate the production of mobilized heavy oil 120 through interaction with the injection well 10, the production well 20, the ventilation wells 30, and/or the combustion area 40 based on results from the different sensors.

[0080] Through the use of the ventilation wells 30 situated along the horizontal segment 12 of the injection well 10, the combustion area 40 can be developed evenly along the horizontal section of the hydrocarbon bearing area 70 of the reservoir 60. The production of the mobilized heavy oil 120 through the production well 20 by gravity drainage is known in the art and is commonly used with other methods of hydrocarbon extractions such as steam assisted gravity drainage (SAGD).

[0081] As illustrated in FIG. 1 and 2, in one embodiment, the ventilation wells 30 are perpendicular to the horizontal segments 12 and 22 of the injection well 10 and the production well 20, respectively. In other embodiments, the ventilation wells 30 are not perpendicular to the horizontal segments 12 and 22 of the injection well 10 and the production well 20, respectively.

[0082] In one embodiment, the ventilation wells 30 are in the combustion area 40 and close to the injection well 10 and the production well 20. In other embodiments, the ventilation wells 30 intersect the injection well 10 at right angles. In other embodiments, the ventilation wells 30 intersect the injection well 10 at other angles that are not right angles.

[0083] As illustrated in FIG. 1 and FIG 2, in one embodiment, the injection well 10 has a horizontal segment 12 which is parallel to the horizontal segment 22 of the production well 20. In other embodiments, the injection well 10 does not have the horizontal segment 12 and is not parallel to the horizontal segment 22 of the production well 20. In other further embodiments, the
injection well 10 has segments at an angle from about 0 to about 90 degrees relative to the horizontal direction.

[0084] In one embodiment, the injection well 10 is cased. In other embodiments, the injection well 10 is open hole. In one embodiment, the ventilation wells 30 are cased. In other embodiments, the ventilation wells 30 are open hole. In one embodiment, the production well 20 is cased. In other embodiments, the production well 20 is open hole.

[0085] In one embodiment, the injection well 10 and the production well 20 are completed with circulation tubing to toe. In alternative embodiments, the injection well 10 and the production well 20 are not completed with circulation tubing to toe. In one embodiment, the ventilation wells 30 contain corrosion resistant tubing. In other embodiments, the ventilation wells 30 do not contain corrosion resistant tubing.

[0086] In one embodiment, there is one injection well 10 and one production well 20. In other embodiments, more than one injection wells 10 may be used with one production well 20. In yet other embodiments, more than one injection wells 10 may be used with more than one production wells 20. In alternative embodiments, one injection well 10 can be used with more than one production wells 20.

[0087] In one embodiment, there is one set of the injection well 10, the production well 20, and the ventilation wells 30 in the reservoir 60. In other embodiments, there are multiple sets of the injection well 10, the production well 20, and the ventilation wells 30.

[0088] The above embodiments may contribute to an improved method of and a system for extracting hydrocarbons and may provide one or more advantages. Firstly, the in situ combustion may be fully controlled from three different kinds of wells. Oxidizing gas injection rate, pressure, and temperature may be controlled from the injection well; production rate and pressure (even temperature) may be controlled from the producer well; and flue gas production rate and pressure may be controlled from the ventilation wells. Secondly, the method or system may require lower capital and operation cost. Thirdly, the method or system may be easier to operate. Fourthly, the method or system may require use of little to no water. Fifthly, the method or system may create less greenhouse gas emission because natural gas is not needed for generating steam. Sixthly, the method or system may be adopted for use with different heavy oil-bearing formations, such as low oil saturation, lean zones, top water, top gas, low pressure, thin pay, and carbonates reservoirs. Seventhly, the method or system may allow flexible well configuration and
completion. Eighthly, the method or system may allow in situ upgrading of low quality hydrocarbons.

[0089] The present invention is described in the following non-limiting Examples, which are set forth to illustrate and to aid in an understanding of the invention, and should not be construed to limit in any way the scope of the invention as defined in the claims which follow thereafter.

EXAMPLES

[0090] In Example 1, the inventors illustrate the air requirement for practicing the method of extracting hydrocarbons in accordance with an embodiment of the invention and the potential recovery factor with use of such method. In Examples 2 and 3, the inventors provide, using computer simulation, a simulation of the performance of the method of and the system for extracting hydrocarbons in accordance with an embodiment of the invention.

EXAMPLE 1 – AIR REQUIREMENT AND POTENTIAL RECOVERY FACTOR

[0091] The following calculations illustrate estimates of the air requirement and potential recovery factor for the method of extracting hydrocarbons from the reservoir in accordance with an embodiment of the invention.

[0092] The assumptions for the reservoir in these calculations are as follows: dimensions are 800m long (x), 70m wide (y) and 20m thick (z), reservoir porosity is 34% ($\phi$), initial oil saturation is 80% ($S_o$), gas saturation is 0 ($S_g$), initial temperature is 15°C ($T_i$), combustion temperature is 500°C ($T_c$), heat capacity is 2,361 kJ/(m³°C) ($C_v$), recovery factor for gravity drainage using two production wells is 50-80% (RF), oil density is 1,000 kg/m³ ($\rho_o$), and project life is 7 years.

[0093] The method of extracting hydrocarbons in accordance with an embodiment of the invention may involve the injection of air into the reservoir to burn with a small fraction of hydrocarbon within the reservoir. This burning generates reaction enthalpy to raise the temperature of the combustion area of the reservoir up to 500°C. The air is injected through the injection well, and the flue gas is removed from the reservoir through the ventilation well. The heated hydrocarbon will become mobilized heavy oil and drained into the production well. The combustion reaction equation is based on Coats, K.H. "In-Situ Combustion Model", *SPE Journal*, Volume 20, Number 6, December 1980, and is shown as follows:

\[
\text{Heavy oil} + 18.5\text{O}_2 = 12\text{CO}_2 + 13\text{H}_2\text{O}
\]
The reaction enthalpy (enthalpy of combustion) is 4.78E04 kJ/kg (En).

Based on material balance, the original oil in place (OOIP) is:

\[ V_o = xyz \phi S_{oi} = 304,680 \text{ m}^3 \]

Based on energy balance, the energy needed to raise the temperature in the reservoir to combustion temperature (i.e. 15°C to 500°C) is:

\[ E = xyz (T_r - T_o) C_v = 1.28E12 \text{ kJ} \]

The volume of oil needed to be burned with air to achieve this energy is:

\[ V_{ob} = \frac{E}{E_n} = 2.69E4 \text{ m}^3 \]

The percentage of oil left in the reservoir that does not burn with air is then:

\[ R_o = \frac{(V_o - V_{ob})}{V_{ob}} \times 100\% = 91.2\% \]

Therefore, the ultimate oil recovery factor is:

\[ URF = R_o \times RF = 46 \text{ to } 73 \% \]

According to the reaction coefficient, one mole of heavy oil needs 18.5 moles of pure oxygen to react. Based on the burnt oil volume, the volume of air (containing 78.09% nitrogen; 20.95% oxygen; 0.039% carbon dioxide) required for in-situ combustion is:

\[ V_{air} = 3.41E08 \text{ m}^3 \]

For a project life of 7 years, the average daily injection rate of air needed to sustain the combustion in the reservoir is:

\[ Q_{air} = 1.35E05 \text{ m}^3/d. \]

**EXAMPLE 2 – COMBUSTION GAS CIRCULATION**

[0094] The method of extracting hydrocarbons in accordance with an embodiment of the invention may be started by a heat transfer process provided by the oxidizing gas in the injection
well and the production well. Such method have been modeled in computer simulation, based on the following properties for the reservoir:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td>0.33</td>
</tr>
<tr>
<td>Rock Heat Capacity</td>
<td>2300 kJ/m³ K⁻¹</td>
</tr>
<tr>
<td>X and Y Permeability</td>
<td>5000 mD</td>
</tr>
<tr>
<td>Z Permeability</td>
<td>2500 mD</td>
</tr>
<tr>
<td>Rock Compressibility</td>
<td>8E-7 kPa⁻¹</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>150 kJ/d.m.K</td>
</tr>
<tr>
<td>Datum Depth</td>
<td>201 m</td>
</tr>
<tr>
<td>Datum Pressure</td>
<td>2000 kPa</td>
</tr>
<tr>
<td>Oil Saturation</td>
<td>0.81</td>
</tr>
<tr>
<td>Initial Reservoir Temperature</td>
<td>10°C</td>
</tr>
<tr>
<td>Critical Water Saturation</td>
<td>0.17</td>
</tr>
</tbody>
</table>

[0095] The simulation used a 30m long segment for the injection well with the flow rate of the oxidizing gas at 50,000 m³/d at 500°C. The injection well has a 250mm diameter casing and 170mm diameter tubings. The path of the injection well is along the x-direction. Each grid block dimension is 3m×1m×1m.

[0096] Figure 3, based on results from the simulation, shows that circulation of oxidizing gas through the injection well can provide an even distribution of heat throughout the injection well and within the combustion area of the reservoir. The circulation process warms up the injection well and the heat assists with the extraction of hydrocarbons in accordance with an embodiment of the invention.

**EXAMPLE 3 – RESERVOIR PRODUCTION SIMULATION**

[0097] The rate of production of oil and gas using the method of and system for extracting hydrocarbons in accordance with an embodiment of the invention has been modeled in computer simulation, based on the following properties: three dimensional model of the reservoir with dimensions of 250m long (x), 50m wide (y) and 25m thick (z), grid block has the dimension of 2.5m×1m×1m, initial reservoir pressure is 2,500 kPa, maximum air injection pressure is 8,000 kPa, injection air temperature is 20°C-100°C, reservoir porosity is 34%, oil saturation is 75%, horizontal permeability is 6,700 mD, vertical permeability is 5,360 mD, and one production well, one injection well, and two ventilation wells.
FIG. 4 illustrates the temperature profile of the hydrocarbon containing reservoir after one year of air injection and using the method and system of extracting hydrocarbons according to an embodiment of the invention. FIG. 5 illustrates the temperature profile of the hydrocarbon containing reservoir after two years of air injection and using the method and system of extracting hydrocarbons according to an embodiment of the invention. FIG. 6 illustrates the temperature profile of the hydrocarbon containing reservoir after four and a half years of air injection and using the method and system of extracting hydrocarbons according to an embodiment of the invention. FIG. 7 is a graph illustrating the production rate from the hydrocarbon containing reservoir using the method and system of extracting hydrocarbons with a well pattern comprising two ventilation wells according to an embodiment of the invention. FIG. 8 is a graph illustrating the cumulative production of oil and gas from the hydrocarbon containing reservoir using the method of and system for extracting hydrocarbons with a well pattern comprising two ventilation wells according to an embodiment of the invention.

As illustrated in Figures 4 to 6, the temperature of the combustion area in the reservoir is primarily around 500°C, with some parts of the reservoir reaching temperatures as high as 700°C to 760°C. Controls may be implemented in the system for extracting hydrocarbons in accordance with an embodiment of the invention to reduce these temperatures for maintaining integrity of the wells.

As illustrated in Figures 7 and 8, in the simulation, the method of and system for extracting hydrocarbons in accordance with an embodiment of the invention (denoted as FC-CAGD (with two vents)) achieved higher oil and gas production when compared to combustion assisted gravity drainage not employing the ventilation wells (denoted as CAGD (without vents)). As illustrated in Figure 7, the method of and system for extracting hydrocarbons in accordance with an embodiment of the invention had a higher oil production rate over time when compared to combustion assisted gravity drainage not employing the ventilation wells. As illustrated in Figure 8, the method of and system for extracting hydrocarbons in accordance with an embodiment of the invention had higher cumulative oil and gas production over time when compared to combustion assisted gravity drainage not employing the ventilation wells.

While the foregoing invention has been described in some detail for purposes of clarity and understanding, it will be appreciated by one skilled in the art, from a reading of the disclosure, that various changes in form and detail can be made without departing from the true scope of the invention in the appended claims. The present invention is not to be limited in scope by the specific embodiments described herein, since such embodiments are intended as but single
illustrations of one aspect of the invention, and any functionally equivalent embodiments are within the scope of thereof. Indeed, various modifications of the invention, in addition to those shown and described herein, will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims. The invention includes all embodiments and variations substantially described herein and with reference to the examples and drawings.

[00102] All publications, patents, and patent applications referred to herein are incorporated by reference in their entirety to the same extent as if each patent or patent application were specifically and individually indicated to be incorporated by reference in its entirety. Nothing herein is to be construed as an admission that the invention is not entitled to antedate the cited references by virtue of prior invention.
WHAT IS CLAIMED IS:

1) A method for extracting hydrocarbons from a hydrocarbon bearing reservoir, the reservoir being in fluid communication with at least one injection well, at least one production well, and at least one ventilation well, the method comprising, injecting an oxidizing gas into the reservoir through the at least one injection well to support in situ combustion in the reservoir to mobilize the hydrocarbons; using the at least one ventilation well to control the ventilation in the in situ combustion area; and recovering the mobilized hydrocarbons by way of the at least one production well.

2) The method of claim 1 wherein the at least one production well has a generally horizontal segment that is vertically spaced below the at least one injection well.

3) The method of claims 1 or 2 wherein the hydrocarbon is heavy oil.

4) The method of claim 2 wherein the at least one injection well has a horizontal segment in the reservoir that is generally parallel to the horizontal segment of the at least one production well.

5) The method of any one of claims 1 to 4 wherein the at least one ventilation well communicates with the at least one injection well within the reservoir.

6) The method of any one of claims 1 to 5 wherein the at least one injection well and/or the at least one production well contains at least one sensor.

7) The method of claim 6 wherein the at least one sensor is a temperature sensor.

8) The method of claim 6 wherein the at least one sensor is a pressure sensor.

9) The method of any one of claims 1 to 8 wherein the at least one production well is at an angle from about 0 to about 30 degrees relative to the horizontal direction.

10) The method of any one of claims 1 to 9 wherein the oxidizing gas contains low ignition point hydrocarbons and/or water mist.
11) The method of any one of claims 1 to 10 wherein the at least one injection well contains circulation tubing to toe.

12) The method of any one of claims 1 to 11 wherein the at least one production well contains circulation tubing to toe.

13) The method of any one of claims 1 to 12 wherein the at least one injection well is open hole or cased.

14) The method of any one of claims 1 to 13 wherein the in situ combustion is initiated by steam circulation, oxidants, electrical heating, electrical-magnetic heating, or other physical/chemical heating methods.

15) The method of any one of claims 1 to 14 wherein more than one ventilation wells are installed in the reservoir.

16) The method of any one of claims 4 to 15 wherein the at least one ventilation well is substantially perpendicular to the horizontal segment of the at least one injection well.

17) The method of any one of claims 1 to 16 wherein the oxidizing gas has an oxygen concentration from about 0% to about 100%.

18) The method of any one of claims 1 to 17 wherein the at least one ventilation well is used to remove combustion gases generated by the in situ combustion in the reservoir.

19) The method of any one of claims 1 to 18 wherein combustion gases generated by the in situ combustion in the reservoir are redirected into the at least one injection well and/or the at least one production well through the at least one ventilation well.

20) The method of any one of claims 1 to 19 wherein the in situ combustion occurs along the at least one injection well.

21) A method for sustaining a continuous in situ combustion in a hydrocarbon bearing reservoir comprising controlling ventilation in the in situ combustion using the at least one ventilation well.

22) Use of at least one ventilation well to sustain a continuous in situ combustion in a hydrocarbon bearing reservoir.
23) A system for extracting hydrocarbons from a hydrocarbon bearing reservoir by in situ combustion, comprising:

at least one injection well;

at least one production well; and

at least one ventilation well,

wherein the hydrocarbon bearing reservoir is in fluid communication with the at least one injection well and the at least one production well.

24) The system of claim 23 wherein the at least one production well has a generally horizontal segment that is vertically spaced below the at least one injection well.

25) The system of claims 23 or 24 wherein the at least one ventilation well communicates with the at least one injection well.

26) The system of any one of claims 23 to 25 wherein the at least one injection well and/or the at least one production well and/or the at least one ventilation well contain at least one sensor.

27) The system of claim 26 wherein the at least one sensor is a temperature sensor.

28) The system of claim 26 wherein the at least one sensor is a pressure sensor.

29) The system of any one of claims 23 to 28 wherein the at least one production well is at an angle from about 0 to about 30 degrees relative to the horizontal direction.

30) The system of any one of claims 23 to 29 wherein the at least one injection well contains circulation tubing to toe.

31) The system of any one of claims 23 to 30 wherein the at least one production well contains circulation tubing to toe.

32) The system of any one of claims 23 to 31 wherein the at least one injection well is open hole or cased.

33) The system of any one of claims 23 to 32 wherein the at least one production well is open hole or cased.
34) The system of any one of claims 23 to 33 wherein more than one ventilation wells are installed in the reservoir.

35) The system of any one of claims 24 to 34 wherein the at least one ventilation well is substantially perpendicular to the horizontal segment of the at least one production well.

36) The system of any one of claims 23 to 35 wherein the in situ combustion occurs along the at least one injection well.
FIG. 3
FIG. 7
FIG. 8
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
   According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
   Minimum documentation searched (classification system followed by classification symbols)
   IPC (2006.01): E21B 43/24, E21B 36/00, E21B 43/18, E21B 43/30

   Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

   Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
   Epame (EPIDOC), combat+, inject+, vent+, well, prod+, sensor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Relevant to claim No.</th>
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<td>WO 2007/095764 A1 (AYASSE, C.) 30 August 2007 (30-08-2007) <em>abstract: fig. 1</em></td>
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<td>CA 2096034 A1 (KISMAN, K. E. et al.) 8 November 1994 (08-11-1994) <em>cited by the applicant</em> <em>abstract: p. 9, 1 20-p. 10, 1 2</em></td>
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Further documents are listed in the continuation of Box C.

[X] See patent family annex

* Special categories of cited documents
  "A" document defining the general state of the art which is not considered to be of particular relevance
  "E" either application or patent Publication on or after the international filing date
  "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
  "O" document relating to an oral disclosure, use, exhibition or other means
  "P" document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search
16 May 2013 (06-05-2013)

Date of mailing of the international search report
22 May 2013 (22-05-2013)

Authorized officer
Christian Oripsi (819) 934-4264

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