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(54) GEOTHERMAL WELL AND TUBING APPARATUS THEREFOR

(57) The invention relates to a tubing apparatus (101, 201) for use in a geothermal well (100). The tubing apparatus (101, 201) includes a vacuum insulated tubing string (102, 202) describing a conduit (122, 222) and a cooling string (107, 207) received within the conduit (122, 222). The conduit (122, 222) is configured to convey a working fluid between a surface location (A) and a subsurface location (B). The cooling string (107, 207) is configured to inject a cooling fluid into the conduit (122, 222) so as to adjust the temperature of the working fluid.

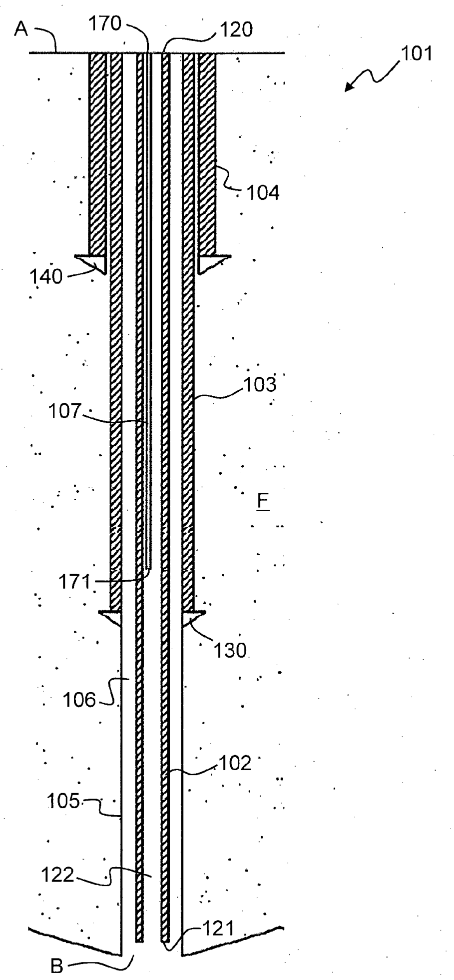

FIGURE 3

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Description

Background of the Invention

[0001] This invention relates generally to geothermal wells and to tubing apparatus for such geothermal wells. More specifically, although not exclusively, this invention relates to such geothermal wells, tubing apparatus for use in a geothermal well and a method of start-up of a geothermal well.

[0002] Geothermal wells and their associated production systems are well known in the art. The basic operation of a geothermal well involves a deep borehole in communication with a hot sedimentary aquifer. The hot fluid from the aquifer, otherwise known as the 'working fluid', is conveyed to the surface through a production well so that the heat can be extracted. The working fluid is then pumped back into the aquifer to recharge the reservoir, generally but not always through a closed-loop system.

[0003] In some cases, the production well comprises an insulated tubing string received within a cased wellbore. During normal operation fluid is pumped down the insulated tubing string, heated and returned up an annular space between the tubing string and cased wellbore toward the surface. The insulated tubing string is provided to reduce heat loss as the working fluid is conveyed up the annular space.

[0004] In the early stages of well operation, the bottom hole temperature is very high, and may exceed 400 degrees Celsius. Following the start-up phase, the bottom hole temperature decreases over time to a steady state temperature, for example 150 degrees Celsius. This is illustrated in Figure 1.

[0005] As such, there is a large temperature difference between the working fluid pumped down the insulated tubing string and the working fluid conveyed up the annular space during start-up.

[0006] Further, due to the insulative properties of the insulated tubing string, the working fluid experiences very little temperature drop as it travels up. Therefore, a large temperature differential can result between the inner diameter and outer diameter of the insulated tubing string which can cause mechanical stress and in some cases failure of the insulated tubing string.

[0007] It is possible to increase the resistance to mechanical stress and failure through design, but this results in a larger, heavier and more expensive insulated tubing string. It has also been possible to reduce the temperature variation by slowing the start-up phase of the geothermal well.

Summary of the Invention

[0008] It is therefore a first non-exclusive object of the invention to provide a tubing apparatus that overcomes, or at least mitigates, the known issues of the prior art. In particular, it is a non-exclusive object of the invention to provide a tubing apparatus that mitigates the aforementioned issues during start-up of a geothermal well.

[0009] Accordingly, an aspect of the invention provides a tubing apparatus for use in a geothermal well, the apparatus comprising an insulated tubing string describing a conduit configured to convey a working fluid between a surface location and a subsurface location, and a cooling string configured to adjust, in use, the temperature of the working fluid within or around the conduit and/or as it is conveyed toward the surface location.

[0010] The provision of a cooling string that adjusts the temperature of the working fluid enables the temperature differential between the fluid conveyed toward the surface location within or around the conduit, typically within the insulated tubing string or within an annular space surrounding the insulated tubing string, and the fluid respectively around or within the conduit to be reduced during start-up.

[0011] The tubing apparatus may further comprise a casing string. The insulated tubing string may be located within the casing string, e.g. such that an annular space is described therebetween.

[0012] Another aspect of the invention provides a geothermal well comprising a wellbore within which is received an insulated tubing string describing a conduit configured to convey a working fluid between a surface location and a subsurface location, and a cooling string configured to adjust, in use, the temperature of the working fluid as it is conveyed toward the surface location.

[0013] The tubing apparatus or the geothermal well may be operable or configured to convey, in use, the working fluid from the subsurface location to the surface location, e.g. through the insulated tubing string. The tubing apparatus may be operable or configured to convey, in use, the working fluid from the surface location to the subsurface location, e.g. through an annular space between the insulated tubing string and the casing string or the wellbore.

[0014] Another aspect of the invention provides a tubing apparatus for use in a geothermal well, the apparatus comprising an insulated tubing string located within a casing string, wherein the apparatus is operable or configured to convey, in use, a working fluid from a subsurface location to a surface location through the insulated tubing string and to convey the working fluid from the surface location to the subsurface location through an annular space between the insulated tubing string and casing string.

[0015] Another aspect of the invention provides a geothermal well comprising an insulated tubing string located within a wellbore, wherein the geothermal well is operable or configured to convey, in use, a working fluid from a subsurface location to a surface location through the insulated tubing string and to convey the working fluid from the surface location to the subsurface location through an annular space between the insulated tubing string and the wellbore.

[0016] The inventor has also observed that, with a conventional flow, the temperature of the working fluid is reduced as it is conveyed up the annular space, via conduction through the wellbore casing. By reversing the direction of flow, the working fluid is heated as it is pumped down the wellbore, by virtue of its exposure to the surrounding formation, whilst heat is retained in the fluid as it is conveyed back up the insulated tubing string.

[0017] The cooling string may be received within the insulated tubing string. The cooling string may be removably received within the insulated tubing string, e.g. to enable it to be removed after start-up. This configuration is useful when the working fluid is conveyed up the insulated tubing string, since the temperature differential can be more acute with such a reverse flow configuration.

[0018] Alternatively, the cooling string may be external of the insulated tubing string and/or between the insulated tubing string and the casing string. The cooling string may be removably received between the insulated tubing string and the casing string, e.g. to enable it to be removed after start-up. This configuration is useful when the working fluid is conveyed up the annular space.

[0019] The insulated tubing string may comprise a pipe-in-pipe insulated tubing string. The pipe-in-pipe insulated tubing string may comprise a vacuum or an inert gas between the pipes making up the pipe-in-pipe insulated tubing string. The insulated tubing string or pipe-in-pipe insulated tubing string may comprise a vacuum insulated tubing string. The insulated tubing string or pipe-in-pipe insulated tubing string may comprise an inert gas, e.g. argon, insulated tubing string.

[0020] The insulated tubing string may be arranged substantially concentrically with the casing string and/or with the wellbore. The insulated tubing string may be longer than the casing string and/or may extend, in use, beyond the casing string, e.g. into the or a wellbore and/or to a bottom hole location.

[0021] The cooling string may be configured to inject or convey, in use, a fluid, e.g. a cooling fluid, into the conduit, e.g. so as to adjust the temperature of the working fluid. The cooling fluid may be configured to reduce the temperature of the working fluid. A bottom end of the cooling string is preferably open or free. The cooling fluid may comprise a cooled portion of the working fluid. The tubing apparatus may comprise a bypass circuit or cooling circuit or bypass cooling circuit, which may be configured to cool a portion of the working fluid. The cooling string may be supplied by the bypass circuit or cooling circuit or bypass cooling circuit.

[0022] By injecting the cooling fluid directly into the working fluid, its temperature can be controlled more simply.

[0023] Alternatively, a bottom end of the cooling string may be closed, in which case the cooling string may comprise one or more holes or perforations on a sidewall thereof or it may comprise a cooling circuit formed by a pair of concentric tubes.

[0024] The cooling string may have a smaller flow area than the insulated tubing string and/or than the annular space. The cooling string may have a smaller diameter than the.insulated tubing string and/or than the radial width of the annular space. This minimises the impact of the cooling string on the flow of working fluid, and reflects the intention for a lower flow rate of the cooling fluid as compared with the working fluid.

[0025] The insulated tubing string may have a substantially circular cross-sectional shape. The cooling string may have a substantially circular cross-sectional shape. Alternatively, the insulated tubing string and/or the cooling string may have a non-round shape, for example a substantially elliptical cross-sectional shape. The cross-sectional shape of the insulated tubing string may be the same, similar or different to that of the cooling string. The shape may be optimised to minimise the impact on the flow of working fluid.

[0026] The cooling string may be located or positioned adjacent an inner wall of the insulated tubing string. Alternatively, the cooling string may be located concentrically with the insulated cooling string. This position also reduces the impact on the flow of working fluid.

[0027] The cooling string may be held in place, e.g. relative to the insulated tubing string, by one or more brackets or supports. The apparatus may comprise one or more brackets or supports configured to mount or support the cooling string relative to the insulated tubing string. The cooling string may be mounted or held in place by a plurality of brackets or supports spaced along the cooling string and/or spaced along the insulated tubing string.

[0028] The brackets or supports may be connected, attached or fixed to the insulated tubing string. Alternatively, the brackets or supports may be connected, attached or fixed to the cooling string.

[0029] The cooling string may be shorter than the insulated tubing string. A bottom end or free end of the cooling string may be arranged to be located short of the bottom end or free end of the insulated tubing string. As a result, the cooling fluid is introduced into upstream of the region with the highest temperature difference.

[0030] The cooling string may be removable from the insulated tubing string. The cooling string may be provided on a coiled tubing arrangement. The cooling string can therefore be removed after the start-up phase. Alternatively, the cooling string may be permanently installed within the insulated tubing string.

[0031] The bottom end of the insulated tubing string may be open and/or arranged to be located in an open-hole portion of a wellbore. An open-hole portion may be an un-cased portion of a wellbore.

[0032] The tubing apparatus may comprise a controller. The controller may be configured to control the flow rate and/or pressure of the working fluid. The controller may be configured to control the flow rate and/or pressure of cooling fluid. This enables the temperature of the working fluid to be adjusted both incrementally and dynamically.

[0033] Another aspect of the invention provides a controller. The controller may be configured to control the flow rate and/or pressure of the working fluid. The controller may be configured to control the flow rate and/or pressure of cooling fluid.

[0034] Another aspect of the invention provides a well head control assembly. The well head control assembly may comprise a controller, which may be configured to control the flow rate and/or pressure of a working fluid and/or the flow rate and/or pressure of cooling fluid through a tubing apparatus of a geothermal well. The tubing apparatus may comprise a tubing apparatus as described above.

[0035] The tubing apparatus or control assembly may comprise one or more flow sensors. One or more flow sensors may be configured to measure, in use, the flow rate through the annular space, insulated tubing string and/or cooling string. The one or more flow sensors may include a first flow sensor configured to measure, in use, the flow rate through the annular space. The one or more flow sensors may include a second flow sensor configured to measure, in use, the flow rate through the cooling string. The one or more flow sensors may include a third flow sensor configured to measure, in use, the flow rate through the insulated tubing string. This enables closed loop feedback of the relative flow rates of the working fluid and cooling fluid.

[0036] The tubing apparatus or control assembly may comprise one or more pressure sensors. One or more pressure sensors may be configured to measure, in use, the pressure in the annular space, insulated tubing string and/or cooling string. The one or more pressure sensors may include a first pressure sensor configured to measure, in use, the pressure in the annular space. The one or more pressure sensors may include a second pressure sensor configured to measure, in use, the pressure in the cooling string. The one or more pressure sensors may include a third pressure sensor configured to measure, in use, the pressure in the insulated tubing string. This enables closed loop feedback of the relative pressures of the working fluid and cooling fluid.

[0037] The tubing apparatus or control assembly may comprise one or more flow control valves. One or more flow control valves may be configured to control the flow of fluid through the annular space and/or insulated tubing string. One or more flow control valves may be configured to control the flow of fluid through the cooling string. The one or more flow control valves may comprise one or more first flow control valves for controlling the flow of fluid through the annular space and/or insulated tubing string. The one or more flow control valves may comprise a second flow control valve for controlling the flow of fluid through the cooling string. This enables the relative flow rates of the working fluid and cooling fluid to be adjusted incrementally and dynamically.

[0038] The tubing apparatus or control assembly may comprise one or more temperature sensors. One or more temperature sensors may be located at or proximate a surface location in the insulated tubing string. One or more temperature sensors may be configured to measure the temperature of the working fluid within the insulated tubing string. One or more temperature sensors may be located at or proximate the bottom end or free end of the cooling string. This enables a closed loop adjustment of the relative flow rates of the working fluid and cooling fluid to achieve the requisite temperature(s) in the working fluid.

[0039] Another aspect of the invention provides geothermal well. The geothermal well may comprise a tubing apparatus as described above. The geothermal well may comprise a controller as described above. The geothermal well may comprise a control assembly as described above.

[0040] In some examples, the geothermal well is a closed-loop geothermal well.

[0041] Another aspect of the invention provides a method of operating or starting up a geothermal well, the method comprising: circulating a working fluid between a surface location and a subsurface location via an insulated tubing string; and adjusting the temperature of the working fluid as it is circulated toward the surface using a cooling string.

[0042] The method may comprise conveying a working fluid from a surface location to a subsurface location, e.g. through an insulated tubing string. The method may comprise conveying the working fluid from the subsurface location to the surface location, e.g. through an annular space between the insulated tubing string and a casing string or wellbore.

[0043] The method may comprise conveying a working fluid from a subsurface location to a surface location, e.g. through an insulated tubing string. The method may comprise conveying the working fluid from the surface location to the subsurface location, e.g. through an annular space between the insulated tubing string and a casing string or wellbore.

[0044] Another aspect of the invention provides a method of operating a geothermal well comprising: conveying a working fluid from a subsurface location to a surface location through an insulated tubing string; and conveying the working fluid from the surface location to the subsurface location through an annular space between the insulated tubing string and a casing string or wellbore.

[0045] The method may comprise injecting a cooling fluid through the cooling string and/or into the working fluid, e.g. so as to adjust the temperature of the working fluid as it is circulated toward the surface. The cooling fluid may be injected so as to reduce the temperature of the working fluid.

[0046] The flow rate of working fluid circulated between the surface location and the bottom hole and/or the flow rate of cooling fluid injected into the working fluid may be controlled, e.g. in order to manage the temperature of the working fluid received back at the surface.

[0047] Injecting the cooling fluid through the cooling string may comprise injecting working fluid. The method may comprise cooling a portion of the working fluid, e.g. before injecting it through the cooling string. The method may comprise bypassing a portion of the working fluid, e.g. through a bypass circuit or cooling circuit or bypass cooling circuit, before injecting it through the cooling string. The working fluid may comprise water or another fluid, e.g. a supercritical fluid.

[0048] The method may comprise removing the cooling string once the temperature of the working fluid received at the surface is below a predetermined threshold.

[0049] For the avoidance of doubt, any of the features described herein apply equally to any aspect of the invention. For example, the tubing apparatus may comprise any one or more features of the method relevant to the tubing apparatus and/or the method may comprise any one or more features or steps relevant to one or more features of the tubing apparatus or the cooling string.

[0050] A further aspect of the invention provides a computer program element comprising computer readable program code means for causing a processor to execute a procedure to implement one or more steps of the aforementioned method.

[0051] A yet further aspect of the invention provides the computer program element embodied on a computer readable medium.

[0052] A yet further aspect of the invention provides a computer readable medium having a program stored thereon, where the program is arranged to make a computer execute a procedure to implement one or more steps of the aforementioned method.

[0053] A yet further aspect of the invention provides a control means or control system or controller comprising the aforementioned computer program element or computer readable medium.

[0054] For purposes of this disclosure, and notwithstanding the above, it is to be understood that any controller(s), control units and/or control modules described herein may each comprise a control unit or computational device having one or more electronic processors. The controller may comprise a single control unit or electronic controller or alternatively different functions of the control of the system or apparatus may be embodied in, or hosted in, different control units or controllers or control modules. As used herein, the terms "control unit" and "controller" will be understood to include both a single control unit or controller and a plurality of control units or controllers collectively operating to provide the required control functionality. A set of instructions could be provided which, when executed, cause said controller(s) or control unit(s) or control module(s) to implement the control techniques described herein (including the method(s) described herein).

[0055] The set of instructions may be embedded in one or more electronic processors, or alternatively, may be provided as software to be executed by one or more electronic processor(s). For example, a first controller may be implemented in software run on one or more electronic processors, and one or more other controllers may also be implemented in software run on or more electronic processors, optionally the same one or more processors as the first controller. It will be appreciated, however, that other arrangements are also useful, and therefore, the present invention is not intended to be limited to any particular arrangement. In any event, the set of instructions described herein may be embedded in a computer-readable storage medium (e.g., a non-transitory storage medium) that may comprise any mechanism for storing information in a form readable by a machine or electronic processors/computational device, including, without limitation: a magnetic storage medium (e.g., floppy diskette); optical storage medium (e.g., CD-ROM); magneto optical storage medium; read only memory (ROM); random access memory (RAM); erasable programmable memory (e.g., EPROM ad EEPROM); flash memory; or electrical or other types of medium for storing such information/instructions.

[0056] Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible.

[0057] For the avoidance of doubt, the terms "may", "and/or", "e.g.", "for example" and any similar term as used herein should be interpreted as non-limiting such that any feature so-described need not be present. Indeed, any combination of optional features is expressly envisaged without departing from the scope of the invention, whether or not these are expressly claimed. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

Brief Description of the Drawings

[0058] Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 shows a graph illustrating an example of a downhole temperature drop during a typical start-up phase;

Figure 2 is a schematic drawing of a tubing apparatus of a geothermal well according to the prior art;

Figure 3 is a schematic drawing of a tubing apparatus of a geothermal well according to an embodiment of the invention;

Figure 4 is a schematic drawing of a geothermal well incorporating the tubing apparatus of Figure 3;

Figure 5 shows a graph illustrating the temperature of a working fluid as it flows along the tubing apparatus of figures 2 during a start-up phase, i.e without the use of the cooling string;

Figure 6 shows a graph illustrating the temperature of a working fluid as it flows along the tubing apparatus of figures 2, when the well is at steady-state; and

Figure 7 is a schematic drawing of a tubing apparatus of a geothermal well according to another embodiment of the invention.

[0059] Referring now to Figure 2, there is shown a tubing apparatus 1 for a geothermal well according to the prior art. The tubing apparatus 1 includes a vacuum insulated tubing string 2 received within an intermediate casing string 3, which is, in turn, received within a surface casing string 4. Together, the vacuum insulated tubing string 2 and casing strings 3, 4 describe a wellbore.

[0060] Each of the vacuum insulated tubing string 2, intermediate casing string 3 and surface casing string 4 extend from a surface location A into a formation F, which is in the form of a hot sedimentary aquifer in this example. The intermediate casing string 3 includes a casing shoe 30 at its lower end. Similarly, the casing string 4 also includes a casing shoe 40 at its lower end.

[0061] The vacuum insulated tubing string 2 has a first open end 20 connected to a source of working fluid located at the surface location A and a second open end 21 located within an open-hole (un-cased) portion of the wellbore 5. The second, open end 21 of the vacuum insulated tubing string 2 is located deeper than the respective casing shoes 30, 40 of the intermediate casing string 3 and surface casing string 4. The vacuum insulated tubing string 2 describes an insulated conduit 22 extending between the surface location A and the formation F.

[0062] An annular space 6 is described between the vacuum insulated tubing string 2 and the intermediate casing string 3, or open-hole portion, of the wellbore 5. The annular space 6 extends between the surface location A and a bottom-hole location B.

[0063] In use, during normal operation of the geothermal well, a working fluid is pumped down the conduit 22 from the surface location A. The fluid exits the vacuum insulated tubing string 2 at the second, open end 21 where it is exposed to the formation F..

[0064] The working fluid then passes along the annular space 6 back toward the surface location A. As the working fluid passes along the annular space 6 it is heated due to the heat of the surrounding formation F. The heat is then extracted from the working fluid when it reaches the surface location A.

[0065] In accordance with one aspect of the invention, the circulation may be reversed. This involves pumping fluid down the annular space 6 between the vacuum insulated tubing string 2 and the intermediate casing string 3. The working fluid is then conveyed up through the conduit 22 from the bottom-hole location B to the surface location A.

[0066] As explained above, reversing the direction of flow improves the efficiency of the geothermal well. More specifically, the working fluid is heated as it is pumped down the wellbore by virtue of its exposure to the surrounding formation, whilst heat is retained in the fluid as it is conveyed back up the insulated tubing string.

[0067] However, to avoid the large temperature difference between the fluid pumped down the annular space 6 and the working fluid conveyed up the vacuum insulated tubing string 2, the start-up phase would need to be carried out over a long period of time.

[0068] Referring now to Figure 3, a tubing apparatus 101 for a geothermal well is shown which incorporates another aspect of the invention. The tubing apparatus 101 is similar to tubing apparatus 1 and like features are denoted by like references incremented by '100', which will not be described further herein.

[0069] The tubing apparatus 101 according to the invention differs from the tubing apparatus 1 of Figure 2 in that there is provided a cooling string 107, such cooling string being arranged within the vacuum insulated tubing string 102 in the embodiment shown in Figure 3. The cooling string 107 is located adjacent a sidewall of the vacuum insulated tubing string 102, thereby to minimise its impact on the flow of working fluid through the vacuum insulated tubing string 102.

[0070] The cooling string 107 has a first open end 170 connected to a source of cooling fluid located at the surface location A and a second, open end 171 located within the conduit 122 and short of the second, open end 121 of the vacuum insulated tubing string 102. The cooling string 107 is configured to inject a cooling fluid, e.g. water or working fluid passed through a bypass cooling circuit, into the conduit 122 in order to adjust the temperature of the working fluid within the conduit 122.

[0071] Referring now to Figure 4, there is shown a geothermal well 100 incorporating the tubing apparatus 101. The geothermal well 100 also includes a well head control assembly 110, which includes a controller 111, a first flow sensor 112 configured to measure the flow rate through the annular space 106, a second flow sensor 113 configured to measure the flow rate through the cooling string 107 and a third flow sensor 114 configured to measure the flow rate through the vacuum insulated tubing string 102.

[0072] The head control assembly 110 also includes a temperature sensor 115 and flow control valves (not shown) The temperature sensor 115 is at a surface location in the vacuum insulated tubing string 102 and proximate the open end 171 of the cooling string 107, which is configured to measure the temperature of the working fluid. The flow control valves (not shown) are configured to control the flow of fluid through the annular space 106, through the vacuum insulated tubing string 102 and trough the cooling string 107.

[0073] Each of the flow sensors 112, 113, 114, the temperature sensor 115 and the flow control valves (not shown) is operatively connected to the controller 111. This may be via a wired or wireless connection.

[0074] In use, during normal operation the geothermal well 100 works in essentially the same manner as described above in relation to a geothermal well with the tubing apparatus 1 of Figure 2. However, the cooling string 107 has a particular purpose in the context of the operation of the geothermal well 100, particularly during the start-up phase.

[0075] More specifically, during a start-up phase of the geothermal well 100 and with the aforementioned reverse circulation of the working fluid, a working fluid is circulated down the annular space 106 and back up the conduit 122 to the surface location A. During reverse circulation, the working fluid enters the vacuum insulated tubing string 102 at the second, open end 121.

[0076] Figure 5 illustrates the temperature of the working fluid within the tubing apparatus 1 during a start-up phase. The temperature of the formation F along the depth of the wellbore is illustrated by a first line Fa. The temperature of the working fluid flowing down the annular space 6 is illustrated by a second line 6a. The temperature of the working fluid flowing up the vacuum insulated tubing string 2 is illustrated by a third line 2a. It is clear from this graph that, at the surface, there is a temperature difference of over 240°C between the fluid temperature in the vacuum insulated tubing string 2, compared with the fluid temperature within the annular space 6 surrounding the vacuum insulated tubing string 2.

[0077] The fluid entering the vacuum insulated tubing string 2 at the second open end 21 is at, or close to, the bottom hole temperature. Due to the insulative properties of the vacuum insulated tubing string 2, there is very little temperature reduction in the working fluid as it makes its way toward the surface location A.

[0078] Figure 6 illustrates the temperature of the working fluid within the tubing apparatus 1 during steady-state. Similar to the graph of Figure 5, a first line Fb represents the temperature of the formation F along the depth of the wellbore, a second line 6b represents the temperature of the working fluid flowing down the annular space 6 and a third line 2b represents the temperature of the working fluid flowing up the vacuum insulated tubing string 2. In this, steady-state the temperature difference at the surface is approximately 40°C.

[0079] The vacuum insulated tubing string 2 therefore must be designed to withstand a very high temperature difference only during the start-up phase, or that start-up phase must be carried out very slowly. The skilled person will appreciate that both of these have substantial cost implications.

[0080] To overcome this issue, a cooling fluid is injected through the cooling string 107 and into the working fluid as it passes along the conduit 122, thereby reducing its temperature. The resulting working fluid has a lower temperature as it reaches the surface location A. This provides a temperature differential between the working fluid within the vacuum insulated tubing string 102 and the working fluid surrounding it, within the annular space 106. Ideally, the cooling fluid is injected to maintain, during the start-up phase, a predetermined temperature difference between the working fluid within the vacuum insulated tubing string 102 and in the annular space 106 surrounding it.

[0081] Thus, the invention reduces the mechanical stress exerted on the vacuum insulated tubing string 102. This is achieved by virtue of the introduction of cooling fluid from the cooling string 107 in the region where the working fluid would otherwise be at or near its highest temperature. The invention thereby avoids the need for larger, heavier and more expensive vacuum insulated tubing string, and without the need to slow the start-up phase.

[0082] The cooling fluid is for instance some working fluid available near the surface location A, such a working fluid available near the surface location A having a low temperature compared to the working fluid traveling up to the surface location A which have been heated while passing through the bottom of the geothermal well.

[0083] Referring now to Figure 7, there is shown a tubing apparatus 201 according to another example, which is similar to tubing apparatus 101 of Figure 3, wherein like features are denoted by like references incremented by ’100’, which will not be described further herein.

[0084] The tubing apparatus 201 according to this example differs from the tubing apparatus 101 of Figure 3 in that the cooling string 207 is within the annular space 206 between the vacuum insulated tubing string 202 and the intermediate casing string 203, or open-hole portion, of the wellbore 205. The cooling string 207 is located adjacent the casing string 203, thereby to minimise its impact on the flow of working fluid through the annular space 206.

[0085] This tubing apparatus 201 is configured to pump the working fluid down the conduit 222 from the surface location A, which is then exposed to the formation F, and is conveyed back up the annular space 206 toward the surface location A. In this example, the cooling fluid is injected into the working fluid via the cooling string 207 and as it passes along the annular space 206, thereby reducing its temperature.

[0086] As with the tubing apparatus 101 of Figure 3, the working fluid has a lower temperature as it reaches the surface location A, by virtue of the cooling fluid introduced by the cooling string 207. This reduces the temperature differential between the working fluid within the vacuum insulated tubing string 202 and the working fluid surrounding it, within the annular space 206.

[0087] It will be appreciated by those skilled in the art that several variations to the aforementioned embodiments are envisaged without departing from the scope of the invention. It will also be appreciated by those skilled in the art that any number of combinations of the aforementioned features and/or those shown in the appended drawings provide clear advantages over the prior art and are therefore within the scope of the invention described herein.

Claims

1. A geothermal well comprising a wellbore within which is received an insulated tubing string describing a conduit configured to convey a working fluid between a surface location and a subsurface location, and a cooling string configured to adjust, in use, the temperature of the working fluid as it is conveyed toward the surface location.

2. A geothermal well according to claim 1, wherein the cooling string is received within the conduit and the geothermal well is configured to convey, in use, the working fluid from the surface location to the subsurface location through an annular space between the wellbore and the insulated tubing string, and from the subsurface location to the surface location through the insulated tubing string.

3. A geothermal well according to claim 2, wherein the cooling string is configured to inject, in use, a cooling fluid into the conduit so as to adjust the temperature of the working fluid.

4. A geothermal well according to claim 3, wherein the cooling string has a smaller flow area than the insulated tubing string.

5. A geothermal well according to claim 3 or claim 4, wherein the cooling string has a smaller diameter than the insulated tubing string.

6. A geothermal well according to any one of claims 3 to 5, wherein the cooling string is located adjacent a wall of the insulated tubing string.

7. A geothermal well according to any one of claims 3 to 6, wherein a bottom end of the cooling string is located short of the bottom end of the insulated tubing string.

8. A geothermal well according to any one of claims 3 to 7, wherein the cooling string is removable from the insulated tubing string.

9. A geothermal well according to any preceding claim, wherein the well is a closed-loop geothermal well.

10. A tubing apparatus for use in a geothermal well according to any preceding claim, the apparatus comprising an insulated tubing string describing a conduit configured to convey a working fluid between a surface location and a subsurface location, and a cooling string configured to adjust, in use, the temperature of the working fluid as it is conveyed toward the surface location.

11. A tubing apparatus according to claim 10 further comprising a casing string, wherein the insulated tubing string is located within the casing string such that an annular space is described therebetween, the cooling string being received within the conduit or within the annular space.

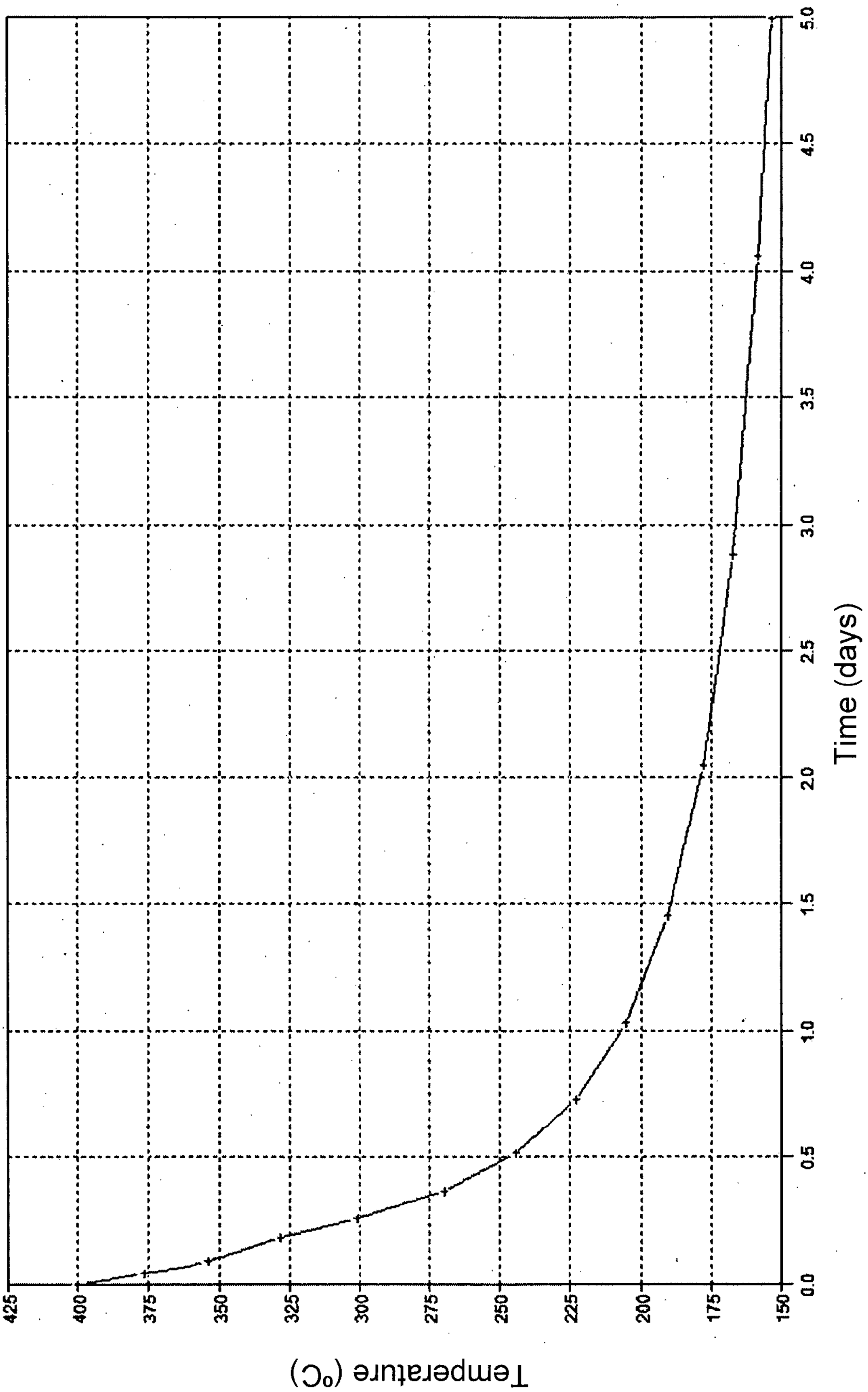
12. A tubing apparatus according to claim 11, wherein the cooling string is received within the conduit and the tubing apparatus is configured to convey, in use, the working fluid from the surface location to the subsurface location through the annular space and from the subsurface location to the surface location through the insulated tubing string.

13. A tubing apparatus according to any one of claims 9 to 12, further comprising a controller configured to control the flow rate of working fluid and/or cooling fluid.

14. A well head control assembly for use with a tubing apparatus according to any one of claims 9 to 12, the assembly comprising a controller and one or more flow valves, wherein the controller is configured to control the flow rate and/or pressure of a working fluid and the flow rate and/or pressure of cooling fluid through the tubing apparatus.

15. A method of starting up a geothermal well, the method comprising:

    circulating a working fluid between a surface location and a subsurface location via an insulated tubing string; and
    adjusting the temperature of the working fluid as it is circulated toward the surface using a cooling string.


Temperature (oC)
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400
375
350
325
300
275
250
225
200
175
150
Time (days)
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1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

FIGURE 1

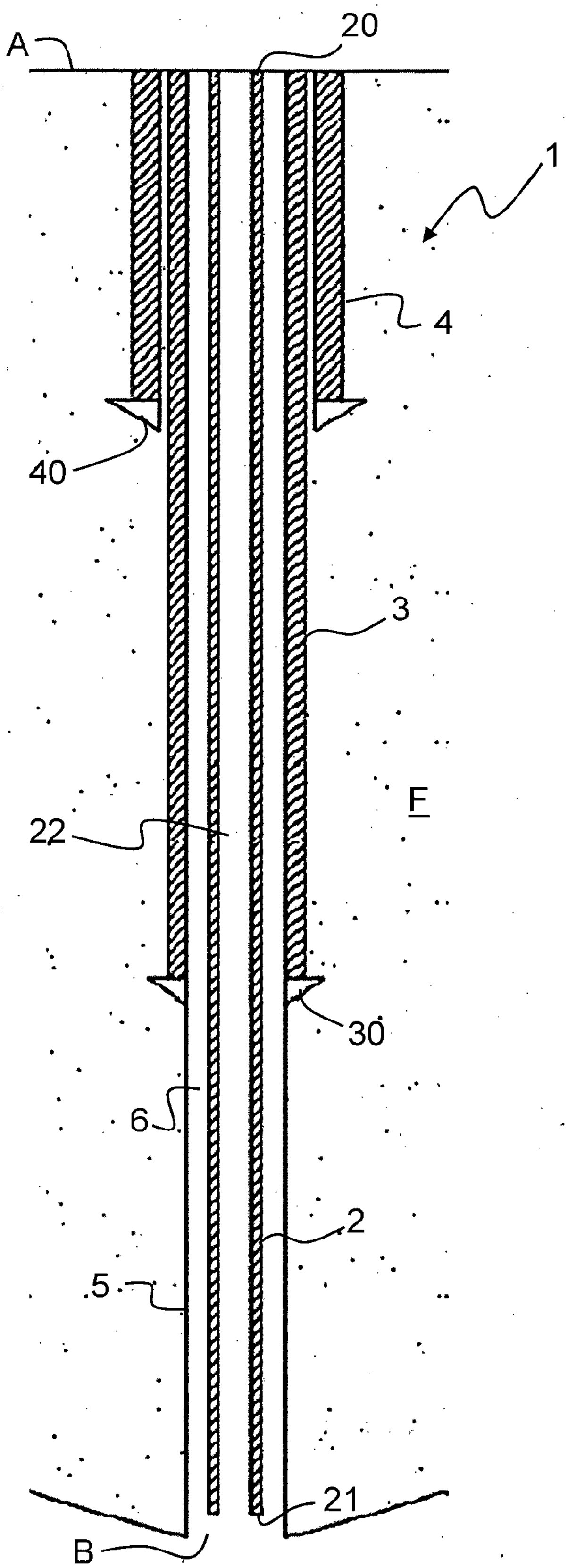


FIGURE 2

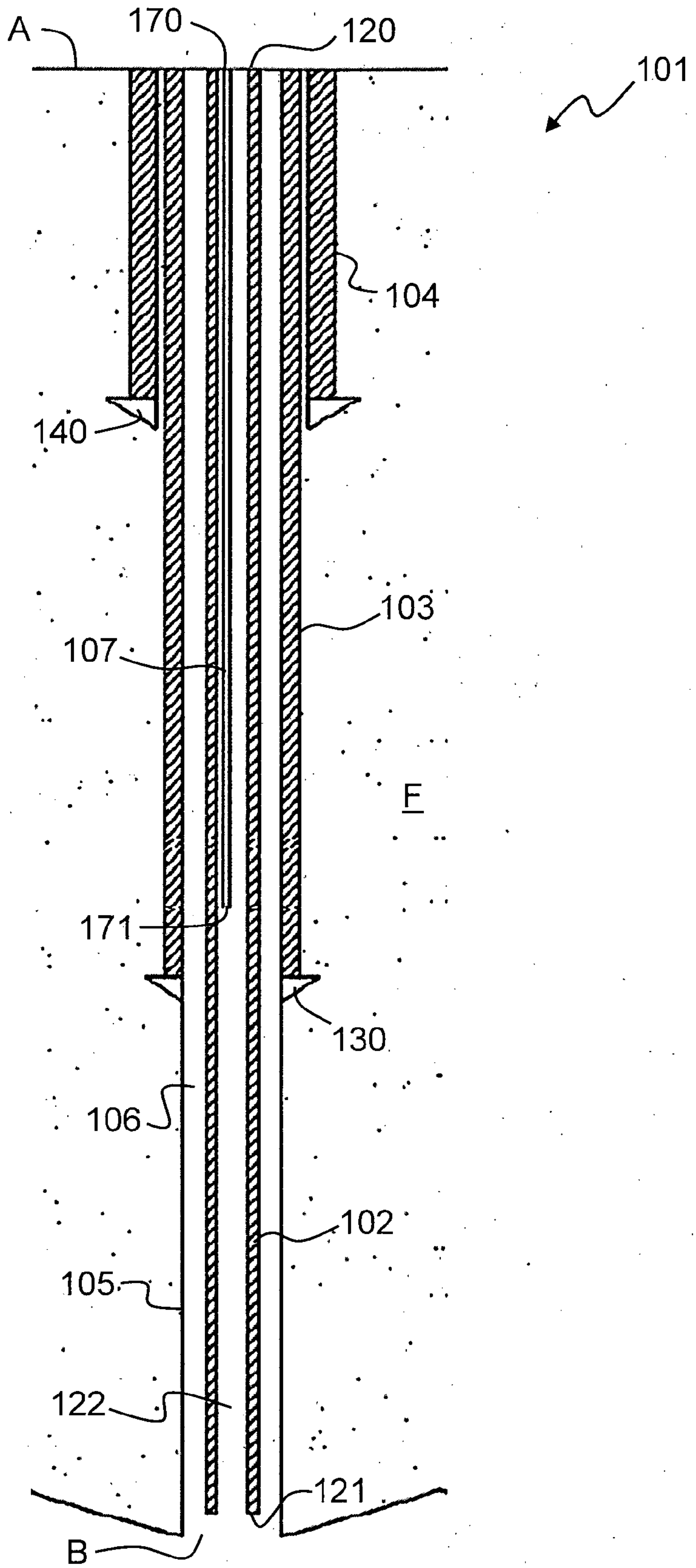


FIGURE 3

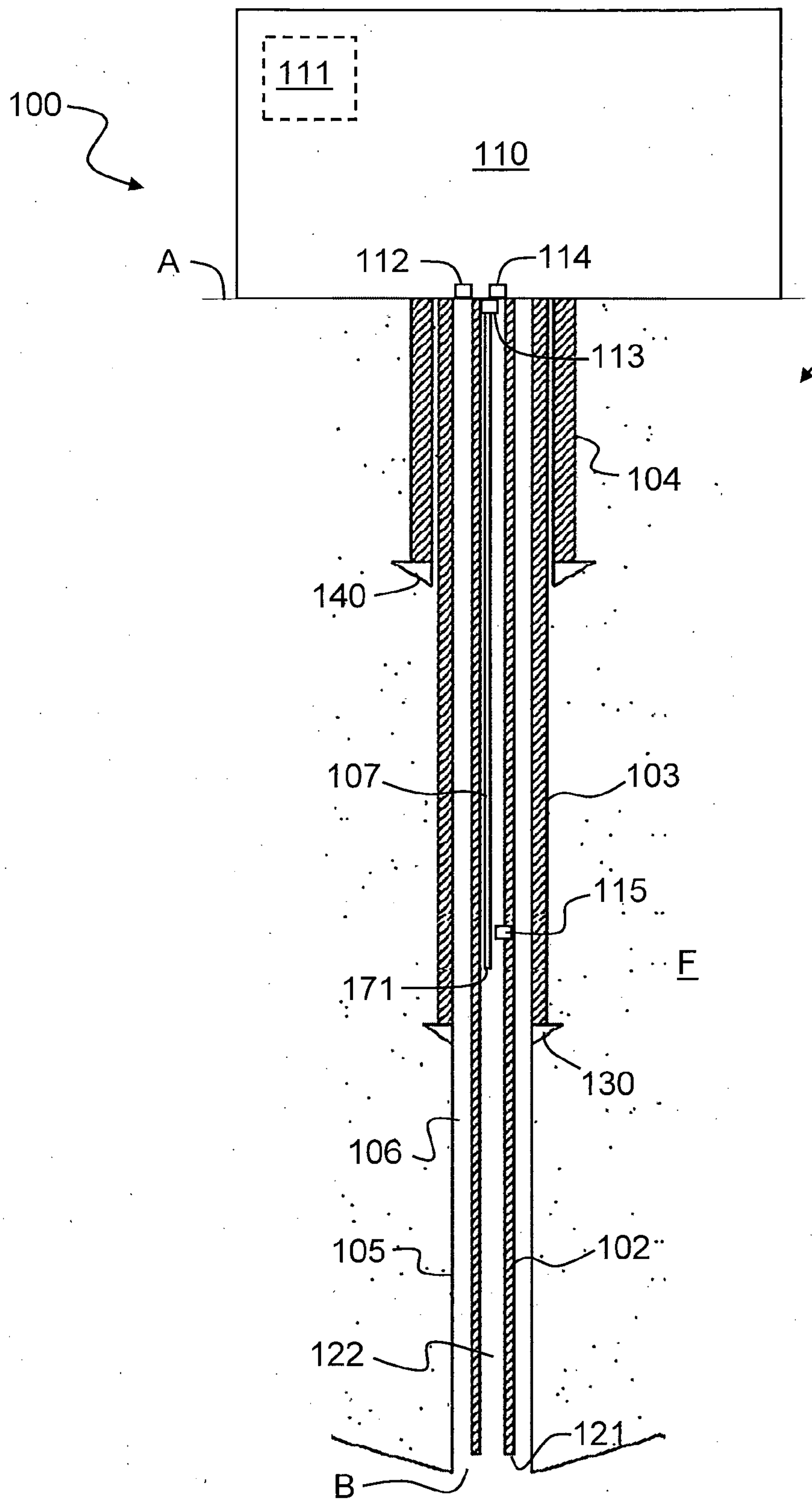
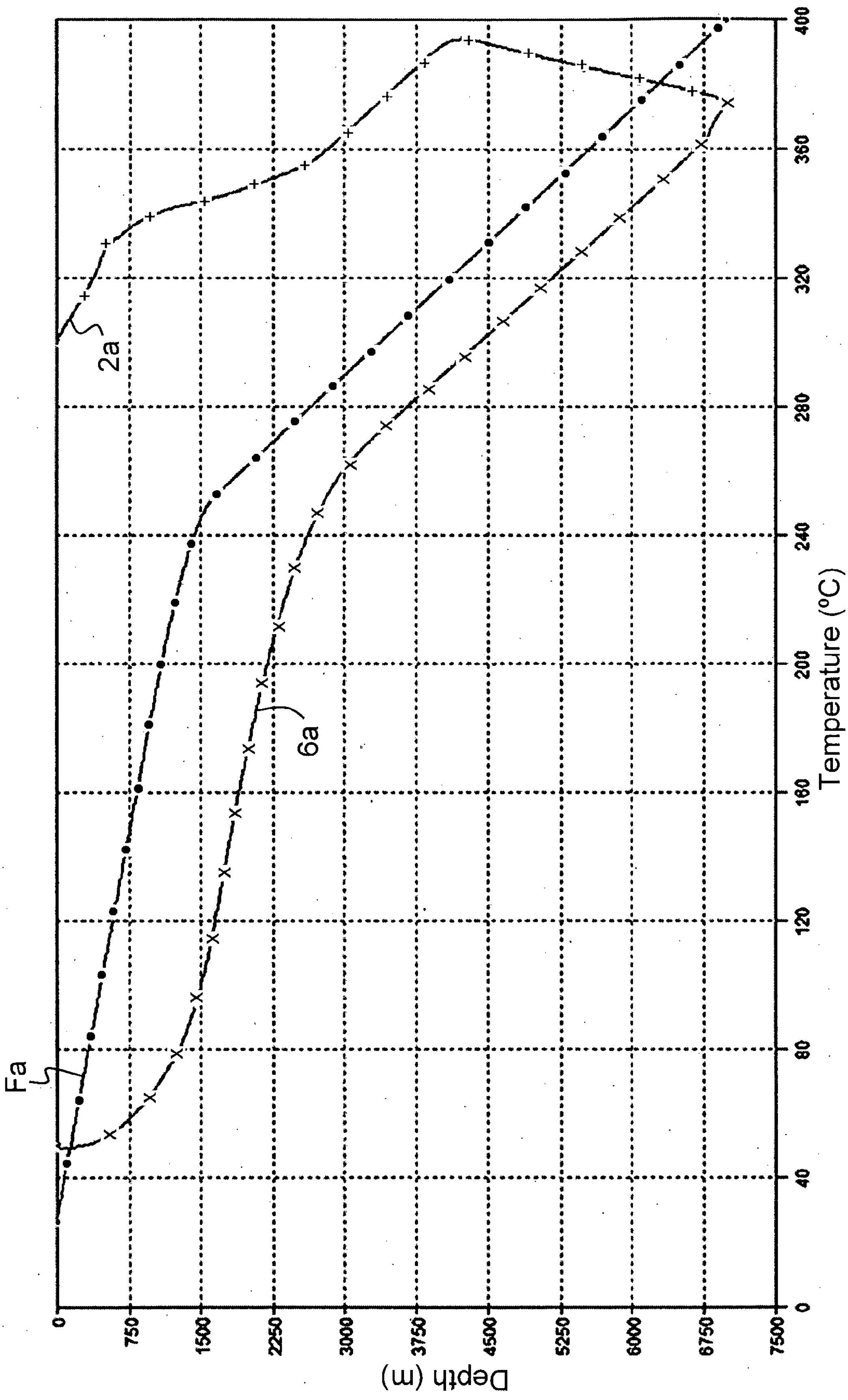

111
110
100
A
112
114
101
113
104
140
107
103
115
F
171
130
106
105
102
122
121
B

FIGURE 4


Depth (m)
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1500
2250
3000
3750
4500
5250
6000
6750
7500
Temperature (ºC)
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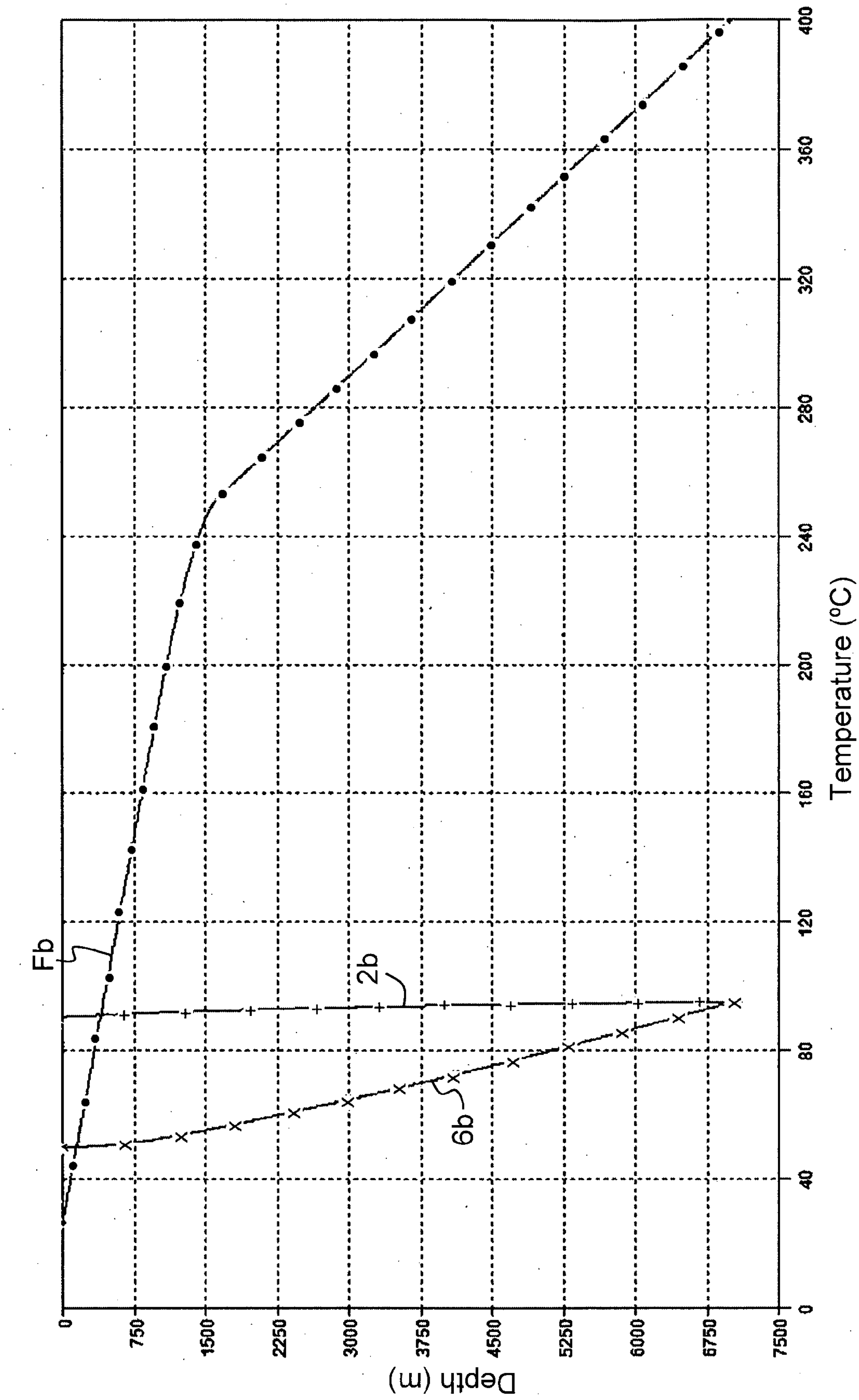
40
80
120
160
200
240
280
320
360
400
Fa
2a
6a

FIGURE 5


Depth (m)
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750
1500
2250
3000
3750
4500
5250
6000
6750
7500
Temperature (°C)
0
40
80
120
160
200
240
280
320
360
400
Fb
2b
6b

FIGURE 6

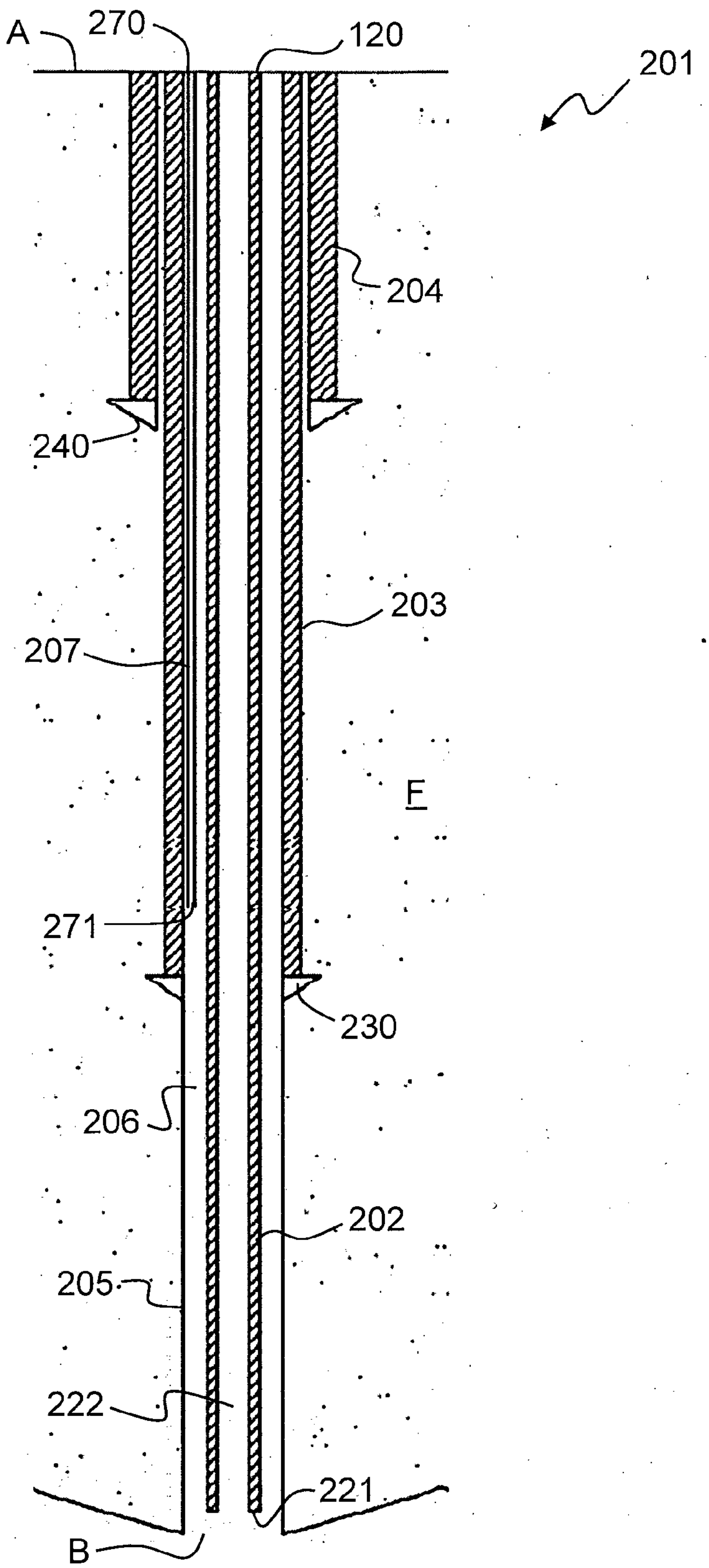

FIGURE 7

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EUROPEAN SEARCH REPORT

Application Number
EP 22 31 5084

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	GB 2 549 832 A (WILLIAM HENDERSON [GB]) 1 November 2017 (2017-11-01) * figure 6 *	1-15	INV. F24T10/20
A	WO 85/03994 A1 (GEO THERMAL MUESZAKI FEJLESZTE [HU]) 12 September 1985 (1985-09-12) * the whole document *	1-15	
A	US 2015/122453 A1 (COLWELL RODNEY GRAHAME [AU]) 7 May 2015 (2015-05-07) * the whole document *	1-15	
A	US 4 030 549 A (BOUCK LARRY S) 21 June 1977 (1977-06-21) * the whole document *	1-15	
A	US 2008/073058 A1 (UEYAMA HIROAKI [JP]) 27 March 2008 (2008-03-27) * the whole document *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

F24T

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	1 September 2022	Fernandez Ambres, A

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01-09-2022

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
GB 2549832	A	01-11-2017	NONE			
WO 8503994	A1	12-09-1985	EP	0173730	A1	12-03-1986
			HU	197063	B	28-02-1989
			WO	8503994	A1	12-09-1985
US 2015122453	A1	07-05-2015	US	2015122453	A1	07-05-2015
			WO	2015066764	A1	14-05-2015
US 4030549	A	21-06-1977	NONE			
US 2008073058	A1	27-03-2008	JP	3927593	B1	13-06-2007
			JP	2008075994	A	03-04-2008
			US	2008073058	A1	27-03-2008

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