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(71) Applicant: **VITO NV**
2400 Mol (BE)

(72) Inventors:
- **Fransaer, Dirk**
  B-2400 Mol (BE)
- **De Keyser, Alain**
  B-2400 Mol (BE)
- **Heremans, Guido**
  B-2400 Mol (BE)
- **Vandeplas, Stefan**
  B-2400 Mol (BE)

(74) Representative: **IPLodge bv**
Technologielaan 9
3001 Heverlee (BE)

(54) DRILL HEAD FOR ELECTRO-PULSE-BORING

(57) The invention relates to a drill head (1) for electro-pulse-boring. The drill head comprises a high-voltage pulse generator enclosed in a hermetically sealed container (10) and a drill bit (20) mechanically coupled to the container. The drill bit (20) comprises an electrode assembly (40) being electrically coupled to the high-voltage pulse generator. The drill head comprises a supply pipe (31) for supplying drill liquid to the drill bit such that when in operation a borehole bottom portion is filled with drill liquid so as to immerse the drill bit with drill liquid. The drill head is characterized in that it comprises an circumferential seal (50) for separating drill liquid in the borehole bottom portion from a stabilisation liquid (80) that is filing up the borehole up to a surface. At least a portion of the circumferential seal is surrounding a circumferential wall (11) of the container. The drill head further comprises one or more return pipes (32a, 32b) for evacuation of excavated matter mixed with drill liquid from the borehole bottom portion, and wherein the one or more return pipes are mechanically coupled to the container.

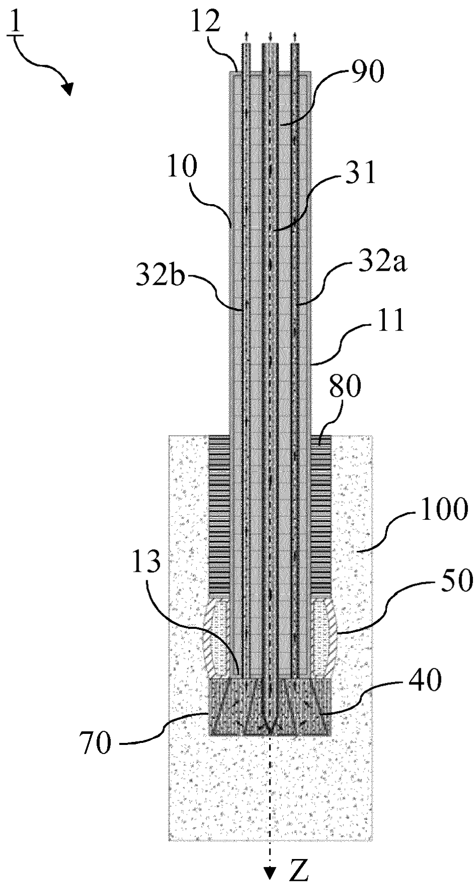

FIG.1

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Description

Field of the invention

[0001] The present invention relates to electro-pulse-boring (EPB). More specifically it relates to a drill head suitable for drilling large-diameter holes, i.e. diameters equal or larger than 40 cm, with EPB.

Description of prior art

[0002] EPB has been proposed as an alternative for rotary drilling of deep holes. The use of a rotary drilling technique is generally limited for holes up to a depth of about 5 km, whereas EPB can be applied going from shallow depth drilling to deep drilling (i.e. 3-5 km) and further to ultra-deep drilling (i.e. 5-10 km). EPB has a higher performance for drilling through hard rock formations when compared with rotary drilling and EPB drilling heads have a longer life span than a rotary drill-bit.

[0003] The drilling of ultra-deep holes has gained interest in view of the ongoing transition from non-renewable primary energies to renewable primary energies. Indeed, by drilling ultra-deep holes, geothermal heat could be recovered and be applied for the generation of electricity or be used as a heat supply.

[0004] The principle of EPB is to apply electro-pulses in the range between 100 and 1000 kV between a high-voltage electrode and a grounded electrode. Each pulse represents an energy in the range between 1 to 10 kJ. The electrodes are part of a drill bit arrangement which forms part of the drill head. The electro-pulses have a typical duration in the nanosecond range, for example a pulse duration of 200 ns, and are applied at intervals in the millisecond range, for example a pulse interval of 100 milliseconds. An electrical discharge passing through for example a rock results in the rock mass to fracture into smaller pieces, i.e. rock cuttings. The electrodes together with the rock portion to be excavated are immersed in a drilling liquid, also named discharge liquid. The drilling liquid is a liquid that has a conductivity that is lower than the conductivity of the material in which the drilling is carried out, such that the generated electric fields are steered into the rock in the region of the electrodes. An example of a typical fluid used as a drilling liquid for EPB is transformer oil.

[0005] For novel geothermal applications large-diameter holes are required. Large-diameter holes have to be construed as holes having a diameter of about 40 cm or more.

[0006] Although the use of EPB has been proposed for drilling ultra-deep holes, no workable solution has been disclosed of an apparatus that efficiently can drill holes suitable for the novel geothermal applications. Developing an EPB apparatus for drilling large diameter holes at km depths is challenging and involves numerous issues to be solved.

[0007] A problem related to large diameter holes is the drill speed that can be obtained, i.e. the number of meters per hour that can be drilled. In order to limit the total drilling time for a 5 to 10 km hole, the drill speed should be of the order of several meters to tens of meters per hour and this high drill speed should be maintained during the entire drilling process. For a 50 cm diameter hole, this corresponds to excavating several m^3 of rock per hour, which is challenging with current technology. It is also important that the high drill speed is maintained when drilling to deeper regions where the environmental conditions become more severe. Examples of environmental conditions are pressure, temperature and the potential occurrence of harder rock formations at large depths.

[0008] To maintain a high drill speed it is also important to efficiently evacuate the excavated matter, e.g. rock cuttings, towards the surface. Even if sufficient power is available to repetitively provide high-energy pulses to crush the rock, a rock debris evacuation system should be able to evacuate at a high rate a large volume of rock cuttings mixed with drill liquid over a long distance from the bore hole up to the surface. For example, if the evacuation rate of the rock is too slow or inefficient, the primary chunks of the rock can be further broken into smaller and smaller pieces before being discharged and which can reduce the efficiency of EPB operation. Ideally, the primary rock cuttings should have a diameter in the range of 2 to 3 cm and the primary rock cuttings should be evacuated without delay after the formation of the cuttings such that no secondary smaller rock cuttings can be formed.

[0009] A further problem is related to the use of the drilling liquid, such as transformer oil. Filling up the bore-hole up to the surface requires large quantities of drill liquid and hence the drill liquid becomes a non-negligible cost of the EPB system. The drill liquid can also be a potential risk of pollution.

[0010] A number of drilling apparatuses based on the EPB concept have been described. However, most of the publications in the field of EPB drilling apparatuses for large diameters are theoretical studies and designs without much comparison with actual drilling tests under deep drilling conditions. As of today, no detailed designs of an operating and hence proven EPB-based drilling apparatus using a down-hole pulse generator that can drill holes having a diameter larger than 40 cm at large depth has been published. Hence there is room for improving designs of EPB apparatuses for solving the above mentioned problems and challenges.

[0011] In patent publication US164388, an EPB apparatus comprising two concentric pipes separated by electric insulators is disclosed, and wherein an inner pipe corresponds to a high-voltage pipe coupled to a high-voltage electrode and an outer pipe is grounded and coupled to a ground electrode. The high voltage pipe is coupled with a pulse generator that is located at the surface, i.e. outside the bore hole. A debris collecting device is described wherein the debris is evacuated through a space between the wall of the drilled hole and part of an external wall of the drilling apparatus.

[0012] In patent publication EP1711679, an EPB-based drilling apparatus is described using a down hole pulse generator and wherein electrodes are moveable relative to each other in order to secure bottom contact for each of the electrodes. A number of hydraulic nozzles for nozzle jetting of the drill fluid and thereby directing and lifting the rock cuttings are described as well. The rock cuttings are removed from the periphery of the bottom-hole up to the surface by pumping the drill fluid together with the cuttings through an annular spacing between the wall of the drilled borehole and an outer perimeter of the drilling apparatus.

[0013] In patent publication RU2477370, a drill head is proposed for drilling bore holes of a diameter of 36 cm using EPB and wherein a high-voltage pulse generator is integrated in the drill head. The drill fluid is supplied to the electrodes through a central pipe and the rock cuttings together with the drill liquid are evacuated through an annular spacing between the drill head and the wall of the drilled borehole.

[0014] In order to fulfil the demand for ultra-deep drilling of large-diameter bore holes, there is a need to provide a reliable, cost-effective and working alternative EPB drilling apparatus that overcomes the problems and challenges mentioned above.

Summary of the invention

[0015] It is an object of the present invention to provide a drilling apparatus using the EPB technique for drilling bore-holes of a diameter of at least 40 cm, preferably at least 50 cm at a speed of several meters per hour and at the same time perform the drilling in a cost-effective way. Nevertheless, although the drilling apparatus of this invention is particularly suitable for the drilling of bore-holes with such large diameters, it is also suitable for drilling bore-holes with smaller diameters of for example 5, 10 or 20 cm or the like.

[0016] The present invention is based on insights of the inventors and based on experiments performed. These insights supported by the experiments resulted in the conclusion that by limiting the volume of the circulating drilling liquid, not only can be saved on the cost price of the drilling liquid, being for example a transformer oil or a bio-oil, but also that the excavated matter, e.g. rock cuttings, can be evacuated in a more efficient way by providing dedicated return pipes for evacuating the rock cuttings mixed with drill fluid from a bottom portion of the borehole.

[0017] The present invention is defined in the appended independent claims. The dependent claims define advantageous embodiments.

[0018] According to a first aspect of the invention, a drill head for electro-pulse-boring suitable for drilling a borehole having a diameter equal or larger than 50 cm is provided.

[0019] The drill head for electro-pulse-boring according to the invention comprises a high-voltage pulse generator enclosed in a hermetically sealed container such that the container is fillable with an electrically insulating fluid. The container comprises i) a circumferential wall extending along a central axis coaxial with a drilling axis of the drill head and ii) a first and a second axial cover for sealingly closing respectively a first and a second end of the circumferential wall. A drill bit is mechanically coupled to the container and comprises an electrode assembly electrically coupled with the high-voltage pulse generator for receiving high-voltage pulses. A supply pipe is configured for supplying drill liquid to the drill bit such that when in operation a borehole bottom portion is filled with drill liquid so as to immerse the drill bit with drill liquid. Generally, the supply pipe is mechanically coupled to the container.

[0020] In a preferred embodiment, the supply pipe is traversing the container along the central axis from a supply pipe entrance portion traversing through the first axial cover to a supply pipe exit portion traversing through the second axial cover.

[0021] The drill head according to the invention comprises a circumferential seal for separating drill liquid in the borehole bottom portion from a stabilisation liquid that is filing up the borehole up to a surface. At least a portion of the circumferential seal is surrounding a part of the circumferential wall of the container.

[0022] Generally, the circumferential seal extends in a direction parallel with the central axis. The circumferential wall of the container has a height measured along the central axis between the first and the second end of the circumferential wall. Hence the circumferential seal can also be construed as extending in a height direction of the container, being parallel with the central axis, along part of the height of the container.

[0023] The drill head according to the invention further comprises one or more return pipes for evacuation excavated matter mixed with drill liquid from the borehole bottom portion. These one or more return pipes are mechanically coupled to the container. The excavated matter comprises for example rock cuttings when a borehole is drilled through rock formations.

[0024] Advantageously, by providing an circumferential seal surrounding the circumferential wall of the container, only a bottom portion of the borehole comprising the drill bit with the electrodes needs to be immersed with the drill liquid and an upper portion of the bore hole up to the surface can be filled with any fluid capable of acting as a stabilisation liquid for example a stabilization liquid such as water. Moreover, as the amount of circulating drill liquid is reduced, the risks and/or effects of environmental pollution by the drill liquid are reduced.

[0025] Advantageously, by providing the return pipe or pipes to evacuate the excavated matter mixed with the drill liquid, an increased flow speed is obtained when compared to prior art drill heads where no return pipes are used and where the excavated matter are to be evacuated through the annular spacing between the bore head and the borehole.

[0026] The skilled person will be capable of configuring a cross sectional area of the return pipes relative to the cross sectional area of the supply pipe such that supply of the drilling liquid is not hampered by evacuation of the excavated matter, or in other words wherein supply of the drilling liquid and evacuation of the excavated matter are equilibrated.

[0027] Advantageously, the return pipe or pipes can be coupled with a return channel of a drill string for transporting the excavated matter mixed with drill fluid from the drill head to the surface, thereby maintaining the increased flow speed to evacuate the excavated matter from the borehole up to the surface.

[0028] By using a combination of return pipes and a seal for sealing a space around the drill head, no drilling liquid mixed with rock cuttings is flushed between the annulus formed by the wall of the borehole and an outer wall of the drill head as is the case with prior art EPB machines. As the mixture of rock cuttings and drill liquid is returning through pipes instead of an annular ring around the drill head and drill string, the overall volume of circulating drill liquid may be further limited. The annulus is filled with stabilisation liquid, which can be selected to provide an optimum compromise between cost and optimal stabilisation of the bore hole wall.

[0029] In some embodiments, the one or more return pipes are either coupled or partly coupled to an inner side of the circumferential wall of the container, while in other embodiments the one or more return pipes are coupled to the outside of the circumferential wall of the container.

[0030] In preferred embodiments, the one or more return pipes are traversing the container and each of the return pipes comprises i) a pipe entrance portion traversing through the second axial cover and ii) a pipe end portion, and wherein the pipe end portions of the return pipes are traversing through the first axial cover. Alternatively, the pipe end portions can also be coupled to a common feedthrough for traversing through the first axial cover.

[0031] Advantageously, by providing the return pipe or pipes having a pipe entrance portion traversing the second axial cover of the container, i.e. the bottom flange of the container, the entrance of the return pipes are located on top of the electrode region allowing to efficiently evacuate the rock cuttings.

[0032] Additionally, by providing the return pipes having a pipe entrance portion traversing the bottom cover of the container, the height of the bottom portion of the borehole to be filled with drill liquid can be limited to a strict minimal height which is the distance between the borehole bottom where the electrodes are resting and the bottom cover of the container.

[0033] According to a second aspect of the invention an electro-pulse boring system is provided. The electro-pulse boring system comprises a drill head for electro-pulse-boring as discussed above, a lifting device located at the surface and configured for lifting the drill head from the borehole, a drill string assembly, a drill liquid circulation system. The electro-pulse boring system will further comprise any additional parts known to the skilled person needed for the functioning of the boring system, for example without being limited thereto, a dedicated power supply, a mud supply system for stabilising the bore hole, a separator for separating the drilling liquid from the excavated matter etc.

[0034] The drill string assembly comprises at least i) a feed channel for supplying drill liquid from the surface to the drill head, ii) a power cable, running from the surface to the drill head for supplying power to the electro-pulse generator and iii) one or more return channels for transporting a mixture of excavated matter and drill liquid up to the surface.

[0035] The drill liquid circulation system comprising at least i) a drill liquid reservoir, ii) a pump for pumping drill liquid from the drill liquid reservoir to the drill head through the feed channel of the drill string assembly, and iii) a drill liquid recovery device configured for receiving the mixture of excavated matter and drill liquid from the one or more return channels of the drill string assembly and configured for separating the excavated matter from the drill liquid and transporting the recovered drill liquid to the reservoir.

Short description of the drawings

[0036] These and further aspects of the invention will be explained in greater detail by way of example and with reference to the accompanying drawings in which:

- Fig.1 shows a cross-sectional view of a first embodiment of a drill head according to the present invention,
- Fig.2 shows a cross-sectional view of part of a second embodiment of a drill head according to the present invention,
- Fig.3 shows an isometric view of a further example of a drill head according to the invention,
- Fig.4 shows an isometric view of an example of drill bit comprising an electrode assembly formed by ground and high-voltage electrode tips,
- Fig.5 shows a projection of a further example of a drill bit comprising an electrode assembly having circumferential electrode components,
- Fig.6 schematically illustrates an example of a container of an electro-pulse generator.

[0037] The drawings of the figures are neither drawn to scale nor proportioned. Generally, identical components are denoted by the same reference numerals in the figures.

Detailed description of embodiments of the invention

[0038] The present disclosure will be described in terms of specific embodiments, which are illustrative of the disclosure and not to be construed as limiting. It will be appreciated by persons skilled in the art that the present disclosure is not limited by what has been particularly shown and/or described and that alternatives or modified embodiments could be developed in the light of the overall teaching of this disclosure. The drawings described are only schematic and are non-limiting.

[0039] Use of the verb "to comprise", as well as the respective conjugations, does not exclude the presence of elements other than those stated. Use of the article "a", "an" or "the" preceding an element does not exclude the presence of a plurality of such elements.

[0040] Furthermore, the terms first, second and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequence, either temporally, spatially, in ranking or in any other manner. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the disclosure described herein are capable of operation in other sequences than described or illustrated herein.

[0041] Reference throughout this specification to "one embodiment" or "an embodiment" or "some embodiment" means that a particular feature, structure or characteristic described in connection with the embodiments is included in one or more embodiment of the present disclosure. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment, but may. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner, as would be apparent to one ordinary skill in the art from this disclosure, in one or more embodiments.

[0042] When the wording "coupled", "mechanically coupled" or "electrically coupled" is used, it is to be construed as either directly or indirectly coupled. An indirectly coupling between a first and a second element can for example be made by placing a third element in between the first and second element.

[0043] The present invention is related to a drill head for electro-pulse-boring of a borehole having a diameter equal or larger than 40 cm, preferably equal or larger than 50 cm. The drill head is a component that is part of an electro-pulse boring system. Some components of the system are located on the surface and some components are located inside the borehole. The EPB boring system typically comprises at least a lifting device, a drill string assembly, a high voltage supply, a drill liquid circulation system and a drill head. The drill head is the component that is lowered in the bore hole and comprises a drill bit with electrodes or drill tips. For EPB systems, a high-voltage generator is required and generally this generator can either be located on the surface or it can be part of the drill head and be lifted down the borehole together with the drill bit. The drill head of the present invention is a drill head configuration that comprises the high-voltage pulse generator, which for these configurations is generally named down-hole generator.

Drill head, general

[0044] Examples of a drill head 1 according to the present invention are schematically shown on Fig.1 to Fig.3. Not all components of the drill head are shown on these figures, only those components needed for understanding the invention are shown. Reference number 100 on Fig.1 schematically illustrates, as an example, a rock formation through which a hole is to be drilled.

[0045] The drill head 1 according to the present disclosure comprises a high-voltage pulse generator enclosed in a hermetically sealed container 10 such that the container can be filled with an electrically insulating fluid 90. An electrically insulating fluid 90 is for example nitrogen or an inert gas. As illustrated on Fig.1, the container 10 of the high-voltage generator comprises a circumferential wall 11 extending along a central axis Z. The central axis Z is coaxial with a drilling axis of the drill head 1. A first axial cover 12 and a second axial cover 13 are sealingly covering respectively a first and a second end of the circumferential wall 11. The first and second axial cover can respectively also be named top and bottom cover in the sense that the bottom cover is positioned deeper in the borehole than the top cover. The high-voltage pulse generator enclosed inside the container 10 is not shown on Fig.1.

[0046] In embodiments, the circumferential wall 11 is for example formed by a hollow pipe and hence has the shape of a cylinder. In other embodiments, the circumferential wall 11 defining the outer wall of the container 10 can have any other shape such as a prism or a square. The circumferential wall of the container has a height measured along the central axis Z between the first and the second end of the circumferential wall. For some embodiments, the height of the container can be several meters, depending on the size of the high-voltage pulse generator.

[0047] The drill head 1 further comprises a drill bit that is mechanically coupled to the container 10, preferably coupled to the second end of the circumferential wall, for example by attachment to the axial cover 12. In other words, the drill bit is mechanically supported through the container, preferably through the bottom side of the container 10. The drill bit comprises an electrode assembly 40 that is electrically coupled with the high-voltage pulse generator for receiving high-voltage pulses. Typically, the electrode assembly 40 includes a ground electrode 41 and a high-voltage electrode 42, as shown for example on Fig.2 and Fig.3.

[0048] The circumferential wall 11 and the first 12 and second 13 axial cover are typically made or partly made of a metal such as stainless steel and are electrically grounded. The ground electrode of the electrode assembly 40 is then coupled with the second cover or with the circumferential wall in order to form a grounded connection. The ground electrode is for example welded to the second cover plate or welded to a portion of the circumferential wall. A high-voltage feed-through is passing through the second axial cover 13 and is configured for providing high-voltage to the high-voltage electrode 42.

[0049] As discussed above, to operate an EPB drill head, a drill liquid, also named discharge liquid, is required. The drill head according to the present disclosure comprises a supply pipe 31 for supplying drill liquid to the drill bit such that when in operation a borehole bottom portion 70 is filled with drill liquid so as to immerse the drill bit with drill liquid.

[0050] Generally, the supply pipe 31 is mechanically coupled to the container. In the embodiment shown on Fig. 1, the supply pipe 31 is traversing the container 10 along the central axis Z from a supply pipe entrance portion traversing through the first axial cover 12 to a supply pipe exit portion traversing through the second axial cover 13. However, any other arrangement of the supply pipe with respect to the container considered suitable by the skilled person may be used as well.

[0051] As further illustrated on Fig. 1 and Fig.3, the drill head 1 according to the present disclosure is characterized in that it comprises a circumferential seal 50 for separating drilling liquid in the borehole bottom portion 70 from a stabilisation liquid 80 that is filing up the borehole up to the surface. At least a portion of the circumferential seal 50 is surrounding part of the circumferential wall 11. The use of the word surrounding has to be construed as enclosing. For example, for a cylindrically shaped circumferential wall 11, as shown in the embodiment on Fig.1, the circumferential seal 50 surrounding the cylindrically shaped circumferential wall corresponds to encircling the circumferential wall by 360°. As illustrated on Fig.1, the circumferential seal 50 surrounding part of the circumferential wall 11 of the container, is also extending in a height direction of the circumferential wall, i.e. in a direction parallel with the central axis Z. The height direction of the container can also be construed as an axial direction of the container, which is a direction parallel with the central axis Z of the container.

[0052] In some embodiments, as shown for example on Fig.1, the entire circumferential seal 50 is surrounding part of the circumferential wall 11 of the container. In this example shown on Fig.1, a lower part of the circumferential wall, near the second end of the circumferential wall where the second axial cover 13 is located, is surrounded by the circumferential seal 50.

[0053] In other embodiments, as shown for example on Fig.3, only a first portion of the circumferential seal 50 is surrounding part of the circumferential wall of the container and a second portion of the circumferential seal is surrounding the drill bit. In other words, when an embodiment of a drill head as shown on Fig.3 is in operation, the second portion of the circumferential seal is located in the bottom portion of the borehole where the drill bit is located.

[0054] The stabilisation liquid 80 is for example water. The stabilisation liquid stabilises the wall of the bore hole. As a circumferential seal is provided that is surrounding the circumferential wall of the container of the high-voltage pulse generator, the excavated matter mixed with the drill liquid cannot be evacuated anymore through an annulus of the borehole, as is the case with prior art devices. The drill head according to the present disclosure is therefore further characterized that it comprises one or more return pipes 32a, 32b for evacuation excavated matter, such as rock cuttings, mixed with drill liquid from the borehole bottom portion 70. In a preferred embodiment, the drill head according to the present disclosure comprises two or more return pipes mechanically coupled to the container 10. The container 10 together with the supply pipe 31 and the return pipes 32a,32b is illustrated in more detail on Fig.6. The electro-pulse generator enclosed inside the container is not shown on Fig.6.

[0055] The drill head according to the present invention is suitable to drill through rock, e.g. sandstone, granite and other hard rock materials, and evacuate the rock cuttings via the return pipes. The drill head is of course also suitable to drill through any sediment underground layer and evacuate debris through the return pipes.

[0056] The circumferential seal is for example made or partly made out of an elastic material and/or a compressible material. The seal is for example made out of rubber. In some embodiments, the circumferential seal 50 is inflatable in order to provide for a robust sealing.

[0057] In embodiments, the return pipes 32a,32b are made of a metal such as stainless steel.

[0058] In embodiments, the supply pipe 31 is made of or partly made of an electrically insulating material such as fiberglass or another insulator.

[0059] To mechanically couple the return pipes to the container 10 of the high-voltage pulse generator a number of options exist. A number of detailed embodiments of a drill head according to the present disclosure will be further discussed.

[0060] In the embodiment schematically shown on Fig.1, the one or more return pipes are traversing the container 10. Therefore, each of the return pipes 32a, 32b comprises a pipe entrance portion traversing through the second axial cover 13 and a pipe end portion traversing through the first axial cover 12. Holes can for example be made through the first and second axial cover to receive the end portions of the return pipes and the end portions can be placed through the holes and welded such that the interior of the container remains hermetically sealed for receiving the electrically insulating fluid 90.

[0061] As further illustrated on Fig.1, each of the one or more return pipes is coupled or partly coupled to an inner side of the circumferential wall 11. In embodiments, the return pipes can be welded to the inner side of the circumferential wall 11.

[0062] In the embodiment shown on Fig.1, an inner circumferential side of the circumferential seal 50 is attached to an outer side of the circumferential wall 11. For example, the inner side of the circumferential seal can be attached to the circumferential wall by using metallic ring connectors, not shown on Fig.1.

[0063] In an alternative embodiment, similar to the embodiment of Fig.1, the pipe end portions of the return pipes are coupled to a common feedthrough for traversing through the first axial cover 12. The feedthrough can then be further coupled to a single return channel to transport the rock cuttings mixed with drill liquid to the surface. Advantageously, with this alternative embodiment, only one dedicated hole needs to be made in the first axial cover for receiving the common feedthrough.

[0064] A cross-sectional view of a second embodiment of a drill head according to the present invention is shown on Fig.2. In this embodiment the return pipes 32a and 32b are mounted on the outside of the circumferential wall 11 of the container. The circumferential seal is not shown on Fig.2.

[0065] On Fig.3 an isometric view of a drill head is shown comprising return pipes 32a and 32b mounted on the outside of the circumferential wall of the container 10. In this embodiment shown on Fig.3, a circumferentially extending flange 15 is surrounding and attached to the circumferential wall 11 so as to form a collar around the circumferential wall 11. The circumferentially extending flange is for example welded to the circumferential wall. In embodiments where the container has a cylindrically circumferential wall 11, the circumferentially extending flange 15 is for example a ring-shaped flange.

[0066] The circumferentially extending flange 15 is used for both coupling the circumferential seal 50 and for coupling the return pipes as discussed below.

[0067] As shown on Fig.3, at least a portion of an inner circumferential side of the circumferential seal 50 is attached to an outer side of the circumferentially extending flange 15. In other words, this is an example of an indirect coupling of the circumferential seal to the circumferential wall by using the circumferentially extending flange located between the circumferential wall and the circumferential seal. As already mentioned above, in this embodiment, the circumferential seal 50 has a first portion, being the portion that is attached to the extending flange 15, and a second portion surrounding the drill bit.

[0068] In the embodiment shown on Fig.3, the one or more return pipes 32a, 32b are attached to the outer side of the circumferential wall 11, for example by welding. The circumferentially extending flange comprises for each of the return pipes a corresponding feedthrough opening and each feedthrough opening is receiving a corresponding return pipe entrance portion. After placing a return pipe entrance portion through a hole of the circumferentially extending flange it can be welded to the circumferentially extending flange 15.

[0069] The invention is not limited to the number of return pipes but there should be at least one return pipe, preferably at least two pipes. The reason being that due to the fact that there is not much space between the circumferential wall and the borehole, the diameter of the return pipes 32a, 32b is limited and more than one pipe is needed for obtaining a combined drill liquid evacuation capacity that is equal or larger than the drill liquid supply capacity through the supply pipe 31.

[0070] In general, the one or more return pipes have a cross sectional area configured such that the sum of the cross sectional areas of each of the return pipes is equal to a cross sectional area of the supply pipe within an accuracy of 30%, preferably within an accuracy of 25%, more preferably within an accuracy of 20%.

Hiah-voltaae pulse generator

[0071] The electro-pulse generator comprises a plurality of capacitors forming part of what is named a Marx generator, known in the art and disclosed in for example RU2477370. The plurality of capacitors are repetitively charged and de-charged and the high-voltage that is outputted is the sum of the voltages on the capacitors. Such a generator is optimized to generate high-voltage pulses with short pulse duration time, typically up to 300 ns, for example in the 100 to 200 ns range or lower, as required for EPB.

[0072] In embodiments where the supply pipe 31 is traversing the container 10 along said central axis Z from a supply pipe entrance portion traversing through the first axial cover 12 to a supply pipe exit portion traversing through the second axial cover 13, the capacitors are positioned around the supply pipe 31. Alternatively, each of the capacitors have a ring-shape and are circumscribing the supply pipe 31.

Electrode assemblies

[0073] As discussed above, the drill bit 20 comprises an electrode assembly 40. The present invention is however not limited to the specific type of electrode assembly 40 or the specific shape or geometry of the electrode assembly 40 , as illustrated on fig. 4 and 5.

[0074] In embodiments, the electrode assembly has for example a circular perimeter with an outer diameter D_E measured in a plane perpendicular to the central axis Z, and wherein $D_E \geq 40$ cm, preferably $D_E \geq 50$ cm. This outer diameter of the electrode assembly defines the diameter of the borehole that can be drilled.

[0075] In embodiments, the circumferential wall 11 of the container has a cylindrical shape with an outer diameter D_{PG} and wherein generally $D_{PG} < D_E$. Indeed, the outer diameter D_{PG} has to be smaller than D_E such that there is at least sufficient space for placing the circumferential seal 50.

[0076] The perimeter of the electrode assembly 40 is not limited to a circular shape but the perimeter can for example also be an oval, a square or any other shape depending on the required cross-sectional shape for the borehole.

[0077] A distinction can also be made between electrode assemblies having a single-segment electrode or a multi-segment electrode. A single-segment electrode assembly 40 is an electrode assembly comprising a single ground-electrode 41 and a single high-voltage electrode 42, as shown for example on fig.3.

[0078] An example of a drill bit 2 comprising a single-segment electrode assembly is shown on Fig. 4. The electrode assembly shown on Fig.4 comprises a single ground electrode and a single high-voltage electrode formed by respectively a plurality of ground electrode tips 41a and a plurality of high-voltage electrode tips 42a. These ground and high-voltage electrode tips are radially positioned with respect to the central axis of the drill head.

[0079] In further embodiments, as illustrated on Fig.5, the drill bit 20 comprise an electrode assembly wherein the ground and high-voltage electrodes have respectively a circumferential ground electrode component 41b and a circumferential high-voltage electrode component 42b. The circumferential ground electrode component 41b and the circumferential high-voltage electrode component 42b are forming an outer perimeter of respectively the ground and high-voltage electrode. These circumferential electrode components 42b,42b have for example a circular shape as shown on Fig.5. An advantage of using electrode components forming a closed periphery of the electrode assembly is that generally a drilled borehole is obtained that has a smoother surface.

[0080] In alternative embodiments, the electrode assembly 40 is not a single-segment electrode assembly but a multi-segment electrode assembly comprising a plurality of electrode segments. In these embodiments, each of the electrode segments has a ground 41 and high-voltage 42 electrode. For example, the electrode assembly can comprise two, three, four or more electrode segments. The segments are preferably connected to each other so that they are capable of drilling as one entity. In an example, the electrode assembly is circular and can comprise two, three, four or more electrode segments which are mechanically coupled to form a unity. The electrode segments may be arranged to be individually steerable or controllable to permit directional boring, or they may be controllable as a whole.

[0081] In embodiments comprising a multi-segment electrode assembly, the high-voltage pulse generator is configured for individually powering each of the electrode segments.

[0082] The use of segmented electrodes has a number of advantages. A first advantage of using a multi-segment electrode is that the power pulses generated by the high-voltage pulse generator can sequentially be applied to each of the plurality of segments and hence the delivered power can be used more efficiently and be better distributed over the entire cross-sectional area of the borehole to be drilled. Remark that if the diameter of the bore hole is increasing, for a given operational frequency of the high-voltage pulse generator, the total power needed to excavate the borehole is in a first approximation quadratically increasing with the diameter of the borehole. The use of a segmented electrode allows to divide the total power to be delivered among the various segments. This may be advantageous in situations where boring of bore holes with large diameters of for example 50 cm or 100 cm diameter is intended, and a drill speed is envisaged which approaches or is the same as a conventional drill speed used for the boring of bore holes with a smaller diameter. The use of a segmented drill head permits limiting the electric power that is supplied to each segment as well as the pulse frequencies to conventionally used values. Drilling of bore holes with increasing diameters would otherwise involve an almost exponential increase of the electric power to be delivered by the high-voltage pulse generator with increasing bore hole diameter.

[0083] A second advantage of using multi-segment electrode assemblies is that the drill direction can be changed or corrected by a proper control of the individual electrode segments. For example, the drill head direction could be changed by delivering more pulses to one of the segments compared to the other segments.

[0084] In a particular embodiment, the electrode assembly is segmented and one of the electrode segments is configured for drilling a locally enlarged bore hole resulting in the formation of a borehole having a longitudinal groove or channel in the wall of the borehole. This makes the device of the present invention suitable for horizontal boring as well. Indeed, the local enlargement may serve as a channel for evacuating the excavated matter mixed with drill liquid.

Rock evacuation testing

[0085] The inventors have performed a series of tests with a drill head according to the present invention to investigate the evacuation efficiency of rock cuttings. A prototype drill head as shown on Fig.3 was used for testing purposes. The supply pipe 31 used has a diameter of 10,16 cm, i.e. 4 inches, and the two return pipes have a diameter of 6,35 cm, i.e. 2.5 inches. The drill head was dimensioned to drill bore holes of 50 cm which results in a bore bottom portion having a volume of 54977 cm^3 and which was filled with 54 liter of drill liquid. The drill liquid supply rate was optimized in order to suck a maximum rate of rock cutting through the two return pipes. An optimum rock cutting recovery was obtained with a drill liquid supply rate of 1000 liter/minute which resulted in a recuperation of 2,35 m^3 of rock cuttings per hour.

[0086] The drill head used for the testing uses a Marx-type high-voltage generator providing pulses of 500kV at a rate between 1 up to 25 Hz. Further experiments have demonstrated that with the drill bit having a 50 cm diameter electrode configuration used in combination with the high-voltage generator, the drill head is capable of crushing 2,35 m^3/ hour of rock. Hence the evacuation system according to the invention using return pipes combined with a seal to reduce the total drill liquid volume is capable of efficiently evacuating the rock cuttings at a rate that is equal to the rate the rock cuttings are produced. With such a system a drill speed of 12 m/hour or more can be reached.

Electro-pulse boring system

[0087] As mentioned above, the drill head is a component of an EPB system. An EPB system comprises besides the drill head also a lifting device located at the surface and configured for lifting the drill head from the borehole. The EPB system also comprises a drill string assembly comprising i) a feed channel for supplying drill liquid from the surface to the drill head, ii) a power cable which may for example run from the surface to the drill head for supplying power to the electro-pulse generator, and iii) one or more return channels for transporting a mixture of excavated matter and drill liquid up to the surface.

[0088] The EPB system also comprises a drill liquid circulation system comprising at least i) a drill liquid reservoir, ii) a pump for pumping drill liquid from said drill liquid reservoir to the drill head through said feed channel of the drill string assembly, and iii) a drill liquid recovery device configured for receiving said mixture of excavated matter and drill liquid from said one or more return channels of the drill string assembly and configured for separating the excavated matter from the drill liquid and transporting the recovered drill liquid to the reservoir.

[0089] In embodiments, the supply pipe entrance portion of the supply pipe comprises a first coupling means configured for coupling with the feed channel of the drill string transporting the drill fluid from the surface to the drill head. The coupling means can for example be a coupling flange.

[0090] In embodiments, each of the pipe end portions of the return pipes traversing the first axial cover comprises a second coupling means and wherein the second coupling means is configured for coupling with the return channel of the drill string transporting the excavated matter mixed with drill fluid from the drill head to the surface. In alternative embodiments comprising a common feedthrough traversing the first axial cover, as discussed above, the common feedthrough comprises a second coupling means configured for coupling with the return channel of the drill string.

Claims

1. A drill head (1) for electro-pulse-boring of a borehole, comprising

- a high-voltage pulse generator enclosed in a hermetically sealed container (10) such that the container (10) is fillable with an electrically insulating fluid, and wherein said container (10) comprises i) a circumferential wall (11) extending along a central axis (Z) coaxial with a drilling axis of the drill head (1) and ii) a first (12) and a second (13) axial cover for sealingly closing respectively a first and a second end of said circumferential wall (11),
- a drill bit (20) mechanically coupled to said container (10) and wherein said drill bit comprises an electrode assembly (40) electrically coupled with said high-voltage pulse generator for receiving high-voltage pulses,
- a supply pipe (31) for supplying drill liquid to said drill bit such that when in operation a borehole bottom portion is filled with drill liquid so as to immerse said drill bit with drill liquid,

characterized in that said drill head (1) comprises

- a circumferential seal (50) for separating drill liquid in the borehole bottom portion from a stabilisation liquid that is filing up the borehole up to a surface, and wherein at least a portion of said circumferential seal (50) is surrounding a part of said circumferential wall (11),
- one or more return pipes (32a, 32b) for evacuation of excavated matter mixed with drill liquid from the borehole bottom portion, and wherein said one or more return pipes are mechanically coupled to said container (10).

2. A drill head (1) according to claim 1 wherein said one or more return pipes are traversing said container (10) and wherein each of said return pipes (32a, 32b) comprises i) a pipe entrance portion traversing through said second axial cover (13) and ii) a pipe end portion, and wherein the pipe end portions of the return pipes are traversing through said first axial cover (12) or the pipe end portions are coupled to a common feedthrough for traversing through the first axial cover (12) .

3. A drill head (1) according to any of previous claims wherein each of said one or more return pipes is coupled or partly coupled to an inner side of said circumferential wall (11).

4. A drill head (1) according to any of previous claims wherein at least a portion of an inner circumferential side of said circumferential seal (50) is attached to an outer side of said circumferential wall (11).

5. A drill head (1) according to any of previous claims wherein a circumferentially extending flange (15) is surrounding and attached to said circumferential wall (11) so as to form a collar around the circumferential wall (11) and wherein at least a portion of an inner circumferential side of said circumferential seal (50) is attached to an outer side of said circumferentially extending flange (15), and
wherein said one or more return pipes (32a, 32b) are attached to an outer side of said circumferential wall (11), and
wherein said circumferentially extending flange (15)

comprises for each of said return pipes a corresponding feedthrough opening, and wherein each feedthrough opening is receiving a corresponding return pipe entrance portion.

6. A drill head (1) according to any of previous claims wherein said one or more return pipes have a cross sectional area configured such that the sum of the cross sectional areas of each of the return pipes is equal to a cross sectional area of the supply pipe within an accuracy of 30%, preferably within an accuracy of 25%, more preferably within an accuracy of 20%.

7. A drill head (1) according to any of previous claims wherein said circumferential seal (50) is inflatable and/or wherein said circumferential seal (50) is made of a compressible material or an elastic material.

8. A drill head (1) according to any of previous claims wherein said electrode assembly has a circular perimeter with an outer diameter D_E measured in a plane perpendicular to the central axis (Z), and wherein $D_E \geq 40$ cm, preferably $D_E \geq 50$ cm and wherein said circumferential wall (11) has a cylindrical shape with an outer diameter DPG wherein DPG < DE.

9. A drill head (1) according to any of claims 1 to 7 wherein said electrode assembly (40) is a segmented electrode assembly comprising a plurality of electrode segments, wherein each electrode segment has a ground (41) and high-voltage (42) electrode, and wherein the high-voltage pulse generator is configured for individually powering each of the electrode segments.

10. A drill head (1) according to claim 9 wherein one of the electrode segments is configured for drilling a locally enlarged bore hole resulting in the formation of a borehole having a longitudinal groove or channel in the wall of the borehole.

11. A drill head (1) according to any of previous claims 1 to 7 wherein said electrode assembly (40) comprises a ground-electrode (41) and a high-voltage electrode (42) and wherein said circumferential wall and said first and second cover are made of a metal and are electrically grounded and coupled with said ground electrode (41), and wherein a high-voltage feed-through passing through said second axial cover (13) is configured for providing high-voltage to said high-voltage electrode (42).

12. A drill head (1) according to any of previous claims wherein said supply pipe (31) is traversing said container (10) along said central axis (Z) from a supply pipe entrance portion traversing through said first axial cover (12) to a supply pipe exit portion traversing through said second axial cover (13), preferably said electro-pulse generator comprises a plurality of capacitors wherein said capacitors are positioned around the supply pipe (31) or wherein each of the capacitors have a ring-shape and are circumscribing the supply pipe (31).

13. A drill head (1) according to anyone of claims 1 to 11 wherein a supply pipe entrance portion of the supply pipe (31) comprises a first coupling means configured for coupling with a feed channel of a drill string transporting the drill fluid from the surface to the drill head.

14. A drill head (1) according to any of previous claims wherein each of said pipe end portions of the return pipes traversing the first axial cover (12) comprises a second coupling means or wherein said common feedthrough traversing the first axial cover (12) comprises a second coupling means, and wherein the second coupling means is configured for coupling with a return channel of a drill string transporting the excavated matter mixed with drill fluid from the drill head to the surface.

15. An electro-pulse boring system comprising

- a drill head (1) according to any of previous claims,
- a lifting device located at the surface and configured for lifting the drill head (1) from the borehole,
- a drill string assembly comprising

  i) a feed channel for supplying drill liquid from the surface to the drill head,
  ii) a power cable running to the drill head for supplying power to the electro-pulse generator,
  iii) one or more return channels for transporting a mixture of excavated matter and drill liquid up to the surface,

- a drill liquid circulation system comprising at least

  i) a drill liquid reservoir,
  ii) a pump for pumping drill liquid from said drill liquid reservoir to the drill head through said feed channel of the drill string assembly, and
  iii) a drill liquid recovery device configured for receiving said mixture of excavated matter and drill liquid from said one or more return channels of the drill string assembly and configured for separating the excavated matter from the drill liquid and transport-

ing the recovered drill liquid to the reservoir.

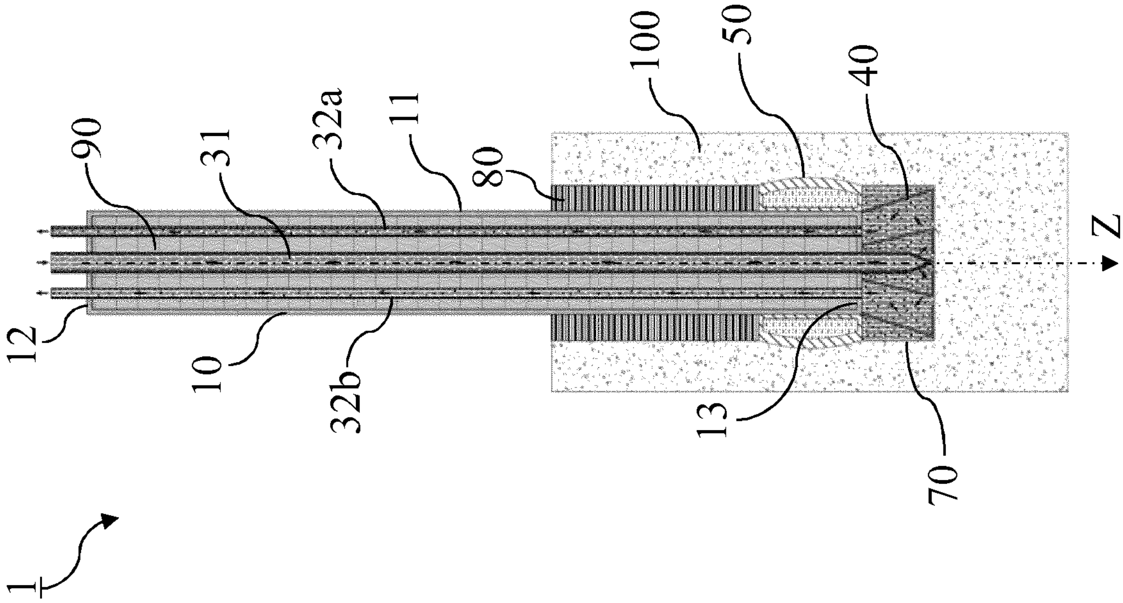

FIG.1

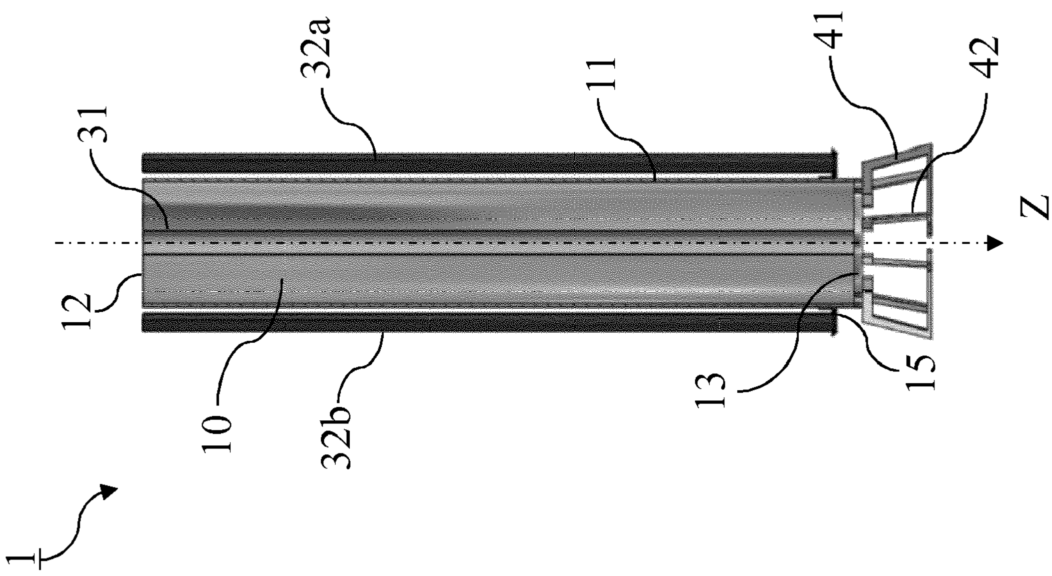

FIG.2

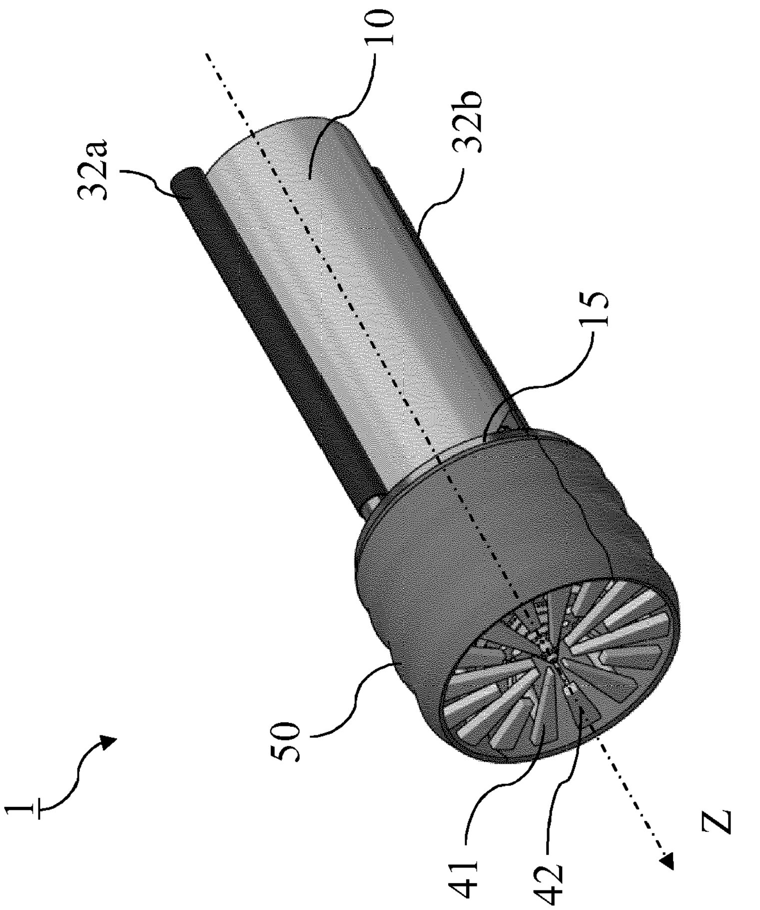

FIG.3

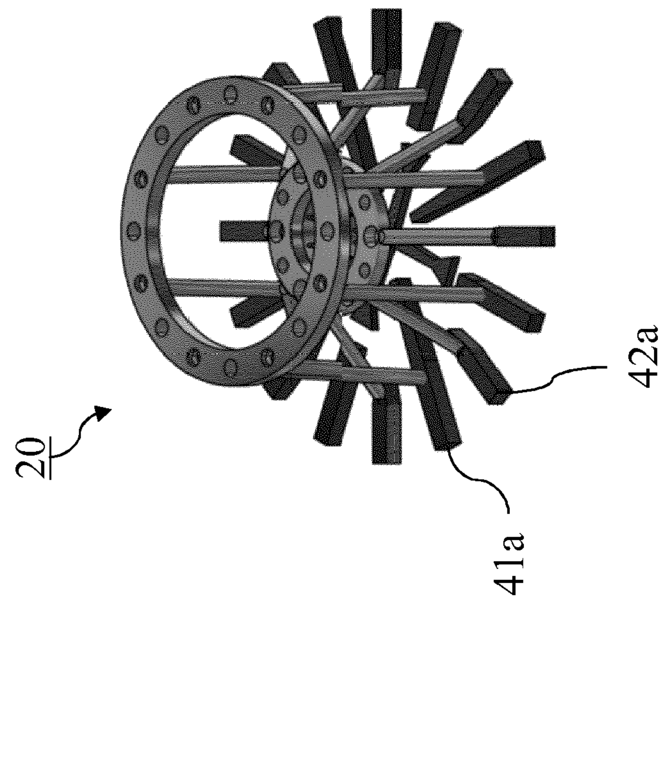

FIG.4

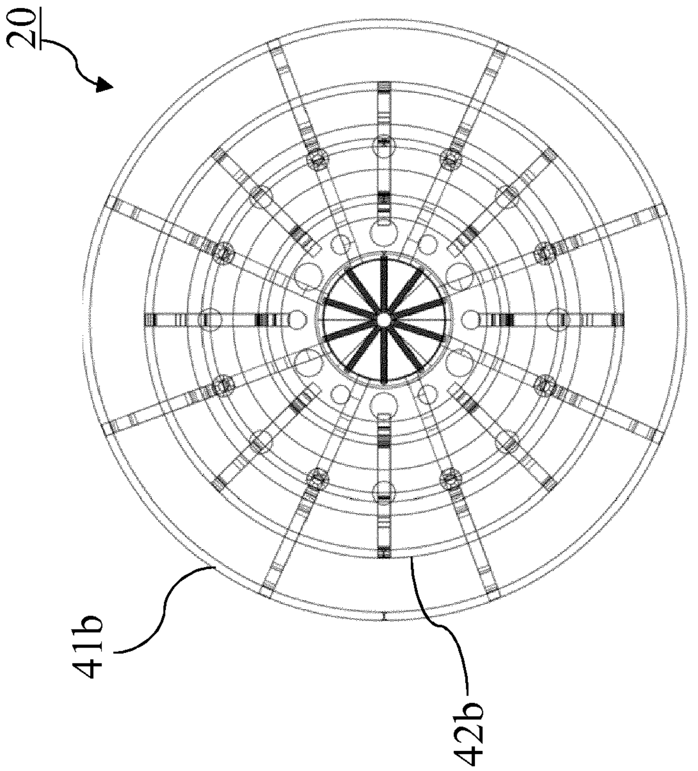

FIG.5

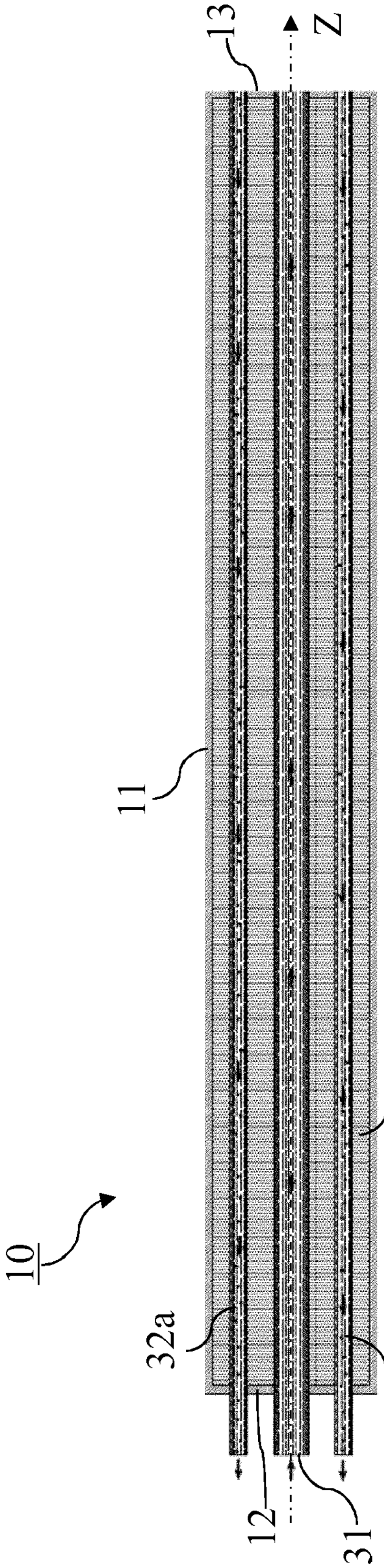

FIG.6

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EUROPEAN SEARCH REPORT

Application Number
EP 19 17 5222

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	US 2018/313158 A1 (GILBRECH JOSHUA A [US]) 1 November 2018 (2018-11-01) * paragraphs [0015], [0019] - [0022], [0023] - [0026], [0030], [0046], [0049] - [0050]; figures 2A, 3, 5 * -----	1-13	INV. E21B7/14 E21B7/15 E21B10/00
Y	US 2018/163478 A1 (DIRKSEN RON [US] ET AL) 14 June 2018 (2018-06-14) * paragraphs [0013], [0023], [0039], [0040], [0041]; figure 4 * -----	1-13	
A	US 2016/017663 A1 (MOENY WILLIAM M [US]) 21 January 2016 (2016-01-21) * the whole document * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			E21B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	5 November 2019	Patrascu, Bogdan

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05-11-2019

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2018313158 A1	01-11-2018	US 2018313158 A1	01-11-2018
		WO 2018186828 A1	11-10-2018
US 2018163478 A1	14-06-2018	AR 096034 A1	02-12-2015
		US 2016060961 A1	03-03-2016
		US 2018163478 A1	14-06-2018
		WO 2014189491 A1	27-11-2014
US 2016017663 A1	21-01-2016	NONE	

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- US 164388 A **[0011]**
- EP 1711679 A **[0012]**
- RU 2477370 **[0013] [0071]**