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(54) **METHOD AND SYSTEM FOR FORMING A NON-CIRCULAR BOREHOLE**

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(60) Provisional application No. 60/786,456, filed on Mar. 27, 2006.

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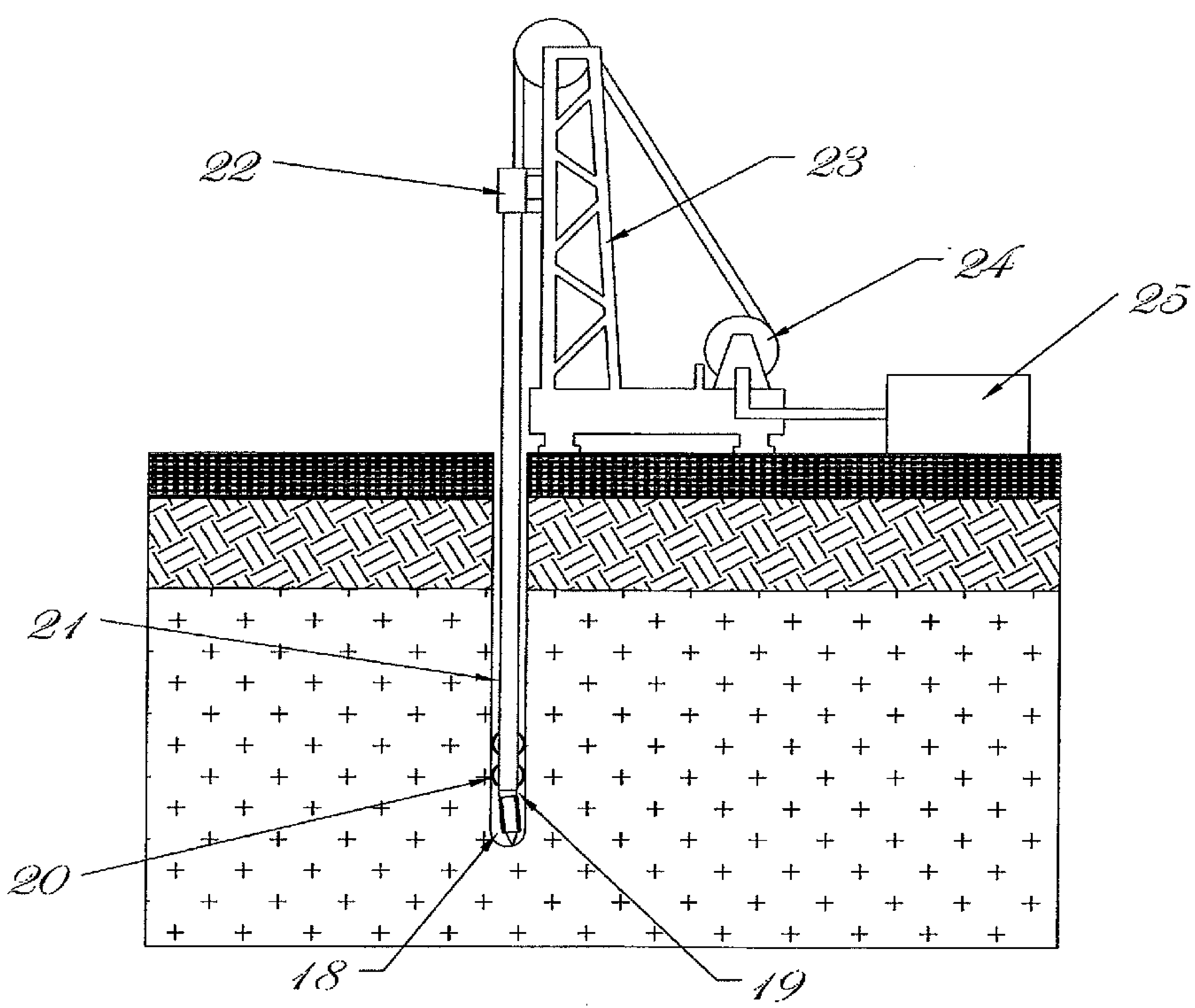
(52) **U.S. Cl.** **175/11**; 175/57; 175/67; 175/64; 175/62; 175/50

(57) **ABSTRACT**

System and methods for creating shaped, non-circular boreholes in rocks especially for use with geothermal heat pump applications and for increasing wellbore support in applications such as horizontal oil and gas drilling are described. The systems and methods when applied to geothermal heat pumps create an elliptical shaped hole that is optimized for placing heat transfer tubes with a minimum of grout used. The significantly reduced cross-sectional area of the elliptical borehole also increases the overall drilling rate in rock and especially in hard rocks. In horizontal hard-rock drilling, creation of a horizontal non-circular borehole or modification of a circular borehole to a non-circular geometry is used to stabilize the borehole prior to casing insertion, and may also allow the use of lower mud pressures improving drilling rates. The system uses a non-contacting drilling system which in one embodiment uses a supersonic flame jet drilling system with a movable nozzle that swings between pivot points. In a second embodiment the elliptical shaped hole is created by an abrasive fluid or particle bearing-fluid or air jet drill that moves between pivot points. In another embodiment a non-contacting drill can use dual parallel nutating nozzles that create a pair of overlapping circular holes. The non-circular shaped hole is created by either the high temperature flame or water-particle jet or chemically active fluid jet as it removes rock material by erosion, dissolution and or thermal spalling. Modifications of circular boreholes to a generally elliptical shape can also be done using milling or jetting techniques.



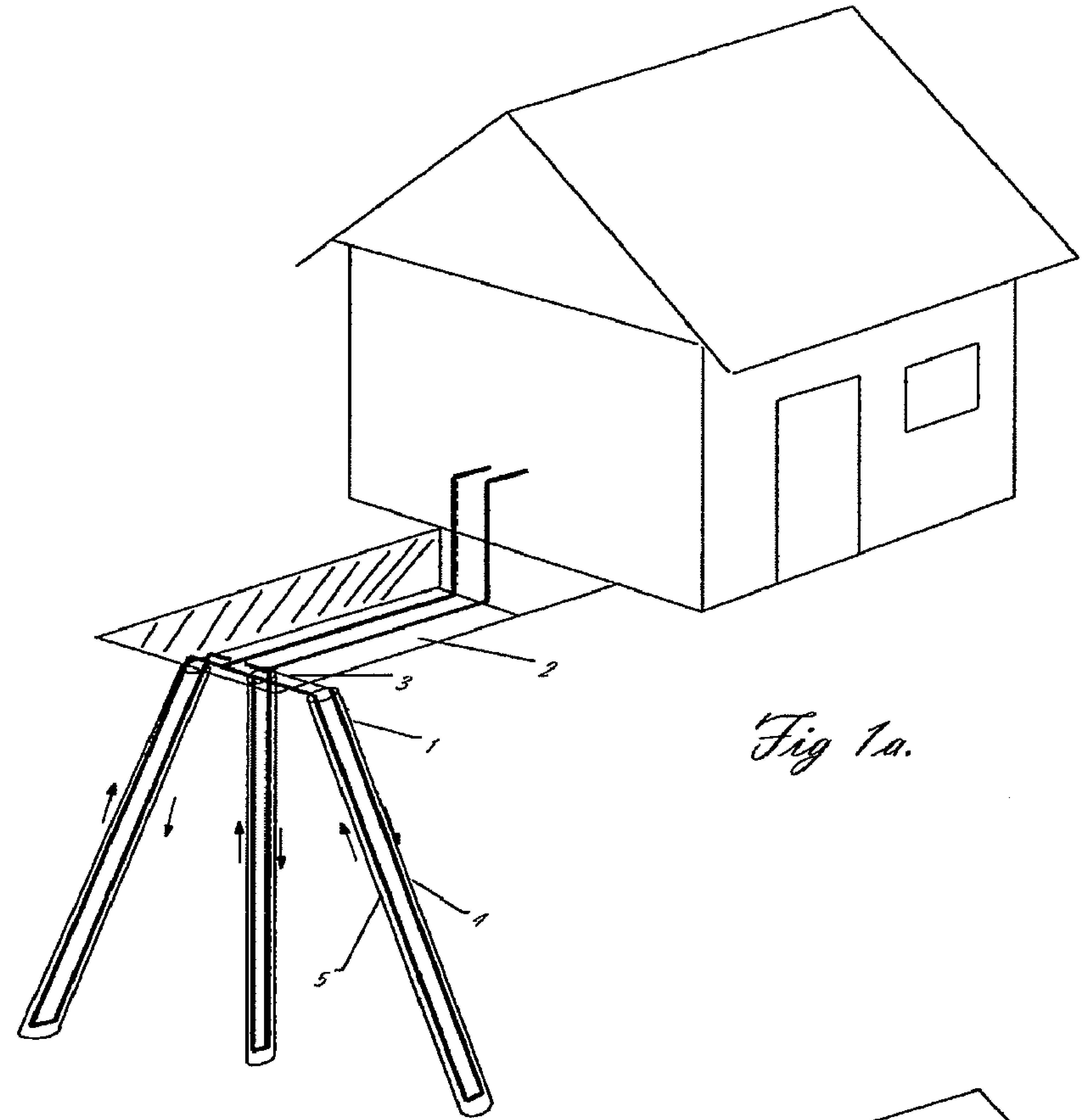


Fig 1a.

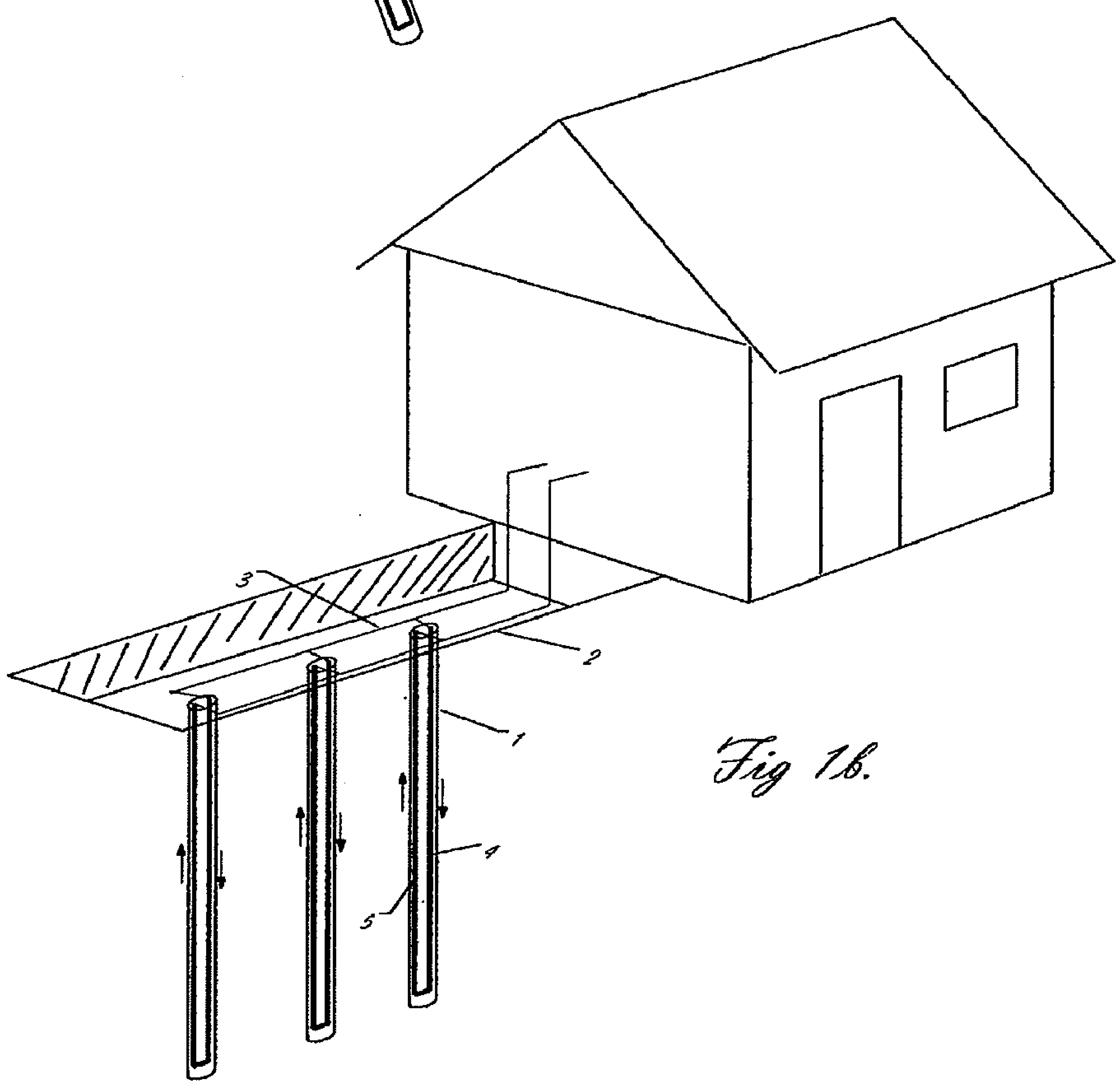


Fig 1b.

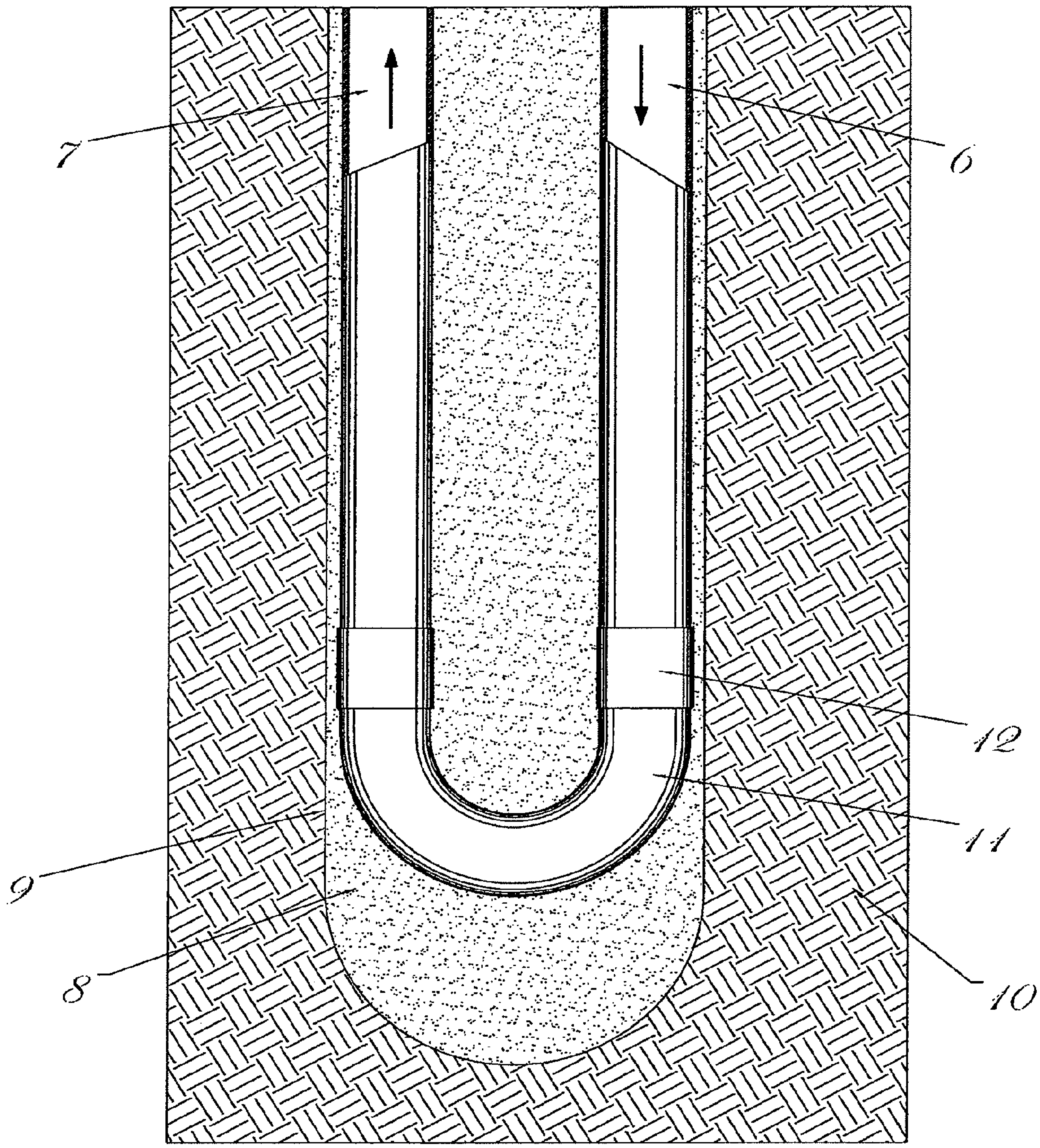


Fig 2

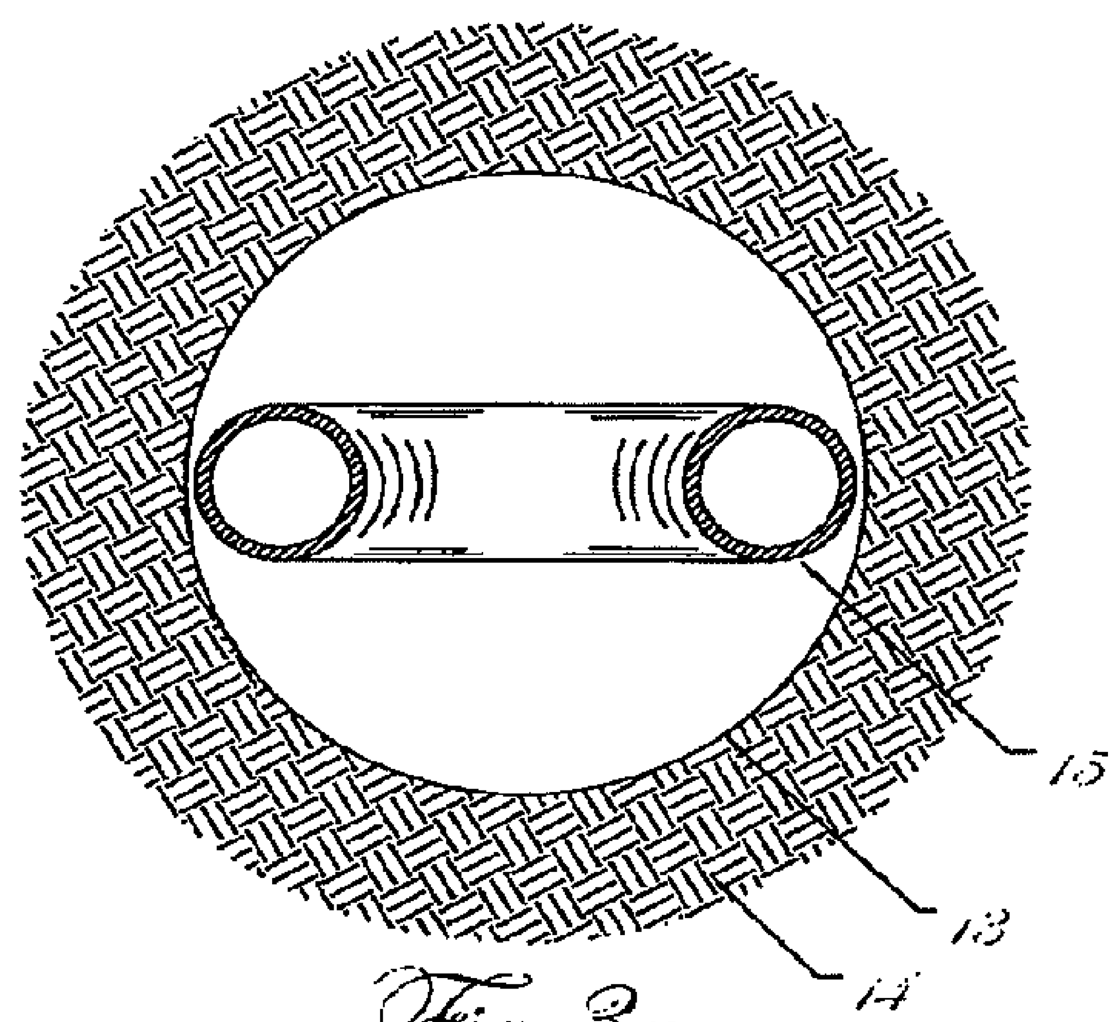


Fig 3a

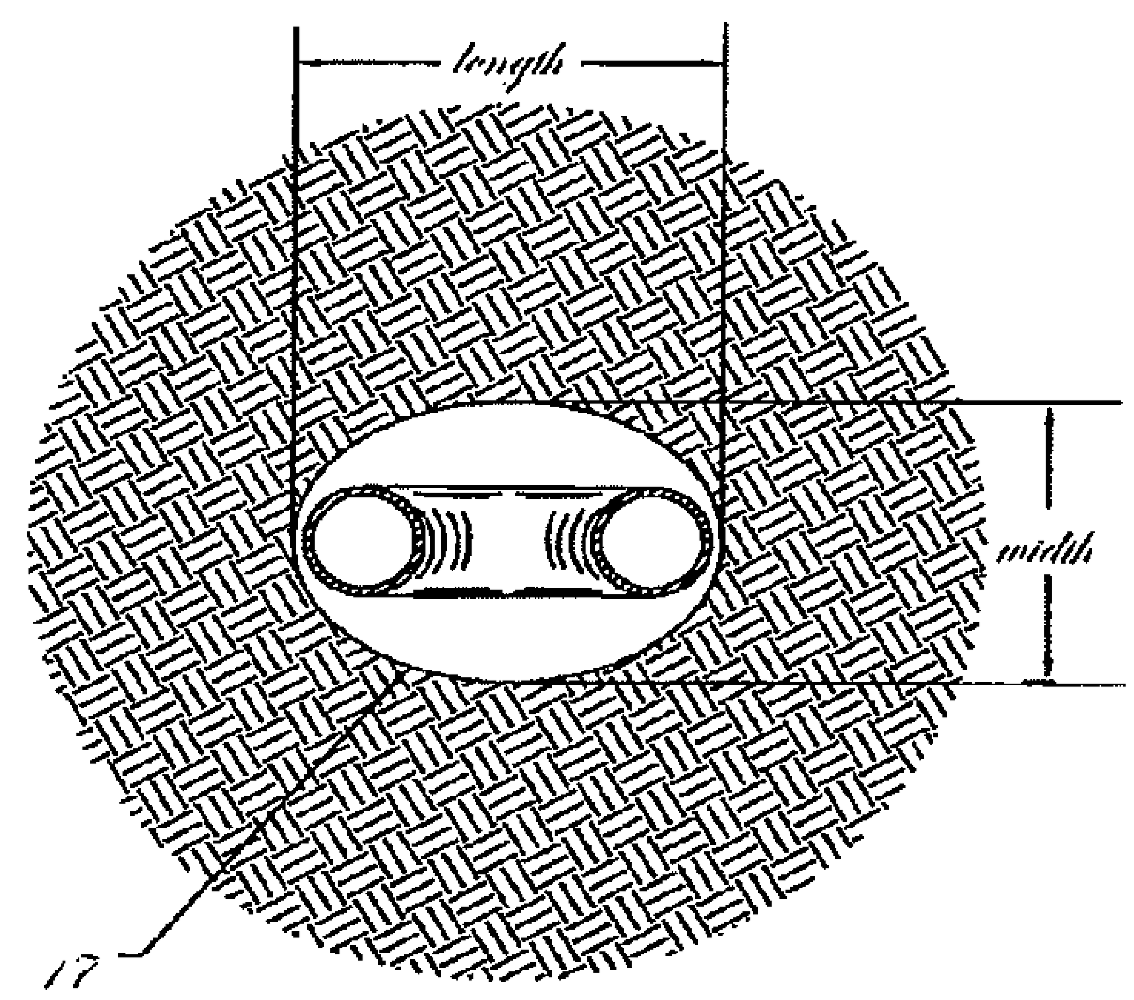


Fig 3c

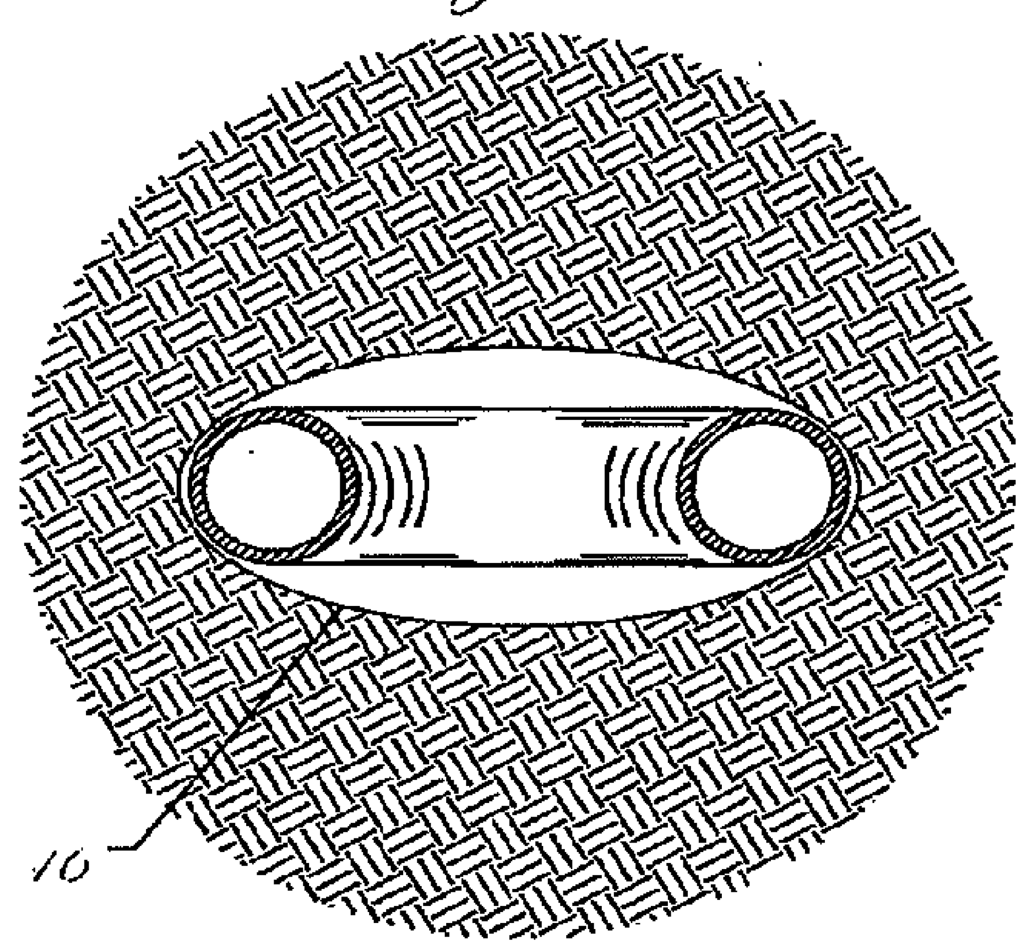


Fig 3b

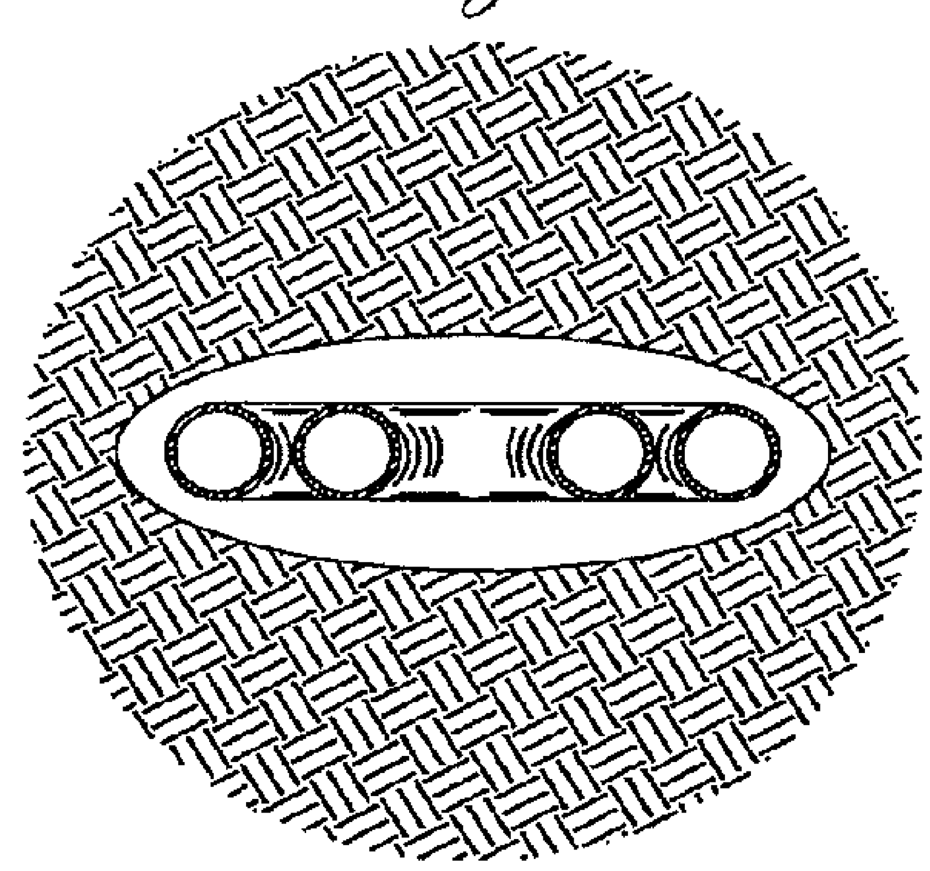


Fig 3d

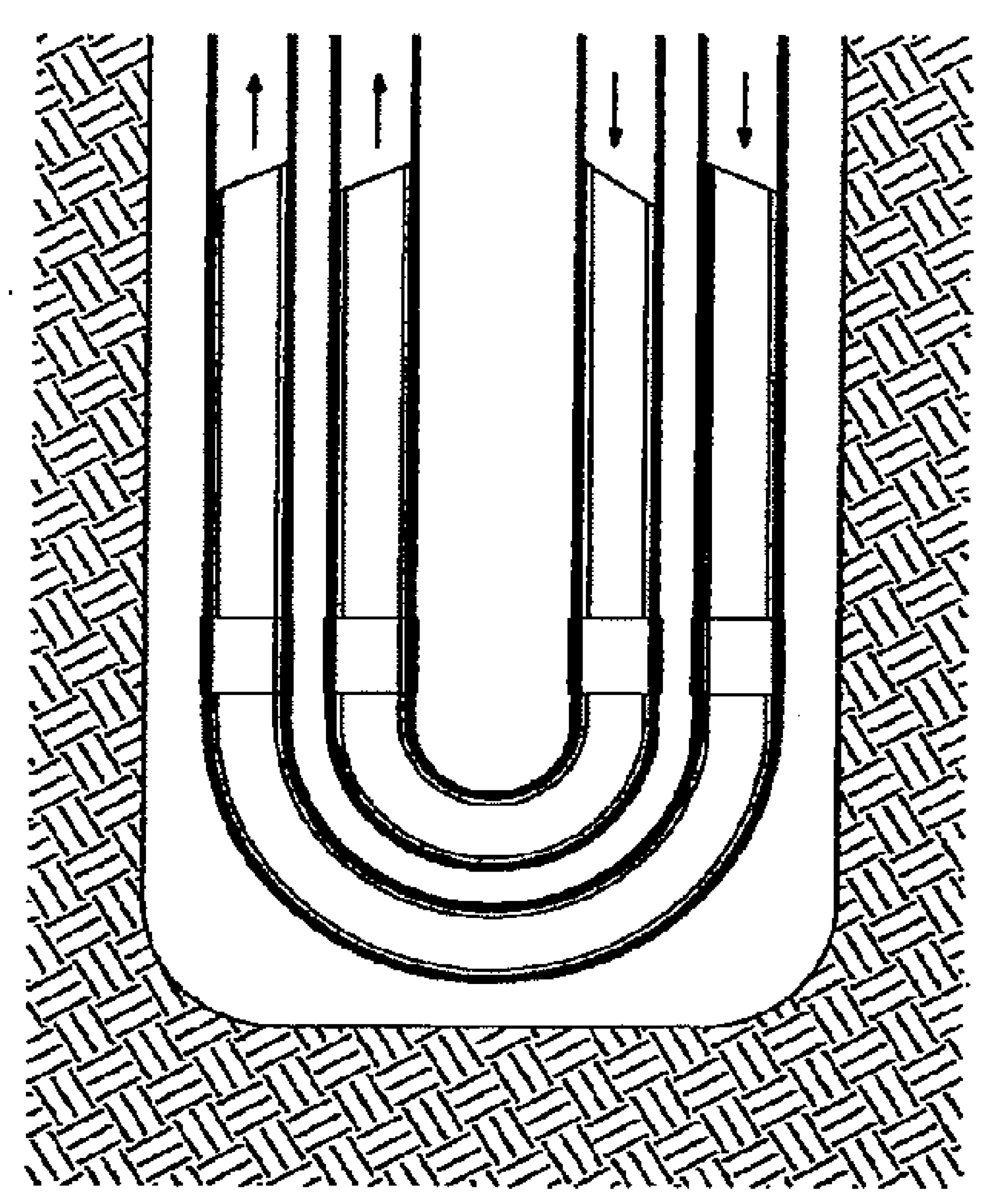


Fig 3e

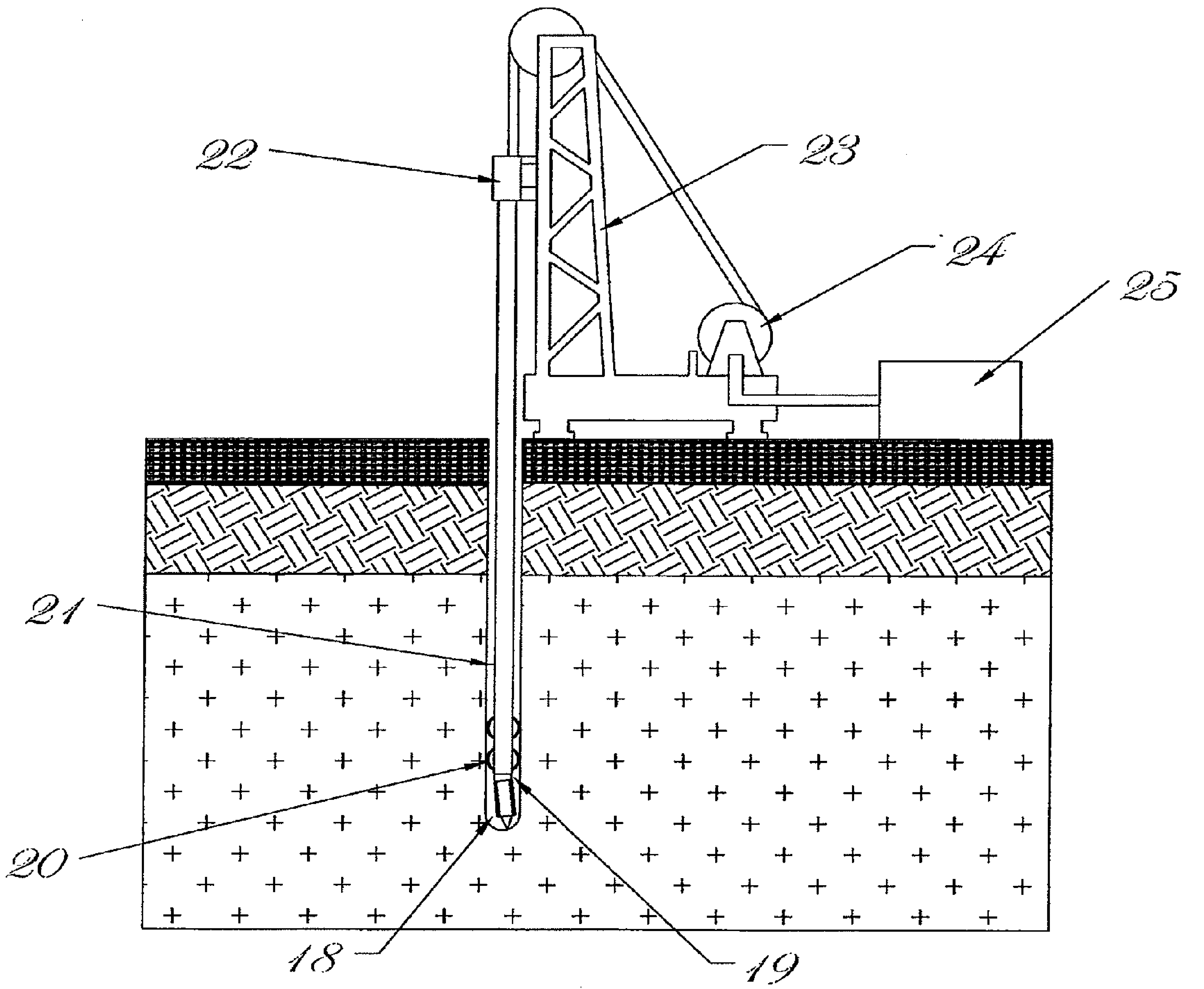


Fig 4

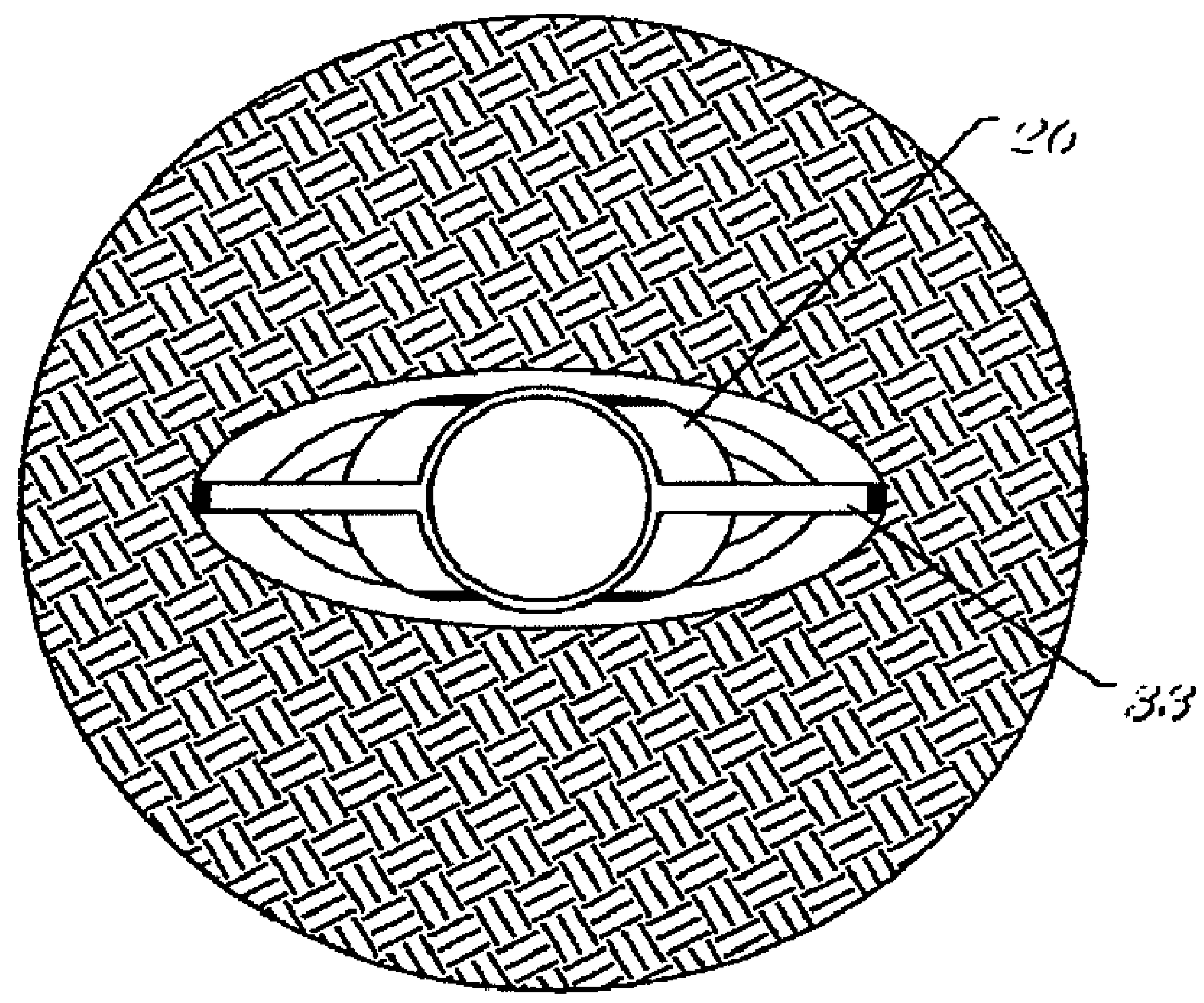


Fig. 5b

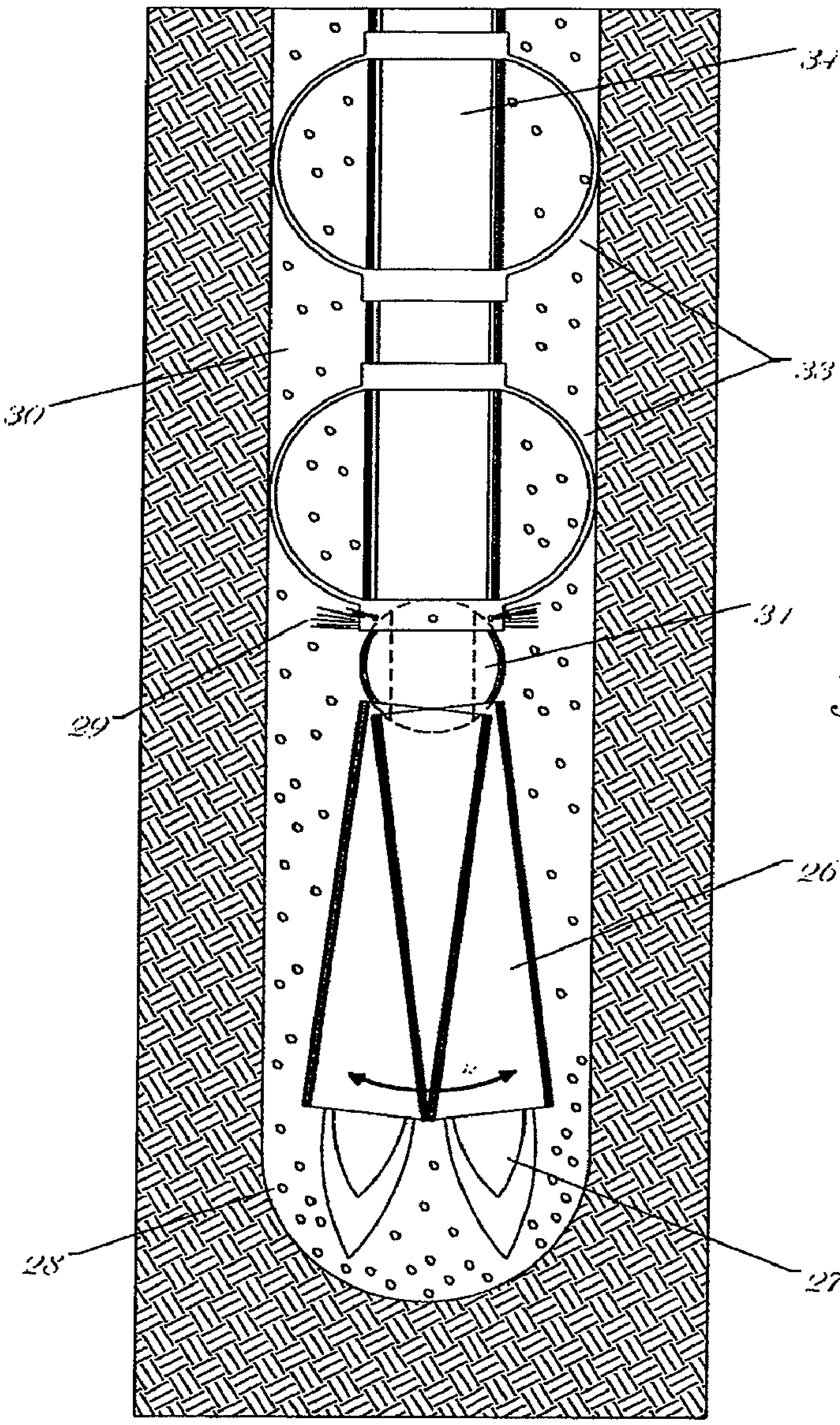


Fig. 5a

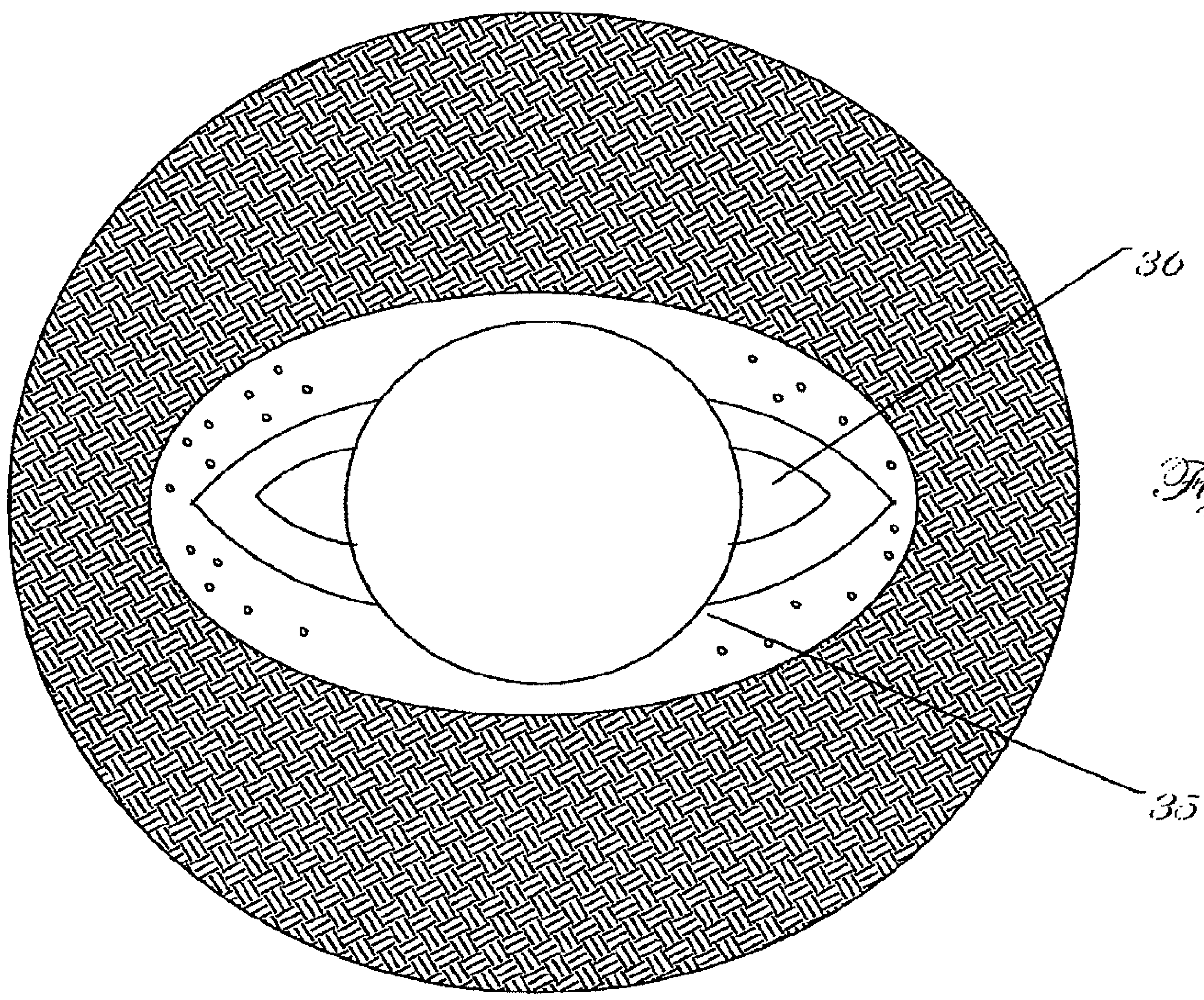


Fig 6b

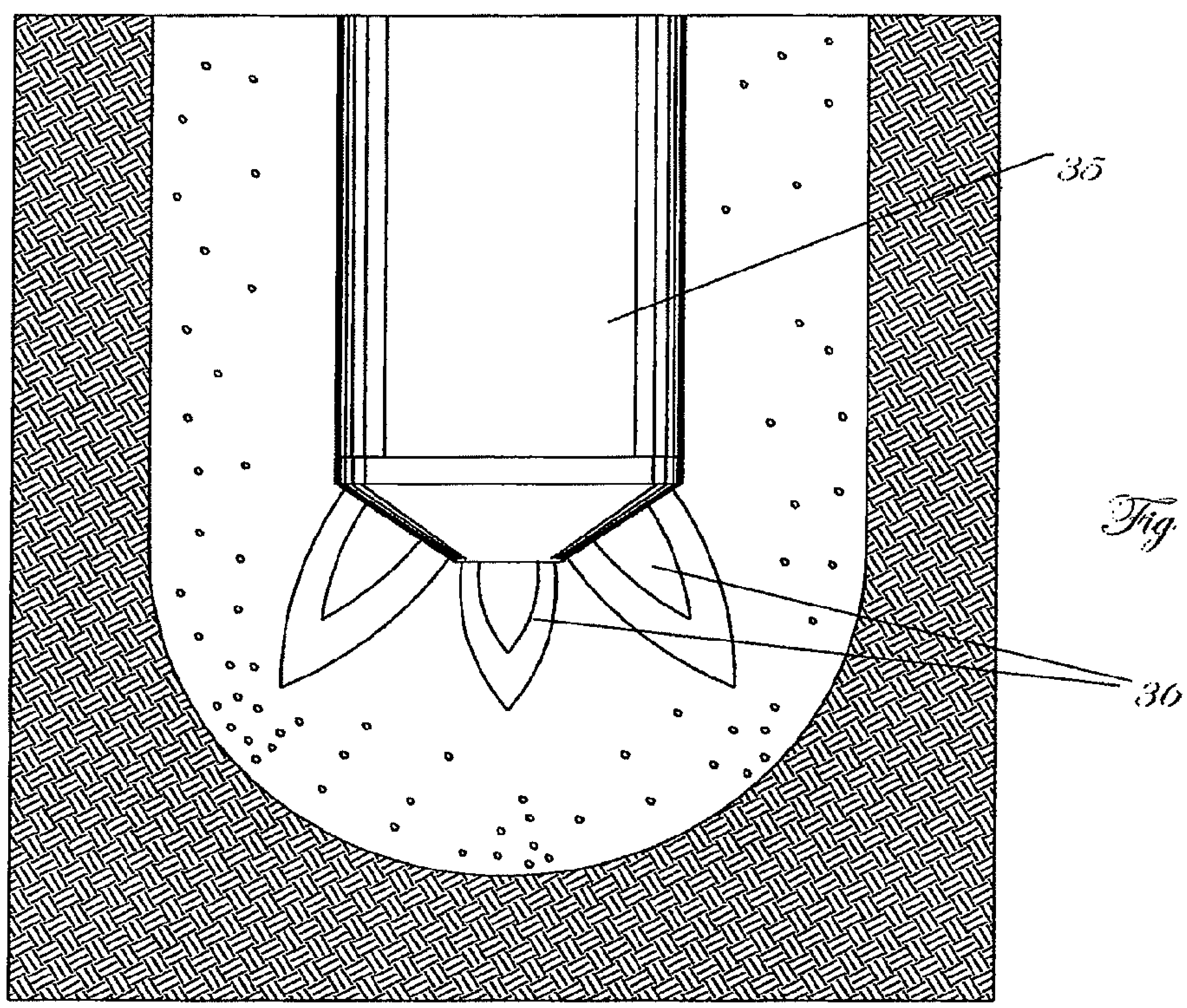


Fig 6a

Figure 7c

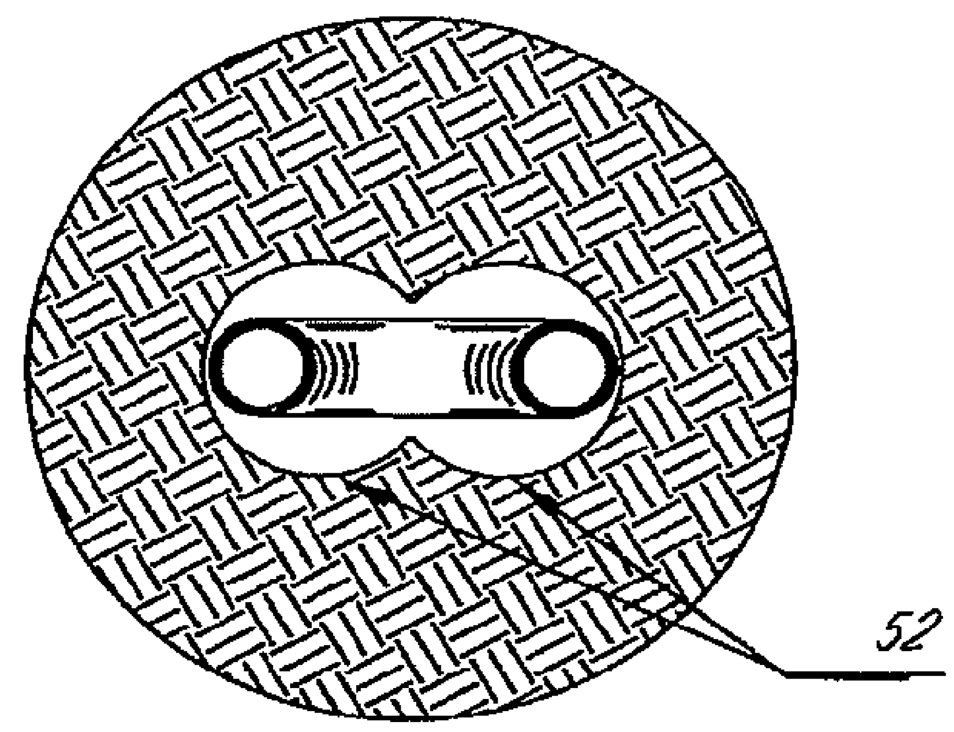


Figure 7a

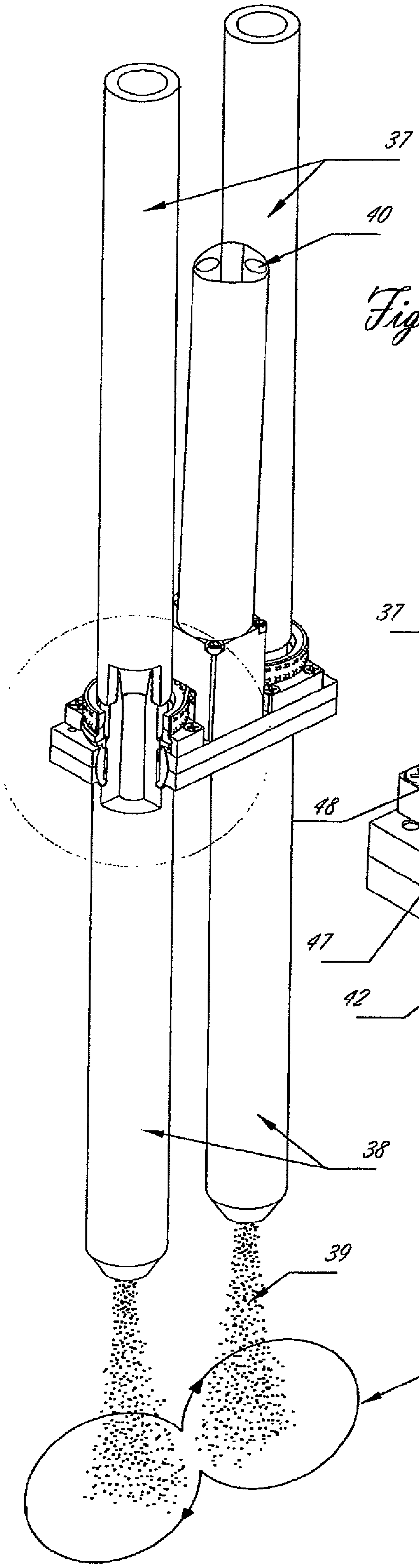
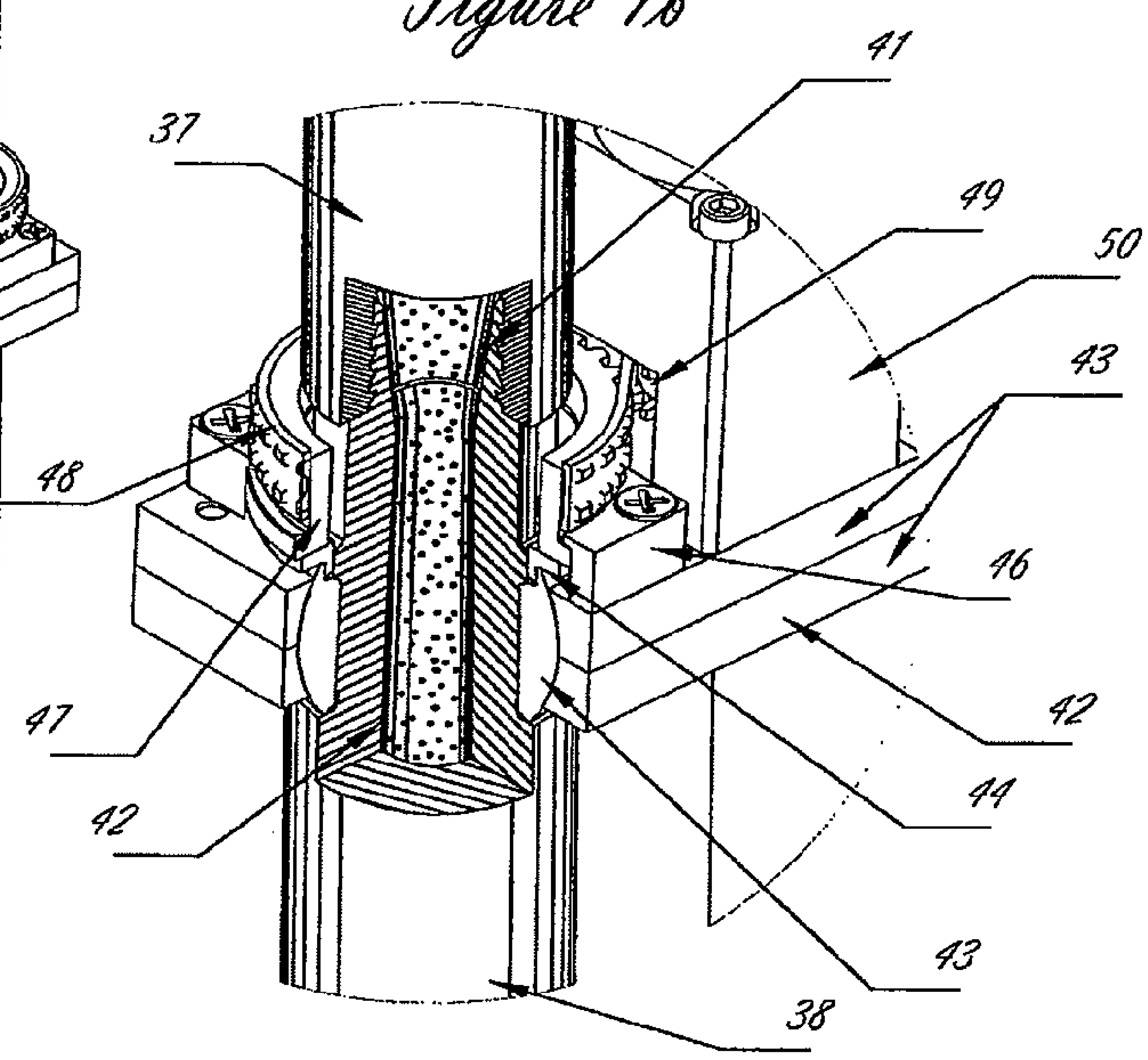


Figure 7b



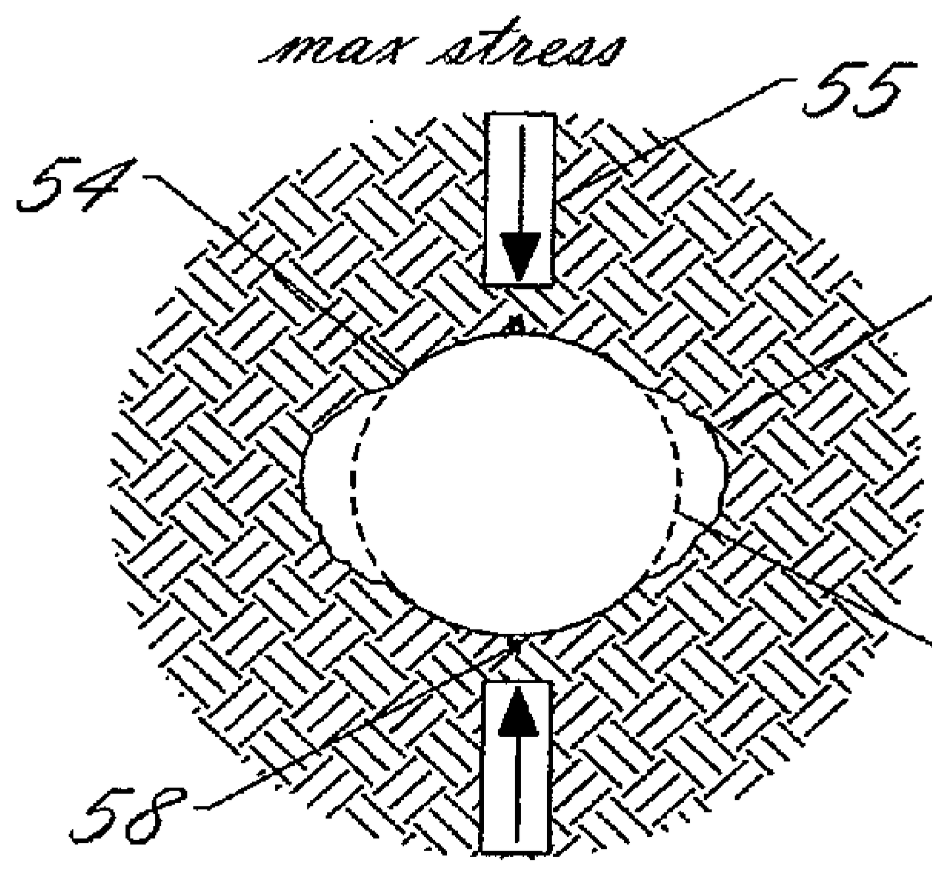


Fig 8a

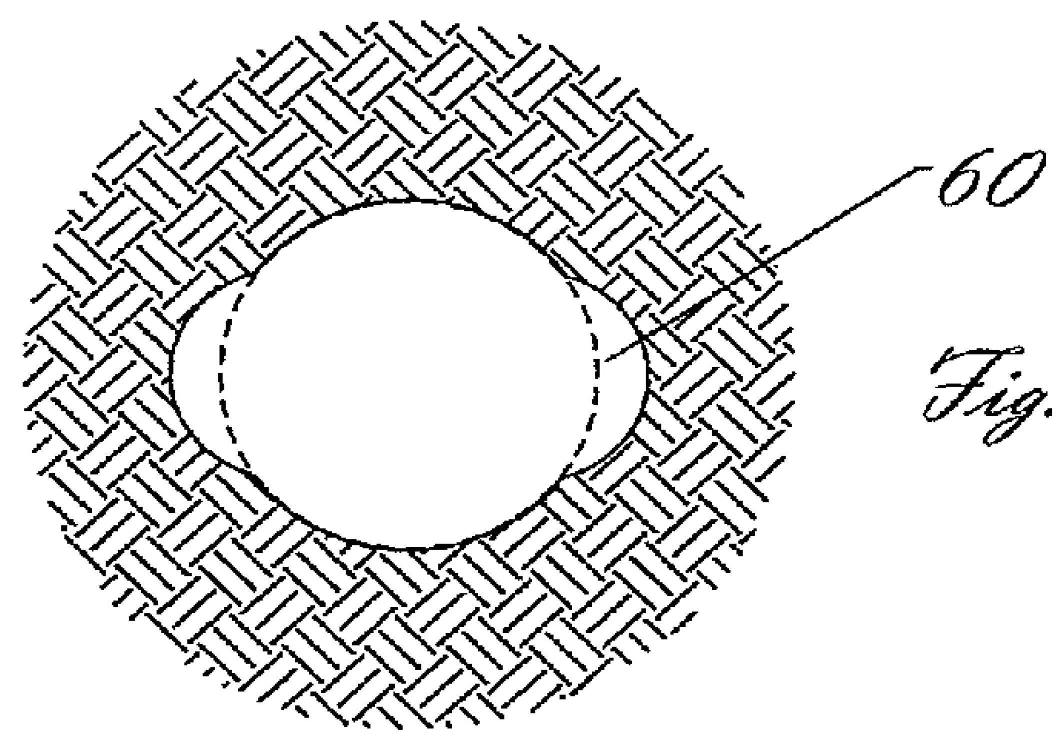


Fig. 8c

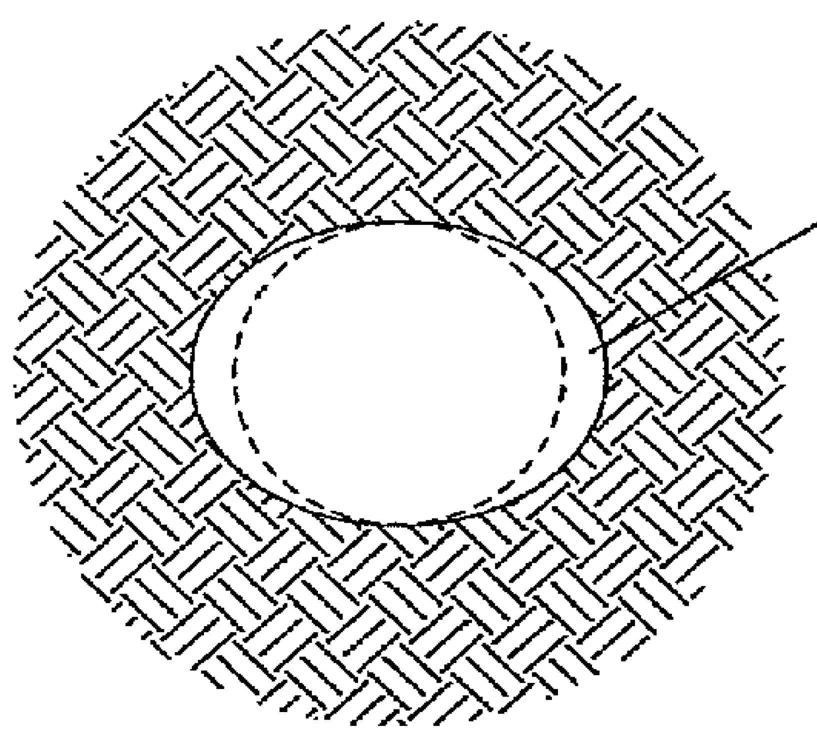


Fig. 8b

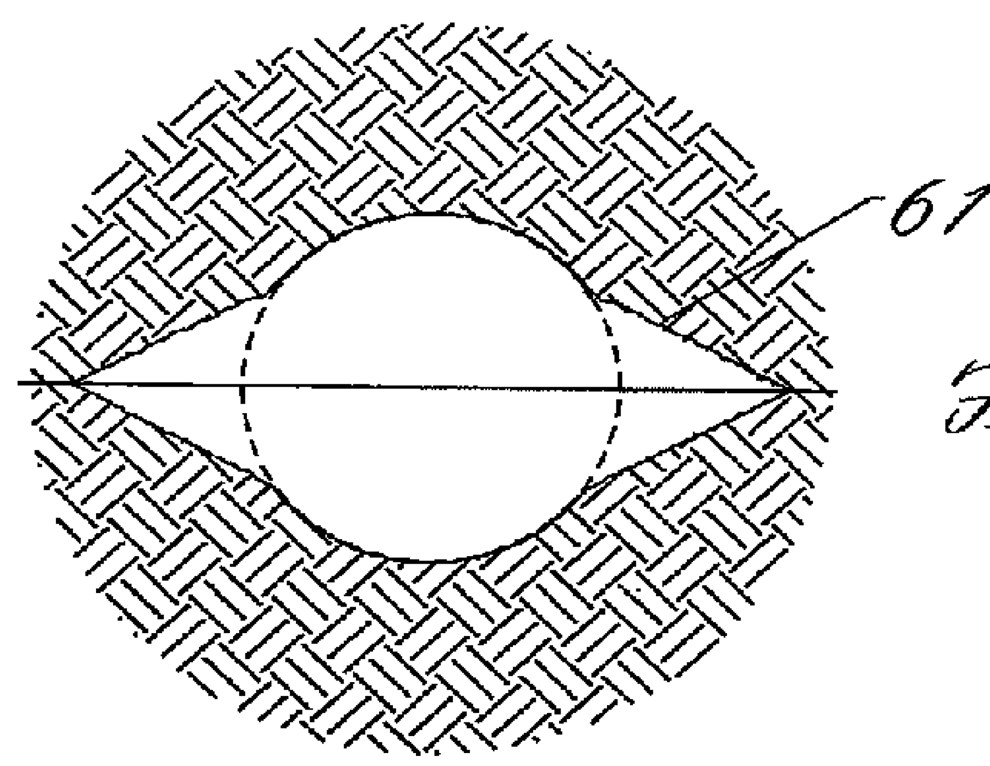


Fig. 8d

METHOD AND SYSTEM FOR FORMING A NON-CIRCULAR BOREHOLE

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 60/786,456, filed Mar. 27, 2006 whose teachings are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates in general to the formation of intentionally non-circular boreholes. These non-circular boreholes may be shaped for optimized use in a specific system or application, such as underground heat exchange systems, or they may be formed as a means to stabilize the borehole during the drilling, casing, and completion or in operation.

[0003] Most conventional and non-conventional drilling techniques are designed to produce boreholes that are substantially circular. In some formations, such as hard rocks with primary stresses oriented vertically, circular boreholes are inherently unstable which might be caused by the non-uniform stress conditions in the rock or from a general weakness in the rock. Once a circular hole is produced, these stresses may cause portions of the formation to break from the wall, often referred to by those skilled in the art, and herein referred to, as "break-out". This uncontrolled break-out often occurs during or sometime after the extraction of the drill string, including during the insertion of the casing, and can cause significant disruptions in the drilling process and completion process. Uncontrolled break-out can be a particular problem in bore sections which have a horizontal or non-vertical orientation. Break-out often creates a substantially non-circular or elliptical cross-section, with the longer axis of the ellipse often in a substantially horizontal plane, or parallel to the earth's surface. To prevent the uncontrolled break-out from occurring, it would be advantageous to be able to drill or create a non-circular bore, or modify a bore so as to be non-circular, in an orientation that partially relieved the stresses in the formation (e.g. see Björn Lund, 2000; Crustal stress studies using micro earthquakes and boreholes, Comprehensive summaries of Uppsala dissertations from the faculty of science and technology, 517, 75 pp, Uppsala University, Sweden)

[0004] There are also specific applications that would benefit from non-circular holes with reduced tendency towards uncontrolled break-out. These applications may include geothermal power generation, such as enhanced or engineered geothermal systems (herein referred to as EGS) and hot dry rock (herein referred to as HDR), or applications where the bore hole will be left unsupported for extended periods (minutes, hours, or days), such as in oil and gas exploration and production (herein referred to as oil and gas E&P) operations, or in situations where the wellbore will be left unsupported indefinitely, such as in an uncased wellbore. An uncased wellbore may have an inner surface that comprises the formation, or one that is substantially comprised of fused rock, ice, a layer of a non-metallic material, such as a thermoplastic, thermoset, composite or ceramic, or a layer of fused metallic material. In addition to EGS-HDR and oil and gas E&P, other conventional applications could benefit by the drilling of non-circular boreholes with reduced tendency towards break-out, including, but not limited to, water well drilling, trenchless pipe installation, sewer and municipal system construction, resource mining, chemical disposal wells, CO_2 or nuclear storage wells, downhole chemical reactions (such as, but not limited to, municipal waste oxidation or biofermentation), bores in ice, or wells for scientific or geologic study, including test holes or secondary holes used for measurements in the above or other operations and applications.

[0005] Another application for non-circular boreholes is the installation of underground heat exchange systems for geothermal or ground source heat pumps (herein referred to interchangeably as GHP or GSHP). GHP's are used throughout the world as a means to effectively heat and cool houses and businesses through a heat exchange loop system located in the earth. A typical heat exchange loop may be comprised of tubing installed in holes 150 feet to 500 feet deep which circulates fluids and extracts or disposes of heat into the ground. The number of holes used depends on the heat exchange requirements for the complete system. In some newer configurations, the drill holes start in the same general location but then divert at approximately a 30 degree angle from the vertical, forming a cone like array, as shown in FIG. **1***a*. This cone shape creates a compact connection point for all of the heat exchange tubes. Many locations, however, use numerous vertical holes, usually aligned in rows, with separation of about 20 feet, as shown in FIG. **1***b*.

[0006] Typically, 4 to 6 inch diameter holes are required in GHP applications when reasonably large heat flow lines need to be installed. Inside the holes, flow lines are inserted which typically range from 0.75 inch to 1.25 inches in inner diameter. If too small a hole is drilled, it is difficult to insert the tubes into the hole as well as get a good placement of grout into the hole and around the tube. A less than optimum grout placement may create a condition where bubbles can get entrained in the grout reducing the effectiveness of the heat exchange system. The in-flowing and out-flowing lines must be adequately separated to prevent the out-going line from transferring heat back into the in-coming line; in a sense, short circuiting the desired heat transfer to the earth.

[0007] GHP's are well known, and there are a number of standard techniques of creating the holes for these systems. Conventional drilling technologies have traditionally been employed for the drilling of holes for geothermal systems including, but not limited to, auger, rotary bit, rotary impact (hammer), percussion, and sonic drilling methods. However, no single system has yet been found to be ideal for drilling in all rock types. Furthermore, any of these technologies using a single bit cannot create a substantially non-circular hole because the required rotation and contact of the drill bit with the rock during the drilling process inherently produces a substantially circular profile.

[0008] Drilling large holes for purposes such as installing heat exchange loops can be especially problematic in hard rock. As used herein, "rock" may loosely refer to any material in the well bore, including loose and unconsolidated soils, consolidated soils, clays, sands, conglomerates, soft or hard rock, or any formation of any naturally occurring composition. As used herein, a hard rock refers to a rock that is well consolidated and typically has a number of hard minerals such as feldspars and quartz and lacks significant amount of clays. Such a hard rock can have a compressive strength of about or greater than 10 ksi. Also as used herein, a large diameter hole refers to a hole having a diameter that is larger than about 5 inches. Drilling holes in hard rock is a time consuming and costly process. In fact, if a large number of holes in the hard rocks are required, the drilling costs can exceed the costs of the rest of the heat pump and flow lines combined. In addition, hard rocks typically have lower fluid contents so that heat exchange from the tubing to the rock is reduced and more flow lines may be needed compared to soft rock for the same amount of heat exchange.

[0009] Hard rock drilling has traditionally been accomplished by several different methods, including impact hammer drill or rotary drilling. Drill rates for these techniques in hard rock can be as slow as 10 feet per hour or less for larger diameter holes. Non-contact drilling technologies such as flame jet spallation, hydrothermal spallation, particle impact drilling, or water jet drilling (with or without abrasive particulates) have the advantage of being able to drill faster in hard rocks. Non-contact drilling is herein defined as technologies which do not require contact between the bottom hole assembly and rock in order to remove the rock by the intended means, but may use the rock wall for secondary purposes, such as orientation, stabilization, propulsion, or the like. For example, tests conducted in the field have shown drilling rates of more than about 30 feet/hr rates for 8 inch holes using air-fuel flame jet combustion drills. A summary of some of the known non-contact drilling techniques is provided below.

[0010] Several flame jet drilling techniques are known. For example, U.S. Pat. No. 3,045,766 discloses a suspension type rotary piercing process and apparatus and describes a blowpipe type rotary flame jet system suspended from a cable to allow for vertical jet drilling. U.S. Pat. No. 3,103,251 is directed to a flame cutting method and describes a flame cutting process improved by the addition of air or inert gas to the jet to increase drill rates. U.S. Pat. No. 3,182,734 is directed to a fusion piercing or drilling machine and discloses a system that uses a rotating combustion chamber in conjunction with outside scrapers to spall and melt rock to create a clean, consistent, circular bore. U.S. Pat. No. 3,322,213 is directed to thermal mechanical mineral piercing and discloses a rotating combination grinding and flame jet drill system for creating consistent, round bores through a process of thermal spallation and wear. U.S. Pat. No. 3,476,194 is directed to flame jet drilling and discloses a method for creating smaller holes by adding coolant closer to the flame outlet to diminish the thermal process away from the flame jet tool. U.S. Pat. No. 4,066,137 is directed to a flame jet tool for drilling cross holes and discloses a method for creating a side bore using thermal flame jet technology. U.S. Pat. No. 4,073,351 is directed to burners for a flame jet drill and discloses a technique for mixing both flame jet and water jets into the same drill head with different options for the shape and orientation of the nozzles and jets. A rotating head is used in this design which creates circular shaped holes. However, none of the known flame jet drilling techniques suggests shaped or non-circular cross-section holes.

[0011] It is known that superheated steam or a high pressure fluid may also be used for drilling. However, such known techniques have only been used for the drilling of round holes. Several water jet drilling techniques are known. For example, U.S. Pat. No. 5,402,855 directed to coiled tubing tools for jet drilling of deviated wells describes a jet nozzle drill for creating deviated (e.g., off vertical) wellbores from a cased vertical well. This patent provides a discussion of how to shift the high pressure nozzle to create a tilt in the jet system. This patent also provides a discussion of how the nozzle is shifted using a series of plungers tied to a control system and a flexible rubber boot assembly. U.S. Pat. No. 4,369,850 uses a rotating fluid jet assembly with multiple nozzles to create circular holes. U.S. Pat. No. 3,576,222 discloses a drill bit with hydraulic action using a number of nozzles and a rotating head for circular shaped hole generation. U.S. Pat. No. 5,111,891 describes a technology for creating a biasing in a wellbore for changing direction using a water jet for soil erosion. When rotated, the nozzle creates a circular hole. When the nozzle is stopped from rotating, it cuts a side bore path to allow the jet to relieve the adjacent area and enable the drill to change directions. U.S. Pat. No. 4,930,586 discloses a hydraulic drilling system with a single outlet jet and a series of four side jets which enable the control of the drilling direction. U.S. Pat. No. 5,944,123 discloses a system for creating holes using a water jet technique with capabilities for controlling orientation and rotation of the head. U.S. Pat. No. 4,871,037 discloses a combination rotating mechanical grinding and jet nozzle drilling system. However, none of these water jet drilling techniques suggest the creation of a non-circular shaped borehole or a shaped nozzle for the same.

[0012] While it is known that particle impact drilling may also be used to form boreholes using either water or mud suited to well drilling, and while such a known technique has been used with a rotating head and for creating circular holes, there is no suggestion in this area for creating shaped or non-circular holes. For example, U.S. Pat. No. 6,386,300 describes the use of a particle impact process using small metal spheres to increase drilling rates in traditional rotating drilling systems as well as a system to remove the spheres from the drilling mud. U.S. Pat. No. 4,768,709 describes a system for using individual fluid particulate jets to create channels and notches into existing boreholes to improve blasting characteristics.

[0013] Another known technology uses a supercritical fluid for the drilling task. Such known techniques create circular holes. For example, U.S. Pat. No. 6,347,675 uses CO_2 as the drilling fluid in a conventional coil tube drill system and as a jet fluid for enhanced drilling rates. The '675 patent describes a system for providing and separating CO_2 from the drilling fluid. There is no disclosure or suggestion for the generation of shaped or non-circular holes.

[0014] Another known drilling technology involves chemical drilling systems. Such known chemical drilling systems also create circular holes and do not suggest techniques for creating shaped or non-circular holes. In particular, the known chemical drilling references are related to using chemical drills to create holes in rocks and removing the reaction products from the hole. For example, U.S. Pat. No. 6,742,603 discloses using a high temperature sodium hydroxide (NaOH) fluid stream to etch a hole in rock. U.S. Pat. No. 4,431,069 describes a system that uses acidic or basic slurries to drill boreholes; the '069 patent also describes some aspect of directing the flow jet to change direction in order to create a directional, yet circular, borehole. U.S. Pat. No. 6,772,847 discusses using acids or other chemicals to create bore holes and suggests creating a cloverleaf shaped hole by using multiple nozzles. A cloverleaf-shaped borehole is not a suitable borehole profile for applications such as heat exchanger tube installations, where a minimal amount of rock removal is desired, nor does it help stabilize the borehole. It may also cause greater head losses for flowing fluids.

[0015] In connection with drilling, tube installation and grout placement for geothermal heat pump applications, a few patents are summarized below. For example, U.S. Pat.

No. 5,590,715 discloses a system for placing heat loops in place and then grouting them using a separate grout filling line. Published Application No. 2005/0139353 describes a system for installing heat loops in conjunction with sonic drilling techniques. U.S. Pat. No. 4,286,651 discusses a technique for driving a pipe into the ground to install shallow geothermal heat loops with a circular design drive pipe. All references discussed above are incorporated by reference herein.

[0016] However, there still exists a need for drilling boreholes where the preferred cross-sectional geometry is non-circular. There are also exist a need for forming boreholes having a non-circular hole geometry that can prevent or reduce break-outs from the wellbore.

BRIEF SUMMARY OF THE INVENTION

[0017] The present invention describes the benefits, methods and systems for creating non-circular, generally elliptical, oval or eccentric shaped holes. The embodiments of the present invention can be applied to the creation of non-circular boreholes or modification of circular boreholes to a more non-circular shape. Certain aspects of the present invention are particularly well suited for making non-circular holes in hard rock.

[0018] A substantially non-circular hole may help stabilize the well bore and prevent break outs. A substantially non-circular hole may also facilitate the installation or operation of a system, such as in the installation of piping for ground source heat pumps. A substantially elliptical hole provides an improved geometry for heat exchange in the ground source heat pump piping loops while also enabling a much faster and more efficient drilling that does not suffer from the shortcomings of the prior techniques.

[0019] In one aspect the present invention provides a system and method for creating shaped drilling holes in rocks especially for the intention of stabilizing the wellbore. The system can create an elliptical shaped hole that intentionally reduces the stresses in the formation around the bore, limiting uncontrolled break-out. Break-out is a process in which rock breaks from the wall of the wellbore, creating a non-circular and substantially elliptical cross-section, often with the longer axis in a substantially horizontal orientation, in order to relieve the stresses in the formation around the well-bore. Break-out may be particularly severe in significantly horizontal or non-vertical portions of the wellbore. Breakout can be caused by significant non-uniform stress concentration in the unsupported borehole resulting in localized shear failure at two opposite nodes in a direction normal to the main stress direction. Once the break-out occurs, the borehole has a more stable geometry but the material generated by the small scale collapse can cause major complications, delays, and expenses in the drilling, casing and completion of wells. By intentionally reshaping or ovalizing the hole under controlled conditions or circumstances, the problems caused by uncontrolled break-out can be reduced or mitigated. It is particularly attractive to intentionally create an oval hole during the actual drilling or just after the drilling operation (such as by a selective milling procedure or spallation or erosion) so that the rock which is cut from the wellbore to form the non-circular cross-section can be removed as part of the cuttings.

[0020] Alternatively, the non-circular hole may be used for optimized drilling, placing and grouting of tubing such as, but not limited to, heat exchange loops. The significantly reduced cross-sectional area of the elliptical borehole increases the overall drilling rate by reducing the amount of material that must be removed by as much as 30-40 percent for the same tube to tube separation of heat exchange loops. The shape of the hole is optimum for heat transfer from the ground and for minimizing heat transfer from the inlet to outlet tubes. The shape of the hole also requires the least amount of grout to be used in the completion of the system. However, it should be realized that non-circular boreholes may find use in various other applications such as, but not limited to, the installation of parallel piping, tubing, conduit, cables or the like.

[0021] One system for drilling non-circular holes uses a non-contacting drilling system which in one embodiment uses a supersonic flame jet drilling system with a movable nozzle. In one embodiment the non-circular shaped hole is created by an abrasive fluid or particle bearing-fluid jet drill. A defined herein, a fluid is any substance that is capable of flow, including liquids, gases, and supercritical fluids. The fluid used in the fluid jet drill can be water, drilling mud, or other fluids such as supercritical carbon dioxide (CO_2) and fluids that erode the rock chemically using basic or acidic chemicals (such as sodium hydroxide, or other bases, or hydrofluoric or other acids) in solution. In another embodiment, a non-contacting drill can be used that uses a high velocity air stream with suspended or entrained particulates as the abrasive drilling means. A shaped jet outlet nozzle may also be used to create the novel asymmetric erosion shape. The non-circular shaped hole is created by either the high temperature flame, high temperature steam or water, water-particle jet or chemically active fluid jet as it removes rock material by erosion, dissolution and/or thermal spalling.

[0022] For a further understanding of the nature and advantages of the invention, reference should be made to the following description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1***a* is an exemplary schematic diagram of a geothermal heat pump setup showing multiple shallow drill holes in an off-vertical configuration.

[0024] FIG. **1***b* is an exemplary schematic diagram of a geothermal heat pump setup showing multiple vertical boreholes in a line.

[0025] FIG. **2** is an exemplary diagram showing a heat pump flow line as well as grout in the ground.

[0026] FIG. **3***a* is an exemplary cross-sectional view of a circular hole.

[0027] FIG. **3***b* is an exemplary cross-sectional view of a long width elliptical hole produced in accordance with the embodiments of the present invention.

[0028] FIG. **3***c* is an exemplary cross-sectional view of a short width non-circular hole produced in accordance with the embodiments of the present invention.

[0029] FIG. **3***d* is an exemplary cross-section view of a shaped hole with an even longer aspect ratio that can accommodate several of the flow tubes in parallel or in a parallel plane.

[0030] FIG. **3***e* is a transverse view corresponding to FIG. **3***d*.

[0031] FIG. **4** is an exemplary schematic diagram of a flame jet drilling system for shallow non-circular holes, in accordance with one embodiment of the present invention.

[0032] FIG. **5***a* is an exemplary diagram of a jet drill head swivel drilling system in accordance with one embodiment of the present invention for drilling a non-circular borehole. FIG. **5***b* is a top view of FIG. **5***a*.

[0033] FIG. **6***a* is an exemplary diagram of a shaped nozzle drilling system for generating elliptical shaped boreholes without swiveling using flame or fluid jets, in accordance with one embodiment of the present invention. FIG. **6***b* is a top view of FIG. **6***a*.

[0034] FIG. **7***a* is an exemplary diagram of a dual nutating (e.g., wobbling or rotating) nozzle particle impact drilling system with a detailed view shown in FIG. **7***b* and the generally elongate overlapping circular borehole shape that results from this type of drilling method shown in FIG. **7***c*.

[0035] FIG. **8***a* is an exemplary diagram of a horizontal circular borehole with the principal stress in the vertical direction and horizontal regions where breakout can occur.

[0036] FIG. **8***b* is an exemplary diagram of a generally elliptical shape created from the circular bore using a borehole milling technique.

[0037] FIG. **8***c* is an exemplary diagram of a version of an elliptical shape with more pronounced milled or eroded lobes.

[0038] FIG. **8***d* is an exemplary diagram of a shaped borehole using a borehole milling technique.

DETAILED DESCRIPTION OF THE INVENTION

[0039] FIGS. **1***a* and **1***b* show the general layout of a geothermal heat pump system which is one such system where oval (e.g., non-circular) boreholes may be beneficial. It should be noted that there exist a number of different ways for locating the boreholes in such a system, and that the general layout of the hole orientation is not critical to the disclosed embodiments of the present invention. In the particular version shown, the heat exchange drill holes are oriented outward from a more or less central point in an excavated trench **2** where the heat exchanger tubes are connected together into a manifold system **3**. The out-flowing **4** and in-flowing **5** tubes or pipes are connected to the manifold system **3**. The holes are directed from substantially central location to simplify the attachment of the flow tubes to a manifold and to minimize the damage to the terrain around the drill site. A trench is typically used to hide the connection holes and tubing. The flow tubes are typically connected in parallel to the manifold system. The flow tubes are installed after drilling and thereafter a typically mineral-based grout is pumped into the wellbore to insulate the tubes from one another and to provide for improved contact between the tubes and the rock, as well as to prevent the thermal short circuiting by fluid around the heat flow tubes. The wellbore detail is described in conjunction with FIG. **2** which shows a detail view of the heat tube in the ground showing the in-flow **6** and out-flow tubes **7**, the grout **8** filling the region between the tubes with the wellbore **9** including the surrounding earth **10**. The rounded connection tube **11** between in-flow and out-flow tubes is attached by a union connection **12**.

Hole Shape

[0040] FIG. **3***a* shows a cross-sectional drawing of a circular hole showing the borehole **13**, earth **14** and heat exchange tube **15**. FIGS. **3***b-c* show two elliptical holes of different length to width ratios (L/W or L:W) showing the elliptical holes **16** and **17**. FIGS. **3***b-c* also shows the ability of varying the length and width of the hole to suit the tube geometry. Depending on the size of the flow tubes and the proximity of the connections of the tubes, a smaller or larger hole width or length to width ratio can be drilled. In a typical installation, this novel non-circular cross-sectional hole will require about 40 percent less rock to be drilled out to make sufficient room to place the heat exchange tubes, as shown in FIGS. **3***a-c*. The reduction in the drilled hole size considerably increases the rate at which the hole can be drilled, possibly decreasing cost, time on site, and amount of cuttings for disposal. A shaped hole with an even longer L:W aspect ratio could accommodate several of the flow tubes in parallel as is shown in FIGS. **3***d* and **3***e*. This allows for drilling half the number of holes in order to obtain a similar heat transfer capability. This shape maximizes the contact between the tubes and the rock while reducing the tube to tube heat exchange. Further, thermal insulation can be placed between the in-flowing and out-flowing tubes to reduce thermal transfer between them.

[0041] The shaped, non-circular hole can have any non-circular cross-section. The non-circular, cross-section holes in accordance with the embodiments of the present inventions are holes that have aspect ratios that are larger than one (1.00), where an aspect ratio is defined as the ratio of a length to a width of the cross-section shape. So, for example, as defined herein, a circle has an aspect ratio of one, and an ellipse has an aspect ratio greater than one since its major axis (length) is larger than its minor axis (width). In one embodiment, an elliptical cross-section hole is formed. The elliptical cross-section hole can be formed by any means, including, but not limited to, a swiveling drill head, or with a shaped nozzle drilling system, as described below. The length or angle of throw of the nozzle as it swivels, or the width of the jet outlet in a shaped nozzle system, determines the overall width of the elliptical hole. The shaped borehole in accordance with the embodiments of the present invention is not limited to an elliptical-shaped hole. Other holes with aspect ratios greater than 1.0 include, but are not limited to, substantially diamond, slotted, eye-shaped, vesica pisces shaped, egg, dog bone, dumbbell, rattle, crescent, "C"-shaped, "T"-shaped, "L"-shaped, "I"-shaped, triangle, square, tetrahedral, rectangular, or parallelogram-shaped boreholes, or variations thereof, including but not limited to "pinched" or distorted versions of each, are also considered as shaped non-circular boreholes within the scope of the present invention. The cross-section may be symmetric or asymmetric. The profile may change along the length of the borehole, may include some circular portions along the length of the borehole, and the orientation of the non-circular shape may rotate along the length of the borehole the x, y, or z planes relative to the surface. Such shaped boreholes may allow for the installation of heat exchange tubes having an optimum separation between them. From a thermodynamic perspective, there is an optimum separation between the tubes. The optimum distance between the tubes is dimensioned to insure that there is a minimum amount of heat transfer from the in-coming to the out-going liquid. The tubes can be made of a rigid, semi-rigid, elastic, or a flexible material.

[0042] In one specific embodiment, an elliptical hole with a cross-section that is about 2 inches wide by about 5-6 inches long will enable the placement of in-flow and out-flow tubes which would have required a 5 inch or 6 inch diameter circular hole. This novel non-circular cross-section hole will require about 40 percent less rock to be drilled out to make sufficient room to place the heat exchange tubes, as shown in FIGS. **3***a-c*. This reduction in the drilled hole size considerably increases the rate at which the hole can be drilled. The hole will also reduce the amount of grout that needs to be replaced, as well as potentially improve the heat transfer properties of the hole.

[0043] The shaped or non-circular cross-section holes of FIGS. **3***b-c* can be formed in a compositions, materials, soils, rocks or formations, including but not limited to soil, consolidated soils and unconsolidated soils, sands, clays, rocks of all geological types, as well as cements and concretes and the embodiments of the present invention are not limited to any one material type.

[0044] The shaped or non-circular cross-section holes of FIGS. **3***b-c* can be drilled with a number of different technologies, and the embodiments of the present invention are not limited to any one exemplary drilling technology. For example, conventional rotary, hammer, or coiled tubing drilling techniques which produce a circular hole can be combined with auxiliary processes to produce a substantially non-circular cross-section. The drilling technologies may include hard rock or non-contact drilling technologies. Exemplary and effective technologies for drilling hard rock efficiently include, but are not limited to, flame jet spallation, hydrothermal spallation, and water and particle jet techniques,

[0045] The substantially non-circular hole can be formed by a single process or mechanism, such as, but not limited to, hydrothermal spallation using a shaped nozzle or nozzles array, or by rotary drilling using a pulsating cutting tool which can vary in distance from the center point of the hole in a regular pattern to produce a non-circular shape, such as that in **8***b*. Alternatively, the non-circular hole can be formed by two or more different processes or mechanisms. In one example, a rotary drill head can drill a circular hole and an abrasive fluid jet can cut triangular indentations to produce a shape such as that shown in **8***d*. The substantially non-circular bore hole can be formed in one step such as, but not limited to, air-particle drilling with shaped nozzles, or multiple steps, such as but not limited to coiled tubing drilling with a mud motor followed by insertion of a secondary abrasive milling mechanism with two counter rotating heads driven by an electric or mud motor to produce a shape such as that in **8***c*. The drilling process or processes can occur concurrently at the bottom of the drilling assembly, such as, but not limited to, a single pulsating cutting tool, or they may be staggered along the drilling assembly such that a "primary" drilling process forms the primary, circular hole while a following "secondary" process higher up the bottom hole assembly (BHA) shapes the hole into a non-circular cross-section. Alternatively, the drilling process or processes can be performed in two separate or independent operations. As one example, a hole is drilled using rotary bit drilling; in a secondary process, an erosive or spallation jet is used to increase the length of the hole without significantly changing the width. The secondary operation or process can take place when the drill string from the primary operation or process is still in place, is being removed, or after the drill string from the primary operation or process has been completely removed.

[0046] The primary drilling process may include, but is not limited to, conventional drilling processes such as, but not limited to, rotary bit, auger, rotary impact, percussion or sonic drilling, or coiled tubing drilling to form a substantially circular hole. The secondary process may include contact or non-contact drilling processes, such as, but not limited to rotary bit, grinding, milling, abrasion, particle abrasion, spallation, sonication, scraping, cutting, melting, or fusing or combinations of these processes. Power to supply the secondary process may be derived from the rotation of the primary or secondary process drill stem, hydraulic flow of fluids, including but not limited to water, circulating fluids, or drilling muds, or from another source, such as, but not limited to, compressed air flow, or by electrical, thermal, mechanical, or chemical means.

[0047] The formation of the non-circular hole can include technologies that use a rotating drill stem, such as, but not limited to, rotary abrasive drilling or auger drilling through the use of multiple drill heads, off-set drill heads, pulsed jets, pulsed cutters, or other mechanisms. There may be one bit or multiple drill bits, nozzles or drilling surfaces. Bits may be vertically or horizontally offset from each other. Bits, nozzles, or drilling surfaces may be oriented vertically, horizontally, or in other directions. The bits, nozzles or drilling surfaces may be opposing or counter-rotating. Nozzle or jets may be oriented to reduce "hold-down" of rock or to aid in cuttings lift and returns. In addition, there may be secondary or operations to reduce the size of the cuttings or particles in the return fluids including grinding, pulverizing, chemical degradation or dissolution, thermal treatments, or the like.

[0048] The formation of the non-circular hole can include technologies which do not require a rotating drill stem, such as, but not limited to, coiled tubing drilling, water jet, air jet, air spallation, particle impact, hydrothermal spallation, fusion, laser, chemical, plasma, sonication, or percussion through the use of multiple or shaped jets, or through the use of a secondary rotating cutting mechanism in a vertical, horizontal or otherwise offset position. There may be one drill head or multiple drill heads or nozzles. Drill heads may be offset from each other or oriented in different directions.

[0049] In another embodiment, a wellbore milling system that cuts an existing circular wellbore into the preferred profile can be used. These drilling techniques can include both drilling techniques that erode away the rock such as fluid and fluid particle jets, high temperature spallation flame jet, or hot fluid or steam drills. In another embodiment, a chemical drill that uses fluids that are either alkaline or acidic can be used. These jets of fluids or gases are either directed in the bore hole to create the non-circular shape, or a shaped nozzle is used to create the desired hole geometry, as described above. There are also ways to create non-circular drills using rotating contacting systems with multiple cutters or by reaming or shaping the hole after drilling to create the optimum profile. Again, this reaming, or milling, spalling or other process can occur slightly behind the drilling head or further up the drill string or in multiple milling tools placed at different point on the drill string.

[0050] It may be necessary or helpful to determine maximum principal stress in borehole, the orientation of the BHA, the orientation of the non-circular borehole, or that orientation of the BHA or borehole relative to the stresses in the borehole during the course of creating the borehole. Either can be achieved by known processes. Information gathered by downhole instrumentation may be communicated to the surface, in real time or with some delay, where it is processed and used to guide the drilling mechanisms in the formation of the borehole shape or orientation. Alternatively, information gathered by the instrumentation may be processed by downhole equipment or "smarts" and fed directly back to the drilling mechanism, with or without storage or the additional relay of the information to the surface. Information of the principal stresses may be gathered by current or future technologies in advance of drilling, in "real-time," periodically during the drilling operation with the drilling mechanism is functioning or stopped, or after the primary drilling has been completed.

[0051] In order to disclose a method for drilling the novel shaped or non-circular cross-section boreholes in accordance with the embodiments of the present invention, one such system (e.g. flame jet drilling) which is improved to enable the formation of the novel shaped holes is described below.

Improved Flame Jet Drilling System

[0052] FIG. **4** shows an exemplary schematic diagram of a flame jet drilling system for shallow shaped holes, in accordance with one embodiment of the present invention. As used herein a shallow hole is a hole having a depth that is no more than about 500 feet. However, the embodiments of the present invention are not limited to the forming of such shallow holes, and deeper holes can be drilled via the techniques disclosed herein. Flame jet drilling has been shown to be most effective when a high velocity, high temperature combustion stream (e.g., burning hydrogen or hydrocarbon fuels with air or oxygen) is forced against a rock surface. The rock may fail by rapid heating and flaking of the mineral structure, sometimes referred to as "spalling." The rapidly moving combustion gases strip the "spalls" from the surface exposing a new surface to be heated, spalled and removed. A flamejet system in accordance with the embodiments of the present invention can include the underground components including the burner head **18** with swivel mechanism **19**, centralizers **20**, all of which are connected to the surface through a tube connection system **21** which conveys the oxidant, fuel, supplemental air, coolant, and water along with the electronic control signals to a coupler **22**. At the surface a rigid frame **23** supports the drill system and a coiled tube spool **24** holds the nested or bundled tubing which is connected with the air compressor and fuel source **25**. During operation the burner is continuously fed or translated into the ground at a fixed rate of penetration. The swivel mechanism **19** oscillates the nozzle and burner head **18** back and forth using an air pressure drive or motor driven head to create the elliptical shaped hole.

[0053] Certain details of the drilling head for the system of FIG. **4** are shown in FIGS. **5***a-b*. FIG. **5***a* shows a simplified exemplary diagram of a jet drill head swivel drilling system in accordance with one embodiment of the present invention for drilling a non-circular borehole; and FIG. **5***b* shows an orthogonal cross-sectional view corresponding to FIG. **5***a*. As set forth above, a flame jet burner head is used to create a supersonic combustion flame burning propane or diesel with compressed air as the oxidant in its spallation mode of operation. Fuel which can be either propane or diesel is mixed using a distributor with air which has been preheated via the cooling of the flame jet chamber. The mixing of the fuel and air creates a rapid combustion process that creates a high velocity stream in the combustion chamber. The diameter and shape of the chamber determines the extent of the combustion as well as heat transfer to the in-coming air stream. A flame holder maintains the combustion during the high flow rate conditions. Further details of the combustion chamber design are described in references related to flame jet drilling, discussed above. The high velocity gas stream is forced out through the nozzle **26** where the gas expands into a supersonic flame **27**. Exit velocities of the high pressure, high temperature combustion product gases in the range of 1.5 to 2 times the speed of sound are typical depending on the inlet pressure and flow rate of the air and fuel. The rock material that spalls off the surface **28** moves upward in the air stream where it is mixed with coolant water **29** or air and transported up the wellbore annulus **30**. The nozzle swivel **31** is a mechanism actuated by air or electronic means to swivel the jet back and forth over a predefined arc **32**. One or more centralizers **33** are attached to the drill head **34** and keep the drill head centered in the wellbore as the nozzle swivels back and forth creating the slot, the elliptical or the non-circular-shaped hole.

[0054] Alternatively, the elliptical, slot-shaped or non-circular hole be made by using a water jet or particulate flow system. A number of water jet designs are already used in rock drilling and typically include a high pressure pump at the surface with a flow line down to the small bore nozzle where a very hard material such as silicon carbide is used to focus the fluid flow into a tight jet. Particulates can be added to the stream to increase formation erosion and drilling rates. In some methods a drilling mud is used for suspending solids and these solids which can be non-metallic or metallic particles which at high velocities can impact and remove the rock. A conical jet method has also been described that creates an erosive cone of fluid that cuts into rock. Such systems can be modified to include a swiveling mechanism as described above to enable the formation of the slot, the elliptical or the non-circular-shaped hole, in accordance with the present invention. Further details of such jet drilling systems are disclosed in the references above, which are incorporated by reference herein.

[0055] In accordance with the embodiments of the present invention, in order to create the non-circular hole design, the drill head may either be shaped to create the non-circular hole or alternatively the head is enabled to swivel between to endpoints at a rate and total movement that is optimized for the drilling process. This process requires that there be flexibility of the head and the flow components. For example, a ball type swivel mechanism **31** is shown in FIG. **5***a*. The swivel system can be actuated using several different mechanisms including pneumatic, hydraulic and electrical actuation. The sweeping process of the swivel also helps remove the spalled material from the rock face when a flame jet technique is used.

[0056] As an alternative to the drill head enhanced with a swiveling mechanism, a shaped jet design for drilling non-circular or elliptical cross-section holes is shown in FIG. **6***a-b*. In this system the non-circular geometry is created by using a slot-forming shaped or multiple outlet jets that erode away rock using either flame jet or other water jet drilling methods described above to create the substantially non-circular and/or elliptical-shaped hole. A nozzle head using three directed nozzles is shown in FIG. **6***a* and a projected view thereof is shown in FIG. **6***b*. The drill head of FIGS. **6***a-b* includes the nozzle body **35** and the multiple openings **36** designed to force fluid or hot gases out at an angle from the drill head, thus creating the elliptical shaped hole. A plurality of smaller openings can be used is place of each jet with the same effect to create an elliptical hole when the smaller openings are oriented in a manner to form the non-circular cross-sectioned hole.

[0057] Another alternative technique for drilling non-circular cross-sectional boreholes is shown in FIG. **7***a*. This system and the resultant hole it drills are shown in FIGS. **7***a-c*. As shown in FIG. **7***b* the system can use particulate flow in a high pressure stream of either air or fluid such as water or drilling mud to create overlapping circular bores that form a more or less elliptical bore hole shape. FIG. **7***a* shows an overall view of the system while FIG. **7***b* is a more detailed drawing of the wobbler-nutating section of the system. The drawing is shown without the cover box installed which protects the components inside from the fluids, air and particulates. The system has two reinforced rubber, thermoplastic, thermoset, or composite flow tubes **37** that provide a mixture of fluid or air with particulates **39** into the dual nozzles **38** which are manufactured from a hard material such as tungsten or silicon carbide. The nozzles **38** have a convergent inlet **41** and a long straight or slightly divergent outlet section **42** where the mixture of fluid or air and particles **39** are accelerated to high velocity and then impacted against the rock surface **51**. To create a wobble motion as is shown in FIG. **7***b*, the nozzles **38** are connected through a spherical ball **43** which is attached to a bearing surface **44** that slides against the inclined surface of the wobble plate **47**. The wobble plate **47** is centered to the main mount plates **42** on the same axis as the spherical ball **43** using several removable bearing plates **46**. The wobble plate **47** and integral gear assembly is then rotated by applying a rotary motion using either an air, hydraulic or electric motor through a belt **48** or by direct drive through a central hub gear **49** on the motor **40** to the side gears **47** on the nutating assemblies. The motor is attached to the block using a motor mount plate **50**. The low spots on the two wobbler plates **47** are oriented at 180 out of phase from one another so that the sideway force of the nozzles counteracts each other helping to keep the drill assembly centered in the wellbore. The nozzles and tubes are kept from rotating by fixing the tubes **37** up at a point above the end of the air motor. The entire assembly is enclosed in a metal cover box (not shown in the drawing) and the nozzles sealed using rubber bellows. The resultant hole shape **52** and the superposition of the heat exchange flow tubes **53** is shown in the cross section FIG. **7***c*. The same general concept can work with rotation of the nozzles instead of wobbling if the outlet holes are offset from the center or have jets that are directed towards the sides of the bore as well.

[0058] It should be realized that the shaped boreholes in accordance with the embodiments of the present invention are not limited to vertically extending holes. The techniques and systems in accordance with the embodiments of the present invention can also be used to form horizontal boreholes. The non-circular boreholes may also improve the drilling and borehole stability. In accordance with this aspect of the present invention, the drilling system can create an elliptical, eye, or slot-shaped hole with the long direction perpendicular to the principal or maximum stress direction. In many cases, this maximum stress direction is vertical, in which can long direction would be in the horizontal direction. This orientation and geometry is desirable for the wellbore to survive in the high vertical stresses found especially in deep subterranean formations by preventing or minimizing uncontrolled well-bore breakouts or cave-ins. In addition, increased stability of the borehole can allow the driller to use lower mud pressures in the borehole possibly increasing the drilling speed by reducing cuttings "hold-down", creating a more underbalanced drilling environment, and other issues. The non-circular hole may also provide conduits for pumping cement in the annulus between the wellbore and outside of the casing in traditional or novel cementing and completion operations.

[0059] The optimum shape of the non-circular, slot-shaped or elliptical hole can be determined by an estimate of the reservoir stresses present and by applying finite element analysis techniques. A system to monitor the bit or BHA position relative to up/down direction in the wellbore can be useful as a part of the system design. Prior drilling experience in the reservoir can help determine the best orientation for the non circular borehole shape. Use of this non-circular approach allows for horizontal bores that can be left uncased (open hole) for more extended periods of time. In one embodiment, the formation of such holes requires the use of a non-contacting flame jet drilling system with a movable nozzle that swings between pivot points. In a second embodiment, the non-circular hole can be created by an abrasive fluid or particle-bearing fluid jet drill that moves between pivot points. In another embodiment a non-contacting drill can be used that uses superheated steam or water to drill by means of abrasion, erosion or spallation. The fluid used in the fluid jet drill can also be water, drilling mud, or other fluids such as supercritical carbon dioxide (CO_2) and fluids that erode the rock chemically using basic or acidic chemicals (such as sodium hydroxide or hydrofluoric acid in solution). A shaped multiple port nozzle may also be used to create the non-circular, slot-shaped, or elliptical hole. The non-circular shaped hole is created by either the high temperature flame or water-particle jet or chemically active fluid jet as it removes rock material by erosion, abrasion, dissolution and or thermal spalling or in some cases melting of the minerals. In one aspect, monitoring of the bit position using a remote position sensor is preferred to control the orientation of the elliptical hole.

[0060] Horizontal or deviated wellbores have become a major part of oil and gas production and stimulation processes. In many areas these horizontal wellbore sections may be hundreds to thousands of feet in length and may produce oil or gas from a large part of the horizontal section. Horizontal wells are also being considered for other applications including production of geothermal fluids. Large vertical stresses may be present in these environments especially at great depths. These stresses can cause the wellbore to collapse where the rocks are of limited strength and/or the pore pressure in the wellbore drops with through production, drilling, or post drilling operations. Horizontal drilling has traditionally been done by rotary drilling either from a coiled tube rig or by conventional drilling systems. The conventional technologies will typically drill a more or less circular wellbore in these horizontal sections. The use of downhole motors and wellbore tractors allows for extended reach wells where the significantly horizontal sections can be over 20,000 feet.

[0061] FIG. **8***a* shows a circular generally horizontal borehole created during conventional drilling for oil and gas exploration. The borehole **54** is typically subjected to high principal stresses in the primarily vertical direction shown by the arrows **55**. Breakouts **56** caused by rock failure are shown as the scooped out regions (e.g., lobes) in the horizontal direction relative to the original circular borehole shape **57**. Tensional fractures **58** created during drilling can also be found parallel to the direction of the maximum principal stress **55**. FIG. **8***b* shows the same circular borehole **54** extended into a more elliptical shape by two lobes **59** created by a secondary drilling process, as described previously. An alternate version of the generally elliptical shape is shown in FIG. **8***c* where the shaped regions **60** are more pronounced and look much like the breakout themselves. The secondary drilling process removes the rock materials that would eventually collapse into the borehole when the drill is removed from the borehole. As a bonus effect, by strengthening the borehole in this manner the driller may be able to use lower mud pressures during drilling and which can lead to increases in the drilling rates. Reaming the entire borehole to a larger circular shape as is commonly done will only lead to break-outs again because the circular geometry in not inherently stable under these stress conditions. FIG. **8***d* shows the bore-hole **54** extended to include regions **61** that have a more pronounced shape that can be a stable hole geometry. FIGS. **8***b-d* show in general the shapes of boreholes that can be possible for achieving a more stable borehole.

[0062] In addition to the so-called non-contact techniques for forming shaped boreholes described above, shaped bore-holes in accordance with the embodiments of the present invention may also be formed using conventional systems that have been modified to enable the formation of the novel shaped boreholes of the present invention. Using these conventional drilling technologies, a way for creating a shaped borehole (e.g., elliptical shape, oval, eye, or slot-shaped) involves using multiple heads that rotate and that are driven individually. Such multiple head bits can be configured to form the shaped boreholes in accordance with the embodiments of the present invention. Exemplary geometries for such multiple head bits are shown in U.S. Pat. No. 4,185,703, which discloses an apparatus for producing deep boreholes, the disclosure of which is herein incorporated by reference.

[0063] In summary, drilling non-circular boreholes has the advantage of improving the efficiency of the drilling and/or completion operation, providing a wellbore with a shape more optimized for the application, and may produce holes that are inherently more stable and resistant to collapse or break-out. These non-circular holes through the use of traditional contact drilling technologies complimented by a secondary operation. In addition, non-contact drilling systems may be even better suited for the task of combination of higher drill rates possible with the spallation or non-contacting systems and the reduced area of cutting provided by the non-circular, shaped, elliptical, or slot-shaped hole concept in accordance with the embodiments of the present invention enable extremely fast drilling rates to be obtained. Drilling a non-circular hole may be more economic in applications such as, but not limited to, GHP's where the non-circular hole requires less time to drill and less grout to secure the heat transfer tube in place for an equivalent outer diameter hole. This shape may also have more optimized heat transfer properties compared to a circular bore. These will dramatically affect the economics of certain drilling projects and make them more feasible in many areas around the world.

[0064] Several embodiments of the present invention have several advantages over prior art methods and systems by being inherently more suitable for forming a non-circular hole. For example, using a swiveling or a shaped jet drilling head, the present system is able to form non-circular cross-sectioned bore holes by using a non contacting drill mechanism. Such holes can be drilled to much greater depths at much faster rates and at a reduced rate of material excavation, leading to significant cost savings. This may also produce boreholes which are inherently more stable, thereby reducing the time and expense of uncontrolled break-out. The non-circular shape may also allow for certain wellbores to be left unsupported or uncased for longer periods of time, including indefinitely.

[0065] The applications for such non-circular shaped bore-holes may include geothermal power generation, such as enhanced geothermal systems (herein referred to as EGS) and hot dry rock (herein referred to as HDR), or applications where the bore hole will be left unsupported for extended periods (minutes, hours, or days), such as in oil and gas exploration and production (herein referred to as oil and gas E&P) operations, or in situations where the wellbore will be left unsupported indefinitely, such as in an uncased wellbore. An uncased wellbore may have an inner surface that comprises the formation, or one that is substantially comprised of fused rock, ice, a layer of a non-metallic material, such as a thermoplastic, thermoset, composite or ceramic, or a layer of fused metallic material. In addition to EGS-HDR and oil and gas E&P, other conventional applications could benefit by the drilling of non-circular boreholes with reduced tendency towards break-out, including, but not limited to, water well drilling, trenchless pipe installation, sewer and municipal system construction, resource mining, chemical disposal wells, CO_2 or nuclear storage wells, downhole chemical reactions (such as, but not limited to, municipal waste oxidation or biofermentation), bores in ice, or wells for scientific or geologic study, including test holes or secondary holes used for measurements in the above or other operations and applications.

[0066] All patents, patent applications, publications, and descriptions mentioned above are herein incorporated by reference. None is admitted to be prior art.

[0067] As will be understood by those skilled in the art, other equivalent or alternative systems and methods for forming shaped boreholes according to the embodiments of the present invention can be envisioned without departing from the essential characteristics thereof. Accordingly, the foregoing disclosure is intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

1. A method of increasing the mechanical stability of a portion of an existing circular borehole, comprising:

providing a means for forming a substantially non-circular-shaped cross-section drill hole in the existing circular borehole; and

using said means to form the substantially non-circular-shaped cross-section drill hole thus limiting uncontrolled breakout in the borehole.

2.-**8**. (canceled)

9. The method of claim **1** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a non-contacting drilling tool.

10. The method of claim **1** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a substantially slotted jet nozzle drill head configured to form a jet having a length longer than the jet width

11. The method of claim **1** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a flame jet drilling tool.

12. The method of claim **11** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a superheated water or steam tool.

13.-**15**. (canceled)

16. The method of claim **1** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a chemical drilling tool using a fluid containing a chemically erosive fluid.

17. The method of claim **16** wherein said erosive fluid is a basic or an acidic solution.

18. The method of claim **1** wherein said means for forming the substantially non-circular-shaped cross-section drill hole comprises a drill body having a diameter that is smaller than the minimum width of the non-circular hole.

19.-**22**. (canceled)

23. A method of forming a drill hole having a substantially non-circular shaped cross-section, comprising:

forming a circular cross-section bore hole with a first drilling tool; and

forming extended regions on two sides of the circular cross-section bore using a second drilling tool, so as to form two lobes extending from the circular cross-section bore, thus forming said substantially non-circular shaped cross-section.

24. The method of claim **23**, wherein said second drilling tool is configured for a milling operation.

25. The method of claim **23**, wherein said second drilling tool is configured for a jet drilling operation.

26. The method of claim **23**, wherein said drill hole having a substantially non-circular shaped cross-section is a horizontal drill hole.

27. The method of claim **23**, wherein said drill hole having a substantially non-circular shaped cross-section is a non-vertical drill hole.

28. The method of claim **23**, wherein said first drilling tool is selected from the group consisting of: a rotary bit, an auger, a rotary impact, a percussion or sonic drill, a coiled tubing drill, and combinations thereof.

29. The method of claim **23**, wherein said second drilling tool is configured to drill using a process selected from the group consisting of: contact drilling, non-contact drilling, rotary bit, grinding, abrasion, particle abrasion, spallation, sonication, scraping, cutting, melting, and fusing.

30.-**31**. (canceled)

32. The method of claim **23** wherein the second drilling tool operates concurrently with the primary drilling tool.

33. The method of claim **23** wherein the second drilling tool operates while the primary drill string is still in the wellbore.

34. The method of claim **23**, wherein the second drilling operation occurs during the removal of the drill string of the primary drilling operation.

35. The method of claim **23**, wherein the second drilling operation occurs after the removal of the drill string from the primary drilling operation.

36. The method of claim **1** further comprising determining the orientation of the stresses in the rock, the orientation of a bottom hole assembly, or the orientation of a bottom hole assembly relative to the stresses, using downhole instrumentation, during the course of forming the substantially non-circular-shaped cross-section drill hole.

37.-**56**. (canceled)

57. The method of claim **1** wherein the substantially non-circular-shaped cross-section drill hole has a L/W ratio greater than 1.0.

58. The method of claim **1** wherein the substantially non-circular-shaped cross-section drill hole has L/W ratio between 1.05 and 10.

59. The method of claim **1** wherein the substantially non-circular-shaped cross-section drill hole is substantially asymmetric.

60. The method of claim **1**, wherein the portion of the existing borehole is significantly horizontal.

61. The method of claim **1**, wherein the portion of the existing borehole is significantly vertical.

62. The method of claim **1**, wherein the means to form the substantially non-circular-shaped cross-section drill hole comprises hydrothermal spallation.

63. The method of claim **1**, further comprising:

obtaining information of principal stresses in the existing borehole, and

guiding the means to form the substantially non-circular-shaped cross section drill hole to said principal stresses.

64. The method of claim **23**, wherein said forming extended regions on two sides of the circular cross-section bore comprises the use of hydrothermal spallation.

65. The method of claim **23**, further comprising:

obtaining information of principal stresses in the existing borehole, and

guiding the second drilling tool to said stresses, thereby relieving the determined stresses.

66. The method of claim **36**, further comprising guiding the means to form the substantially non-circular-shaped cross section drill hole to said principal stresses.

67. A method of reducing uncontrolled breakout in portion of a circularly formed wellbore, comprising

hydrothermally spalling rock in said portion thereby forming a non-circular shaped cross section of said wellbore.

68. The method of claim **65**, wherein said hydrothermally spalling comprises use of a shaped nozzle.

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