PRODUCING HYDROCARBON FLUID FROM A LAYER OF OIL SAND

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ABSTRACT

A method of producing hydrocarbons from a layer of oil sand located in a formation comprises creating a plurality of boreholes in the formation, including a first borehole and a second borehole spaced from the first borehole in a selected direction along which the layer of oil sand extends, and creating a cavity in the layer, the cavity being in fluid communication with the first borehole; extending the cavity in the selected direction by operating fluid jetting means via the first borehole to jet a stream of fluid against the cavity wall; when the cavity is in fluid communication with the second borehole, operating the fluid jetting means via the second borehole to jet a stream of fluid against the cavity wall so as to further extend the cavity; and transporting a slurry of fluid and oil sand from the cavity to a processing facility.
Producing Hydrocarbon Fluid from a Layer of Oil Sand

[0001] In the industry of hydrocarbon fluid production from subterranean reservoirs, it is conventional practice that oil is produced from wellsbores by virtue of the high fluid pressures existing downhole. In case of high viscosity oil, downhole pumps can be applied to pump the oil to surface, or other methods can be applied to increase the oil production rate such as steam injection or CO₂ injection into the formation. However, the conventional methods are not adequate for the production of bituminous oil such as occurring in the oil sand reservoirs in Canada. As some oil sand layers occur at relatively shallow depths, typically between 0 to 200 meters, it is common practice to produce oil from these layers by surface mining whereby the overburden layer is removed using draglines and/or shovels and trucks. The produced oil sand is transported to one or more processing facilities for separation of hydrocarbon fluid from the sand slurries. However, for oil sand layers at greater depths, removal of the overburden is costly and has a significant impact on the environment. Therefore alternative methods for producing oil sands have been proposed.

[0002] One such alternative method is disclosed in a technical paper published in CIM magazine by the Canadian Institute of Mining & Metallurgy, 2001, Vol. 94, No. 1054, pages 63-66, entitled “Hydraulic underground mining of oil sands—the next big step”. This publication discloses a method of producing hydrocarbon fluid from an oil sand layer located in an earth formation, wherein a discharge borehole is drilled into the oil sand layer and a fluid jetting device is operated to excavate the oil sand layer and thereby form a cavity in the oil sand layer, wherein a slurry of fluid and oil sand is formed in the cavity as a result of the fluid jetting operation. The produced slurry is transported via the discharge borehole to a processing facility for processing the slurry.

[0003] A different method is disclosed in WO 2007/050180, wherein a subsurface formation comprising heavy oil and solids is accessed via vertical injection and production boreholes, pressurized sufficiently to relieve overburden pressure, and wherein solids and heavy oil are mobilized and caused to flow through one of the vertical boreholes by means of varying differential pressure between the injection and production boreholes. Optionally water jetting can be used in a short transitional step and used intermittently or for short periods of time, to locally improve the flow of slurry towards the production wellbore.

[0004] However, there is still a need for an improved method of producing hydrocarbon fluid from an oil sand layer.

[0005] In accordance with the invention there is provided a method of producing hydrocarbon fluid from a layer of oil sand located in an earth formation, the method comprising:

[0006] creating a plurality of boreholes in the earth formation, including a first injection borehole and a second injection borehole spaced from the first injection borehole in a selected direction in which the layer of oil sand extends, and creating a cavity in the layer of oil sand, the cavity being in fluid communication with the first injection borehole;

[0007] extending the cavity in the selected direction by operating fluid jetting means via the first injection borehole to jet a stream of fluid against a wall of the cavity;

[0008] when the cavity is in fluid communication with the second injection borehole, operating the fluid jetting means via the second injection borehole to jet a stream of fluid against the wall of the cavity so as to further extend the cavity; and

[0009] transporting a slurry of fluid and oil sand, resulting from operation of the fluid jetting means, from the cavity via a discharge borehole to a processing facility for processing the slurry, the discharge borehole having a lower section extending in the selected direction and being in fluid communication with the cavity at said wall of the cavity.

[0010] In this manner it is achieved that the fluid jetting means is close to the cavity wall being excavated throughout the fluid jetting operation, so that the fluid jet always impacts the cavity wall with great force.

[0011] Suitably the step of further operating the fluid jetting means comprises removing the fluid jetting means from the first injection borehole and inserting the fluid jetting means into the second injection borehole.

[0012] The injection boreholes can be created simultaneously if desired, however it may be more economical that the second injection borehole is created after creating the first injection borehole, in correspondence with extension of the cavity in the selected direction.

[0013] In order to reduce or prevent subsidence of the overburden formation, being the earth formation on top of the oil sand layer, the method preferably further comprises inserting a stream of refill material into the cavity via the first injection borehole. Suitably, the stream of refill material comprises sand, for example cleaned sand transported from the processing facility to the cavity.

[0014] To accommodate extension of the cavity in the selected direction, the lower section of the discharge borehole is suitably provided with a liner adapted to be changed in length, and wherein the method further comprises changing the length of the liner in correspondence with movement of the front surface of the cavity in the selected direction.

[0015] If the lower section of the discharge borehole shortens as a result of extending the cavity, the liner is suitably adapted to be shortened, and wherein the step of changing the length of the liner comprises shortening the liner in correspondence with movement of the front surface of the cavity in the selected direction. For example, the step of shortening the liner can comprise operating a cutting device to cut the liner.

To this end the liner is suitably made from a material that can be cut. The liner can be made of metals softer than steel, e.g. aluminium. Preferably the liner is made of a non-metal material, and in particular the liner can be made of a plastics material. The liner can also be shortened by the action of a fluid jet. Shortening can be done by cutting or jetting away coarse discrete pieces of the liner, such as at suitable time intervals, or by producing small chips of the liner material.

[0016] Suitably, the discharge borehole is provided with pumping means for pumping the slurry via the discharge borehole to the processing facility. Preferably the pumping means includes a pump sealed to an inner surface of the liner. In order to accommodate the change of length of the liner, it is preferred that the pump is axially movable through the discharge borehole, and that the method further comprises axially moving the pump through the discharge borehole in correspondence with changing the length of the liner. Suitably the pump is driven by a stream of fluid pumped through a conduit extending into the discharge borehole. In such case, preferably at least a portion of said stream of fluid is injected.
into the slurry of fluid and oil sand present in the cavity in order to stir the slurry in the cavity if desired.

[0017] The invention will be described hereinafter in more detail, and by way of example, with reference to the accompanying drawings in which:

[0018] FIG. 1 schematically shows a system for use in an embodiment of the method of the invention; [0019] FIG. 2 schematically shows a detail of the system of FIG. 1; [0020] FIG. 3 schematically shows the system of FIG. 1 during a further stage of the method of the invention; [0021] FIG. 4 schematically shows a top view at surface of a layout using the system of FIG. 1; and [0022] FIG. 5 schematically shows a top view at surface of another layout using the system of FIG. 1.

[0023] In the Figures, like reference numerals relate to like components.

[0024] Referring to FIGS. 1 and 2 there is shown an earth formation containing an oil sands layer 2 located between an overburden layer 4 above the oil sand layer 2 and an underburden layer, shown as a layer of rock material 6, such as limestone, below the oil sand layer 2. The oil sand layer 2 has respective upper and lower boundaries 20, 22 extending horizontally. Thus, the layer of oil sand extends in an extension direction, in particular a non-vertical extension direction, in this example horizontally between an overburden and an underburden. The layer of oil sand has a thickness defining a thickness direction, which is in this example vertical. The extension direction is different from, often perpendicular to, the thickness direction, and is in this example in the horizontal plane. The layer extends more in the extension direction that its thickness, typically for more than twice its thickness, such as for more that

[0025] or 10 times its thickness, or even more. It will typically extend for less than 10000 times its thickness. It will be understood that the layer can extend along a plane.

[0026] A first injection borehole 8 extends vertically from a mobile injection rig 10 at the earth surface 11 to a cavity 12 formed in the layer of oil sands 2. The cavity has an upper portion 12a filled with air and a lower portion 12b containing a mixture (referred to hereinafter as "slurry") of water and oil sand particles.

[0027] A deviated discharge borehole 14 extends from a production station 15 at the earth surface to the cavity 12 whereby the production station 15 is horizontally spaced from the mobile injection rig 10. The discharge borehole 14 has an upper section 16 extending vertically and a lower section 18 extending substantially parallel to the upper boundary 20 and/or lower boundary 22 of the oil sands layer 2. Thus, in the present example the lower section 18 extends horizontally. Furthermore, the lower borehole section 18 extends in a selected direction within the layer 2, in this example an azimuthal direction from the cavity 12, and deboches into the lower cavity portion 12b at some distance above the bottom of the cavity. The intersection between the lower borehole section 18 and the cavity 12 defines a front surface 23 of the cavity 12.

[0028] The selected direction suitably is a direction within the layer, in particular a non-vertical direction, at an angle of less than 45 degrees with an upper and/or lower boundary of the layer, preferably substantially parallel to the upper boundary and/or lower boundary of the layer. In particular the selected direction can be at least 45 degrees away from the thickness direction, in particular at least 45 degrees away from the vertical. Suitably the selected direction substantially coincides with the extension direction, so that the cavity is extended within the layer, substantially parallel with its upper and/or lower boundary, for more than the layer thickness, such as for between 2 and 3000 times the layer thickness. The expression substantially parallel herein accounts for the precision with which deviated boreholes can be drilled in an underground layer.

[0029] The upper section 16 is provided with a conventional casing (or liner) 24, whereas the lower section 18 is provided with a liner 26 of plastics material, for example glass fibre reinforced plastic, whereby the liner 26 extends a minimal distance into the cavity 12. Furthermore, a jet pump 28 is positioned in the liner 26 in a manner that the jet pump 28 is sealed relative to the inner surface of the liner 26 and is axially movable through liner 26. A fluid conduit 30 for driving the jet pump 28 extends from the production station 15 through the casing 24 and the liner 26 to the jet pump 28. When driven by fluid pumped through the fluid conduit 30, the jet pump 28 is arranged to pump the slurry 13 of fluid and particles from the lower cavity portion 12b, via the annular space between the fluid conduit 30 on one hand and the liner 26 and casing 24 on the other hand, to the production station 15. The jet pump 28 is thereto provided with one or more flow channels 32 (FIG. 2) allowing the slurry to flow in axial direction through the jet pump 28. The fluid conduit 30 extends further from the jet pump 28 through liner 26 to the cavity 12. A lower end part 34 of the fluid conduit 30 is provided with a cutter 36 for cutting the liner 26, one or more nozzles 38 for initially forming the cavity 12 and for stirring the slurry present in the cavity 12, and a bit or mill 39 for crushing lumps of rock material that may be present in the cavity 12.

[0030] An injection string 40 for injecting fluid into the cavity 12 extends from the injection rig 10 via the first injection borehole 8 into the cavity 12, the injection string 40 having a lower end provided with jetting nozzles 42 located in the upper portion 12a of cavity 12. An annular seal 43 (such as a rotating head) is arranged in an upper part of the first injection borehole 8 to seal the annular space formed between the injection string 40 and the wall or casing of the first injection borehole 8.

[0031] Referring further to FIG. 3 there is shown the earth formation and several of the components shown in FIGS. 1 and 2 during a further stage of operation. The cavity 12 has been extended in the azimuthal direction of the lower borehole section 18 whereby the front surface 23 of the cavity has moved in said azimuthal direction. As a result, the lower borehole section 18 has become shorter. The liner 26 has been shortened at the side of the cavity 12 in correspondence with shortening of the lower borehole section 18. The fluid conduit 30 with the jet pump 28 connected thereto has been pulled upward through discharge borehole 14 over a distance about equal to the reduction in length of liner 26. Furthermore, a second injection borehole 44 extends vertically from a mobile injection rig 46 to the cavity 12. The second injection borehole 44 is spaced from the first injection borehole 8 in the azimuthal direction. As is illustrated in FIG. 3, the lower end of the second injection borehole 44 is positioned closer to the front surface 23 of cavity 12 than the lower end of the first injection borehole 8.

[0032] The injection string 40 has been removed from the first injection borehole 8 and has been installed in the second injection borehole 44 so as to extend from the injection rig 46 into the cavity 12 whereby the jetting nozzles 42 again are
positioned in the upper portion 12a of cavity 12. Alternatively another injection string, similar to injection string 40, can be applied in the second injection borehole 44. An annular seal 47 (such as a rotating head) is arranged in an upper part of the second injection borehole 44 to seal the annular space formed between the injection string 40 and the wall or casing of the second injection borehole 44.

[0033] The first injection borehole 8 is now provided with a sand injection string 48 for inserting clean sand into the cavity 12. The sand injection string 48 is suspended at surface by the mobile injection rig 10 or by any other suitable means. A rear portion of the cavity 12 is filled with a body of sand 49, which preferably includes a binder material such as cement.

[0034] In this example the first and second injection boreholes and the discharge boreholes form a plurality of boreholes.

[0035] In the context of the present description, the assembly of cavity, discharge borehole, one or more injection boreholes, and production station is referred to as a “production unit”. In the example described above, the production unit includes two injection boreholes. However, depending on the stage of operation, the production unit can include only one, or more than two, injection boreholes. Generally, the production unit can include any suitable number of injection boreholes mutually spaced in the azimuthal direction.

[0036] Referring further to FIG. 4, there is schematically shown a top view at surface of a layout of a plurality of production units 50, 52, 54, 56, 58. Each production unit 50, 52, 54, 56, 58 is substantially similar to the production unit described hereinabove with reference to FIGS. 1-3, albeit that the number of injection boreholes varies per production unit depending on the stage of operation. For ease of reference, the respective discharge boreholes and cavities are shown in dotted lines.

[0037] Production unit 50 includes discharge borehole 60, cavity 61, injection boreholes 62, 63 and production station 64. Production unit 52 includes discharge borehole 65, cavity 66, injection boreholes 67, 68 and production station 69. Production unit 54 includes discharge borehole 70, cavity 71, injection boreholes 72, 73, 74 and production station 75. Production unit 56 includes discharge borehole 76, cavity 77, injection boreholes 78, 79, 80 and production station 81. Production unit 58 includes discharge borehole 82, cavity 83, injection boreholes 84, 85, 86, 87 and production station 88. The cavities 61, 66, 71, 77, 83 have respective front surfaces 90, 92, 94, 96, 98. Mobile injection rigs 100, 102, 104, 106, 108, 110 are provided at surface, whereby injection rigs 100, 102, 104, 106, 108 are in fluid communication with respective injection boreholes 62, 67, 72, 78, 84, and whereby injection rig 110 is in fluid communication with each one of injection boreholes 68, 73, 74, 79. The discharge boreholes 60, 65, 70, 76, 82 extend substantially parallel to each other at selected mutual horizontal spacings. Similarly, the cavities 61, 66, 71, 77, 83 extend substantially parallel to each other at selected horizontal spacings. The production stations 64, 69, 75, 81, 88 are in fluid communication with a separation plant 112 via a common pipeline 114 so as to allow pumping of the respective slurries of fluid and oil sand particles from the production units 50, 52, 54, 56, 58 via the common pipeline 114 to the separation plant 112 where hydrocarbon fluid is separated from the produced oil sand particles.

[0038] Furthermore, reference numerals 116 relate to locations of injection boreholes yet to be drilled at a further stage of operation, reference numerals 118 relate to injection boreholes already drilled but not yet in fluid communication with the respective cavities 61, 66, 71, 77, 83, and reference numerals 120 relate to injection boreholes currently being drilled.

[0039] In the context of the present description, the assembly of production units 50, 52, 54, 56, 58 is referred to as a “field section”. The field section described in the example above includes five production units, however it is to be understood that a field section can include any suitable number of production units.

[0040] Referring further to FIG. 5 there is schematically shown a top view at surface of an exemplary layout of a plurality of field sections 140, 142, 144, 146 whereby field section 140 represents the assembly of production units 50, 52, 54, 56, 58 described above. Field sections 142, 144, 146 are substantially similar to field section 140 albeit these are mirrored relative to field section 140. Furthermore, field sections 140, 142 are fluidly connected to separation plant 112 via common pipeline 114, and field sections 144, 146 are fluidly connected to separation plant 112 via a common pipeline 148.

[0041] During normal operation of the system of FIGS. 1-3, the first injection borehole 8 and the discharge borehole 14 are drilled into the oil sand layer 2 using one or more conventional drilling rigs and the casing 24 and liner 26 are arranged in the discharge borehole 14. The mobile injection rig 10 and the production station 15 are installed at their respective positions as indicated in FIG. 1. In a next step, the fluid conduit 30 with the jet pump 28 connected thereeto is lowered through the discharge borehole 14 until end part 34 of the fluid conduit 30 extends just beyond the far end of the liner 26. Water at high pressure is then pumped from the production station 15 into the fluid conduit 30 so that the pumped water is jetted through the nozzles 38 to impact the formation at the end of the liner 26 with great force. If desired, the fluid conduit 30 is simultaneously rotated about its longitudinal axis to induce the bit or mill 39 to crush the rock formation. As a result the oil sand layer 2 is gradually excavated so that the cavity 12 and the slurry 13 of water and oil sand particles are initially formed. Furthermore, by virtue of pumping of water through fluid conduit 30, the jet pump 28 is operated to pump the slurry 13 from the cavity 12 via the flow channels 32 of the jet pump 28 and via the annular space between the fluid conduit 30 and the liner 26 casing 24, to the production station 15. In an alternative embodiment, the cavity 12 is initiated by underreaming a lower portion of the first injection borehole 8 and/or a lower portion of the discharge borehole 14 under fluid communication between said boreholes 8, 14 is established, or by enlarging said lower portion(s) in any other suitable manner.

[0042] Once the cavity 12 is sufficiently large so that fluid communication between the cavity 12 and the injection borehole 8 is established, in particular so that both boreholes 8, 14 are intersecting the cavity 12, the injection string 40 is lowered into the first injection borehole 8, and water is pumped at high pressure from the injection rig 10 into the injection string 40. The pumped water is jetted through the jetting nozzles 42 and impacts the wall of the cavity 12 with great force. As a result, the oil sand layer 2 is further excavated and the slurry 13 of water and oil sand particles is continuously formed in the cavity 12. The size of the cavity increases as jetting of water through the nozzles 42 continues. Water is pumped at a somewhat suitable lower pressure from production station 15 into the fluid conduit 30 to operate the jet pump 28. Thereby, the jet pump 28 pumps the slurry of fluid and particles from
the lower cavity portion 12a, via the annular space between the fluid conduit 30 and the liner 26 or casing 24, and the flow channels 32 of the jet pump 28, to the production station 15. Arrows 115 (FIGS. 1 and 2) indicate the direction of flow of water pumped through fluid conduit 30, and arrows 116 indicate the direction of flow of the slurry of water and oil sand through said annular space and channels 32. If desired, pumping of the slurry of fluid and particles from the cavity 12 to the production station 15 can be enhanced by pressurising the cavity 12 up to a few bars with a gas, such as compressed air or CO₂. Furthermore, a portion of the water pumped through fluid conduit 30 is jetted into the lower cavity portion 12b through nozzles 38 in order to achieve some stirring of the slurry 13 in the cavity 12.

Jetting of water through nozzles 42 is continued so as to extend the cavity 12 in the azimuthal direction of the lower borehole section 18 whereby the front surface 23 of the cavity moves in said azimuthal direction. As a result, a portion 116 of the liner 26 (FIG. 2) gradually becomes protruding into the cavity 12. In order to reduce the length of, or completely remove, the protruding liner portion 116, the cutter 36 is operated to cut the protruding liner portion 116 at time intervals selected in accordance with the speed of movement of the front surface 23 in the azimuthal direction. The fluid conduit 30 is moved upwardly in correspondence with shortening of the liner 26 whereby the jet pump 28 slides along the inner surface of the liner 26. If desired, the fluid conduit 30 is rotated to induce bit 39 to crush rock particles that may be present in the cavity 12.

The second injection borehole 44 is drilled into the oil sand layer 2 before the front surface 23 of the cavity 12 reaches the location where the second injection borehole 44 intersects the cavity 12. Alternatively, the second injection borehole 44 can be drilled after the front surface 23 of the cavity 12 reaches said location. Next, the mobile injection rig 46 is installed, and the injection string 40 is removed from the first injection borehole 8 and lowered into the second injection borehole 44. The cavity 12 is then further excavated in the azimuthal direction of the lower borehole section 18 in a manner similar to the manner described above with reference to the situation whereby the injection string 40 extends through the first injection borehole 8. When the second injection borehole is drilled before the cavity 12 reaches the location where the second injection borehole 44 intersects the cavity, fluid jetting can already be started via the second injection borehole when there is still a remaining wall with the cavity, but fluid communication with the cavity is already established. Powerful jetting action can lead to breaking through to the front surface 23 of the cavity 12 from the second injection borehole, removing the remaining wall.

Simultaneously with, or subsequent to, jetting of water into the cavity 12 via the second injection borehole 44, sand is pumped into the rear portion of cavity 12 via the sand injection string 48 (FIG. 3). In this manner, the rear portion of cavity 12 is gradually filled with the body of sand 49. In the context of the present description, any reference to “the cavity” is meant to include the upper cavity portion 12a, the lower cavity portion 12b, and the rear portion filled with sand. In the above example, two injection boreholes 8, 44 have been described for excavating the cavity 12 in the desired azimuthal direction. In practice, any suitable number of injection boreholes can be applied whereby the injection boreholes are mutually spaced in the desired azimuthal direction and whereby each pair of adjacent injection boreholes is operated in a manner similar to operation of the injection boreholes 8, 44 described above. However, in case more than two injection boreholes are applied, one or more of the injection boreholes can be positioned between the injection borehole instantaneously used for further excavating the cavity, and the injection borehole(s) instantaneously used for pumping sand into the cavity.

The slurry 13 of water and oil sand is transported from the production station 15 to a separation plant (not shown) for separating hydrocarbon fluid and sand particles from the slurry. Alternatively, the production station 15 and the separation plant can be integrated in a single unit. Suitably, cleaned sand produced from the separation plant is used to refill the cavity 12 with the body of sand 49.

During normal operation of the system shown in FIG. 4, the discharge borehole 82 and first injection borehole 87 of cavity 83 are drilled first whereby production from cavity 83 is started. Next, the discharge borehole 76 and first injection borehole 80 of cavity 77 are drilled whereby production from cavity 77 is started. Similarly, the discharge boreholes 70, 65, 60 and first injection boreholes 74, 68, 63 of respective cavities 71, 66, 61 are drilled in subsequent order, and production from these cavities also is started in subsequent order. As a result, the degree to which the various cavities instantaneously extend in the azimuthal direction increases from, in subsequent order, cavity 61, to cavity 66, to cavity 71, to cavity 77, to cavity 83. Alternatively, production from the various cavities can be started simultaneously or in any other suitable order, so that the cavities instantaneously extend in the azimuthal direction to any suitable degree.

Each production unit 50, 52, 54, 56, 58 is operated substantially similar to normal operation of the production unit described with reference to FIGS. 1-3. Thus, the front surfaces 90, 92, 94, 96, 98 of the respective cavities 61, 66, 71, 77, 83 gradually move in the azimuthal direction of respective discharge boreholes 60, 65, 70, 76, 82 as excavation of the cavities proceeds. The rear portions of the cavities are refilled with sand in correspondence with forward movement of the front surfaces. In the current situation, shown in FIG. 4, mobile injection rig 110 is used to inject sand via injection boreholes 68, 73, 74, 79 into the rear portions of respective cavities 66, 71, 77. For this purpose, mobile injection rig 110 is fluidly connected to injection boreholes 68, 73, 79 via respective conduits 130, 132, 134. Injection boreholes 59, 86 and 87 already have been used for sand injection, therefore these injection boreholes have been disconnected from mobile injection rig 110. As illustrated in FIG. 4, the injection boreholes 118 have been drilled before being in fluid communication with the respective cavities. In this manner, drilling of the injection boreholes does not delay excavation of the oil sand layer. Some water is separated from the slurries of fluid and oil sand particles at the respective production stations 64, 69, 75, 81, 88. The slurries are then commingled in common pipeline 114 and transported to the separation plant 112 where hydrocarbon fluid is separated from the commingled stream of water and oil sand particles.

Instead of excavating the cavities 61, 66, 71, 77, 83 such that these are separated from each other by portions of rock material, as shown in FIG. 4, the cavities can be excavated so that such portions of rock material vanish. In that case, two or more of the cavities are integrated with each other so as to form a single large cavity.

During normal operation of the system shown in FIG. 5, each field section 142, 144, 146 is operated in sub-
stantially the same manner as field section 140 described with reference to FIG. 4. Thus, the slurries of water and oil sand particles produced from the field sections 140, 142, 144, 146 are transported to common separation plant 112 for separation of hydrocarbon fluid from sand particles.

With the method described above it is achieved that hydrocarbon fluid is produced from the oil sand layer without removing the overburden layer. Moreover, by refilling the cavities with sand it is achieved that any subsidence of the overburden layer is reduced to a minimum. In a preferred embodiment, the cavities are refilled with sand from the produced slurries of water and oil sand after cleaning at the separation plant. Suitably a binding material like cement is mixed into the sand.

In the examples described above, the discharge borehole is provided with a single pump (jet pump 28) for pumping the slurry of fluid and oil sand particles via the discharge borehole to the production station at surface. However, depending on the depth of the cavity and/or other operational parameters, a single pump may not suffice to pump the slurry to surface at an efficient flow rate. In that case, one or more additional pumps can be applied in the discharge borehole. For example, the upper section of the discharge borehole can be provided with a single-stage or multi-stage centrifugal pump driven by a hydraulic or electric motor, to pump the slurry to surface. Such centrifugal pump can be positioned, for example, in the lower end part of the casing provided in the discharge borehole, just above the liner.

In the examples described above, the injection boreholes extend from surface locations mutually spaced in a horizontal direction. In an alternative arrangement, the injection boreholes extend as deviated boreholes from a single surface location, or as branch boreholes of a multilateral borehole. Such arrangement can be attractive in applications whereby the surface area is difficult accessible, for example if the oil sand layer is located below a body of water or a swamp area.

1. A method of producing hydrocarbon fluid from a layer of oil sand located in an earth formation, the method comprising:

a. creating a plurality of boreholes in the earth formation, including a first injection borehole and a second injection borehole spaced from the first injection borehole in a selected direction along which the oil sand extends, and creating a cavity in the layer of oil sand, the cavity being in fluid communication with the first injection borehole;

b. extending the cavity in the selected direction by operating fluid jetting means via the first injection borehole to jet a stream of fluid against a wall of the cavity; and when the cavity is in fluid communication with the second injection borehole, operating the fluid jetting means via the second injection borehole to jet a stream of fluid against the wall of the cavity so as to further extend the cavity; and

c. transporting a slurry of fluid and oil sand, resulting from operation of the fluid jetting means, from the cavity via a discharge borehole to a processing facility for processing the slurry, the discharge borehole having a lower section extending in the selected direction and being in fluid communication with the cavity at said wall of the cavity.

2. The method of claim 1, wherein the step of operating the fluid jetting means via the second injection borehole comprises removing the fluid jetting means from the first injection borehole and inserting the fluid jetting means into the second injection borehole.

3. The method of claim 1, wherein the second injection borehole is created after creating the first injection borehole, in correspondence with extension of the cavity in the selected direction.

4. The method of claim 1 wherein the method further comprises inserting a stream of refill material into the cavity via the first injection borehole.

5. The method of claim 4, wherein the stream of refill material comprises sand.

6. The method of claim 4 wherein the stream of refill material is transported from the processing facility to the cavity.

7. The method of claim 1 wherein the lower section of the discharge borehole is provided with a liner adapted to be changed in length, and wherein the method further comprises changing the length of the liner in correspondence with extension of the cavity in the selected direction.

8. The method of claim 7 wherein the liner is adapted to be shortened, and wherein the step of changing the length of the liner comprises shortening the liner in correspondence with extension of the cavity in the selected direction.

9. The method of claim 8 wherein shortening the liner comprises operating a cutting device to cut the liner, preferably wherein the liner is made of a non-metallic material, more preferably of a plastics material.

10. The method of claim 1 wherein the discharge borehole is provided with pumping means for pumping the slurry via the discharge borehole to the processing facility.

11. The method of claim 10 wherein the pumping means includes a pump sealed relative to an inner surface of the liner.

12. The method of claim 10 wherein the pumping means is axially movable through the discharge borehole, and wherein the method further comprises axially moving the pumping means through the discharge borehole in correspondence with changing the length of the liner.

13. The method of claim 1 wherein the pumping means is driven by a stream of fluid pumped through a conduit extending through the discharge borehole.

14. The method of claim 13 wherein at least a portion of said stream of fluid is injected into the slurry of fluid and oil sand present in the cavity.

15. (canceled)