A well completion for use in enhanced recovery of heavy oil includes a compressor for pressurizing natural gas captured from a heavy oil formation to a specified pressure while maintaining the pressurized gas at a specified temperature by controlling conduction from the pressurized gas of adiabatic heat produced in its pressurization. The pressurized and heated natural gas is then reintroduced to the heavy oil formation to enhance production therefrom.
WELL COMPLETION AND RELATED METHODS FOR ENHANCED RECOVERY OF HEAVY OIL

FIELD OF THE INVENTION

[0001] The present invention relates to petroleum production. More particularly, the invention relates to the utilization of pressurized and heated natural formation gas for enhanced recovery of petroleum from heavy oil formations.

BACKGROUND OF THE INVENTION

[0002] Although technically referring to liquid petroleum having an American Petroleum Institute ("API") gravity of less than 22.3° (i.e., having a relative density of greater than about 0.92), "heavy oil" generally denotes any type of crude oil which does not flow easily. Compared to light or even medium crude oil, the production, transportation and refining of the denser and more viscous heavy crude oil present many special challenges, which not only increase the cost of production but also result in discounted pricing. Because it conservatively accounts for more than double the worldwide resources of conventional oil, however, heavy oil cannot be ignored to satisfy current and future oil demand notwithstanding that character generally renders conventional production methods ineffective. As a result, such tertiary techniques as steam flooding, steam assisted gravity drainage and cyclic steam injection have traditionally been employed in attempts to reach this increasingly important resource.

[0003] Steam flooding, also sometimes referred to as continuous steam injection or steam drive, is a method of thermal recovery in which steam is generated at the well surface and then injected into the reservoir through specially distributed injection wells. As the steam enters the reservoir, two mechanisms become available to improve the amount of oil recovered. First, the steam heats up the crude oil, reducing its viscosity and enabling it to more easily flow through the formation toward a producing well. Second, the hot water that condenses from the steam and the steam itself generate an artificial drive that sweeps oil toward the producing well. While steam flooding is of the most part considered as a more generalized recovery method, steam assisted gravity drainage ("SAGD") is a thermal production method typically only utilized for heavy oil. In any case, SAGD pairs a high-angle injection well with a nearby production well drilled along a parallel trajectory, the pair of wells being typically drilled with a vertical separation of only a few meters distance. Steam is then injected into the reservoir through the upper well and as the steam rises and expands it heats up the heavy oil, reducing its viscosity in the manner of steam flooding generally. In SAGD, however, gravity is relied upon to force the oil to drain into the lower well where it is otherwise produced. Both techniques, however, require enormous quantities of fresh water and considerable energy to generate the necessary large quantities of steam as well as multiple, specialized wells and, in the end, are only modestly effective for the enhancement of heavy oil production.

[0004] As an alternative to steam flooding, cyclic steam injection, which is sometimes referred to as steam soak or the "luff-n-puff" method, is a method of thermal recovery used extensively in heavy oil reservoirs in which a well is removed from production, injected with steam and then subsequently put back on production. In particular, cyclic steam injection is conducted in three phases: (1) the injection phase, during which a slug of steam is introduced into the reservoir; (2) the soak phase, which requires that the well be shut in for several days to allow uniform heat distribution to thin the oil; and (3) the production phase, during which the thinned oil is produced through the same well. While requiring less steam than steam flooding and capable of implementation through a single well, cyclic steam injection is nonetheless costly and, like steam flooding, is only modestly effective for the enhancement of heavy oil.

[0005] Given the shortcomings of more the generalized and closely related techniques, but faced with the fact that heavy oil has become increasingly more important in many countries, greater and greater resources have been focused on the task of improving the available methods for recovery and, as a result, the state of the art increasingly encompasses more extreme or experimental as well as more costly techniques. For example, in a non-thermal process very similar to SAGD, hydrocarbon solvents, instead of steam, are injected into the upper well to dilute the bitumen and allow it to flow into the lower well. Although the process has garnered some attention due to its much better energy efficiency than steam injection, the process is thought to be cost effective only under narrow circumstances.

[0006] In a further example, however, of new and experimental methods being brought to bear for the recovery of heavy oil, toe-to-heel air injection is a method that modifies conventional fire flooding techniques to combine a vertical air injection well with a horizontal production well. The process ignites oil in the reservoir and creates a vertical wall of fire moving from the "toe" of the horizontal well toward the "heel," which burns the heavier oil components and upgrades some of the heavy bitumen into lighter oil right in the formation. Like vapor extraction, however, toe-to-heel air injection is limited to only certain formations and also carries high well costs.

[0007] With the foregoing limitations of the prior art clearly in mind, it is therefore an overriding object of the present invention to improve over the prior art by setting forth a well completion and related methods adapted to more generalized application for enhanced recovery of petroleum from heavy oil formations. Additionally, it is an object of the present invention to set forth such a well completion and related methods that are cost effective in practice. Still further, it is an object of the present invention to set forth such a well completion and related methods that are flexible in specific implementation. Finally, it is an object of the present invention to set forth such a well completion and related methods that are environmentally conscientious.

SUMMARY OF THE INVENTION

[0008] In accordance with the foregoing objects, the present invention—a well completion for use in enhanced recovery of heavy oil—generally comprises means for capturing from a heavy oil formation of natural gas; means for pressurizing said captured natural gas, said means for pressurizing said captured natural gas comprising means for controlling the temperature of said pressurized natural gas; and means for reintroduction to said formation of said pressurized captured natural gas.

[0009] In use of the well completion, a method for enhancing production of petroleum from a heavy oil formation generally comprises comprising the steps of: producing a hydrocarbon mixture from within a heavy oil formation; extracting a quantity of natural formation gas from said hydrocarbon...
mixture; pressurizing said quantity of natural formation gas to a specified pressure; maintaining said pressurized natural formation gas at a specified temperature by controlling conduction from said pressurized natural formation gas of adiabatic heat produced in said pressurizing step; and reintroducing said pressurized and heated natural formation gas to said heavy oil formation.

[0010] Finally, many other features, objects and advantages of the present invention will be apparent to those of ordinary skill in the relevant arts, especially in light of the foregoing discussions and the following drawings, exemplary detailed description and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Although the scope of the present invention is much broader than any particular embodiment, a detailed description of the preferred embodiment follows together with illustrative figures, wherein like reference numerals refer to like components, and wherein:

[0012] FIG. 1 shows, in a functional block diagram, the preferred embodiment of the surface components of the well completion of the present invention;

[0013] FIG. 2 shows, in a partially cut away side-elevation cross-section view taken through the center axis of a well bore, a first preferred embodiment of the downhole components of the well completion of the present invention;

[0014] FIG. 3 shows, in a partially cut away side-elevation cross-section view taken through the center axis of a well bore, details of an extension of the embodiment of the downhole components as shown in FIG. 2, the details shown therein, however, being generally applicable to other embodiments as well;

[0015] FIG. 4 shows, in a partially cut away side-elevation cross-section view taken through the center axis of a well bore, a second preferred embodiment of the downhole components of the well completion of the present invention;

[0016] FIG. 5 shows, in a partially cut away side-elevation cross-section view taken through the center axis of a well bore, an alternative implementation of the embodiment of the downhole components as shown in FIG. 4;

[0017] FIG. 6 shows, in a partially cut away side-elevation cross-section view taken through the center axis of a well bore, a third preferred embodiment of the downhole components of the well completion of the present invention;

[0018] FIG. 7 shows, in a functional block diagram, an alternative implementation of the embodiment of the surface components as shown in FIG. 1; and

[0019] FIG. 8 shows, in a partially cut away side-elevation view cross-section view taken through the center axis of a well bore, an extension of the invention of the embodiments of FIGS. 4 and 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0020] Although those of ordinary skill in the art will readily recognize many alternative embodiments, especially in light of the illustrations provided herein, this detailed description is exemplary of the preferred embodiment of the present invention, the scope of which is limited only by the claims appended hereto.

[0021] Referring now to the figures, the preferred embodiments of the well completion 10 for enhanced recovery of heavy oil of the present invention are shown to generally comprise various surface components 11, such as particularly shown in FIGS. 1 and 7, cooperatively arranged at or adjacent one or more wellheads 53 and various cooperatively arranged downhole components 83, such as particularly shown in FIGS. 2 through 6, placed within one or more wellbores 85 through a heavy oil containing formation 84. Although it is to be understood that any particular implementation of the presently contemplated well completion 10 will in practice likely include many additional elements peculiar to the circumstances of the formation about which such implementation is had and, similarly, that in various circumstances many of the features described herein as being preferred or generally desirable will not be required to take at least some advantage of the teachings hereof, the various components 11, 83 of the well completion 10 of the present invention will in any case include or otherwise cooperatively comprise at least means for capture from the formation 84 of natural formation gas; means for temperature controlled pressurization of previously captured natural formation gas; and means for reintroduction to the formation 84 at a selected temperature and at a selected pressure of previously captured and pressurized natural formation gas, wherein the selected pressure is greater that the natural formation pressure and the selected temperature is greater than the natural formation temperature. Additionally, and as will be better understood further herein, the well completion 10 of the present invention realizes the necessary heating of previously captured natural formation gas as a byproduct of the necessary pressurization of the same natural formation gas, thereby resulting in extremely energy efficient utilization of natural formation gas for enhanced production of heavy oil.

[0022] As particularly shown in FIG. 1, the preferred embodiment of the present invention contemplates a substantially conventional completion of the wellhead 53, wherein a production string 90 terminates through a conventional casing spool 87 or like structure into the topside “Christmas tree,” through which, as also is conventional, the production string 90 will be placed in fluid communication with a production line 54 at the surface. In accordance with the present invention, fluid flow from the production string 90 into the production line 54 is under ordinary operations controlled through an automated flow control valve 55. As is otherwise conventional, the automated flow control valve 55, which is provided in connection with the Christmas tree structure, may be actuated by hydraulic, gas, electric or other means and is remotely operated through a provided valve controller 56. While, for clarity, the graphical depictions of the figures as well as this exemplary only discussion omit many features necessary in actual implementation of a well completion, such as, for example, a manually operated backup flow control valve 57, check valves and the like, all such features are otherwise conventional in the art and their necessity and manner of implementation will be well known to those of ordinary skill in the art. In any case, the production line 54 is in fluid communication with a means for the separation of natural formation gas from other production fluids with which such gas is associated.

[0023] In particular, the production line 54 terminates at the inlet 62 to a conventional two-phase or, as shown in FIG. 1, three-phase separator 61, wherein oil, gas and water are separated from the total fluid stream flowing through the production line with any recovered free water flowing through the free water effluent 63 to a wastewater storage tank 64 for further treatment as may be necessary, any produced petro-
leum flowing through an oil effluent 65 to local storage battery 66 or production pipeline and any produced natural formation gas flowing through a gas outlet 67 (and, if necessary or otherwise desired, a provided mist extractor 68) to a raw gas line 69 from the separator 61.

[0024] Because the raw formation gas flow stream will at this point likely still contain dirt or other foreign matter and water or other undesired liquids, none of which should be introduced to downstream rotating equipment or the gathering system pipeline 113, the most preferred embodiment of the present invention contemplates that the raw gas line 69 from the separator 61 should terminate at the inlet 71 of a conventional scrubber 70, the outlet 73 of which is preferably connected to an outlet gas line 74 also forming the inlet gas line 76 in fluid communication with the inlet 77 of a conventional dehydrator 76. Although the present invention contemplates implementation with any dehydrator 76 otherwise appropriate for the circumstances of the greater completion, it is noted that the raw gas is at this point in the implementation likely not at the very high pressure required for solid-desiccant dehydration. As a result, the dehydrator 76 of the present invention is appropriately implemented as a glycol absorption dehydrator.

[0025] In any case, as particularly shown in FIG. 1, the well completion 10 of the present invention at this juncture departs from convention. In particular, whereas in a typical completion the outlet 79 from the dehydrator 76 would connect directly (or through a meter 115 or the like) to an offshore gas line 114 in communication with a gathering system pipeline 113, in the present invention the outlet 79 from the dehydrator 76 connects through a provided outlet gas line 80 to a specially provided valve unit 116, which valve unit 116 in turn connects to the offshore gas line 114 leading ultimately to the gathering system pipeline 113. As will be better understood further herein, the provided valve unit 116 enables the gas flow through the offshore gas line 114 to be selectively controlled through an associated valve controller 117 such that in certain circumstances flow from the outlet gas line 80 from the dehydrator 76 provides raw gas to the gathering system pipeline 113 while in other circumstances the gathering system pipeline 113 acts as a source of gas for use by additional components of the well completion 10 of the present invention, which additional components are located in the completion 10 opposite the dehydrator 76 downstream of the valve unit 116. As also will be better understood further herein, the associated valve controller 117 is in electrical communication with a system controller 82, which controller 82 is programmed or otherwise adapted to collect and analyze data and other information, collected in real time and historically, and, based upon the analysis thereof, to operate the various valves (such as, for example, the previously discussed valve controller 56 associated with the automated flow control valve 55 upstream the production line 54), motors and other components of the well completion 10 in order to safely and efficiently enhance the production of petroleum from the heavy oil formation 84 in connection with which the well completion 10 of the present invention is implemented.

[0026] In any case, the well completion 10 of the present invention comprises a gas heater 12 adapted to pressurize and heat a quantity of the natural formation gas extracted and captured from the heavy oil formation 84 through which the wellbore 85 extends, whereafter the pressurized and heated natural formation gas is reintroduced to the formation 84 in a manner that enhances production from the formation 84 of additional hydrocarbon products. As will be better understood further herein, and in a critical aspect of the present invention, the gas heater 12 is consistent with this purpose further adapted to enable precise control of both the temperature and the pressure at which the natural formation gas is reintroduced to the formation 84, which precise control is necessary not only for maximizing production from the formation 84 but also for ensuring the safe operation of the well completion 10. Still further, in order to provide an energy efficient contribution to the art, the gas heater 12 of the present invention is adapted to maintain the desired temperature of the reintroduced natural formation gas solely by controlling conduction heat from pressurization of the natural formation gas to the desired pressure of reintroduction.

[0027] As shown in FIG. 1, such a gas heater 12 may be readily implemented with a preferably multistage gas compressor 13, such as the depicted three-stage gas compressor, having integrated therewith a controllable, preferably interstage, cooling system 23. In the most preferred embodiment of the present invention, the natural formation gas from the upstream components is conveyed through a compressor gas supply line 75 into the gas inlet 15 of the first compressor stage 14 wherein the gas is pressurized by an initial amount. The initially pressurized natural formation gas then exits the first compressor stage 14 through a gas outlet 16 in fluid communication with a gas inlet 25 to a provided first radiator 24 or like heat exchanger. As will be better understood further herein, this first radiator 24 is adapted to conduct from the initially pressurized natural formation gas substantially all of the adiabatic heat produced in the gas in the first compressor stage 14. In any case, the initially pressurized natural formation gas exits the first radiator 24 through a gas outlet 27 in fluid communication with the gas inlet 18 of the second compressor stage 17 wherein the gas is pressurized by an additional amount.

[0028] The subsequently pressurized natural formation gas then exits the second compressor stage 17 through a gas outlet 19 in fluid communication with a gas inlet 33 to a provided second radiator 32 or like heat exchanger. As will be better understood further herein, this second radiator 32 is adapted to conduct from the further pressurized natural formation gas substantially all of the adiabatic heat produced in the gas in the second compressor stage 17. In any case, the subsequently pressurized natural formation gas exits the second radiator 32 through a gas outlet 35 in fluid communication with the gas inlet 21 of the third compressor stage 20 wherein the gas is pressurized by a final amount.

[0029] The finally pressurized natural formation gas then exits the third compressor stage 20 through a gas outlet 22 in fluid communication with a gas inlet 41 to a provided third radiator 40 or like heat exchanger. As will be better understood further herein, this third radiator 40 is adapted to conduct from the finally pressurized natural formation gas substantially all of the adiabatic heat produced in the gas in the third compressor stage 20. In any case, the finally pressurized natural formation gas exits the third radiator 40 through a gas outlet 43 in fluid communication with an injection line 58, which, as will also be better understood further herein, is configured to selectively convey the pressurized natural formation gas back to the wellhead 53 for reintroduction to the heavy oil formation 84 in accordance with the present invention through an injection string 93 originating at the casing spool 87 or like structure part of or adjacent the topside Christmas tree. As a safety feature, and to prevent damage
the gas compressor 13, especially during periods of suspended operation, appropriate check valves and/or an automated flow control valve 59 is preferably provided in the injection line 58 between the gas outlet 43 from the third radiator 40 and the injection string 93. In such a case, the automated flow control valve 59 is provided with an associated valve controller 60, which valve controller 60 is like the other automated components of the present invention is electrical communication with and under the operable control of the system controller 82.

[0030] A power source 49 is provided in connection with the gas compressor 13 for operation thereof. Although any conventional power source otherwise utilized for the operation of gas compressors, such as, for example, an electric motor, may be utilized in connection with well completion 10 of the present invention, the most preferred implementations of the present invention will utilize a power source 49 that itself may be powered at least in part with natural formation gas otherwise produced in accordance with the teachings hereof. For example, a gas powered motor 50 or, in the alternative, a gas powered generator and electric motor combination, is preferably implemented. To this end, a T-connection 81 is provided for appropriating from the compressor gas supply line 75 an operable quantity of natural gas, which is conveyed from the T-connection 81 through a compressor motor gas supply line 52 to a gas inlet 51 provided on the gas powered motor 50 (or gas powered generator). Although for clarity not specifically depicted in the figures, it should be understood that the depicted T-connection 81 includes any check valves, pressure regulators, flow control valves and the like as may be necessary for actual implementation of this aspect of the present invention. These additional components, however, are, especially in light of this exemplary description, all well within the ordinary skill in the art and should be considered within the scope of the present invention.

[0031] As shown in FIG. 1, the provided radiators 24, 32, 40 are preferably provided in connection with a forced air system such as may be readily implemented with a preferably adjustable speed blower 48 in order to facilitate their operation in conduction from the pressurized gas flow of adiabatic heat. While, as previously mentioned in connection with the discussion of gas flow through the radiators 24, 32, 40, the radiators are adapted to collectively conduct from the gas flow substantially all of the adiabatic heat of the pressurization applied by the three gas compressor stages 14, 17, 20, the present invention further comprises means for precisely controlling the amount of adiabatic heat conducted from the gas flow following each compressor stage 14, 17, 20 by each of the provided radiators 24, 32, 40, respectively. To this end, as shown in FIG. 1, each radiator 24, 32, 40 is provided with an independently controllable airflow regulator 29, 37, 45, respectively.

[0032] In particular, in the most preferred embodiment of the present invention, a first adjustable louver 30 is provided adjacent the first radiator 24, the first adjustable louver 30 being adapted and arranged to regulate the volume of airflow in convection about the first radiator 24 by selectively interfering with the portion of the airflow generated by the blower 48 that would without interference from the second louver 38 ordinarily flow through and about the second radiator 32; and, finally, a third adjustable louver 46 is provided adjacent the third radiator 40, the third adjustable louver 46 being adapted and arranged to regulate the volume of airflow in convection about the third radiator 40 by selectively interfering with the portion of the airflow generated by the blower 48 that would without interference from the third louver 46 ordinarily flow through and about the third radiator 40. In order to effect independent control of the adjustable louver 30, 38, 46, the first adjustable louver 30 is provided with a remotely controllable actuator 31 in electrical communication with the system controller 82, the second adjustable louver 38 is provided with a remotely controllable actuator 39 in electrical communication with the system controller 82 and, finally, the third adjustable louver 46 is provided with a remotely controllable actuator 47 in electrical communication with the system controller 82.

[0033] Additionally, in order to provide the necessary system status data to enable precise control throughout the system of both the pressurization of the natural formation gas and the temperature thereof, one or more inlet gas monitoring transducers 26, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 16 from the first compressor stage 14 and the gas inlet 25 to the first radiator 24; one or more outlet gas monitoring transducers 28, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 27 of the first radiator 24 and the gas inlet 18 to the second compressor stage 17; one or more inlet gas monitoring transducers 34, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 19 from the second compressor stage 17 and the gas inlet 33 to the second radiator 32; one or more outlet gas monitoring transducers 36, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 35 of the second radiator 32 and the gas inlet 21 to the third compressor stage 20; one or more inlet gas monitoring transducers 42, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 22 from the third compressor stage 20 and the gas inlet 42 to the third radiator 40; and one or more outlet gas monitoring transducers 44, capable of measuring and reporting both gas pressure and gas temperature, are provided between the gas outlet 43 of the third radiator 40 and the injection line 58 leading to the injection string 93.

[0034] As generally shown in FIGS. 2 through 6, the well completion 10 of the present invention will generally include a well casing 86 extending substantially throughout the length of the wellbore 86 through a heavy oil formation 84. As is otherwise conventional, the well casing 86 will comprise a number of perforations 88 through the walls thereof in the production zone of the heavy oil formation 84. In accordance with the present invention, the well completion will also comprise at least one injection string 93 extending into the interior of the wellbore 86 is bounded by the well casing 86 and at least one production string 90 extending therefrom. The particular arrangement of the injection strings 93 and production strings 90, including the termination and origination, respectively, thereof, however, will vary among multiple possible embodiments. While several embodiments are shown and described herein, it should be noted that the
present invention is broader in scope than represented by the particular downhole components 83 shown herein. [0035] In any case, a first preferred embodiment of the downhole components 83 of the well completion 10 of the present invention is particularly shown in FIG. 2. As shown in FIG. 2, an otherwise conventional dual string packer 107 is operably placed within the wellbore 85 at a location just above the production zone perforations 88 through the well casing 86 and otherwise conventionally seated against the interior of the well casing 86 with its provided preferably high temperature rated elastomeric packer elements 108. As shown in the figure, the injection string 93 terminates below the packer 107 in the area of the production zone. Similarly, as also shown in the figure, the production string 90 originates below the packer 107 in the area of the production zone.

[0036] Referring now to FIGS. 1 and 2, in particular, and with a view toward exemplifying the broader concepts of the present invention, the simplest mode of operation of the well completion 10 of the present invention is described. As previously discussed, the well completion 10 of the present invention is particularly adapted to reintroduce into a heavy oil formation 84 some quantity of natural formation gas, which gas, as will be appreciated by those of ordinary skill in the art, may generally be regarded as being “wet” gas. Wet gas, as is known in the art, denotes natural gas containing significant heavy hydrocarbons, often referred to as condensate. Unlike dry gas, which is composed almost entirely of methane, Applicant has found that wet, natural formation gas is particularly suited for conveyance into the heavy oil formation 84 of heat due to its unique ability to hold heat for an extended time period. With that in mind, a first mode of operation of the well completion 10 of the present invention comprises the creation of a simple gas lift type arrangement, wherein the lift gas comprises natural formation gas introduced through the injection string 93 to the production zone at a controlled, elevated temperature wherein the temperature is selected with a view toward heating up the heavy crude oil, reducing its viscosity and enabling it to more easily flow from the formation 84 and into the production string 90. Because, in this embodiment, a quantity of the heated formation gas will also travel with and draw the heated heavy oil through the production string 90, the heated natural formation gas will operate to maintain the heavy oil in a flowable viscosity throughout the production string 90 to the wellhead 53.

[0037] In this mode of operation, the produced hydrocarbon mixture, which will typically comprise petroleum and some quantity of associated natural gas in addition to some recovered quantity of previously injected natural formation gas, passes normally through the valves 55, 57 at the wellhead 53 and into the production line 54 leading to the separator 61. Although not shown in the figures, it should at this point be noted that in actual implementation a conventional boiler system or and/or other heating apparatus will likely be necessary to maintain a flowable viscosity in the recovered hydrocarbon mixture. Such systems and their implementations, however, are well known to those of ordinary skill in the art. In any case, the recovered natural formation gas (considered to encompass the combination of newly produced and previously injected gases) passes normally through the separator 61, scrubber 70 and dehydrator 76.

[0038] As previously discussed, however, in accordance with the present invention the outlet gas line 80 from the dehydrator 76 terminates into a specially provided valve unit 116, which valve unit is remotely operated by a specially provided valve controller 117 under the operable control of the system controller 82. As also previously discussed, the valve unit 116 is adapted to selectively enable and/or otherwise control gas flow between the well completion 10 of the present invention and a gathering system pipeline 113. In all operations of the present invention, however, the valve unit 116 is operable in one of two basic modes. In particular, if the quantity of natural formation gas produced through the production line 54 from the wellhead 53 is at any particular time insufficient to support all other requirements of the present invention (which, as will be better understood further herein, include primarily delivery of natural formation gas through the compressor gas supply line 75 for delivery through the injection line 58 to the formation 84, but also include any requirements such as operation of a gas powered motor 50, boiler system, or the like), then the valve unit is operated through the valve controller 117 by the system controller 82 to deliver any excess gas through the offshore gas line 114 and meter 115 where it is sold into the gathering system pipeline 113. If, on the other hand, for any reason the quantity of natural formation gas is produced through the production line 54 from the wellhead 53 is at any particular time insufficient to support all other requirements of the present invention (which may, as will also be better understood further herein, include times of “suspended” production during which no gas is produced from the formation 84), then the valve unit is operated through the valve controller 117 by the system controller 82 to allow any additionally required gas from the gathering system pipeline 113.

[0039] In any case, the system controller 82 for the well completion 10 of the present invention is programmed and/or otherwise adapted to determine and effect, based upon the desired quantity, pressure and temperature of natural formation gas to be injected into the heavy oil formation 84, the quantity of natural formation gas to be delivered through the compressor gas supply line 75 to the gas compressor 13, the levels of compression to be applied to the natural formation gas by each individual compression stage 14, 17, 20; the positioning of each adjustable lower 30, 38, 46; and, as will be better understood further herein, the states of the injection side automated control valve 60 and production side automated control valve 55 (often referred to as the “motor control valve” due to the propensity for implementation with a “motorized” valve).

[0040] As will be appreciated by those of ordinary skill in the art, especially now in light of the foregoing exemplary description, the basic operation of the present invention as thus far described is readily extensible to any number of more complex modes. For example, it should be recognized that because the present invention contemplates the ability to automatically supplement locally produced natural formation gas with natural formation gas produced in neighboring wells, the present invention may be operated in a gas flooding type mode. In this case, the controller 82 operates to shut off the automated flow control valve 55 ahead of the production line 54, thereby enabling the injection through the injection line 58 of high pressure natural formation gas, which, of course, can be injected at the very high temperatures resultant such high pressurization. The result, as will be understood by those of ordinary skill in the art, is that the highly pressurized, hot formation gas will force its way through the production zone perforations 88 into the formation 84 and, over time, will heat the heavy oil located therein resulting in the highly enhanced recovery thereof. In the extreme, the technique may
also be applied to fracture the formation 84. Finally, as also will be appreciated by those of ordinary skill in the art, this technique can be cycled at any desired interval with the previously described mode of operation in order to optimize recovery.

[0041] The exact mode of operation of the well completion 10 of the present invention will vary widely depending upon the peculiarities of any given formation. In all cases, however, it must be recognized that special attention should be vigilantly given to considerations of safety. To this end, the present invention is particularly adapted to stepwise application. For example, in order to "purge" a well of any oxygen content, such as may result in inadvertent flashing of superheated natural formation gases, the well completion 10 of the present invention may readily be operated to flood the formation 84 with pressurized cool gas prior to the heating thereof in subsequent operations. Likewise, by operating the well completion 10 of the present invention with close reference to the logged characteristics of the well and production thereof, the well completion 10 is particularly suited to gradually introduce heat and pressure, and, over time, to refine, injection gas quantity, injection gas temperature and injection gas pressure to maximize safe well operation while minimizing the chances of such occurrences as premature formation breakthrough and the like.

[0042] While the foregoing description is exemplary of the preferred embodiment of the present invention, those of ordinary skill in the relevant arts will recognize the many variations, alterations, modifications, substitutions and the like as are readily possible, especially in light of this description, the accompanying drawings and claims drawn thereon. For example, as particularly shown in FIGS. 2 and 3, one or more check valves 91, such as are conventionally implemented with caged ball and seat valves 92 are preferably interposed the production string 90 between the packer 107 and casing string 87 in order to facilitate extraction from the wellbeing 85 of recovered products. Likewise, as particularly shown in FIG. 3, a conventional heater rod 94 may be located in the lower section of the injection string 93 in order to supplement the adiabatic heat already applied to the natural formation gas. While such an implementation should be required in only the most extreme circumstances, it is nonetheless readily within the ordinary skill in the art utilizing, for example, a wireline 95 or the like.

[0043] Additionally, as particularly shown in FIGS. 4 and 5, Applicant has found that implementation of the well completion 10 of the present invention may be facilitated by the provision of a specialized downhole packer tool 96. As shown in the figures, such a downhole packer tool 96 generally comprises an otherwise typical packer body 97 modified to provide for the intersection at an interior location 98 thereof of an injection joint 99 and a production joint 103. To this end, the production joint 103, which extends top to bottom entirely through the packer body 97, comprises a section of upwardly oriented tubing 105 extending above the packer body 97 and a downwardly oriented stub 106 extending below the packer body 97. The injection joint 99, on the other hand, comprises an upwardly oriented tubing 102 originating above the packer body 97, but terminates in a J-shaped return 100 within the interior location 98 of the packer body 97. As shown in the figures, the distal end 101 of the return 100 then forms an upwardly oriented intersection with an injection aperture 104 from in the side wall of the production joint 103.

[0044] As particularly shown in FIG. 5, the specialized downhole packer tool 96 may be advantageously utilized in a very shallow well (as is often the case for heavy oil formations) to omit some of the otherwise required injection string 93, thereby reducing well completion costs. In particular, as shown in FIG. 5, the injection string 93 may in such a case terminate just below the casing spool 87 in a downwardly oriented stub 121, the pressurized and/or heated natural formation gas injected therethrough being contained by the well casing 86 down to an upwardly oriented stub 122 extending from above the specialized packer tool 96 to the short injection joint 99 contained substantially within the tool 96.

[0045] As shown in FIG. 6, the well completion 10 of the present invention may be implemented with a plurality of injection strings 93, 123, whereby natural formation gas may be simultaneously injected into multiple zones. For example, as shown in the figure, a first injection string 93 and a production string 90 may extend into a production zone as previously described, the only difference being that a triple string packer 109 is seated above this production zone and an additional injection string 123 is passed through the packer 109. As shown, the second injection string 123 extends beyond the production zone and through a single string packer 111 seated below the production zone, but above a flood zone defined by additional perforations 89 through the well casing 86. As is otherwise conventional, preferably high temperature rated elastomeric packer elements 110 about the triple string packer 109 and preferably high temperature rated elastomeric packer elements 112 about the single string packer 111 separate the well zones, enabling different injection pressures and/or temperatures to be applied as desired.

[0046] On the other hand, the gas flooding type mode as previously discussed may be implemented in an embodiment of the present invention comprising a single string doubling as both an injection string and a production string. In such an embodiment, a single string packer as generally shown in FIG. 7 suffices to isolate the production zone of the formation 84 from the upper regions of the wellbeing 85. As will be apparent to those of ordinary skill in the art, such an embodiment will also require that both the injection line 58 and the production line 54 be placed in fluid communication with the single, dual purpose string into the wellbeing 85, the respective automated flow control valves 59, 55 being adapted to control the mode of use of the string to toggle the same between injection and production mode as required.

[0047] Still further, as particularly shown in FIG. 7, it should be appreciated that the gathering system pipeline valve unit 113 may be located between the raw gas line 69 from the separator 61 and an inlet gas line 72 leading to the inlet of the scrubber 70. This configuration, of course, will be recognized as particularly advantageous in implementations of the present invention where a single very large gas compressor 13 is implemented for providing injection gas to a single injection well servicing multiple production wells and/or a number of otherwise described completions. In these cases, of course, it is to be expected that the gathering pipeline implemented between the related wells may not be "cleaned.

[0048] Further still, yet, as particularly shown in FIG. 8, the specialized downhole packer tool 96 as otherwise described with respect to FIGS. 4 and 5 may readily be implemented to form an aspirator 127 (also referred to as an eductor-jet pump) embedded within the interior 98 of the tool 96. As shown in FIG. 8, the aspirator 127 is formed by gradually narrowing the injection string 102 over the region.
thereof extending generally between the section of upwardly oriented tubing 102 and the intersection of the aperture 104 into the production string 106, thereby forming a constriction 125. Additionally, the production string 103 is gradually widened between the downwardly oriented stub 106 and the upwardly oriented tubing 105, thereby forming an expansion 126. In this manner, a region of relatively low pressure will through the Venturi effect be formed as the constriction 125 gives way to the expansion 126, in turn causing a suction to be formed at the inlet to the production tubing 103. In any case, because the scope of the present invention is much broader than any particular embodiment, the foregoing detailed description should not be construed as a limitation of the scope of the present invention, which is limited only by the claims appended hereto.

What is claimed is:
1. A well completion for use in enhanced recovery of heavy oil, said well completion comprising:
   means for capture from a heavy oil formation of natural gas;
   means for pressurizing said captured natural gas, said means for pressurizing said captured natural gas comprising means for controlling the temperature of said pressurized natural gas; and
   means for reintroduction to said formation of said pressurized captured natural gas.
2. The well completion for use in enhanced recovery of heavy oil as recited in claim 1, wherein said means for pressurizing comprises a gas compressor.
3. The well completion for use in enhanced recovery of heavy oil as recited in claim 2, wherein said gas compressor comprises a multistage compressor.
4. The well completion as recited in claim 3, wherein said means for controlling the temperature of said pressurized natural gas comprises an interstage cooler associated with said multistage compressor.
5. The well completion as recited in claim 4, wherein said interstage cooler comprises a radiator.
6. The well completion as recited in claim 5, wherein said means for controlling the temperature of said pressurized natural gas further comprises means for controlling airflow about said radiator.
7. The well completion as recited in claim 6, wherein said means for controlling airflow about said radiator comprises an adjustable louver.
8. The well completion as recited in claim 7, wherein said adjustable louver is remotely operable.
9. The well completion as recited in claim 8, wherein the operation of said adjustable louver is automated.
10. The well completion for use in enhanced recovery of heavy oil as recited in claim 9, wherein said well completion further comprises means for introduction of remotely produced natural gas to said means for pressurizing.
11. The well completion for use in enhanced recovery of heavy oil as recited in claim 10, wherein said means for introduction comprises an interface with a pipeline system.
12. The well completion for use in enhanced recovery of heavy oil as recited in claim 11, wherein said means for introduction comprises a remotely operable valve system.
13. The well completion for use in enhanced recovery of heavy oil as recited in claim 12, wherein the operation of said valve system is automated.
14. The well completion for use in enhanced recovery of heavy oil as recited in claim 13, wherein said valve system is adapted to selectively control the direction of gas flow between said well completion and said pipeline system.
15. A method for enhancing production of petroleum from a heavy oil formation, said method comprising the steps of:
   producing a hydrocarbon mixture from within a heavy oil formation;
   extracting a quantity of natural formation gas from said hydrocarbon mixture;
   pressurizing said quantity of natural formation gas to a specified pressure;
   maintaining said pressurized natural formation gas at a specified temperature by controlling conduction from said pressurized natural formation gas of adiabatic heat produced in said pressurizing step; and
   reintroducing said pressurized and heated natural formation gas to said heavy oil formation.
16. A downhole tool for use in oilfield production, said downhole tool comprising:
   a packer body, said packer body comprising an upper surface, a lower surface and an interior region bounded by said upper surface and said lower surface;
   a first tubular member, said first tubular member extending through said packer body to provide open communication between said upper surface and said lower surface; and
   a second tubular member, said second tubular member originating above said upper surface of said packer body and terminating within said interior region of said packer body in an intersection with said first tubular member, said first tubular member comprising an orifice at said intersection.
17. The downhole tool for use in oilfield production as recited in claim 16, said downhole tool further comprising an aspirator formed within said interior region of said packer body.
18. The downhole tool for use in oilfield production as recited in claim 17, wherein said aspirator is formed at said intersection of said second tubular member with said first tubular member.
19. The downhole tool for use in oilfield production as recited in claim 18, wherein said aspirator comprises a constriction formed in said second tubular member.
20. The downhole tool for use in oilfield production as recited in claim 19, wherein said aspirator comprises an expansion formed in said first tubular member.
21. The downhole tool for use in oilfield production as recited in claim 18, wherein said aspirator comprises an expansion formed in said first tubular member.

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