ABSTRACT

Embodiments of the disclosure pertain to a system for production of a hydrocarbonaceous fluid, the system having a tubing string deployed within a wellbore; a first pump system having a pump assembly operably engaged with a motor; and a control system operably engaged with the first pump system. The pump assembly includes a housing with a stator and rotor disposed therein. The first pump system is operable to aid in production of the hydrocarbonaceous fluid from the wellbore to a production facility.
SYSTEM FOR PRODUCTION OF A HYDROCARBONACEOUS FLUID

CROSS-REFERENCE TO RELATED APPLICATIONS AND INCORPORATION BY REFERENCE

[0001] This application is a continuation of U.S. Non-Provisional patent application Ser. No. 14,433,970, filed Apr. 7, 2015, which is a §371 national application of PCT Application No. PCT/GB2013/052773, filed Oct. 24, 2013, which claims foreign priority to GB Application No. GB 1219547.5, filed on Oct. 31, 2012. The disclosure of each application is hereby incorporated herein by reference in its entirety for all purposes.

STATEMENT REGARDING FEDERALALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND

[0003] Field of the Disclosure

[0004] The present disclosure relates to the field of hydrocarbon exploration. More specifically, embodiments disclosed herein pertain to a method of pumping hydrocarbons that finds particular application for use with heavy and extra heavy fluids commonly found within the field of hydrocarbon exploration.

[0005] Background of the Disclosure

[0006] The definition of heavy and extra heavy oil is not strictly defined within the art. For the purposes of the following discussion the term heavy oil may be used to refer to a hydrocarbon fluid mixtures or emulsions with a viscosity between 1,000 cP (centi-Poise) and 20,000 cP while the term extra heavy oil may be used to refer to a hydrocarbon fluid mixtures or emulsions with a viscosity greater than 20,000 cP.

[0007] Horiztonal drilling and horizontal wells have transformed the productivity of many conventional oil & gas wells by providing considerably greater reservoir inflow capability compared to vertical and deviated wells. Generally, horizontal wells are formed by initially drilling a vertical section to a specified depth. The high angle or horizontal section of the well is then drilled at a depth to maximize the contact between the wellbore and the reservoir. Increasing the contact between the wellbore and the reservoir can provide greater inflow potential. Long horizontal sections two kilometers or more are known in the art.

[0008] The above horizontal drilling techniques have been successfully employed by those skilled in the art in order to extract hydrocarbons. However, when deployed with heavy oil and extra heavy oil reservoirs the results have been poor due to the effects of friction loss and pseudo-plastic “gelling” of the reservoir fluids within the wellbore. In a long horizontal wellbore employed with a heavy oil reservoir, up to 90% of the theoretical inflow potential may be lost due to friction loss and pseudo-plastic “gelling”.

[0009] In order to improve the production of heavy oils some operators have experimented with employing larger diameter horizontal wellbores (e.g. 12¼" (311.15 mm) bore cased with 9⅝" (234.32 mm) casing instead of the normal 8⅝" (215.90 mm) bore cased with 7" (177.80 mm) casing). However, such wells are technically challenging, very expensive to drill and case and have only had limited beneficial effect. As a result, long horizontal wells are not proved effective in heavy and extra-heavy oil fields.

[0010] A second solution to this problem is for operators to drill multiple short horizontal wells, perhaps 100 meters in length. These wells may be drilled in a “crow’s foot” or “herring bone” configuration or equivalent array structure to reduce the problems associated with a long wellbore. However, as appreciated by those skilled in the art, the drilling of multiple wells significantly increases the production costs for heavy oils and extra-heavy oils.

[0011] It is frequently required when exploring for hydrocarbons to provide artificial lift to the production fluid e.g. when extracting hydrocarbons from an oil bed it may be required to employ the assistance of a pump when the pressure of the hydrocarbon deposit is insufficient to bring the hydrocarbons to the surface. Some examples of such pumps known in the art include Electric Submersible Pumps (ESP), Progressing Cavity Pumps (PCP) or positive displacement; centrifugal pumps; single helix pumps; and dual-helix axial or compressor pumps.

[0012] Including a pump system with the above described wellbore arrangements may help heavy oil and extra-heavy oil production for some reservoirs. However, other factors exists which still limit the levels of heavy oil and extra-heavy oil that can be extracted. By way of example, the preferred pump for such production is an Electric Submersible Pumps (ESP).

[0013] When an ESP is employed within a wellbore it is required to be deployed at a lesser depth (i.e., nearer the surface of the wellbore) than the wellbore perforations in order to allow the production fluid to cool the motor and pump modules as it passes over the outer surface of ESP. This configuration has an inherent benefit for the production of heavy oil and extra-heavy oil in that heat is transferred from the ESP to the production fluid as it passes into the tubing string thus making it less viscous and thus easier to pump to the surface. The benefit of heating a heavy oil with an ESP is known in the art, see for example US patent numbers U.S. Pat. No. 8,037,936; U.S. Pat. No. 6,318,467 and U.S. Pat. No. 6,564,874.

[0014] However with this arrangement the high viscosity of the heavy oil in the reservoir itself is found to cause preferential production from the “heel” end of the reservoir with little or no production from the “toe” end. As reservoir fluid viscosity increases, this effect becomes more severe. Typically, only the first 50 meters of a reservoir will contribute to the production process with such an arrangement. In these circumstances operators are again forced to consider multiple wells and the associated increases in the production costs.

[0015] In addition, although ESP systems have been demonstrated to be capable of pumping fluids with viscosities up to around 1,500 cP to 2,000 cP, the performance of an ESP is greatly reduced when operating with a fluid at such viscosities. The ESPs known in the art are simply unable to pump fluids with viscosities greater than 2,000 cP and so are not suitable for use with extra-heavy oils or even many heavy oils.

[0016] It is recognized that in accordance with the disclosure considerable advantage is to be gained in a completion design that is capable of producing heavy and extra heavy oil from wells and in particular long horizontal or high angle wells.
SUMMARY

[0017] Embodiments of the disclosure pertain to a system for production of a hydrocarbonaceous fluid that may include a tubing string deployed within a wellbore; a first pump system having a pump assembly operably engaged with a motor, and a control system operably engaged with the first pump system; wherein the first pump system may be operable to aid in production of a hydrocarbonaceous fluid from the wellbore to a production facility. The hydrocarbonaceous fluid may have a viscosity of greater than 1,000 cP.

[0018] The pump assembly may include a stator with an inner stator surface having one or more stator vanes thereon. The assembly may include a rotor having an external stator surface configured with an one or more rotor vanes thereon. The assembly may include a housing having the stator and the rotor disposed therein. A radial gap may be provided or otherwise exist between the one or more stator vanes and the one or more rotor vanes along a length of the pump assembly. A radial length of the one or more rotor vanes may be greater than a radial length of the one or more stator vanes. A thickness of the one or more stator vanes may be greater than a thickness of the one or more rotor vanes.

[0019] There may be one or more stator channels on the inner stator surface. The one or more stator channels may have a constant inner diameter. There may be one or more rotor channels on the rotor outer surface. The rotor channels may have a constant outer diameter. The first pump system may be in fluid communication with the tubing string.

[0020] The first pump system may include a cooling shroud that depends from the pump assembly so as to define a flow path that requires the hydrocarbon fluid to pass over the motor before entering the pump assembly.

[0021] There may be a protector seal module located between the pump assembly and the motor. The control system may be operable to change a set of operating parameters of the pump assembly so as to optimize the hydrocarbon fluid production from the wellbore. There may be an operating frequency as one of the set of operating parameters. The control system may be operable to control a choke. The system may include a second pump system like that of the first pump system. The second pump system may also be in fluid communication with the tubing string. In aspects, the hydrocarbonaceous fluid may have a viscosity of greater than 20,000 cP. The first pump system may be operable and located 75% to 95% of the way along a length of the wellbore. The rotor channels and stator channels may be all of the same lengths and cross-sectional area.

[0022] The pump assembly may further include an inlet; an outlet; and two bearings separated along a longitudinal axis of the pump assembly, one of which being proximate to the inlet, and the other being proximate to the outlet.

[0023] Other embodiments of the disclosure pertain to a system for production of a hydrocarbonaceous fluid that may include a tubing string deployed within a wellbore; a first pump system having a pump assembly operably engaged with a motor; and a control system operably engaged with the first pump system. The first pump system may be operable to aid in production of a hydrocarbonaceous fluid from the wellbore to a production facility. The hydrocarbonaceous fluid may have a viscosity of greater than 1,000 cP.

[0024] The pump assembly may include a stator having an inner stator surface configured with an at least one stator vane thereon; a rotor having a external stator surface configured with an one or more rotor vanes thereon; and a housing having the stator and the rotor disposed therein. There may be a radial gap provided or otherwise existing between the one or more stator vanes and the one or more rotor vanes along a length of the pump assembly. A radial length of the one or more rotor vanes may be greater than a radial length of the one or more stator vanes. A thickness of the one or more stator vanes may be greater than a thickness of the one or more rotor vanes.

[0025] Stator channels on the inner stator surface may include a constant inner diameter. Rotor channels on the rotor outer surface may include a constant outer diameter. The first pump system may be in fluid communication with the tubing string.

[0026] The first pump system may include a cooling shroud that depends from the pump assembly so as to define a flow path. This may result in the requirement that hydrocarbon fluid should pass over the motor before entering the pump assembly.

[0027] The system may include a protector seal module is located between the pump assembly and the motor.

[0028] The control system may be operable to change a set of operating parameters of the pump assembly so as to optimize the hydrocarbon fluid production from the wellbore. An operating frequency may be one of the set of operating parameters. The control system may be operable to control a choke.

[0029] The system may include a second pump system like that of the first pump system. The second pump system may also be in fluid communication with the tubing string.

[0030] In aspects, the hydrocarbonaceous fluid may have a viscosity of greater than 20,000 cP. The first pump system may be located 75% to 95% of the way along a length of the wellbore.

[0031] The rotor channels and stator channels may be all of the same lengths and cross-sectional area.

[0032] The pump assembly may further include an inlet; an outlet; two bearings separated along a longitudinal axis of the pump assembly, one of which being proximate to the inlet, and the other being proximate to the outlet.

[0033] These and other embodiments, features and advantages will be apparent in the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] A full understanding of embodiments disclosed herein is obtained from the detailed description of the disclosure presented herein below, and the accompanying drawings, which are given by way of illustration only and are not intended to be limiting of the present embodiments, and wherein:

[0035] FIG. 1 shows a section view of a horizontal reservoir with a single pump hydrocarbon completion in accordance with embodiments of the disclosure;

[0036] FIG. 2 presents a schematic representation of the pump system of FIG. 1 in accordance with embodiments of the disclosure;

[0037] FIG. 3 presents a cross-sectional assembled view of a pump assembly of the pump system of FIG. 2 in accordance with embodiments of the disclosure;

[0038] FIG. 4 presents a section view of the horizontal section of a horizontal well showing the fluid flow paths and heat transfer paths in accordance with embodiments of the disclosure;
[0039] FIG. 5 presents a section view a horizontal reservoir with a multiple pump hydrocarbon completion in accordance with embodiments of the disclosure;
[0040] FIG. 6 presents a section view of an electro-hydraulic diverter employed within the multiple pump hydrocarbon completion of FIG. 5 in accordance with embodiments of the disclosure; and
[0041] FIG. 7 presents a section view of a horizontal reservoir with an alternative multiple pump hydrocarbon completion in accordance with embodiments of the disclosure.

DETAILED DESCRIPTION

[0042] Embodiments of the present disclosure are described in detail with reference to the accompanying Figures. In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, such as to mean, for example, “including, but not limited to.” While the disclosure may be described with reference to relevant apparatuses, systems, and methods, it should be understood that the disclosure is not limited to the specific embodiments shown or described. Rather, one skilled in the art will appreciate that a variety of configurations may be implemented in accordance with embodiments herein.

[0043] The terms “upper”, “lower”, “downward” and “upward” are relative terms used herein that may be indicative of directions in a wellbore, with “upper” and equivalents referring to the direction along the wellbore towards the surface, and “lower” and equivalents referring to the direction towards the bottom hole. It will be appreciated that embodiments of the disclosure may have application to deviated and lateral wellbores.

[0044] A hydrocarbon completion in accordance with an embodiment of the present disclosure, and generally depicted by reference numeral 1, will now be described with reference to FIGS. 1 to 4. The completion design 1 can be seen deployed with a substantially horizontal reservoir 2 comprising heavy and or extra heavy oil 3.

[0045] The hydrocarbon completion 1 can be seen deployed in a well 4 formed from a casing 5, which is cemented into a wellbore 6. The casing 5 may comprise perforated casing or screen installed casing as is known to those skilled in the art. The horizontal section of the well 4b is at a depth to maximize the contact between the wellbore 6 and the heavy or extra heavy oil 3 within the reservoir 2.

[0046] A tubing string 7 is supported via a tubing hanger 8 located at the surface 9. The tubing string defines an annulus 10 with the surrounding wellbore. Also located at the surface 9 is a wellhead 11 comprising a production choke 12, a control system 13 and a production facility 14.

[0047] A pump system 15, which is connected to tubing string 7, is located within the horizontal section of the well 4b. As described in further detail below, it is preferable for as many well perforations 16 to lie between the pump system 15 and the surface 9 i.e. the pump system is located further into the well 4 than one or more of the well perforations 16. Preferably, the pump system 15 is located 75% to 95% of the way along the horizontal section of the well 4b.

[0048] The pump system 15 is employed to artificially lift the production fluid 17 up the tubing string 7 and through the wellhead 11, where the fluid 17 is then controlled and distributed to the production facility 14. The pump system 15 is controlled at surface 9 by the control system 13 connected to the pump system 15 by a down-hole electrical cable 18.

[0049] Further detail of the pump system 15 will now be described with reference to FIGS. 2 and 3. From FIG. 2 the pump system 15 can be seen to comprise a motor 19 and a pump assembly 20. Preferably a protector seal module 21 is located between the motor 19 and the pump assembly 20. A cooling shroud 22 depends from the pump assembly 20 so as to define a flow path that requires the heavy oil 3 to pass over the motor 19 before entering the pump assembly 20.

[0050] The pump assembly 20, as shown schematically in FIG. 3, is preferably a pump assembly of the type described by the inventor within PCT publication number WO 2012/013973. Here the pump assembly 20 can be seen to comprise a rotor 23 which is surrounded by an annular stator 24 that is arranged to be coaxial with, and extend around, the rotor 23. The rotor 23 is externally screw-threaded in a right-handed sense by the provision of three rotor vanes 25 located on its external surface. The stator 24 is correspondingly internally screw-threaded in a left-handed sense through the provision of three stator vanes 26 located on its internal surface. The rotor vanes 25 and the stator vanes 26 are threaded so as to exhibit equal pitch and have radial heights such that they approach each other sufficiently closely so as to provide rotor channels 27 and stator channels 28 within which a fluid can be retained for longitudinal movement upon rotation of the rotor 23. In the presently described embodiment the rotor channels 27 and stator channels 28 are all of the same length and cross sectional area.

[0051] The pump assembly 20 can be seen to further comprise a cylindrical housing 29 within which the remaining components are located. The rotor 23 is connected to the motor 19 by means of a central shaft 30 such that operation of the motor 19 induces relative rotation between the rotor 23 and the stator 24.

[0052] An inlet 31 and an outlet 32 of the pump assembly 20 are defined by the location of two bearings 33 separated along the longitudinal axis of the device. The bearings 33 assist in securing the rotor 23 and the stator 24 within the cylindrical housing 29 while reducing the effects of mechanical vibration thereon during normal operation. The inlet 31 and outlet 32 are obviously determined by the orientation in which the pump assembly 20 is operated i.e. with reference to FIG. 3 the fluid flow is substantially along the positive z-axis but can be reversed depending on whether the rotation of the rotor 23 is clockwise or anticlockwise.

[0053] By setting:

- 1) the size of a radial gap between the rotor vanes 25 and the stator vanes 26;
- 2) the relative heights of the rotor vanes 25 and the stator vanes 26; and
- 3) the relative thicknesses of rotor vanes 25 and the stator vanes 26, the pump assembly 20 provides an efficient and robust means for pumping high viscosity and/multifluid fluids. Significantly, the pump assembly design allows it to be run at operating temperature as high as 400°C, almost twice the highest operating temperatures achievable with an E&P. This high operating temperature makes the pump assembly 20 particularly suitable for use within the presently described completion 1, as will be described in further detail below.
[0057] The operation of the completion 1 of FIG. 1 will now be described with reference to FIG. 4 which shows a section view of the horizontal section 4b of a horizontal well showing both fluid flow paths (as generally indicated by the direction of the arrows) and heat transfer paths (as generally indicated by the size of the arrow heads, larger arrow heads represents a higher fluid temperature at the location of the arrow).

[0058] In the first instance the heavy oil 3 contained within the reservoir 2 is at a typical temperature of ~55° C. and viscosity of ~5,000 cP. The heavy oil 3 flows from the reservoir 2 into the wellbore 6, as represented by arrows 34.

[0059] When the pump system 15 is activated heavy oil 3 is pumped into the tubing string 7, as described above, so as to produce a production fluid 17 that has a direction of flow towards the surface 9, as indicated by arrows 35. The pump assembly 20 is run at a fluid discharge temperature of ~300° C., and as will be described below, since a pre-warmed fluid flows past the motor 19 in a turbulent flow a significant enhancement of the motor 19 cooling process is observed. The produced fluid then passes through the pump assembly 20 resulting in the pressure being considerably increased (potential energy). Therefore, by the time the heavy oil 3 has entered the shroud 22, passed over the motor 19 and the protector seal module 21 and through the pump assembly 20 into the tubing string 7 it has been heated to a temperature of ~150° C. and has a viscosity of ~50 cP. It is obviously significantly easier for the pump system 15 to pump the production fluid 17 towards the surface 9 where it exhibits a significantly lower viscosity as it flows through the tubing string 7.

[0060] It will be appreciated by those skilled in the art that a production fluid 17 having a temperature of ~150° C. cannot be easily handled by an operator at the surface 9. Indeed in a normal production completion this temperature would be regarded as unacceptable since it is desirable for the temperature of the production fluid 17 to be below 100° C. at the surface 9 so as to avoid the problem size of flash evaporation of water from the production fluid 17 and any consequent salt deposition.

[0061] As can be seen from FIG. 4, the design of completion 1 is such that the production fluid 17 in the tubing string 7 cools as it is pumped towards the surface 9 by transferring heat to the surrounding heavy oil 3 located in the annulus 10 of the wellbore 6 and the reservoir 2.

[0062] In the presently described embodiment, the production fluid 17 cools from ~150° C. at it leaves the pump assembly to ~90° C. by the time it reaches the surface 9. The viscosity of the production fluid 17 thus correspondingly increases from ~50 cP to ~250 cP.

[0063] The production fluid 17 in the tubing string 7 however simultaneously acts as a counter current heat exchanger with the annulus fluid flow, as indicated by arrows 36. This heating of the fresh reservoir production commences immediately on the oil contacting the hot tubing string 7. This heating is continuous as the oil flows alongside the tubing string 7 (but counter to the flow within the tubing string 7). As a result, the heavy oil 3 is heated from the reservoir temperature of ~55° C. to ~100° C. before it enters the pump system 15. The viscosity of the heavy oil 3 within the annulus fluid flow 36 thus falls from ~5,000 cP to ~200 cP as a result of this counter current heat exchange mechanism.

[0064] The pump system 15 can be employed so as to optimize the operation of the completion 1, as and when required. There are two available options for this which can be employed independently or in conjunction with each other.

[0065] The first option involves employing the control system 13 to change the operation frequency of the pump assembly 20. By changing the operation frequency of the pump assembly 20 the operating temperature and temperature rise created within the pump system 15 can be adjusted. In general, if the completion 1 is running too hot then the operating frequency of the pump assembly 20 is lowered. Similarly, if the completion 1 is running too cold then the operating frequency of the pump assembly 20 is increased.

[0066] The second option involves adjusting the choke 12 within the wellhead 11 so as to alter the operating point of the pump assembly 20 along its head capacity curve and efficiency capacity curve.

[0067] These optimization techniques allow for complete control over the temperature and heat transfer characteristics of the fluids within the completion 1. For example, if some degree of tubing fouling occurs such that heat transfer is less effective, the pump assembly 20 can be adjusted to re-optimize the thermal behavior of the well 4. Alternatively, as the water cut rises, the Specific Heat (thermal capacity) of the fluid will change coupled with a possible change in fluid viscosity. The operation of the well 4 can then be re-optimized by adjusting the pump assembly 20 operating frequency and or operating point of the pump assembly 20 on the head capacity curve.

Multiple Pump Hydrocarbon Completions

[0068] It will be appreciated that the above techniques are not limited to the employment of a single pump system 15. Two multiple pump hydrocarbon completions will now be described with reference to FIGS. 5, 6 and 7.

[0069] FIG. 5 presents a section view of a horizontal reservoir 2 with a multiple pump hydrocarbon completion, as depicted generally by reference numeral 1b. The completion 1b comprises many of the elements described above in relation to the single pump completion 1 of FIG. 1 and these elements are therefore marked with the same reference numerals. However, in the presently described embodiment the single pump system 15 is replaced by a multiple pump system 37. For ease of understanding, the presently described embodiment has a multiple pump system 37 that comprises two pump modules, 38a and 38b. However, it will be appreciated by those skilled in the art that in alternative embodiments the number of pump modules 38 employed may be increased and that the actual number employed will depend on the well 4 and reservoir 2 characteristics.

[0070] Each of the pump modules 38a and 38b can be seen to comprise a pump system 15a and 15b and a bypass tubing 39a and 39b both of which are connected to an associated electro-hydraulic diverters 40a and 40b. As can be seen from FIG. 6 the electro-hydraulic diverters 40a and 40b comprise a main tubing 41 and an integrated secondary tubing 42 such that it forms a substantially Y-shape. The main tubing comprises a first 43 and a second aperture 44 for the diverter 40 while a third aperture 45 is provided by the integrated secondary tubing 42.
[0071] Each electro-hydraulic diverter 40 further comprises an internal control valve 46 that provides a means for selecting between four modes of operation for the diverter 40, namely:

[0072] 1) the internal control valve 46 is configured such that both the second aperture 44 and third apertures 45 are open to allow fluid to flow through;

[0073] 2) the internal control valve 46 is configured such that the second aperture 44 is sealed to prevent fluid flow while the third aperture 45 is open to allow fluid flow;

[0074] 3) the internal control valve 46 is configured such that the third aperture 45 is sealed to prevent fluid flow while the second aperture 44 is open to allow fluid flow; and

[0075] 4) the internal control valve 46 is configured such that both the second aperture 44 and third apertures 45 are closed to prevent fluid to flow through.

[0076] With regards to the pump module 38a the first opening 43 is arranged to be in fluid communication with the tubing string 7, the second opening 44 with the bypass tubing 39a and the third opening 45 with the pump system 15a. The arrangement for pump module 38b, and indeed any additional pump modules 38, is similar but for the fact that the first opening 43 is arranged to be in fluid communication with the bypass tubing 39a of the pump module 38a.

[0077] FIG. 7 presents a section view of a horizontal reservoir 2 with an alternative multipurpose pump hydrocarbon completion, as depicted generally by reference numeral 1c. The completion 1b comprises many of the elements described in relation to the multiple pump hydrocarbon completion 1b of FIG. 5 and these elements are marked with the same reference numerals. In this embodiment however the electro-hydraulic diverter 40b connects only to pump system 15b i.e. it does not connect to an associated bypass tubing. Therefore, unlike multiple pump hydrocarbon completion 1b, multiple pump hydrocarbon completion 1c does not provide a means to allow logging or intervention tools to reach the bottom of the well 4.

[0078] The employment of the electro-hydraulic diverters 40 allow for the multiple pump hydrocarbon completions 1a and 1b to operate in a range of production modes and well service modes as will now be described in further detail.

Production Modes

[0079] 1) Production from Upper Pump System 15a

[0080] In this mode electro-hydraulic diverter 40a would be configured such that that internal control valve 46a operates in its second mode of operation i.e. the second aperture 44a is sealed while the third aperture 45a is open while the electro-hydraulic diverter 40b would be configured such that that internal control valve 46b operates in its fourth mode or operation i.e. both the second 44b and third apertures 45b are closed to prevent fluid flow through. Upper pump system 15a would then be operated in a forward pumping regime.

[0081] 2) Production from Lower Pump System 15b

[0082] Here electro-hydraulic diverter 40b would be configured such that that internal control valve 46b operates in its second mode of operation i.e. the second aperture 44b is sealed while the third aperture 45b is open. However, in this production mode the electro-hydraulic diverter 40a would be configured such that that internal control valve 46a operates in its third mode of operation i.e. the second aperture 44a is open while the third aperture 45a is sealed to stop re-circulation of the production fluid 17. The lower pump system 15b would then be operated in a forward pumping regime.

[0083] 3) Production from Upper & Lower Pump Systems 15a and 15b

[0084] In this production mode the electro-hydraulic diverter 40a would be configured such that that internal control valve 46a operates in its first mode of operation i.e. both the second 44a and third apertures 45a are open to allow fluid to flow through while the electro-hydraulic diverter 40b would be configured such that that internal control valve 46b operates in its second mode of operation i.e. the second aperture 44b is sealed while the third aperture 45b is open. Both the upper 15a and lower 15b pump systems would then be operated in a forward pumping regime.

Well Service Modes

[0085] 1) Reverse Pumping of Production Fluid 17 from Upper Pump System 15a

[0086] In this mode of operation the internal control valve 46a of electro-hydraulic diverter 40a would be configured to operate in the second mode of operation such that the second aperture 44a is sealed to prevent fluid flow while the third aperture 45a is open to allow fluid flow. The electro-hydraulic diverter 40b would be configured such that that internal control valve 46b operates in its fourth mode or operation i.e. the third aperture 45b is sealed to prevent fluid flow while the second aperture 44b is open. Lower pump system 15b would then be operated in a reverse pumping regime, which will allow hot produced fluid from tubing string 7 to wash the horizontal well 4.

[0087] 2) Reverse Pumping of Production Fluid 17 from Lower Pump System 15b

[0088] The internal control valve 46b of electro-hydraulic diverter 40b would be configured to operate in the second mode of operation such that the second aperture 44b is sealed to prevent fluid flow while the third aperture 45b is open to allow fluid flow. The electro-hydraulic diverter 40a would be configured such that that internal control valve 46a operates in its third mode or operation i.e. the third aperture 45a is sealed to prevent fluid flow while the second aperture 44a is open. Lower pump system 15b would then be operated in a reverse pumping regime.

[0089] It will be appreciated that the above described well service modes could be controlled such that alternating between forward and reverse pumping could be employed to provide an effective well service program.

[0090] 3) Circulation of Production Fluid 17 or Stimulation Fluid between Upper & Lower Pump Systems 15a and 15b

[0091] The internal control valves 46a of electro-hydraulic diverter 40a would be configured to operate in the first mode of operation such that both the second 44a and third 45a apertures are open to allow fluid flow. The internal control valve 46b of electro-hydraulic diverter 40b would be configured to operate in the second mode of operation such that the second aperture 44b is sealed to prevent fluid flow while the third aperture 45b is open to allow fluid flow. The production choke 12 in the wellhead 11 would also be closed so as to allow pump systems 15a and 15b to circulate fluid in horizontal well 4 when the upper pump system 15a
is operated in a reverse pumping regime and lower pump system 156 is operated in a forward pumping regime, or vice versa.

[0092] The above methods and apparatus have particular application in improving the efficiency of production of heavy and extra heavy oils. The apparatus may comprise a single pump system or multiple pump system's combined with 'intelligent completion' technology so as to allow for its use in a range of production and well servicing modes.

[0093] Although not so limited, the described methods and apparatus find particular application within horizontal, high angle or vertical wells in heavy or extra heavy oil fields. It is particularly advantageous to arrange these wells to have a long inflow section located within the reservoir.

[0094] The completion designs allow for full and optimally efficient use of all of the electrical energy supplied to the well. This energy may be used to provide hydraulic power to the pumped fluids so as to controllably increase the tubing string, wellbore annular and reservoir fluid temperature. Increasing the fluid temperature substantially reduces the viscosity of the heavy and extra heavy oil, thus reducing the tubing string and wellbore annular friction.

[0095] A direct result of this arrangement is that most of the oil is pre-heated as it flows into the wellbore and alongside the tubing string towards the pump intake (whether single or multiple pump embodiments). A shroud is preferably incorporated within the pump system so as to allow the hydrocarbon fluid in the annulus 10 to flow past the motor. Therefore heavy and extra heavy oils may achieve a viscosity reduction typically greater than 95% before they enter the pump intake.

[0096] The pre-warmed oil provides a much improved cooling for the pump system motor as well as increasing the hydraulic efficiency of the pump assembly.

[0097] It is recognized that the wellbore cross-section area is reduced by the presence of the tubing string and power cable(s) but this is entirely mitigated by the substantially reduced fluid viscosity of the heavy and extra heavy oil and the reduced effects of wellbore annular and tubular string friction.

[0098] The described completion arrangements also act to minimize the deposition of wax and other materials within the well. However, in the event of such deposition the completion designs can be operated in easily configured modes so as to perform a hot oil or hot water wash on the inflow sections or a hot well stimulation fluid wash.

[0099] The above described multiple pump systems provide a unique capability to selectively producing different parts of the reservoir at different rates. These systems also provide a unique capability to perform a balanced circulation (i.e. in hydraulic balance, even within a depleted reservoir) for placement of well servicing materials e.g. water shut-off gels, treatment slurries, etc. traditionally these can be problematic to deploy on long horizontal wells (and virtually impossible within heavy and extra heavy oil wells) as the fluid always enters the reservoir at the heel or the tubing shoe. Accurate ‘placement’ of fluids is therefore not possible. Utilizing the above described methods and apparatus the pump systems can be used to circulate treatment fluids or slurries to a precise location by a combination of forward and reverse pumping. This occurs irrespective of depleted reservoir pressure, such that accurate placement is achieved without hardware intervention.

[0100] As a direct consequence of embodiments herein, heavy and extra heavy oil fields can now be developed using efficient and effective long horizontal wells with full and appropriate inflow and production developed along the entire length of the horizontal section. Of further advantage is that the completion designs also includes measures to deal with wax precipitation, emulsions, sand production and other operational issues without the need for further well intervention.

[0101] A method of pumping a hydrocarbon fluid from a wellbore and a hydrocarbon completion implementing the methodology is described. The method comprises deploying a tubing string and a first pump system within a wellbore, the first pump system being arranged to be in fluid communication with the tubing string. The first pump system is further arranged such that a counter current heat exchanger is formed between a production fluid pumped by the first pump system within the tubing string and the hydrocarbon fluid located within the wellbore. The formation of the counter current heat provides a means for pre-heating the hydrocarbon fluid before it reaches the first pump system. As a result the viscosity of the hydrocarbon fluid is reduced thus making it easier to pump to the surface. The method finds particular application within horizontal, high angle or vertical wells in heavy or extra heavy oil fields.

[0102] The foregoing description of embodiments of the disclosure has been presented for purposes of illustration and description and is not intended to be exhaustive or to limit the embodiments herein to the precise form disclosed. The described embodiments were chosen and described in order to best explain the principles of the disclosure and its practical application to thereby enable others skilled in the art to best utilize the disclosure in various embodiments and with various modifications as are suited to the particular use contemplated. Therefore, further modifications or improvements may be incorporated without departing from the scope of the disclosure as defined by the appended claims.

What is claimed is:

1. A system for production of a hydrocarbonaceous fluid, the system comprising:
   a tubing string deployed within a wellbore;
   a first pump system comprising a pump assembly operably engaged with a motor; the pump assembly further comprising:
   a stator comprising an inner stator surface configured with an one or more stator vanes thereon;
   a rotor comprising an external stator surface configured with an one or more rotor vanes thereon;
   a housing having the stator and the rotor disposed therein;
   wherein a radial gap is provided between the one or more stator vanes and the one or more rotor vanes along a length of the pump assembly, wherein a radial length of the one or more rotor vanes is greater than a radial length of the one or more stator vanes, wherein a thickness of the one or more stator vanes is greater than a thickness of the one or more rotor vanes,
   wherein stator channels on the inner stator surface comprise a constant inner diameter, wherein rotor channels on the rotor outer surface comprise a constant outer diameter, and wherein the first pump system is in fluid communication with the tubing string; and
a control system operably engaged with the first pump system;
wherein the first pump system is operable to aid in production of the hydrocarbonaceous fluid from the wellbore to a production facility, the hydrocarbonaceous fluid having a viscosity of greater than 1,000 cP.

2. The system of claim 1, wherein the first pump system further comprises a cooling shroud that depends from the pump assembly so as to define a flow path that requires the hydrocarbon fluid to pass over the motor before entering the pump assembly.

3. The system of claim 1, wherein a protector seal module is located between the pump assembly and the motor.

4. The system of claim 1, wherein the control system is operable to change a set of operating parameters of the pump assembly of so as to optimize the hydrocarbon fluid production from the wellbore, wherein an operating frequency is one of the set of operating parameters, and wherein the control system is operable to control a choke.

5. The system of claim 1, the system further comprising a second pump system like that of the first pump system, the second pump system also in fluid communication with the tubing string.

6. The system of claim 1, wherein the hydrocarbonaceous fluid has a viscosity of greater than 20,000 cP, and wherein the first pump system is located 75% to 95% of the way along a length of the wellbore.

7. The system of claim 1, wherein rotor channels and stator channels are all of the same lengths and cross-sectional area.

8. The system of claim 1, the pump assembly further comprising:
an inlet;
an outlet;
two bearings separated along an longitudinal axis of the pump assembly, one of which being proximate to the inlet, and the other being proximate to the outlet.

9. A system for production of a hydrocarbonaceous fluid, the system comprising:
a tubing string deployed within a wellbore;
a first pump system comprising a pump assembly operably engaged with a motor, the pump assembly further comprising:
a stator comprising an inner stator surface configured with an at least one stator vane thereon;
a rotor comprising an external stator surface configured with an one or more rotor vanes thereon;
a housing having the stator and the rotor disposed therein;
wherein a radial gap is provided between the one or more stator vanes and the one or more rotor vanes along a length of the pump assembly, wherein a radial length of the one or more rotor vanes is greater than a radial length of the one or more stator vanes, wherein a thickness of the one or more stator vanes is greater than a thickness of the one or more rotor vanes,
wherein stator channels on the inner stator surface comprise a constant inner diameter, wherein rotor channels on the outer surface comprise a constant outer diameter, and wherein the first pump system is in fluid communication with the tubing string; and
a control system operably engaged with the first pump system;
wherein the first pump system is operable to aid in production of a hydrocarbonaceous fluid from the wellbore to a production facility, the hydrocarbonaceous fluid having a viscosity of greater than 1,000 cP.

10. The system of claim 9, wherein the first pump system further comprises a cooling shroud that depends from the pump assembly so as to define a flow path that requires the hydrocarbon fluid to pass over the motor before entering the pump assembly.

11. The system of claim 10, wherein a protector seal module is located between the pump assembly and the motor.

12. The system of claim 11, wherein the control system is operable to change a set of operating parameters of the pump assembly of so as to optimize the hydrocarbon fluid production from the wellbore, wherein an operating frequency is one of the set of operating parameters, and wherein the control system is operable to control a choke.

13. The system of claim 12, the system further comprising a second pump system like that of the first pump system, the second pump system also in fluid communication with the tubing string.

14. The system of claim 12, wherein the hydrocarbonaceous fluid has a viscosity of greater than 20,000 cP, and wherein the first pump system is located 75% to 95% of the way along a length of the wellbore.

15. The system of claim 14, wherein rotor channels and stator channels are all of the same lengths and cross-sectional area.

16. The system of claim 14, the pump assembly further comprising:
an inlet;
an outlet;
two bearings separated along an longitudinal axis of the pump assembly, one of which being proximate to the inlet, and the other being proximate to the outlet.