

GUIDANCE METHOD FOR MULTILATERAL DIRECTIONAL DRILLING

TECHNICAL FIELD

[0001] The present invention relates to a method for guiding, positioning and spacing multiple wells in various environments, such as high temperature, irregular formation geology, etc. and more particularly, the present invention relates to an efficient method to effectively control trajectory drift in multilateral drilling operations.

BACKGROUND OF THE INVENTION

[0002] The need for precision in drilling is clear. The operation is exceedingly expensive and complications or improper alignment, spacing and connection of wells exacerbates the capex cost to prohibitive levels. Accordingly, over several decades the prior art has evolved to promulgate sophisticated solutions. Many of the solutions have taken shape in the oil industry as applied to SAGD operations for well pairs, however beyond well pairs, the art has not addressed the usefulness of multilateral drilling precision which is of particular benefit in the geothermal industry. Exemplary of relatively contemporary developments are presented in the following paragraphs.

[0003] Clark et al., in United States Patent Publication No.US2009/0255661, published October 15, 2009, teach a method for drilling a multilateral well by drilling and casing a mother wellbore into which is installed a multilateral junction. A first lateral well from the multilateral junction is drilled and cased. Subsequently, a second lateral well is drilled from the multilateral junction using magnetic ranging while drilling such that the second lateral well has a controlled relationship relative to the first. The methodology is focussed on the oil industry and thus does not delineate any further details in respect of a multitude of lateral wells. Trajectory deviation is not specifically addressed.

[0004] In United States Patent Publication US2018/0313203, published November 1, 2018, Donderici et al., teach an effective system utilizing electromagnetic and survey

measurements from a first well in order to calibrate a formation model. This is then used to improve the interpretation of measurements from a second well. The methods are indicated to use a relative approach. Accordingly, even though the exact position of each wellbore may not be accurately identified, their relative positions can be accurately identified. This results in better positioning of the well pairs

[0005] In United States Patent Publication No. 2016/0273345, published September 22, 2016, Donderici et al., disclose a method and system for magnetic ranging and geosteering. In the disclosure, it is indicated in paragraph [0019]:

“ As described herein, the present disclosure describes illustrative ranging methods and systems that utilize a magnetic dipole beacon to guide one wellbore towards another wellbore. In a generalized embodiment, the beacon induces low frequency magnetic fields into the formation from a first wellbore, which are then sensed by one or more dipoles (acting as receiver(s)) in a second wellbore. The beacon and/or receiving dipoles are magnetic dipoles, and in certain embodiments one or both may be a triaxial magnetic dipole. Nevertheless, in either embodiment, the magnetic fields that are emitted from the beacon form a natural path of approach to the first wellbore. As a result, the second wellbore can be steered to align with the magnetic field direction, which will automatically establish the ideal approach towards the first wellbore.”

[0006] The system is clearly useful for dual well systems to maintain consistency during drilling.

[0007] In further developments, Yao et al., in United States Publication No. US 2017/0122099, published May 4, 2017, provide systems and methods for multiple downhole sensor digital alignment using spatial transforms. The arrangement incorporates numerous sensor nodes which convey data eventually used in a mathematical transform to ensure accuracy in downhole drilling.

[0008] In PCT/US2012/036538, published November 7, 2013, systems and methods for optimal spacing of horizontal wells is disclosed. The methods and systems employ a magnetic dipole beacon to guide one wellbore towards another wellbore. One embodiment includes a beacon for inducing low frequency magnetic fields into the formation from a first wellbore. These are then sensed by one or more dipoles in a second wellbore. The beacon and/or receiving dipoles are magnetic dipoles and the disclosure states that in some embodiments one or both may be a triaxial magnetic dipole. The magnetic fields emitted from the beacon form a natural path of approach to the first wellbore. Consequently, the second wellbore can be steered to align with the magnetic field direction, which establishes the preferred approach towards the first wellbore.

[0009] Rodney, in United States Patent No. 9,581,718, issued February 28, 2017, teaches a ranging while drilling system having a drillstring with a magnetic source that induces a magnetic moment in a casing string. The magnetic source includes at least one dipole with a non-orthogonal tilt relative to a longitudinal axis of the drillstring. A three-axis magnetometer that detects a field from the induced magnetic moment is provided and has a sensor that provides a signal indicative of a rotational orientation of the magnetic source. A processor determines a relative distance and direction of the casing string from measurements by the sensor and the three-axis magnetometer.

[0010] In light of the prior art, it would be desirable to facilitate guided multilateral well directional drilling where the wells can be positioned in a predetermined manner with predetermined spacing with drilling from one or plural directions absent deleterious trajectory drift.

[0011] The present invention, in the multiple embodiments, achieves these attributes amongst others with methods and arrangements having applicability in the geothermal industry as well as the oil and gas industry.

SUMMARY OF THE INVENTION

[0012] One object of one embodiment of the present invention is to provide methodology for more efficiently positioning, connecting and spacing wells in a subterranean formation.

[0013] A further object of one embodiment of the present invention is to provide a method for drilling in a predetermined configuration within a geologic formation, comprising:

drilling in the formation a well having an inlet well and an outlet well;

drilling with signalling for communication between the inlet well and the outlet well to form a continuous well having an interconnecting well segment between the inlet well and the outlet well, the interconnecting well segment having a predetermined geometric configuration relative to the inlet well and the outlet well within the formation; and

signalling for communication from at least one of the inlet well, the outlet well and the interconnecting well segment to drill a second interconnecting well segment operatively connected to the continuous well in a predetermined geometric configuration within the formation.

[0014] To enhance thermal recovery effectiveness of the methods further, the interconnecting well segment(s) may be conditioned.

[0015] The conditioning may be effected by at least one of continuously, discontinuously, during, after and in sequenced combinations of drilling introducing sealant compounds to at least seal the interconnecting wellbore segment(s) so that casing, liner or other thermal transfer reducing elements can be avoided.

[0016] In greater detail, conditioning may include introducing at least one composition not native to the formation and a unit operation and combinations thereof.

[0017] To augment the effectiveness of the method, one may dynamically modify the conditioning operations responsive to signalling data from at least one of the drilling operations of the inlet and outlet wells.

[0018] Depending on the specific situation the unit operation may include controlling the temperature of drilling fluid, pre-cooling a rock face in the formation being drilled, cooling drilling apparatus and modifying pore space of wellbores formed from drilling in the formation.

[0019] Modification of the pore space may include activating the pore space for subsequent treatment to render it impermeable to formation fluid ingress into the interconnecting segment or egress of the working fluid into the formation, sealing the pore space during drilling in a continuous operation, sealing pore space during drilling in a discontinuous operation and combinations thereof.

[0020] Operational conditioning modification may also be based on signalling data from signalling between the inlet well and the outlet well.

[0021] A further object of one embodiment of the present invention is to provide a method for drilling in a predetermined configuration within a geologic formation, comprising:

drilling in the formation a well having an inlet well and an outlet well;

drilling a partial well proximate or distal from at least one of the inlet well and the outlet well for signalling for communication with at least one of the inlet well and the outlet well; and

drilling an interconnecting well segment continuously connecting the inlet well and the outlet well with signalling for communication between at least one of the inlet well, the outlet well and the partial well.

[0022] As a convenience, the inlet well and outlet well may be co-located for a reduced footprint. If the geologic formation has an irregular and inconsistent thermal gradient it may be necessary to position an inlet well and outlet well in spaced locations.

[0023] The partial well can be proximate or distal from at least one of the inlet well and the outlet well for signalling for communication with at least one of the inlet well, the outlet well and the interconnecting well segment. This permits an even greater degree of well formation and positioning despite the possibility of an inconsistent, discontinuous or disparate thermal gradient.

[0024] Further signalling may be conducted from a formed continuous well and the second interconnecting well segment for guiding the drilling of further interconnecting well segments and continuous wells in operative connection in a predetermined configuration within the formation. In this manner, a network of wells may be formed with precision to capture a wide area of a thermally productive formation.

[0025] Having thus generally described the invention, reference will now be made to the accompanying drawings.

INDUSTRIAL APPLICABILITY

[0026] The invention has applicability in the drilling art.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Figure 1 is a flow diagram indicating the general steps of the method;

[0028] Figures 2 and 2A are schematic illustrations of multilateral well arrangements;

[0029] Figure 3 is a top plan view of Figure 2;

[0030] Figure 4 is a variation of the well arrangement according to a further embodiment;

[0031] Figure 5 is another variation of the well arrangement according to a further embodiment;

[0032] Figure 6 is a further variation of the well disposition of the multilateral arrangement;

[0033] Figure 7 is another variation of the well disposition of the multilateral arrangement;

[0034] Figure 8 is a still further variation of the well disposition of the multilateral arrangement;

[0035] Figure 9 is another embodiment of the present invention with multilateral wells having a significantly reduced surface footprint; and

[0036] Figure 10 is a schematic illustration of the closed loop system applicable to the geothermal embodiments; and

[0037] Figure 11 is a schematic illustration of a further embodiment of the present invention.

[0038] Similar numerals used in the Figures denote similar elements.

BEST MODE FOR CARRYING OUT THE INVENTION

[0039] Referring now to Figure 1, shown is a general flow diagram for the overall steps in the method.

[0040] Figure 2 is a schematic illustration of one embodiment of the present invention generally denoted by numeral 10. In the example, a U shaped well includes a pair of spaced apart generally vertical wells 12 (inlet) and 14 (outlet) and an interconnecting well segment 16, shown as a horizontal well, interconnecting the wells 12 and 14. This well may be pre-existing from an unused well, i.e. a SAGD arrangement or may be newly drilled. The technology discussed further herein is particularly useful to repurpose unused oil wells and it will become evident in the forthcoming disclosure that many aspects of the disclosed technology may be easily appended or substituted into existing oil and gas environments as easily as it is positioned in the geothermal industry.

[0041] In the example shown, a plurality of ancillary lateral horizontal wells 18, 20, 22 and 24 extend from a junctions 26 and 28, shown in the example as horizontal wells. In this manner all wells are commonly connected to a respective vertical well 12 or 14. In the scenario where the U shaped well is pre-existing, signal devices may be positioned along the vertical wells 12, 14 and the interconnecting well 16. These are schematically illustrated and represented by numeral 30. Suitable signal devices may be selected from the panacea of devices known in the art and may comprises receivers, transmitters, transceivers, *inter alia*. For purposes of suitable device examples, reference to Baker Hughes, Scientific Drilling, Halliburton etc. may be had for reference.

[0042] The devices can be modified or selected to be capable of monitoring at least one of drilling rate, spacing between wells, well to junction connection integrity, bit wear, temperature and fluid flow rate within a drilled well.

[0043] This area is mature in the art and thus detailed description is not necessary.

[0044] In situations where the U shaped well is not pre-existing, the well can be drilled in any configuration as an initial basis well with the signalling devices placed therein at a suitable time in the process with the view to either leaving them *in situ* permanently or positioned for time dependent retrieval.

[0045] Once positioned, in one embodiment, this provides a “master” for signal communication with the directional drilling of the second lateral well 20. The drilling arrangement (not shown) can include the capacity to receive guiding signals as a slave from the signal devices 30 and leave further signal devices 32 along the course of the horizontal well 20. Additional communication with the drilling arrangement and signal devices 30 and 32 is also possible.

[0046] Having established a second well 20 with signal devices 32, this can then act as a master for guidance signalling for a third lateral well 22. The drilling arrangement referenced previously functions in a similar manner for this drilling procedure. Further signal devices 34 are positioned along the course of well 22. By this arrangement, the second well benefits from the guidance of signal devices 30 and 32 either together or independently in any continuous or discontinuous sequence. As will be appreciated, this has the effect of significantly reducing trajectory drift during drilling owing to the plurality of sensor positions and locations.

[0047] In respect of the third lateral well 22, The drilling arrangement can include the capacity to receive guiding signals as a slave from the signal devices 30, 32 and 34 and leave further signal devices 36 along the course of the horizontal well 22. As with the previous examples, this well then benefits from the guidance of devices 30,32 and 34.

[0048] Finally, in the spirit of the above examples, signal devices 38 can be positioned in fourth lateral well 24 and communicate with devices 30,32,34 and 36.

[0049] It will be appreciated that the signal devices, as they are cumulative for the last multilateral well, progressively reduce the drift for each additional multilateral segment. This allows for the use of pre-existing/unused/ abandoned wells since the initial well has less importance in the multilateral scenario. The initial “master” status diminishes in importance as more lateral wells are augmented to form the multilateral arrangement.

[0050] As delineated in the prior art, much of the existing technology in this area of technology has focused on the dual well or injection and production well systems inherent in SAGD environments. However, the precision associated with the technology allows for exceptional application in the geothermal area of technology and reference in that capacity will now be set forth.

[0051] The interconnecting segment 16 is shown as horizontal, however, the geometric disposition may be any angle that is suitable to maximize thermal recovery within the formation. To this end, Figure 2A illustrates the other possibilities.

[0052] Figure 3 is a top plan view of the disposition of the wells of Figure 2.

[0053] Referring now to Figure 4, shown is a variation of the well arrangement, generally referred to as a “stacked” arrangement, positioned within a geothermal gradient, G. In this embodiment, each multilateral arrangement 40 in the stack may have its own inlet well, 12, 12', 12'', 12''' and outlet well, 14, 14' and, 14'' and 14'''. If feasible, each of the stacks 40 may be commonly connected to a single inlet well 12 and single outlet well 14. The appeal of the stacked arrangement is the possibility for higher thermal recovery in a smaller footprint.

[0054] Figure 5 illustrates a further variation referenced as a “fork” arrangement. In this arrangement, the multilateral well arrangements 40 may be arranged in spaced apart coplanar relation or spaced apart parallel plane arrangement. Such arrangements are suitable where the overall footprint of the system is not an issue. The stacks of multilateral wells 40 may also be inclined, as illustrated, at any angle to be effective in

capturing thermal energy from within the gradient ,G, where the gradient is irregular and/or dispersed.

[0055] Turning now to Figure 6, shown is an arrangement of multilateral wells 20, 22, 24, 26 and 28 dispersed in a radial spaced apart array relative to interconnecting well 16 referenced *supra*. The arrangement in the example is coaxial, however other variations will be appreciated by those skilled in the art.

[0056] Parts have been removed for clarity, but it will be understood that wells 20,22,24, 26 and 28 all have common connection with vertical wells 12 and 14 and junctions 26 and 28, the wells and junctions not being shown. This radial dispersion is of particular value in geothermal environments, since a greater amount of heat can be extracted within a given heat producing volume. In light of the directional drilling advancements set forth in the disclosure, such arrangements are possible and customizable depending upon the surrounding environment.

[0057] Figure 7 illustrates a further variation. In this embodiment, a pair of the arrangements shown in Figure 6 are interdigitated with similar wells 18', 20', 22', 24' and 26'. The precision attributed to the drilling method established herein facilitates the inter digitation. This arrangement enhances the thermal recovery within, for example a geothermal zone, without an impact on footprint. This clearly has capital expenditure benefits, but also allows for even greater energy servicing capability within a given area.

[0058] Figure 8 schematically illustrates another variation where a pair of the arrangements from Figure 7 are spaced, but in thermal contact.

[0059] For mitigation of temperature deviation from the heel of a well to its toe, the arrangements depicted in Figures 7 and 8 are useful. As an example, the direction of flow of a fluid within wells 18, 20, 22, 24 and 26, in reference to Figure 7, may be opposite to the flow within wells 18', 20', 22', 24' and 26'. In this manner, the heel of one well will be in thermal contact with the toe of another well, i.e. counter current.

[0060] Referring now to Figure 9, shown is another embodiment of the present invention. In this embodiment, separate multilateral wells 40 may be geographically spread apart within a formation G. This embodiment connects multilateral wells, such as 42 and 44 to loop back together at terminus 46 for connection with outlet well 14. A second set of multilateral wells 42' and 44' may be coplanar or in a parallel plane with multilateral wells 42 and 44 and similarly loop back at terminus 46'. The advantage in this arrangement is that the inlet/outlet footprint 48 is relatively small, however the thermal energy recovery capacity is very significant. This allows for one site at the footprint 48 to be multiply productive without the requirement for large plots of land.

[0061] In all examples, the inlet 12 and outlet 14 will include the known ancillary components, i.e. power generating devices, energy storage devices, linking arrangements to the power grid, cogeneration systems *inter alia*. This has been omitted from Figures 1 through 9 for clarity. Further, it will be understood that the geothermal systems will be closed loop, meaning that the inlet, junctions, multilateral wells intervening power generating devices, etc., and outlet well will form a continuous circuit with the minimum of connecting conduit disposed in a superterranean position. General reference to this can be made with respect to Figure 10.

[0062] The ancillary or intervening devices are referenced with numeral 50 which are positioned above ground level 52. The closed loop below ground level 52 is exaggerated in the example. Numeral 54 represents a superterranean transceiver device capable of communication with any one of or all the devices 30,32,34, 26 and 38.

[0063] As an alternative, as opposed to the master and slave communication arrangement described, signalling communication may be effected simultaneously with all devices selectively, continuously or in a predetermined sequence. This will depend on the specifics of the individual situation.

[0064] Figure 11 illustrates a variation in the embodiments where a partially drilled well or borehole 56 may be positioned proximate other multilateral arrangements and include a signalling/transceiver device 56. The latter may communicate with other such devices 30, 38, 54 to guide the formation of the well arrangements as noted herein previously. Bore hole 56 may be further drilled to be integrated with the other wells as denoted by dashed line 60. Any number of bore holes 56 may be included to form further networked well arrangements within a formation.

CLAIMS:

1. A method for drilling in a predetermined configuration within a geologic formation, comprising:

drilling in said formation a well having an inlet well and an outlet well;

drilling with signalling for communication between said inlet well and said outlet well to form a continuous well having an interconnecting well segment between said inlet well and said outlet well, said interconnecting well segment having a predetermined geometric configuration relative to said inlet well and said outlet well within said formation; and

signalling for communication from at least one of said inlet well, said outlet well and said interconnecting well segment to drill a second interconnecting well segment operatively connected to said continuous well in a predetermined geometric configuration within said formation.

2. The method as set forth in claim 1, wherein said inlet well and said outlet well are co-located.

3. The method as set forth in claim 1 or 2, wherein said geologic formation has an irregular and inconsistent thermal gradient.

4. The method as set forth in any one of claims 1 through 3, further including the step of drilling a partial well proximate or distal from at least one of said inlet well and said outlet well for signalling for communication with at least one of said inlet well, said outlet well and said interconnecting well segment.

5. The method as set forth in any one of claims 1 through 4, further including the step of establishing further signalling for communication from said continuous well and said second interconnecting well segment for guiding the drilling of further interconnecting well segments and continuous wells in operative connection in a predetermined configuration within said formation.
6. The method as set forth in any one of claims 1 through 5, wherein signalling for communication comprises transceiving between said wells.
7. The method as set forth in any one of claims 1 through 6, wherein signalling for communication is conducted simultaneously between wells.
8. The method as set forth in any one of claims 1 through 7, wherein signalling for communication is conducted in a predetermined sequence between wells.
9. The method as set forth in any one of claims 1 through 8, wherein said drilling is conducted independently from discrete locations for said inlet well and said outlet well for intersection to form said continuous well with said interconnecting well segment.
10. The method as set forth in claim 2, further including providing superterranean signalling devices, subterranean signalling devices and combinations thereof proximate said discrete locations for guiding drilling.
11. The method as set forth in any one of claims 1 through 10, wherein said formation is a thermally productive formation.
12. The method as set forth in any one of claims 1 through 11, wherein said formation is a geothermal formation.
13. The method as set forth in any one of claims 1 through 12, further including conditioning at least said interconnecting well segment to facilitate thermal recovery by

working fluid flow through said continuous well without casing or liner material in said interconnecting well segment.

14. The method as set forth in claim 13, wherein conditioning is effected by at least one of continuously, discontinuously, during, after and in sequenced combinations of drilling of at least one of said inlet well, said outlet well and said and said interconnecting segment.

15. The method as set forth in claim 13, further including the step of dynamically modifying said conditioning responsive to signalling data from at least one of the drilling operations of said inlet well, said outlet well and said interconnecting well segment.

16. A method for drilling in a predetermined configuration within a geologic formation, comprising:

drilling in said formation a well having an inlet well and an outlet well;

drilling a partial well proximate or distal from at least one of said inlet well and said outlet well for signalling for communication with at least one of said inlet well and said outlet well; and

drilling an interconnecting well segment continuously connecting said inlet well and said outlet well with signalling for communication between at least one of said inlet well, said outlet well and said partial well.

17. The method as set forth in claim 16, further including the step of forming a second well having an inlet well and an outlet well from said partial well.

18. The method as set forth in claim 16 or 17, wherein said partial well comprises a plurality of individual spaced apart wells.

19. The method as set forth in claim 18, further including signalling between said plurality of individual spaced apart wells to form connected continuous wells.

20. The method as set forth in any one of claims 16 through claim 19, wherein signalling comprises transceiving between wells.