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(54) **Geothermal method.**

(57) In a geothermal method thermal energy is extracted from a subsurface reservoir (3) comprising rock, wherein a working fluid (9) flows (17) through fractures (8A) in the rock. During an initial opening phase of the method, the fractures are being brought from their closed natural condition into their opened operation condition in that the fractures are being opened by the pressure of the working fluid being pressurized. During a subsequent thermal energy extraction phase of the method, the fractures are kept in their opened operation condition by maintaining the working fluid to be pressurized.

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Title: Geothermal method.

The invention relates to geothermal technology for extracting thermal energy from a subsurface reservoir comprising rock, wherein:

- at least one fluid injection well and at least one fluid extraction well are each extending from a nearsurface area into the subsurface reservoir;

- at least one injection pump is in fluid communication with the fluid injection well;

- the subsurface reservoir comprises a subsurface fluid flow path structure extending through said rock of the subsurface reservoir; and

- said extracting of thermal energy takes place in that under the action of the injection pump a working fluid is pumped to flow from the nearsurface area, via, succesively, the fluid injection well, the subsurface fluid flow path structure and the fluid extraction well, back to the nearsurface area, the working fluid thus gaining thermal energy from heat exchange with the subsurface reservoir, and said gained thermal energy thus being delivered by the working fluid to the nearsurface area.

More in particular, the invention relates to the abovementioned geothermal technology, wherein said subsurface fluid flow path structure comprises fractures in the rock of the reservoir.

In the present geothermal context it is noted that the term “subsurface reservoir”, as used in the present document, refers to an underground reservoir, i.e. a reservoir below the outer surface of the earth, while the term “nearsurface area”, as used in the present document, refers to an area at or near to said outer surface of the earth, and above said subsurface reservoir.

Indicative calculations demonstrate that geothermal energy, often referred to as “heat from the earth”, can theoretically supply 100% of the total current global energy consumption for 1000 years, resulting in only

0,1°C cooling of the earth. Approximately 99% of the earth's mass is hotter than 1000°C.

The challenge of geothermal technology is to extract heat in a technically and economically feasible manner. On the one hand, with increasing depth of the subsurface reservoir, the temperature of the subsurface reservoir increases and thus the thermal capacity of a geothermal system increases. The earth's average temperature gradient is approximately 30°C per km depth. However, this gradient varies strongly depending on region and/or depth. On the other hand, with increasing depth the cost of drilling increases exponentially. As a rule of thumb, assuming an average temperature gradient > 35°C/km and a flow rate > 100 kg/sec of the working fluid being delivered at the nearsurface area from the at least one extraction well, the unit cost price of the extracted thermal energy (or e.g. of the electrical energy into which the thermal energy is converted) decreases with increasing depth. It is noted, however, that drilling technology sets a limit to the depth. The world record is over 12 km depth, though with current standard available drilling technology the limit is around 7-8 km depth.

In some volcanic/seismic active areas of the world, such as Indonesia, the Philippines and Iceland, there exists subsurface rock having natural rock fractures therein. These natural fractures have been caused by said volcanic/seismic activity. Often, the high shear stresses present in the rock of these volcanic/seismic active areas have caused mutual lateral displacements, along the rock fractures, of teared-apart rock parts. Due to these lateral displacements, the teared-apart rock parts do not mutually fit in a form-matching manner anymore. For these reasons, these natural rock fractures are open, i.e. along the natural rock fractures there is ample open space between the teared-apart rock parts for fluid flow. This openness of the rock fractures is stable and long-lasting for very many years. In applying geothermal technology as initially identified hereinabove, these open rock fractures are being used as “the subsurface fluid flow path structure”, which extends through the rock of the subsurface reservoir. Such geothermal technology can also be applied in areas that once were seismic active and where the fractures are still open. Such geothermal systems can be found for example in the German Rhein Graben.

A major advantage of natural fractures in volcanic areas is that these areas usually have a higher than average temperature gradient. With a relatively modest drilling depth significant amounts of thermal energy can be extracted. In fact, the largest share of geothermal capacity installed on earth has been realised in volcanic regions by using open, natural fractures.

In some other areas of the world, there exists subsurface rock which also has high internal shear stresses, but which does not, or not yet, have natural rock fractures therein. In these areas one can artificially create fractures in the rock, a process which usually is referred to as “stimulation”. When artificially creating fractures in these areas where there are high shear stresses present in the rock, these high shear stresses automatically cause mutual lateral displacements of teared-apart rock parts. Thus, the artificial creation of fractures in the rock may automatically result into fractures being similar to the abovedescribed open natural fractures, i.e. fractures which are stably and long-lastingly open for very many years. Accordingly, also these open, artificially created rock fractures can similarly be used for geothermal use.

It is noted that different “stimulation” techniques for artificially creating rock fractures are known. “Thermal” stimulation, e.g., refers to a method of creating a network of cracks in the rock by means of applying sudden temperature changes to the rock by injecting cold water into the hot rock. And “chemical” stimulation, e.g., refers to a method of applying specific liquids to a rock reservoir, such as acid, aiming at dissolving certain minerals present in the rock. Another technique, known as “hydraulic” stimulation refers to a method of injecting a liquid under high pressure into the rock, thereby fracturing the rock. Also, it is known to perform stimulation by means of combined thermal and/or chemical and/or hydraulic stimulation techniques. It is noted that for the artificial creation of open rock fractures, the rock needs to be hard enough to guarantee that any created opening would not be closed under crushing pressure of the rock.

In summary, there are different kinds of areas in the world which are suitable for application of geothermal technology thanks to the presence in these areas of subsurface rock with sufficiently high internal shear stresses.

However, it is disadvantageous that the earth has only a limited number of these areas with sufficiently high internal rock shear stresses. For example, in many regions of Europe there is ample deep hot rock available, which in principle would be suitable for application of geothermal technology. However, the internal shear stresses in this deep hot rock are too low, in the sense that these shear stresses are insufficient to automatically open fractures that would be artificially created therein. It is noted that, in order to render an application of geothermal technology profitable, i.e. to make the application of geothermal technology economically feasible, it is typical that a geothermal system has to be installed in an area close to the area where the thermal energy to be extracted is being used in the society. This is a major difference as compared to the oil and gas industry, because oil and gas are more suitable for transportation over long distances than thermal energy and because transportation costs of oil and gas over long distances are more easily gained back by the relatively higher pricing of oil and gas.

In geographical areas having deep hot rock with too low internal shear stresses, it is known from the oil and gas industry to artificially create rock fractures, which fractures then are filled with so-called “proppant”. Proppant is material which is pumped into the fractures. The proppants remain in the opened fractures and long-lastingly keep these fractures open for fluid flow. Proppant-based technology is expensive, but in the oil and gas industry the proppant related costs are gained back by the relatively high pricing of oil and gas. For the substantially lower pricing of energy acquired from geothermal technology, on the other hand, the proppant-based technology generally would be too expensive, especially since geothermal technology generally involves very large dimensions of the fractures to be filled with proppants. In the first place, the initial installing of proppants would require a too high initial investment for realizing the geothermal system, and the proper installation of proppants has to be monitored and maintained during the service life of the geothermal system. In the second place, the presence of the proppants in the fractures would cause permanently present additional resistance for the working fluid of the geothermal system to flow through the fractures, which in many cases would cause increased energy consumption by the injection pump(s) of the geothermal system and thus would cause increased operational costs of the geothermal system.

For the above reasons, there currently is hardly or no use of deep geothermal energy in geographical areas where the internal shear stresses in the deep hot rock are too low to automatically keep artificially created rock fractures open. Unfortunately therefore, a huge available potential of thermal energy, present at or close to areas where there is a continuous local demand for that thermal energy, is left unused. For example, in The Netherlands and in Germany there is a huge potential of thermal energy available at 5.0-7.5 km depth range, in rock with low internal shear stresses.

It is an object of the present invention to provide a reliable and economically profitable solution for extracting thermal energy from hot subsurface rock having relatively low internal shear stresses.

For that purpose, the invention provides a geothermal method of extracting thermal energy from a subsurface reservoir comprising rock, wherein:

- at least one fluid injection well and at least one fluid extraction well are each extending from a nearsurface area into the subsurface reservoir;

- at least one injection pump is in fluid communication with the fluid injection well;

- the subsurface reservoir comprises a subsurface fluid flow path structure extending through said rock of the subsurface reservoir, said subsurface fluid flow path structure comprising fractures in the rock of the reservoir;

- said extracting of thermal energy takes place in that under the action of the injection pump a working fluid is pumped to flow from the nearsurface area, via, succesively, the fluid injection well, the subsurface fluid flow path structure and the fluid extraction well, back to the nearsurface area, the working fluid thus gaining thermal energy from heat exchange with the subsurface reservoir, and said gained thermal energy thus being delivered by the working fluid to the nearsurface area;

characterized in that

- said fractures have a closed natural condition and an opened operation condition, respectively preventing and allowing said working fluid to perform its aforementioned flow through the fractures, said closed natural condition being defined as occurring under influence of the natural forces in the rock in case there is no working fluid in the rock;

- the geothermal method is started up in an initial opening phase of the method and said extracting of thermal energy is subsequently carried out in a thermal energy extraction phase of the method, wherein

- during said initial opening phase the fractures are being brought from their closed natural condition into their opened operation condition in that the fractures are being opened by the pressure of the working fluid being pressurized at least by the injection pump, to thereby allow said pumped working fluid to perform its aforementioned flow through the thus opened fractures during said subsequent thermal energy extraction phase; and

- during said thermal energy extraction phase the fractures are kept in their opened operation condition by maintaining the working fluid to be pressurized at least by the injection pump.

Hence the invention provides that during said initial opening phase the fractures are being opened by the pressure of the pressurized working fluid, while during the subsequent thermal energy extraction phase the fractures are kept open by maintaining the working fluid to be pressurized. As a rule of thumb it is noted that said initial opening phase may last between approximately 0.1 hour and a few hours (order of magnitude, depending on the dimensions, configurations, etc. of the system), while said subsequent thermal energy extraction phase may last at least half a day, or at least one day, or at least one week, or at least one month (order of magnitude). A thermal energy extraction phase may for example be terminated for reasons of maintenance of system components or for reasons of temporarily decreased demand for extracted thermal energy. After termination of the thermal energy extraction phase, the method may be started up again in a new initial opening phase, followed by a new thermal energy extraction phase.

Since, according to the invention, the fractures are kept open by the pressure of the pressurized working fluid, the invention does not require rock having high internal shear stresses. Therefore, the invention can be applied in many regions of the world, at or close to the local demand for thermal energy. Furthermore, the invention does not require the application of proppant techniques, which, as explained above, saves considerable costs, e.g. for installation of proppants and, probably in many cases during the service life of the geothermal system, for monitoring, maintenance and extra energy consumption for operating the system. Thus, the invention can be applied in an economically profitable manner, the absence of proppants allowing for low resistance for the working fluid to flow through the open fractures.

The invention can be applied in a technically feasible and reliable manner, because the required pressurization of the working fluid to open, and to subsequently keep open, the fractures is not higher (in fact lower) than the required pressurization of such fluid for creating artificial rock fractures using the proven technology of “hydraulic” stimulation. Hence, for applying the invention it is possible to use pressurization levels comparable to or lower than those used in “hydraulic” stimulation. Also, the invention can be applied with system components (pumps, wells, etc.) similar to those used in “hydraulic” stimulation, i.e. system components which are able to withstand the relatively high pressure levels of the working fluid.

A further advantage of the present invention is that the knowledge that the present invention is available can beneficially be used as a risk management tool. Sometimes there is uncertainty about the subsurface shear stress regime present in subsurface rock at a certain location one desires to explore. In these cases one sometimes decides not to explore the location (by expensive investigations, expensive drilling operations, etc.) to avoid the risk that it would eventually turn out that at the location the rock shear stress would be insufficient for artificially created fractures to remain open by lateral rock displacements along the created fractures. However, knowing that the present invention is available, makes it easier to decide in favour of exploring the location. After all, if after exploration it would turn out that the rock shear stress would be insufficient, one could simply decide to apply the present invention to exploit the location. In that case, the costs spended for the expensive exploration activities have not been in vain. In other words, the present invention increases the overall probability of success of projects under consideration.

As regards the inventive merits of the present invention, it is important to realize that the skilled person has never considered keeping subsurface rock fractures open by the pressure of pressurized working fluid during a thermal energy extraction phase of a geothermal method. Conventionally, in the geothermal arena one either is seeking for rock having sufficiently high internal shear stresses, or one is using proppants inside artificially created fractures in rock having insufficiently high internal shear stresses. In addition it is noted that practicing the idea of the inventor of the present invention would immediately be expected to be a futile enterprise, which no one would ever try, since practicing the idea is expected to require a huge amount of parasitic energy consumed for the highly pressurized working fluid to continuously keep rock fractures open during the thermal energy extraction phase.

In a preferable embodiment of a geothermal method according to the invention, an “overall drilling depth” is at least 3000 meter, said “overall drilling depth” being defined as the maximum of the respective drilling depths of the at least one fluid injection well and of the at least one fluid extraction well. More preferably, said overall drilling depth is at least 4000 meter, yet more preferably at least 5000 meter, yet more preferably at least 6000 meter, yet more preferably at least 7000 meter, yet more preferably at least 8000 meter, yet more preferably at least 9000 meter, yet more preferably at least 10000 meter, yet more preferably at least 11000 meter. The reason that it is relatively more favourable to apply the invention with relatively higher overall drilling depths, is that the unit cost price of the extracted thermal energy (or e.g. of the electrical energy into which the thermal energy is converted) decreases with increasing depth, as mentioned above.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, a “total flow rate” is at least 40 kg/sec, said “total flow rate” being defined as the flow rate of said flow of the working fluid in total being delivered by the at least one extraction well at the nearsurface area. More preferably, said total flow rate is at least 50 kg/sec, yet more preferably at least 60 kg/sec, yet more preferably at least 70 kg/sec, yet more preferably at least 80 kg/sec, yet more preferably at least 90 kg/sec, yet more preferably at least 100 kg/sec. The reason that it is relatively more favourable to apply the invention with relatively higher total flow rates, is that the unit cost price of the extracted thermal energy (or e.g. of the electrical energy into which the thermal energy is converted) decreases with increasing total flow rate. It is noted that the flow rate can be increased for example by increasing the power of the at least one injection pump, optionally in combination with increasing the number of the fractures in the rock of the reservoir. In case of using artificially created fractures, the number of the fractures can be influenced at the time of artificially creating the fractures, i.e. at the time of “stimulation”, described above.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, said thermal energy extraction phase is continuously carried out for at least half a day, more preferably at least one day, yet more preferably at least one week, yet more preferably at least one month. Typically, for a subsurface reservoir together with the corresponding at least one fluid injection well and the corresponding at least one fluid extraction well, the thermal energy extraction phases of successive methods according to the invention, carried out with said subsurface reservoir together with said corresponding at least one fluid injection well and said corresponding at least one fluid extraction well, will be in effect for approximately in-between 6500 and 8500 hours per year, for a total of approximately in-between 20 and 50 years.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, a “first value” of power delivered to the at least one injection pump to operate the at least one injection pump during said thermal energy extraction phase, said “first value” of power being time-averaged over the total duration of said thermal energy extraction phase, is between 60% and 95% of a “second value” of power delivered to the at least one injection pump to operate the at least one injection pump during said initial opening phase, said “second value” of power being time-averaged over the total duration of said initial opening phase. That the power required to operate the at least one injection pump during said thermal energy extraction phase thus, in average, is substantially lower than the power to operate the at least one injection pump during said initial opening phase, is possible because, once the fractures have been opened, the flow resistance in the fractures has decreased substantially.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, said fractures are artificially created fractures in the sense that said fractures have been artificially created prior to performing the method. This offers the advantage that the invention can be practiced in many areas of the earth. It is, however, noted that in principle the invention may also be practiced with fractures not being artificially created fractures in the abovementioned sense, but with fractures that were created in the rock by nature. That is, sometimes nature has created “closed” rock fractures, i.e. fractures which are not open for fluid flow.

Preferably, said artificially created fractures have been artificially created by means of performing at least hydraulic stimulation prior to performing the method. This is advantageous and efficient, since hydraulic stimulation is effective and proven technology for creating artificial rock fractures, and, when hydraulic stimulation has been used, the injection and extraction wells and other components that were used for the hydraulic stimulation, can be re-used for carrying out the method according to the invention as well. The reason is that the required pressurization of the working fluid to open, and to subsequently keep open, the fractures is lower than the required pressurization of such fluid for creating artificial rock fractures using hydraulic stimulation. It is, however, noted that in principle the invention may also be practiced with fractures not being artificially created by means of performing at least hydraulic stimulation prior to performing the method, but by means of other stimulation techniques, such as combined thermal and/or chemical and/or hydraulic stimulation techniques.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, the working fluid substantially is water. Using water as the working fluid in the method according to the invention provides the advantages that water incurs relatively little friction losses, is very suitable for heat exchange, readily available and cheap. It is noted that the aforementioned phrase “the working fluid ‘substantially’ is water”, is meant to indicate that the working fluid, of course, not necessarily has to be 100% fresh water, but may comprise certain additives of various kinds. In fact working fluid “substantially” being water, as used herein, may for example be any kind of what one refers to as water in daily life, such as tap/mains water, seawater, water from waterways, etc.

In another preferable embodiment of a geothermal method according to the invention, which can be applied in combination with any one of the aforementioned preferable embodiments of the invention, at least during said thermal energy extraction phase the pressurized working fluid is additionally pressurized by further, controllably adjustable pressurizing structure which is located downstream of the subsurface fluid flow path structure. In combination with the at least one injection pump, which is located upstream of the subsurface fluid flow path structure, said further pressurizing structure allows for optimally steering the various process parameters in dependence of various circumstances and various requirements that may arise in various stages of performing the method.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter by way of non-limiting examples only and with reference to the schematic figures in the enclosed drawing.

Fig. 1 shows, in a vertical cross-sectional view, an example of an embodiment of an arrangement for use in an example of an embodiment of a geothermal method according to the invention, said arrangement comprising a subsurface rock reservoir, a fluid injection well, a fluid extraction well, as well as an injection pump and a heat exchanger at a nearsurface area of the earth.

Fig. 2 shows the subsurface rock reservoir of Fig. 1 in a perspective view, be it in a highly schematical degree.

Fig. 3 shows the fluid injection well and the fluid extraction well of Figs. 1 and 2 in a more detailed manner.

Fig. 4 shows, in an upper view, a horizontal cross-section of a part of the subsurface rock reservoir of Figs. 1 and 2, said part containing a part of a rock fracture being in its “closed natural condition”.

Fig. 5 shows the situation of Fig. 4 again, however this time with the rock fracture of Fig. 4 being in its “opened operation condition”.

In the Figures, the earth's surface and the nearsurface area of the earth are denoted by reference numerals 1 and 2, respectively (see Fig. 1), while the subsurface reservoir comprising rock is denoted by reference numeral 3. Fig. 1 also shows injection pump 6, which is in fluid communication with the fluid injection well 4.

In the shown example, use is made of one fluid injection well 4 and one fluid extraction well 5, each of which is extending from the nearsurface area 2 into the subsurface reservoir 3. These wells 4 and 5, as such, may be configured and arranged as known in the art, using steel casings 15 and concrete 16 (see Fig. 3). In their upper parts, the wells 4 and 5 are extending in a substantially vertical direction, while towards their lower parts (i.e. closer to the reservoir 3) their directions are deflecting so as to gradually extend more and more in horizontal directions (see Fig. 2). In Fig. 3, the lower parts of the wells 4 and 5, which lower parts are extending to a high degree in horizontal directions, have been indicated with reference numerals 41 and 51, respectively. It is noted that in Fig. 3 these lower well parts 41 and 51 have schematically been depicted vertically, but, as mentioned, it has to be understood that they are substantially horizontally directed in the shown example. It is furthermore noted that the present invention may be practiced with fluid injection and fluid extraction wells, which may have various ways in which their longitudinal directions change as regards their vertical and horizontal components, as known in the art of drilling technology.

As shown in Fig. 2, the rock of the reservoir 3 has several fractures 8A, 8B, 8C, 8D, 8E, 8F, 8G, 8H and 8I. In the shown example, each of these fractures 8A-8I is extending more or less in a vertical plane. Fig. 4 shows, in an upper view, a horizontal cross-section of a part of the subsurface rock reservoir of Figs. 1 and 2, said part containing a part of rock fracture 8A of Fig. 2. In Fig. 4, the fracture 8A is in its “closed natural condition”, as described hereinabove. Each of the other fractures 8B-8I has a similar closed natural condition.

Said closed natural condition of the fractures 8A-8I correspond to the situation in which the geothermal method according to the present invention has not yet been started up.

As mentioned, during the “initial opening phase” of the geothermal method the fractures 8A-8I are being brought from their closed natural condition into their “opened operation condition” in that the fractures 8A-8I are being opened by the pressure of working fluid being pressurized by the injection pump 6. As an example, the resulting opened operation condition of the specific fracture 8A is shown in Fig. 5. In Fig. 5 (and also in Fig. 1) the working fluid has been indicated by reference numeral 9. In Fig. 5 the high pressure of the pressurized working fluid 9 has symbolically been indicated by a number of reference signs “+” depicted inside the opened fracture 8A.

In Fig. 5 (and also in Fig. 2) the arrow 17 indicates the flow direction of the working fluid 9 inside the opened fracture 8A. It is noted that, within the reservoir 3, the working fluid 9 leaves the fluid injection well 4 via side openings (not shown) in the well 4, while the working fluid 9 enters the fluid extraction well 5 via further side openings (not shown) in the well 5.

In the shown example, the fractures 8A-8I form together the abovedescribed “subsurface fluid flow path structure”, which in Fig. 2 has been indicated by reference numeral 7.

As mentioned, during the “thermal energy extraction phase” of the geothermal method the fractures are kept in their opened operation condition by maintaining the working fluid 9 to be pressurized by the injection pump 6.

As also follows from Fig. 1, it has now been elucidated that the extracting of thermal energy according to the present invention takes place in that the working fluid 9, under the action of the injection pump 6, is pumped to flow from the nearsurface area 2, via, succesively, the fluid injection well 4, the subsurface fluid flow path structure 7 and the fluid extraction well 5, back to the nearsurface area 2, the working fluid 9 thus gaining thermal energy from heat exchange with the subsurface reservoir 3, and said gained thermal energy thus being delivered by the working fluid 9 to the nearsurface area 2.

Fig. 1 furthermore shows that, in this example, the fluid extraction well 5 at the nearsurface area 2 is connected to a heat exchanger 14. The working fluid 9 coming from the fluid extraction well 5 first enters into the heat exchanger 14 and, next, leaves the heat exchanger 14, whereafter it enters again into the fluid injection well 4 under the pumping action of the injection pump 6. Hence, in this example, the working fluid 9 circulates in a first fluid flow circuit. Via the heat exchanger 14 the working fluid 9 can transfer its thermal energy, which it has acquired from the reservoir 3, to a second fluid flow circuit, which second fluid flow circuit in the shown example comprises fluid conduits 11 and 12, which also connect to the heat exchanger 14, as known in the art.

Fig. 1 furthermore shows, in a highly schematical way, controllably adjustable pressurizing structure 10 which is located downstream of the subsurface fluid flow path structure 7. Such controllably adjustable pressurizing structure 10 provides additional assistance in controlling the pressurization of the working fluid 9 during the thermal energy extraction phase of the method and/or during the initial opening phase of the method.

As an example, the following rough calculations are made for a typical arrangement as depicted in Figs. 1-5. In this example, it is assumed that the overall drilling depth is in a range of 6000 to 7000 meter and the working fluid is water. For the considered situation it has been calculated with software simulations, similarly to those commonly used in predicting hydraulic stimulation, that the initial opening phase of the present method according to the invention requires the injection pump to have a differential pressure of 390 bar (39000000 Pa), while during the thermal energy extraction phase the required differential pressure would be 350 bar (35000000 Pa). Using safety margins of 30% and 10% for these differential pressure values, one arrives at 507 bar (50700000 Pa) and 385 bar (38500000 Pa) for the initial opening phase and the thermal energy extraction phase, respectively.

Using the formula $P = (q \Delta p) / (\rho \eta)$, wherein P is the required power of the injection pump [W], q is the abovedescribed “total flow rate” of the working fluid [kg/s], Δp is the differential pressure of the pump [Pa], ρ is the density of the working fluid [kg/m^3], and η is the pump efficiency ratio, one arrives at required pump power values of 7.1 MW and 5.4 MW for the initial opening phase and the thermal energy extraction phase, respectively. Note that herein use has been made of $q = 110$ kg/s, $\rho = 980$ kg/m^3, and $\eta = 0.8$.

Hence, the thermal energy extraction phase requires a pump power, roughly being about 5.4 MW.

Furthermore, using available simulation software, the total thermal capacity of the system has been predicted to be about 65.0 MW.

As a result, the predicted “Coefficient of Performance” (COP) is about 12, i.e. 65.0 MW / 5.4 MW. In other words, the system is predicted to produce 12 MWh thermal energy for each 1 MWh of electrical energy required for pumping the working fluid.

In summary, an attractive business case is to be expected at a depth range of 6000 to 7000 meter.

In the foregoing specification, the invention has been described with reference to a specific example of an embodiment of the invention. However, various modifications and changes may be made therein without departing from the broader scope of the invention as set forth in the appended claims.

For instance, in the shown example, the invention is practiced using one fluid injection well, one fluid extraction well, one injection pump and one heat exchanger at the nearsurface area. Instead, it is also possible to practice the invention with more than one (e.g. two, three, four, etc.) fluid injection well and/or more than one (e.g. two, three, four, etc.) fluid extraction well and/or more than one (e.g. two, three, four, etc.) injection pump and/or more than one (e.g. two, three, four, etc.) heat exchanger at the nearsurface area.

Also it is possible to practice the invention with various other nearsurface arrangements, in addition to or instead of the shown nearsurface arrangement formed by the shown parts 6, 10, 11, 12, 14.

Furthermore, it is possible to practice the invention in combination with various kinds of technologies for directly using the extracted thermal energy, or, e.g., for converting the extracted thermal energy in other kinds of energy, such as e.g. electrical energy.

For example, is is also noted that, in the shown example, the working fluid circulates in a more or less closed first fluid flow circuit. Instead, it is possible to not, or not fully, recycle the working fluid coming from the fluid extraction well into the fluid injection well. For example, one could lead steam coming from the fluid extraction well directly to other destinations, such as to a steam turbine for generation of electrical energy.

Furthermore, various fluids, other than water, may be used as working fluid. For example, carbondioxide can be used as the working fluid in a geothermal method according to the present invention.

Also, the structural components for practicing the invention may comprise various further stucture, such as by-pass structure enabling the continuation of the thermal energy extraction phase in case of disturbances of the process, thus preventing that an ongoing energy extraction phase of the method would have to be terminated and that, later on, the method would have to be re-started by means of a new initial opening phase of the method.

However, other modifications, variations and alternatives are also possible. The specifications and drawings are, accordingly, to be regarded in an illustrative rather than in a restrictive sense.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word ‘comprising’ does not exclude the presence of other features or steps than those listed in a claim. Furthermore, the words ‘a’ and ‘an’ shall not be construed as limited to ‘only one’, but instead are used to mean ‘at least one’, and do not exclude a plurality. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to advantage.

CONCLUSIES

1. Een geothermische werkwijze voor het onttrekken van thermische energie uit een onderaards reservoir (3) dat gesteente omvat, waarbij:

- tenminste één fluïduminjectieput (4) en tenminste één fluïdumonttrekkingsput (5) zich elk uitstrekken van een nabij het aardoppervlak gelegen gebied (2) tot in het onderaardse reservoir;

- tenminste één injectiepomp (6) in fluïdumcommunicatie is met de fluïduminjectieput;

- het onderaardse reservoir een onderaards fluïdumstromingspadstructuur (7) omvat die zich uitstrekt door genoemd gesteente van het onderaardse reservoir, waarbij genoemde fluïdumstromingspadstructuur breuken (8A-8I) in het gesteente van het reservoir omvat;

- genoemd onttrekken van thermische energie plaatsvindt doordat onder de actie van de injectiepomp een werkfluïdum (9) verpompt wordt om te stromen van het nabij het aardoppervlak gelegen gebied, via, achtereenvolgens, de fluïduminjectieput, de onderaardse fluïdumstromingspadstructuur en de fluïdumonttrekkingsput, terug naar het nabij het aardoppervlak gelegen gebied, waarbij het werkfluïdum aldus thermische energie verkrijgt van warmteuitwisseling met het onderaardse reservoir, en waarbij genoemde verkregen thermische energie aldus door het werkfluïdum naar het nabij het aardoppervlak gelegen gebied geleverd wordt;

met het kenmerk, dat

- genoemde breuken (8A-8I) een gesloten natuurlijke toestand en een geopende bedrijfstoestand hebben, welke respectievelijk tegengaan en toestaan dat genoemd werkfluïdum (9) zijn voorgenoemde stroming door de breuken uitvoert, waarbij genoemde gesloten natuurlijke toestand gedefinieerd is als op te treden onder invloed van de natuurlijke krachten in het gesteente in het geval geen werkfluïdum in het gesteente aanwezig is;

- de geothermische werkwijze opgestart wordt in een initiële openingsfase van de werkwijze en genoemd onttrekken van thermische energie vervolgens wordt uitgevoerd in een ‘thermische energie’-onttrekkingsfase van de werkwijze, waarbij

- gedurende genoemde initiële openingsfase de breuken van hun gesloten natuurlijke toestand in hun geopende bedrijfstoestand worden gebracht doordat de breuken geopend worden door de druk van het werkfluïdum (9) dat onder druk gezet is tenminste door de injectiepomp (6), teneinde daardoor toe te staan dat genoemd verpompt werkfluïdum zijn voorgenoemde stroming door de aldus geopende breuken uitvoert gedurende genoemde navolgende ‘thermische energie’-onttrekkingsfase; en

- gedurende genoemde ‘thermische energie’-onttrekkingsfase de breuken in hun geopende bedrijfstoestand worden gehouden door het instandhouden van het tenminste door de injectiepomp onder druk zetten van het werkfluïdum.

2. Een geothermische werkwijze volgens conclusie 1, waarbij een “overall” boordiepte tenminste 3000 meter is, waarbij genoemde “overall” boordiepte gedefinieerd is als het maximum van de respectieve boordiepten van de tenminste ene fluïduminjectieput (4) en van de tenminste ene fluïdumonttrekkingsput (5).

3. Een geothermische werkwijze volgens conclusie 1 of 2, waarbij een totaaldebiet tenminste 40 kg/sec is, waarbij genoemd totaaldebiet gedefinieerd is als het debiet van genoemde stroming van het werkfluïdum (9) dat in totaal door de tenminste ene fluïdumonttrekkingsput (5) geleverd wordt ter plaatse van het nabij het aardoppervlak gelegen gebied (2).

4. Een geothermische werkwijze volgens een der voorgaande conclusies, waarbij genoemde ‘thermische energie’-onttrekkingsfase continu wordt uitgevoerd gedurende tenminste een halve dag.

5. Een geothermische werkwijze volgens een der voorgaande conclusies, waarbij een eerste waarde van vermogen geleverd aan de tenminste ene injectiepomp (6) voor het in werking doen zijn van de tenminste ene injectiepomp gedurende genoemde ‘thermische energie’-onttrekkingsfase, genoemde eerste waarde van vermogen zijnde een tijdsgemiddelde over de gehele duur van genoemde ‘thermische energie’-onttrekkingsfase, tussen 60% en 95% bedraagt van een tweede waarde van vermogen geleverd aan de tenminste ene injectiepomp (6) voor het in werking doen zijn van de tenminste ene injectiepomp gedurende genoemde initiële openingsfase, genoemde tweede waarde van vermogen zijnde een tijdsgemiddelde over de gehele duur van genoemde initiële openingsfase.

6. Een geothermische werkwijze volgens een der voorgaande conclusies, waarbij genoemde breuken (8A-8I) kunstmatig gecreëerde breuken zijn in de zin dat genoemde breuken kunstmatig gecreëerd zijn voorafgaand aan het uitvoeren van de werkwijze.

7. Een geothermische werkwijze volgens conclusie 6, waarbij genoemde kunstmatig gecreëerde breuken kunstmatig gecreëerd zijn door middel van tenminste hydraulische stimulatie voorafgaand aan het uitvoeren van de werkwijze.

8. Een geothermische werkwijze volgens een der voorgaande conclusies, waarbij het werkfluïdum (9) in hoofdzaak water is.

9. Een geothermische werkwijze volgens een der voorgaande conclusies, waarbij tenminste gedurende genoemde ‘thermische energie’-onttrekkingsfase het onder druk gezette werkfluïdum additioneel onder druk gezet wordt door verdere, regelbaar aanpasbare onderdrukzettingsstructuur (10) die stroomafwaarts van de onderaardse fluïdumstromingspadstructuur (7) gesitueerd is.

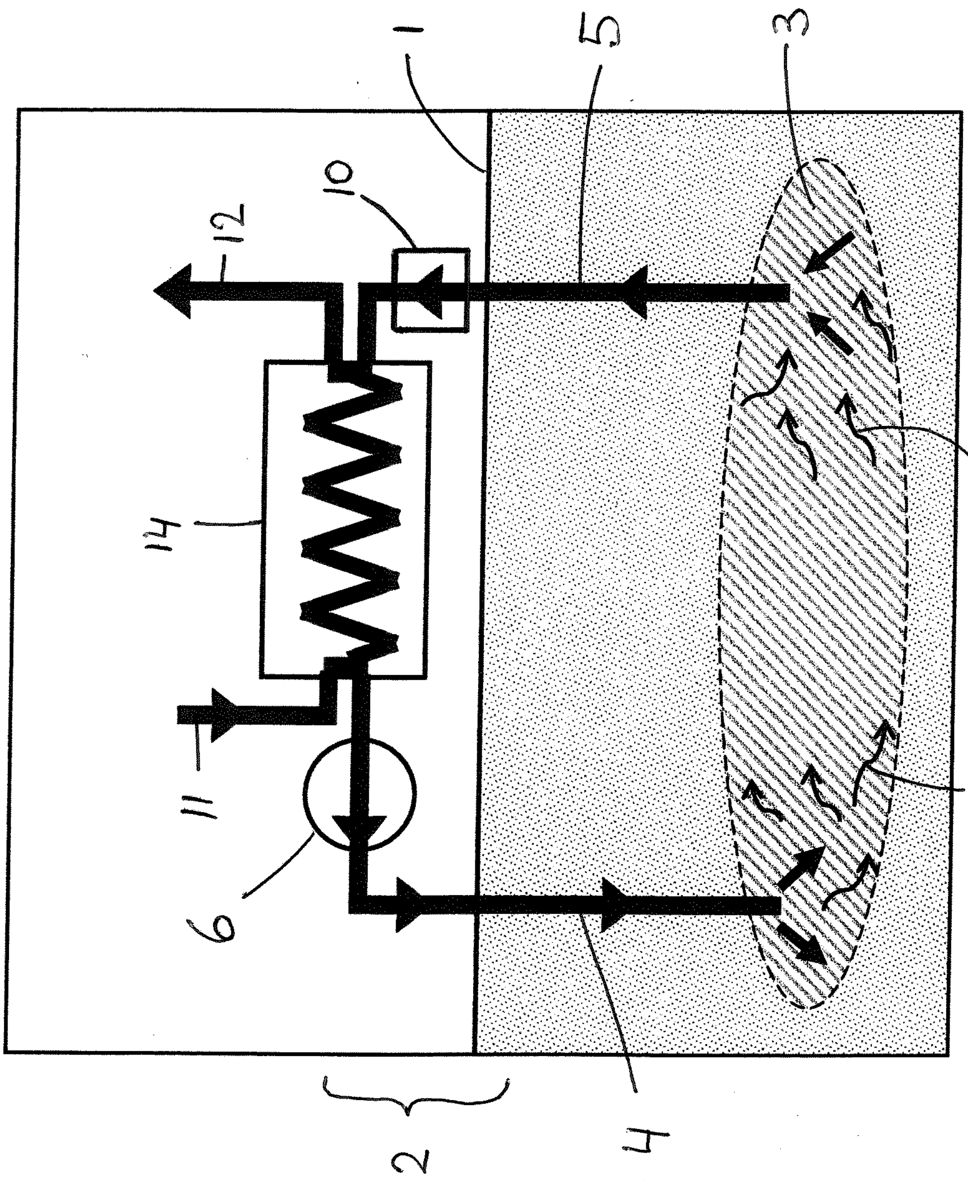
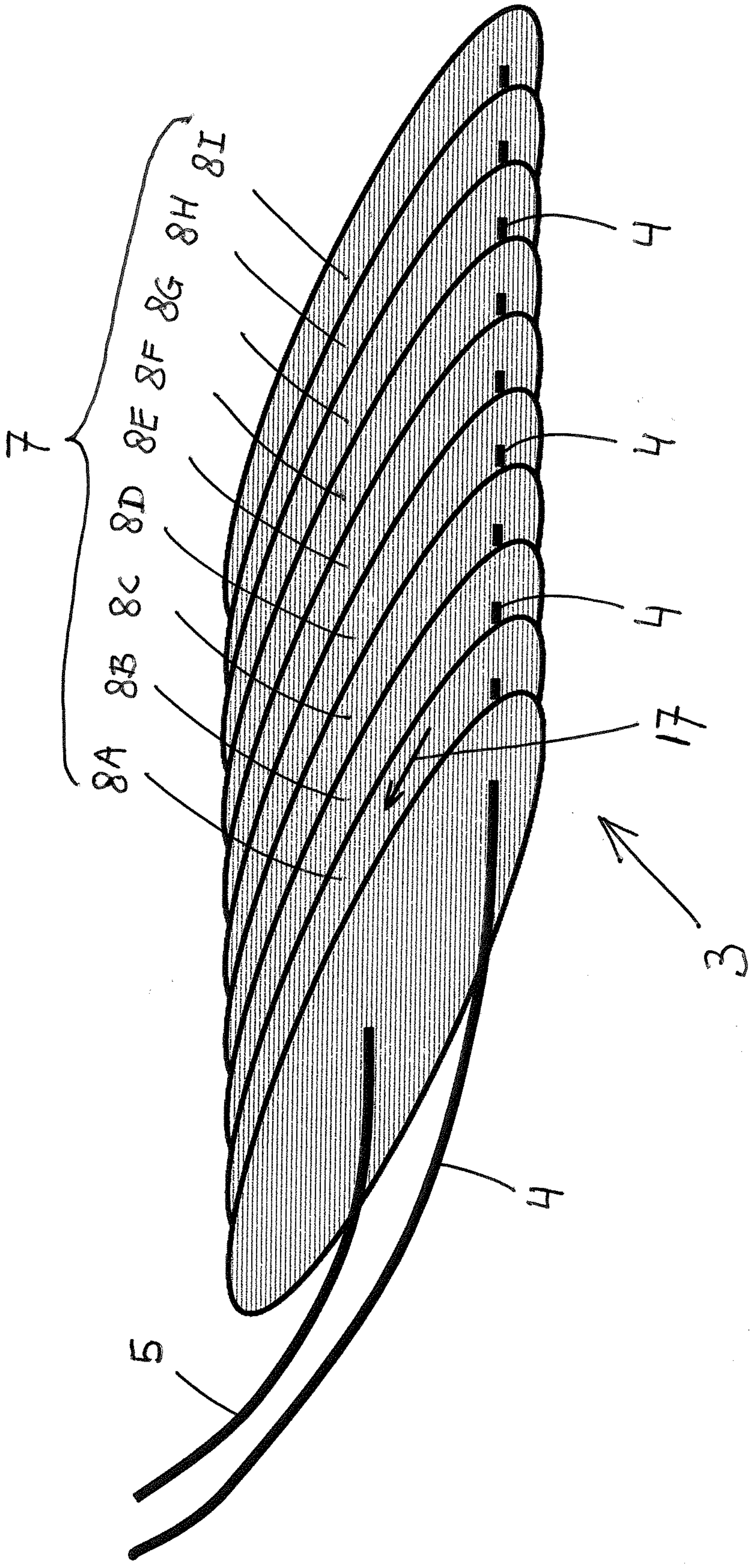


Fig. 1

Fig. 2



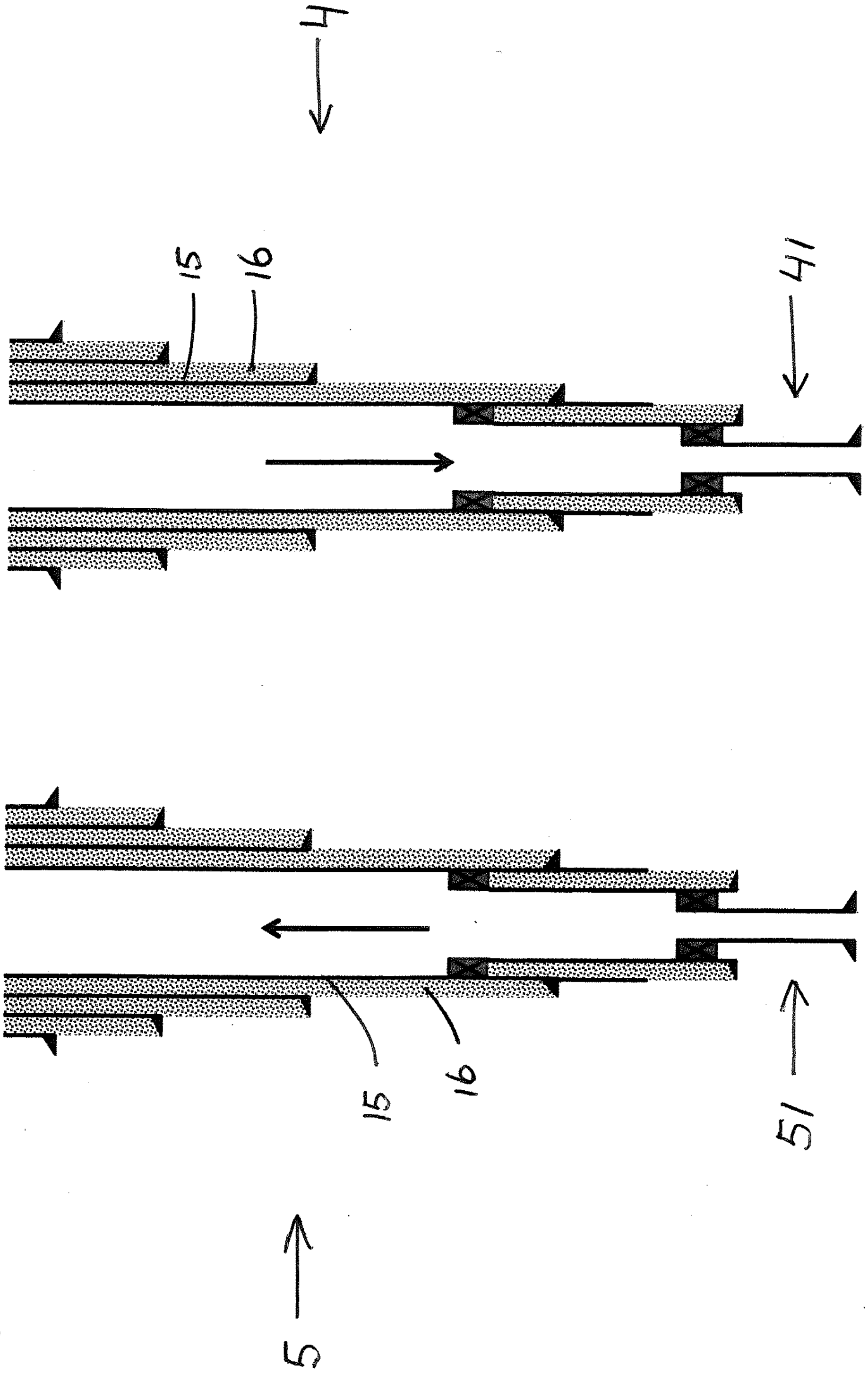


Fig. 3

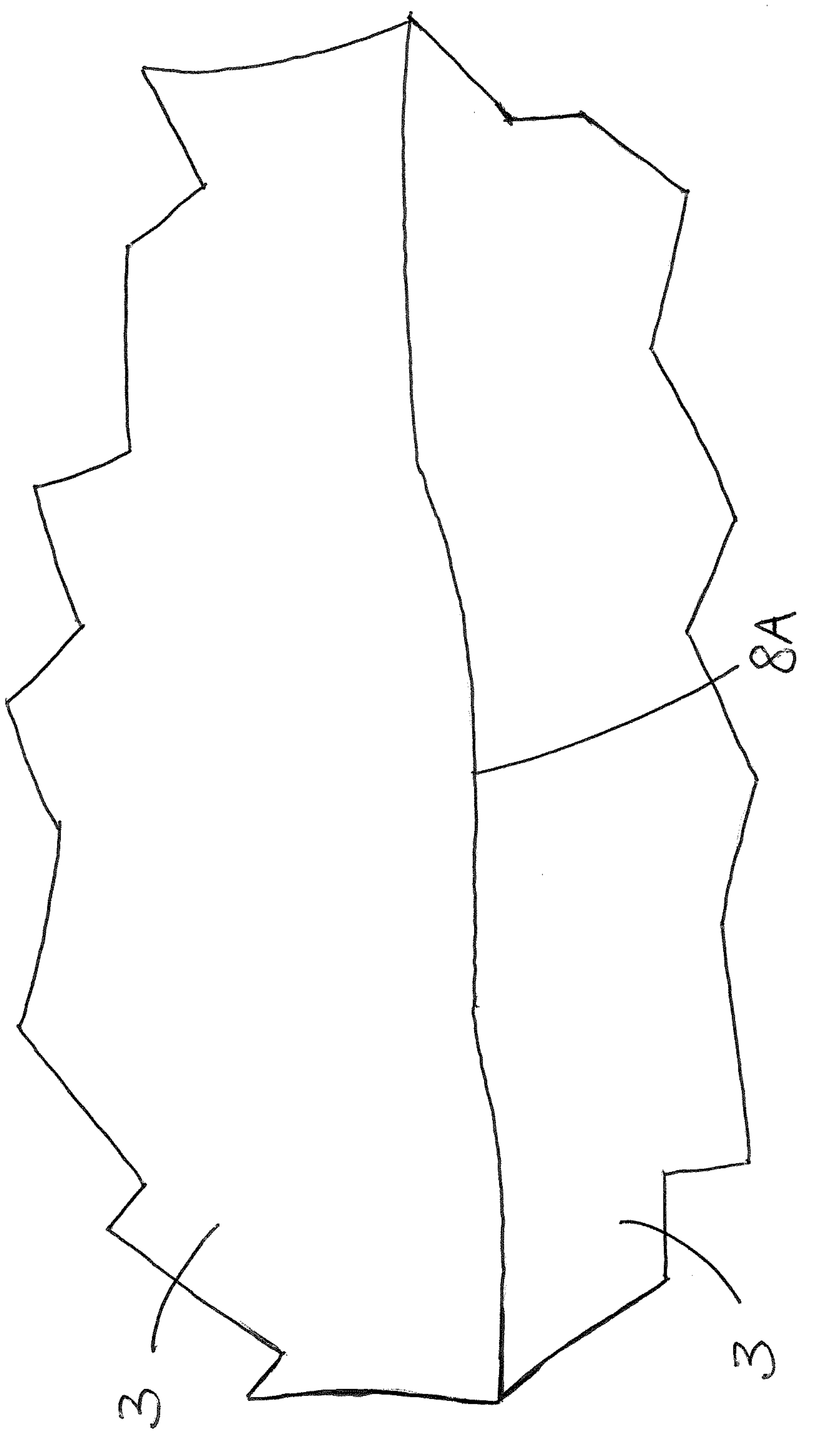


Fig. 4

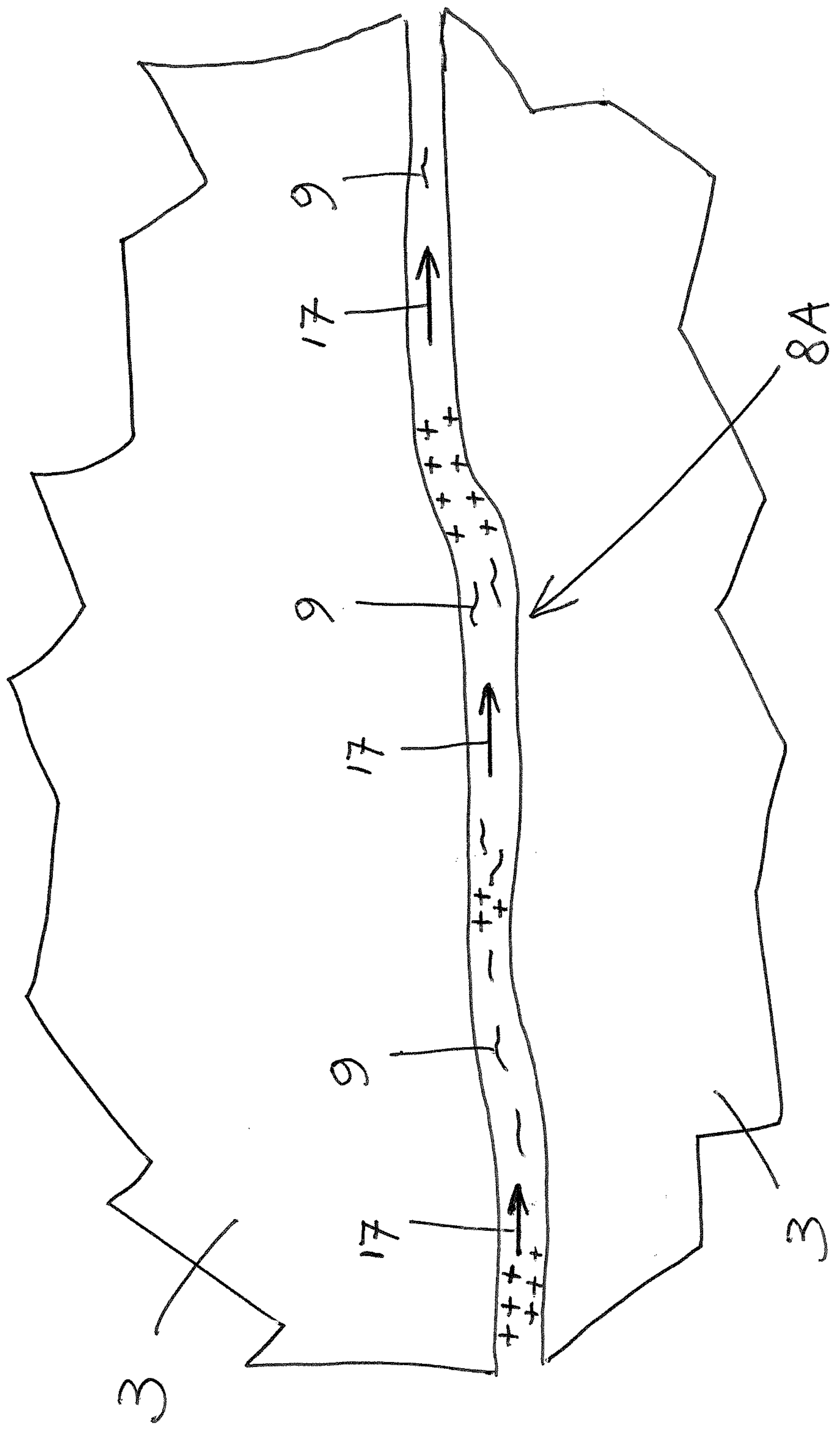


Fig. 5

SAMENWERKINGSVERDRAG (PCT)

RAPPORT BETREFFENDE NIEUWHEIDSONDERZOEK VAN INTERNATIONAAL TYPE

IDENTIFICATIE VAN DE NATIONALE AANVRAGE	KENMERK VAN DE AANVRAGER OF VAN DE GEMACHTIGDE
	P101718NL00
Nederlands aanvraag nr. **2011040**	Indieningsdatum **26-06-2013**
	Ingeroepen voorrangsdatum
Aanvrager (Naam) **Source Geothermal B.V.**	
Datum van het verzoek voor een onderzoek van internationaal type **21-09-2013**	Door de Instantie voor Internationaal Onderzoek aan het verzoek voor een onderzoek van internationaal type toegekend nr. **SN 60672**

I. CLASSIFICATIE VAN HET ONDERWERP (bij toepassing van verschillende classificaties, alle classificatiesymbolen opgeven)

Volgens de internationale classificatie (IPC)

F24J3/08

II. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte minimumdocumentatie

Classificatiesysteem	Classificatiesymbolen
IPC	**F24J**

Onderzochte andere documentatie dan de minimum documentatie, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

III.	☐	GEEN ONDERZOEK MOGELIJK VOOR BEPAALDE CONCLUSIES	(opmerkingen op aanvullingsblad)
IV.	☐	GEBREK AAN EENHEID VAN UITVINDING	(opmerkingen op aanvullingsblad)

Form PCT/ISA 201 A (11/2000)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2011040

A. CLASSIFICATIE VAN HET ONDERWERP
INV. F24J3/08
ADD.

Volgens de Internationale Classificatie van octrooien (IPC) of zowel volgens de nationale classificatie als volgens de IPC.

B. ONDERZOCHTE GEBIEDEN VAN DE TECHNIEK

Onderzochte miminum documentatie (classificatie gevolgd door classificatiesymbolen)
F24J

Onderzochte andere documentatie dan de mimimum documentatie, voor dergelijke documenten, voor zover dergelijke documenten in de onderzochte gebieden zijn opgenomen

Tijdens het onderzoek geraadpleegde elektronische gegevensbestanden (naam van de gegevensbestanden en, waar uitvoerbaar, gebruikte trefwoorden)

EPO-Internal, WPI Data

C. VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	WO 2011/154984 A2 (CONGIU IGNAZIO [IT]; ISOPO CRISTIAN [IT]) 15 december 2011 (2011-12-15) * conclusie 6; figuur 8 * -----	1-9
X	US 2012/018120 A1 (DANKO GEORGE L [US]) 26 januari 2012 (2012-01-26) * figuren 12, 13 * -----	1-9
X	US 2011/082592 A1 (SAITO SEIICHI [JP] ET AL) 7 april 2011 (2011-04-07) * het gehele document * -----	1-9
X	WO 2011/049675 A1 (EXXONMOBIL UPSTREAM RES CO [US]; KAMINSKY ROBERT D [US]) 28 april 2011 (2011-04-28) * het gehele document * -----	1-9
	-/--	

[X] Verdere documenten worden vermeld in het vervolg van vak C.

[X] Leden van dezelfde octrooifamilie zijn vermeld in een bijlage

° Speciale categorieën van aangehaalde documenten

"A" niet tot de categorie X of Y behorende literatuur die de stand van de techniek beschrijft

"D" in de octrooiaanvrage vermeld

"E" eerdere octrooi(aanvrage), gepubliceerd op of na de indieningsdatum, waarin dezelfde uitvinding wordt beschreven

"L" om andere redenen vermelde literatuur

"O" niet-schriftelijke stand van de techniek

"P" tussen de voorrangsdatum en de indieningsdatum gepubliceerde literatuur

"T" na de indieningsdatum of de voorrangsdatum gepubliceerde literatuur die niet bezwarend is voor de octrooiaanvrage, maar wordt vermeld ter verheldering van de theorie of het principe dat ten grondslag ligt aan de uitvinding

"X" de conclusie wordt als niet nieuw of niet inventief beschouwd ten opzichte van deze literatuur

"Y" de conclusie wordt als niet inventief beschouwd ten opzichte van de combinatie van deze literatuur met andere geciteerde literatuur van dezelfde categorie, waarbij de combinatie voor de vakman voor de hand liggend wordt geacht

"&" lid van dezelfde octrooifamilie of overeenkomstige octrooipublicatie

Datum waarop het onderzoek naar de stand van de techniek van internationaal type werd voltooid	Verzenddatum van het rapport van het onderzoek naar de stand van de techniek van internationaal type
6 december 2013	

Naam en adres van de instantie	De bevoegde ambtenaar
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Louchet, Nicolas

1

Formulier PCT/ISA/201 (tweede blad) (Januari 2004)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Nummer van het verzoek om een onderzoek naar de stand van de techniek
NL 2011040

C.(Vervolg). VAN BELANG GEACHTE DOCUMENTEN

Categorie °	Geciteerde documenten, eventueel met aanduiding van speciaal van belang zijnde passages	Van belang voor conclusie nr.
X	WO 2006/002325 A2 (CURLETT HARRY B [US]) 5 januari 2006 (2006-01-05) * het gehele document *	1-9
X	DE 10 2010 017154 A1 (HOU MICHAEL Z [DE]) 1 december 2011 (2011-12-01) * het gehele document *	1-9
X	DE 10 2008 009499 A1 (JUNG REINHARD [DE]) 20 augustus 2009 (2009-08-20) * het gehele document *	1-9
X	WO 2007/122003 A1 (RADERMACHER FRANZ JOSEF [DE]; FOPPE WERNER [DE]) 1 november 2007 (2007-11-01) * het gehele document *	1-9

1

Formulier PCT/ISA/201 (vervolg tweede blad) (Januari 2004)

ONDERZOEKSRAPPORT BETREFFENDE HET RESULTAAT VAN HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK VAN HET INTERNATIONALE TYPE

Informatie over leden van dezelfde octrooifamilie

Nummer van het verzoek om een onderzoek naar de stand van de techniek

NL 2011040

In het rapport genoemd octrooigeschrift	Datum van publicatie	Overeenkomend(e) geschrift(en)	Datum van publicatie
WO 2011154984 A2	15-12-2011	GEEN	
US 2012018120 A1	26-01-2012	GEEN	
US 2011082592 A1	07-04-2011	CN 102032627 A	27-04-2011
		GB 2474347 A	13-04-2011
		JP 2011080645 A	21-04-2011
		US 2011082592 A1	07-04-2011
WO 2011049675 A1	28-04-2011	AU 2010308522 A1	10-05-2012
		US 2012198844 A1	09-08-2012
		WO 2011049675 A1	28-04-2011
WO 2006002325 A2	05-01-2006	AU 2005258224 A1	05-01-2006
		BR PI0512499 A	11-03-2008
		CA 2560331 A1	05-01-2006
		EA 200700100 A1	26-10-2007
		EP 1966489 A2	10-09-2008
		JP 2008504470 A	14-02-2008
		KR 20070050041 A	14-05-2007
		LT 5472 B	25-02-2008
		US 2007223999 A1	27-09-2007
		US 2010272515 A1	28-10-2010
		WO 2006002325 A2	05-01-2006
DE 102010017154 A1	01-12-2011	GEEN	
DE 102008009499 A1	20-08-2009	AT 537330 T	15-12-2011
		DE 102008009499 A1	20-08-2009
		EP 2255067 A1	01-12-2010
		US 2010307756 A1	09-12-2010
		WO 2009100695 A1	20-08-2009
WO 2007122003 A1	01-11-2007	DE 102006018215 A1	22-11-2007
		EP 2010831 A1	07-01-2009
		US 2010031653 A1	11-02-2010
		WO 2007122003 A1	01-11-2007

OCTROOICENTRUM NEDERLAND

WRITTEN OPINION

File No. SN60672	Filing date *(day/month/year)* 26.06.2013	Priority date *(day/month/year)*	Application No. NL2011040
International Patent Classification (IPC) INV. F24J3/08			
Applicant Source Geothermal B.V.			

This opinion contains indications relating to the following items:

- ☒ Box No. I — Basis of the opinion
- ☐ Box No. II — Priority
- ☐ Box No. III — Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV — Lack of unity of invention
- ☒ Box No. V — Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI — Certain documents cited
- ☐ Box No. VII — Certain defects in the application
- ☐ Box No. VIII — Certain observations on the application

	Examiner
	Louchet, Nicolas

Application number

WRITTEN OPINION

NL2011040

Box No. I Basis of this opinion

1. This opinion has been established on the basis of the latest set of claims filed before the start of the search.
2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the application and necessary to the claimed invention, this opinion has been established on the basis of:

   a. type of material:

   ☐ a sequence listing

   ☐ table(s) related to the sequence listing

   b. format of material:

   ☐ on paper

   ☐ in electronic form

   c. time of filing/furnishing:

   ☐ contained in the application as filed.

   ☐ filed together with the application in electronic form.

   ☐ furnished subsequently for the purposes of search.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.
4. Additional comments:

Box No. V Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Yes:	Claims	
	No:	Claims	1-9
Inventive step	Yes:	Claims	
	No:	Claims	1-9
Industrial applicability	Yes:	Claims	1-9
	No:	Claims	

2. Citations and explanations

see separate sheet

Re Item V

Reasoned statement with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Reference is made to the following documents:

D1	WO 2011/154984 A2 (CONGIU IGNAZIO [IT]; ISOPO CRISTIAN [IT]) 15 december 2011 (2011-12-15)
D2	US 2012/018120 A1 (DANKO GEORGE L [US]) 26 januari 2012 (2012-01-26)
D3	US 2011/082592 A1 (SAITO SEIICHI [JP] ET AL) 7 april 2011 (2011-04-07)
D4	WO 2011/049675 A1 (EXXONMOBIL UPSTREAM RES CO [US]; KAMINSKY ROBERT D [US]) 28 april 2011 (2011-04-28)
D5	WO 2006/002325 A2 (CURLETT HARRY B [US]) 5 januari 2006 (2006-01-05)
D6	DE 10 2010 017154 A1 (HOU MICHAEL Z [DE]) 1 december 2011 (2011-12-01)
D7	DE 10 2008 009499 A1 (JUNG REINHARD [DE]) 20 augustus 2009 (2009-08-20)
D8	WO 2007/122003 A1 (RADERMACHER FRANZ JOSEF [DE]; FOPPE WERNER [DE]) 1 november 2007 (2007-11-01)

1. The present application does not meet the criteria of patentability, because the subject-matter of claim 1 is not new.

1.1. D1 discloses:

Een geothermische werkwijze voor het onttrekken van thermische energie uit een onderaards reservoir (11) dat gesteente omvat, waarbij:
- tenminste één fluïduminjectieput (figure 9) en tenminste één fluïdumonttrekkingsput zich elk uitstrekken van een nabij het aardoppervlak gelegen gebied tot in het onderaardse reservoir;
- tenminste één injectiepomp (claim 6) in fluïdumcommunicatie is met de fluïduminjectieput;

- het onderaardse reservoir een onderaards fluïdumstromingspadstructuur (claim 6) omvat die zich uitstrekt door genoemd gesteente van het onderaardse reservoir, waarbij genoemde fluïdumstromingspadstructuur breuken (figure 8) in het gesteente van het reservoir omvat;
- genoemd onttrekken van thermische energie plaatsvindt doordat onder de actie van de injectiepomp een werkfluïdum verpompt wordt om te stromen van het nabij het aardoppervlak gelegen gebied, via, achtereenvolgens, de fluïduminjectieput, de onderaardse fluïdumstromingspadstructuur en de fluïdumonttrekkingsput, terug naar het nabij het aardoppervlak gelegen gebied, waarbij het werkfluïdum aldus thermische energie verkrijgt van warmteuitwisseling met het onderaardse reservoir, en waarbij genoemde verkregen thermische energie aldus door het werkfluïdum naar het nabij het aardoppervlak gelegen gebied geleverd wordt; waarbij
- genoemde breuken een gesloten natuurlijke toestand en een geopende bedrijfstoestand hebben, welke respectievelijk tegengaan en toestaan dat genoemd werkfluïdum zijn voorgenoemde stroming door de breuken uitvoert, waarbij genoemde gesloten natuurlijke toestand gedefinieerd is als op te treden onder invloed van de natuurlijke krachten in het gesteente in het geval geen werkfluïdum in het gesteente aanwezig is;
- de geothermische werkwijze opgestart wordt in een initiële openingsfase van de werkwijze en genoemd onttrekken van thermische energie vervolgens wordt uitgevoerd in een 'thermische energie'- onttrekkingsfase van de werkwijze, waarbij
- gedurende genoemde initiële openingsfase de breuken van hun gesloten natuurlijke toestand in hun geopende bedrijfstoestand worden gebracht doordat de breuken geopend worden door de druk van het werkfluïdum dat onder druk gezet is tenminste door de injectiepomp (claim 6), teneinde daardoor toe te staan dat genoemd verpompt werkfluïdum zijn voorgenoemde stroming door de aldus geopende breuken uitvoert gedurende genoemde navolgende 'thermische energie'-onttrekkingsfase; en
- gedurende genoemde 'thermische energie'-onttrekkingsfase de breuken in hun geopende bedrijfstoestand worden gehouden door het instandhouden van het tenminste door de injectiepomp onder druk zetten van het werkfluïdum.

1.2. it is to be noted that documents D2-D8 disclose also the subject-matter of independent claim 1.

2. Dependent claims 2-9 do not appear to contain any additional features which, in combination with the features of any claim to which they refer, meet the requirements of novelty, because the features of claims 2-9 are already known from D1.