

(19) World Intellectual Property Organization  
International Bureau



(43) International Publication Date  
16 September 2010 (16.09.2010)

PCT

(10) International Publication Number  
**WO 2010/104835 A1**

(51) International Patent Classification:  
C04B 14/00 (2006.01)

(21) International Application Number:  
PCT/US2010/026634

(22) International Filing Date:  
9 March 2010 (09.03.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
61/158,556 9 March 2009 (09.03.2009) US

(71) Applicant (for all designated States except US): **RYGAN CORP.** [US/US]; 5016 S. 167th E. Ave., Tulsa, OK 74134 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **LAWLESS, Lane** [US/US]; 5010 S. 167th E. Ave., Tulsa, OK 74134 (US). **FRAIM, Michael** [US/US]; 440 Alamos Road, Corrales, NM 87048 (US). **LARSON, Brandon A.** [US/US]; 4716 River Hill Circle, Dallas, TX 75287 (US).

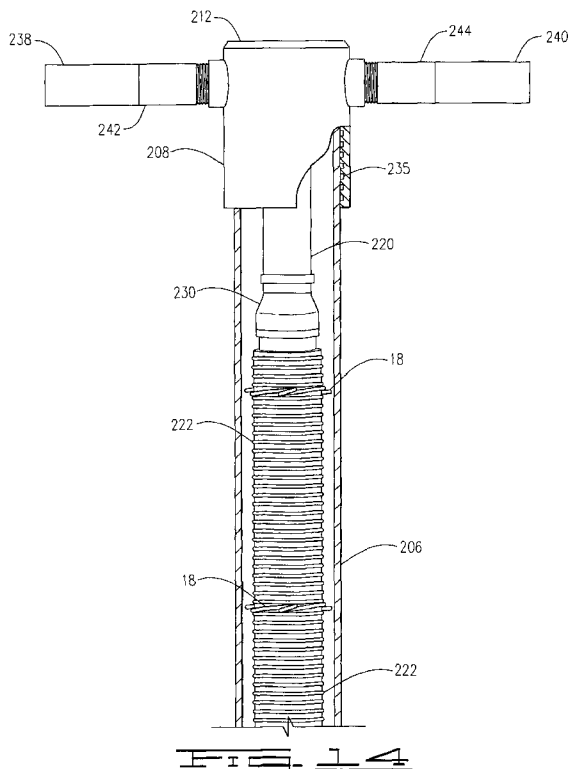
(74) Agent: **BROWN, Dennis D.**; Fellers, Snider, Blankenship, Bailey & Tippens, P.C., 321 South Boston, Suite 800, Tulsa, OK 74103-3318 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM,

[Continued on next page]

(54) Title: METHOD, APPARATUS, HEADER, AND COMPOSITION FOR GROUND HEAT EXCHANGE



(57) Abstract: A subterranean ground heat exchange system, a method of installation, and a grout composition therefor. The grout composition is a pumpable slurry formed of from about 70 to about 85 parts by weight natural flake graphite and from about 30 to about 15 parts by weight bentonite. The solids content of the pumpable grout slurry is preferably at least 35% by weight and is more preferably at least 40% by weight. The ground exchange apparatus preferably utilizes an improved supply and return header comprised of supply and return ports which are provided through the vertically extending outer wall of a header housing. The header also includes an interior supply conduit which extends from the supply port into the interior of the header housing and includes a bend positioned in the interior of the housing for directing the heat transfer fluid downwardly.

WO 2010/104835 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG). **Published:**

— with international search report (Art. 21(3))

## METHOD, APPARATUS, HEADER, AND COMPOSITION FOR GROUND HEAT EXCHANGE

### 1. Field of the Invention

This invention relates to the exchange of heat with the earth for heating, cooling and thermal energy storage applications. In one particular aspect, but not by way of limitation, the invention relates to cost effective materials, devices, systems, compositions, and methods which lower the thermal resistance between the working fluid (i.e., the heat exchange fluid) of a closed loop ground heat exchanger and the earth and to working fluid supply and return headers for concentric subterranean ground heat exchange systems.

### 2. Background of the Invention

Ground heat exchangers provide more efficient heating and cooling of building spaces by exchanging heat based on the average yearly temperature of the soil and on a higher thermal conductivity of soil as compared to air. The relatively constant temperature of the earth provides a more favorable temperature gradient for heat transfer for both heating and cooling than conventional atmospheric air source systems because the atmospheric air experiences an average daily temperature swing of 20°F and an average seasonal temperature swing of 80°F on the North American continent. Heat is rejected to the earth by the heat exchange fluid when in the cooling mode and absorbed from the earth by the heat exchange fluid when in the heating mode. Ground heat exchange is synonymous with the terms geothermal, shallow geothermal, ground source and geexchange when used in the context of subterranean heat exchange with the earth at the earth's ambient temperature.

Ground heat exchange systems can provide direct cooling or heating to a building space so long as an appropriate temperature gradient exists between the working fluid used in the system (e.g., water) and the earth and the ground loop is large enough to handle the heat load. The ground loop comprises the buried piping for the ground heat exchanger and for distribution of the working fluid. For most urban applications, a heat pump is also typically installed in the system to increase the thermal gradient to provide "on demand" efficient heating and cooling to a building space. The heat pump greatly increases the load capacity of the ground loop so that

residential and business customers can afford the cost of installing the ground loop for their homes or businesses.

Various methods have been developed to exchange heat with the earth. Both vertical and horizontal pipe installations have been used to make subterranean ground loops. Experience has shown that horizontal loops are inefficient ground loops because the shallow depth of burial causes the ambient soil temperature to track the surface ground temperature. Horizontal loops buried below the frost line are, however, excellent for melting snow on pedestrian pathways and removing ice from bridges. Vertical ground loops can be open or closed. An open loop is where at least two wells are completed in a high productivity aquifer and water is circulated from one well to another. This method can be no longer used in urban areas due to drinking water safety standards enacted to prevent aquifer contamination.

The vertical closed ground loop heat exchanger uses piping inserted in a drilled hole in the ground. The configuration of the pipe loop is either side-by-side (U-tube) or concentric. The pipe loop can be made of metal or plastic. Initially, metal pipe loops were used in both concentric and U-tube installations to save capital cost, but experience has shown that metal pipe loop installations eventually fail due to anodic corrosion from conducting telluric or man-made electrical currents from one formation layer to another. Experience has also shown that plastic ground loop installations can last indefinitely, but the local ground temperature will heat up or cool down if the seasonal load is not balanced.

Currently, the most common type of vertical closed loop ground heat exchanger is a U-tube installation, which consists of inserting two lengths of high density polyethylene (HDPE) pipe, with a U-bend joint on the bottom, into a 4 to 6 inch diameter borehole. The borehole depth typically ranges from 150 to 400 feet deep into the earth. To prevent aquifer contamination, the bore hole is backfilled with impermeable grout formed of a high solids bentonite slurry or neat cement. The grout backfill keeps the piping in thermal contact with the wall of the borehole and provides a permeability barrier to reduce the vertical movement of ground water from one aquifer to another or to prevent surface water contamination of an aquifer.

The vertical, closed-loop, ground heat exchanger typically uses water or a water antifreeze mixture as a working thermal fluid. Refrigerants such as Freon<sup>®</sup> typically are not used due to expense and possible aquifer contamination. The water

based fluid is circulated through the closed piping system, which consists of a distribution system to the vertical wellbores. The wellbore loop provides a downward path and an upward path that is arranged in either a U-tube or concentric pipe configuration. The U-tube configuration is about 30-60% as efficient as the concentric pipe configuration because, in the U-tube configuration, the returning fluid will reabsorb about 50% of the heat transfer to the ground on the way back up.

The concentric pipe configuration comprises a smaller diameter pipe arranged concentrically within a larger diameter outer pipe (i.e., the "casing"). The inside surface of the smaller diameter pipe provides a center flow channel and the annulus between the outer surface of the smaller diameter pipe and inner surface of the larger diameter pipe provides an annular flow channel. In most concentric pipe designs, the returning fluid should reabsorb less than 10% of the heat transferred to ground. Reference may be had to US Patent No. 4,574,875 "Heat Exchanger for Geothermal Heating and Cooling Systems" and US Patent Application Publication No. 20070029066 "Coaxial-Flow Heat Transfer Exchanging Structure for Installation in the Earth and Introducing Turbulence into the Flow of the Aqueous-Based Heat Transfer Fluid Flowing Along the Outer Flow Channel while Its Cross-Sectional Characteristics Produce Fluid Flows There-along Having Optimal Vortex Characteristics that Optimize Heat Transfer with the Earth", which describe prior concentric piping designs.

The objective of the concentric pipe design is to maximize the heat exchanged between the bulk fluid in the annular flow channel and the earth. As illustrated in FIG. 3, for heat conduction to the earth, the heat must pass through three thermal resistances: (1) the resistance **2** of the fluid boundary layer separating the bulk fluid and pipe wall; (2) the resistance **4** of the pipe material; and (3) the resistance **6** of the grout or slurry backfill. Heat loss can also occur between the center channel and annular channel, which reduces heat exchange with the earth. This undesirable condition is known as thermal short circuit. Minimizing thermal resistance between the bulk fluid and earth and maximizing thermal resistance between the center channel and the annular channel allows more heat to be exchanged for a given temperature gradient between the fluid and the earth. Prior U-tube designs have been particularly inadequate in minimizing thermal short circuit while prior concentric pipe

designs have been particularly inadequate in minimizing thermal resistance of the grout and pipe wall.

Vertical, concentric-pipe, ground-loop, heat exchangers are also used as thermal banks for thermal energy storage applications. U-tube designs do not have  
5 enough water storage volume or high enough pulse heat transfer to make a thermal bank. Ground loops have greater thermal storage capacity than water tanks and they do not take up any valuable building space. For example, a heat pump can run at night to inject or remove heat from an isolated portion of a ground loop with cheaper electrical rates; then, during the day only a pump circulates fluid from the ground loop  
10 thermal bank to handle the heating and cooling loads of the building.

Minimizing the fluid boundary layer thermal resistance 2 requires: (1) maintaining separation between the smaller diameter pipe and the larger diameter pipe to prevent low flow zones in the annular channel and (2) preventing the development of laminar flow in the annular channel. The design in US Patent No. 4,574,875  
15 disposes spacers (i.e., centralizers) periodically along the outer surface of the smaller diameter pipe to maintain alignment between the smaller diameter pipe and the larger diameter pipe (i.e., to assist in centralizing the smaller pipe within the larger pipe). The spacers have projecting spoke-type contacting fins which are also said to generate an amount of beneficial turbulence in the annular channel.

20 The design in US Patent Application Publication No. 20070029066 employs the method of disposing a helically-wrapped turbulence generator along the outer surface of the smaller diameter pipe to generate additional vorticity. Cost effectively manufacturing such a pipe with helical fluting disposed along the entire length of the outer surface has proven difficult and such fluting, and pipe, are easily damaged,  
25 making the fluted pipe difficult to insert into a larger diameter pipe. Attaching the fluting as a separate piece to a smooth pipe makes the fluting susceptible to slipping along the outer surface of the pipe, which would allow the smaller diameter pipe to come in contact with the larger diameter pipe, thus creating low flow zones.

Minimizing the thermal resistance 4 of the larger diameter pipe requires using  
30 a material that: (1) has minimal wall thickness; (2) has enhanced thermal conductivity; (3) has sufficient mechanical strength to prevent collapse during installation; and (4) does not corrode in soil or degrade in antifreeze environments. Thermoplastic resins such as HDPE and PVC offer sufficient mechanical strength and

corrosion resistance but they also have high thermal wall resistances that would classify them as thermal insulators. Metal pipe offers very low thermal resistance, but corrosion resistant alloys are very expensive, and their weight makes them more expensive to ship and more difficult to install. US Patent No. 4,574,875 prefers the use of plastic for the larger diameter pipe while US Patent Application Publication  
5 No. 20070029066 prefers the use of metal or a fluted plastic for the larger diameter pipe. Neither prior design addresses the mechanical strength of thin pipe walls as a function of bore depth.

Minimizing the backfill thermal resistance 6 requires a slurry composition  
10 that: (1) has enhanced thermal conductivity; (2) has low permeability; (3) has sufficiently long set times to allow deployment; (4) is environmentally safe with no organic leachate and less than 1 PPM for all metals as defined by a TCLP (Toxic Chemical Leaching Procedure); and (5) does not substantially dissipate in geologies with high groundwater flow. It is common practice to add silica sand to a bentonite  
15 and water slurry to enhance thermal conductivity to approximately 1.4 Btu/hr-ft-°F. Reference may be had to US Patent Application Publication No. 20070125274 “Thermally Conductive Grout for Geothermal Heat Pump Systems”, which describes the use of graphite particles, ranging from 10 to 1000 microns in size, added to the slurry in concentrations from 2 to 25% by weight to produce a backfill with thermal  
20 conductivity greater than 4 W/m-K (2.3 Btu/hr-ft-°F) that has lower permeability. The prior art is inadequate in providing details specifying a backfill composition that would be pumpable, would enable sufficiently long set times for deployment, and would resist dissipation due to high ground water flow rates. US Patent No. 4,574,875 does not address backfill composition and US Patent Application Publication No.  
25 20070029066 prefers the use of thermally conductive cement but is not specific in backfill mixture composition, nor does it address permeability, environmental safety or dissipation.

Minimizing thermal short circuit requires that the center channel be sufficiently insulated from the annular channel to prevent significant heat flow  
30 between the channels. The design in US Patent No. 4,574,875 offers no solution while the design in US Patent Application Publication No. 20070029066 prefers relying on laminar flow in the center channel or using an insulating gas within the smaller diameter pipe, which are both impractical solutions to implement.

The designs in both US Patent No. 4,574,875 and US Patent Application Publication No. 20070029066 also fail to provide solutions that: (1) minimize pressure drop across the system; (2) prevent blockage of the center channel outlet; and (3) facilitate installation.

5 In addition to the above, further shortcomings and problems with existing concentric ground exchange assemblies arise due to the design of the heat transfer fluid supply and return headers currently used in these systems. A concentric ground exchange assembly **102** of a type heretofore known in the art is depicted in FIG. 8. The prior art assembly **102** comprises: an elongate outer casing string **104** which  
10 extends into the ground; a smaller diameter elongate inner pipe string **106** which extends downwardly inside the casing **104** such that a return flow annulus **108** is provided between the exterior of the inner conduit **106** and the interior wall of the casing **104**; a plurality of centralizing elements or structures (not shown) which are positioned at intervals along the exterior of the inner conduit **106** for maintaining the  
15 inner conduit **106** in a substantially concentric alignment within the interior of the casing **104**; an optional turbulence generating structure **110** (i.e., helical fluting) extending along the exterior of the inner conduit **106** for producing flow turbulence within the return flow annulus **108**; and a heat transfer fluid supply and return header **112** secured at the upper end of the concentric ground exchange assembly **102**.

20 The prior art concentric ground exchange assembly **102** will typically be installed in a vertical borehole which has been drilled to a depth in a range of from about 100 to about 500 feet and has a diameter in the range of from about five to about eight inches. As mentioned above, the concentric exchange assembly **102** is inserted into the borehole and the borehole is typically backfilled with a grout slurry  
25 composition which hardens to form a substantially impermeable grout barrier. The grout barrier prevents or at least reduces the vertical movement of ground water within the borehole and provides a heat transfer bridge between the exterior of the casing and the interior wall of the borehole.

The heat transfer working fluid employed in the concentric ground exchange  
30 assembly **102** will typically be either water or a mixture of water and antifreeze. Again, although refrigerants such as FREON<sup>®</sup> or other materials can alternatively be used, such materials are typically not employed due to the cost of materials and the danger of aquifer contamination.

During the operation of the concentric exchange assembly **102**, the working fluid is delivered from a fluid supply line (not shown) to the inlet port **114** of the supply and return header **112**. The supply line typically extends horizontally underground and is therefore often referred to as a “lateral.” Moreover, as a consequence of the substantially horizontal orientation of the supply lateral, it is necessary that the header inlet include an elbow **115** which directs the fluid supplied to the inlet port **114** downwardly through the inner conduit **106**. The fluid flows out of the lower end portion of the inner conduit **106** and is then directed upwardly through the return flow annulus **108** provided between the inner wall of the casing **104** and the exterior of the inner conduit **106**. As the working fluid flows upwardly through the return flow annulus **108**, the fluid is either heated or cooled by heat transfer with the earth and then discharged to a return line (lateral) (not shown) connected to the header discharge port **116**.

Unfortunately, the supply and return header **112** used in the prior art concentric ground exchange assembly **102** has presented numerous problems and difficulties. The prior art supply and return header **112** comprises: a tall vertical inlet conduit **118** which includes the inlet elbow **115** at the top thereof and extends downwardly to the upper end of the inner conduit **106**; a horizontally oriented connector **122** extending from the elbow **115** for connection of the working fluid supply line (lateral); an outer housing **124** provided around the lower exterior of the inlet conduit **118**, below the elbow **115**, for receiving fluid from the return flow annulus **108**; a horizontal connector **126** extending from the outer housing **124** for attachment of the working fluid return line (lateral); a flange **128** provided at the lower end of the supply and return header **112** for attaching the header **112** to a corresponding flange **130** which must be installed on the upper end of the casing **104**; a plurality of (typically 4) bolts **132** and associated nuts and washers for securing the header flange **128** on the casing flange **130**; and a flange gasket **134** positioned between the header flange **128** and the casing flange **130**.

In addition to other shortcomings, the underground flange connection required by the prior art supply and return header **112** is susceptible to significant leakage and other problems resulting from: (a) thermal contraction and expansion of the header material (typically high density polyethylene), (b) deterioration of the gasket **134** and/or the bolts **132** and associated nuts and washers, (c) the application of

insufficient or excessive torque to the flange bolts **132** during installation, (d) torque created by surface vehicular loads, and/or (e) the loosening of the nuts and bolts over time. Moreover, due to its excessive height required for accommodating the inlet elbow configuration **115**, the installation of the prior art supply and return header **112** requires a trenching depth of between 5 to 6 feet or more.

#### SUMMARY OF THE INVENTION

The present invention satisfies the needs and alleviates the problems discussed above. The invention provides a system, equipment, devices, compositions, and a method for subterranean ground heat exchange which minimize both (a) thermal short circuit and (b) the three thermal resistances between the working fluid and the earth, while also providing solutions to other problems not addressed in prior art.

In addition, the present invention provides an improved supply and return header and an improved concentric ground exchange assembly having the inventive supply and return header installed on the upper end thereof. The inventive supply and return header satisfies the needs and alleviates the problems discussed above by: (a) eliminating the flange connection to the casing required by the prior art header; (b) replacing the flange connection with a header skirt or collar which is chemically fused directly to the upper end of the casing; and (c) significantly reducing the height of the header to as little as 1/3 or less of the height of the prior art structure so that significantly less trenching and digging is required when installing the inventive system. The inventive supply and return header therefore has a much greater life, is much more reliable, is much better able to withstand surface vehicular loads, and is less costly and much easier to install.

In one aspect, there is provided a system, assembly, and method for low thermal resistance ground heat exchange between a working fluid and the earth. The system can be used for the heating and cooling of building spaces and can provide thermal energy storage. The system can be coupled to a heat pump or provide direct cooling by being coupled to a fluid cooler. The system preferably comprises: a low thermal resistance casing; a ribbed drop tube inserted into the casing; standoffs disposed on the exterior of the drop tube to maintain separation between the drop tube and the casing; an end cap to seal the bottom of the casing; and a header with supply

and return ports. The system is preferably installed using an inventive, thermally conductive grout composition.

In another aspect, there is provided an apparatus and system for heating, cooling, and thermal energy storage using low thermal resistance ground heat exchange, the apparatus and system preferably comprising:

- (a) an outer cylindrical, fiber-resin composite casing which provides a pressure boundary;
- (b) a smaller diameter cylindrical drop tube arranged substantially concentrically within the cylindrical casing to create a center channel and an annular channel whereby the cross sectional area of the annular channel is preferably greater than cross sectional area of the center channel;
- (c) the interior surface of the drop tube being smooth to minimize pressure drop and heat transfer along the center channel;
- (d) the exterior surface of the drop tube being ribbed to create flow vortices and induce flow turbulence in the annulus to disrupt the thermal boundary layer on the interior casing surface to increase heat transfer to the earth;
- (e) standoffs disposed along the outer surface of the drop tube such that the drop tube is substantially centralized in the casing, heat transfer is increased, and pressure drop is reduced;
- (f) an end cap which seals the bottom of the casing; and
- (g) a header to seal the top of the casing, the header providing a port to connect the center channel to a supply line and a port to connect the annular channel to a return line.

In another aspect, there is provided a conduit for conductive heat transfer comprising a composite wall structure formed from a thermosetting plastic composition and a reinforcing fiber material, wherein: (a) a flow passageway extends through the composite wall structure; (b) the reinforcing fiber material is fiberglass, carbon fiber, aramid fiber, or a combination thereof; (c) the thermosetting plastic composition from which the composite wall structure is formed includes an amount of a thermal conductivity enhancing additive of at least 1.5% by weight based upon the total weight of the thermosetting plastic composition; and (d) the thermal conductivity

enhancing additive is aluminum flake, aluminum powder, aluminum oxide, aluminum nitride, graphite, boron nitride, silicon carbide, Raney nickel, silver-coated nickel, silver-coated copper, or a combination thereof.

5 The inventive conduit can be used for conductive heat transfer and/or other purposes in numerous types of applications, exchangers, and systems. The inventive conduit is particularly well suited for use as a casing for any type of ground heat exchange system including, but not limited to, both U-tube and concentric exchanger configurations, as well as ground loops having any type of vertical, horizontal, angled, or deviated orientation.

10 In another aspect, there is provided a method of forming a conduit for conductive heat transfer. The method comprises the steps of: (a) applying a thermosetting epoxy composition to a continuous fiber material and (b) winding the continuous fiber material around a mandrel. The continuous fiber material is preferably fiberglass, carbon fiber, aramid fiber, or a combination thereof. The thermosetting epoxy composition includes an amount of medium grade aluminum powder in the range of from about 1.5% to about 8% by weight (more preferably at least 2% by weight) based upon the total weight of the thermosetting epoxy composition.

15 20 In another aspect, there is provided a method of subterranean ground heat exchange comprising the step of flowing a fluid medium through an underground casing such that thermal energy is conducted through a wall of the casing between the fluid medium and an underground environment surrounding the casing. The wall of the casing is a composite wall formed from a thermosetting plastic composition and a reinforcing fiber material wherein: (a) the reinforcing fiber material is fiberglass, carbon fiber, aramid fiber, or a combination thereof; (b) the thermosetting plastic composition from which the composite wall is formed includes an amount of a thermal conductivity enhancing additive of at least 1.5% by weight based upon the total weight of the thermosetting plastic composition; and (c) the thermal conductivity enhancing additive is aluminum flake, aluminum powder, aluminum oxide, aluminum nitride, graphite, boron nitride, silicon carbide, Raney nickel, silver-coated nickel, silver-coated copper, or a combination thereof.

25 30 In another aspect, there is provided a method of subterranean ground heat exchange comprising the step of flowing a fluid medium through a flow annulus in an

underground casing such that thermal energy is conducted through a wall of the casing between the fluid medium and an underground environment outside of the casing. The flow annulus is formed between an interior wall of the casing and an internal conduit which extends into the casing. The internal conduit has a series of discrete, spaced-apart, radial ribs such that the series of ribs extends along an exterior of the internal conduit and such that the radial ribs project into the flow annulus toward the interior wall of the casing.

In another aspect, there is provided an apparatus for subterranean ground heat exchange comprising: (a) a casing which extends underground; (b) an internal delivery conduit extending into the casing for delivering a fluid medium to a distal end portion of the internal delivery conduit such that the fluid medium will flow from the distal end portion of the internal delivery conduit into a flow annulus formed between the internal delivery conduit and an interior wall of the casing; and (c) a series of discrete, spaced-apart, radial ribs wherein the series of ribs extends along an exterior of the internal delivery conduit such that the radial ribs project into the flow annulus.

In another aspect, the inventive system is installed using a novel backfill slurry composition. The composition preferably comprises bentonite (or cement), graphite and water such that the composition preferably has a solids content of at least 25% solids by weight. The slurry is used to backfill a borehole and provides a thermal communication path between the outer casing and the wall of the borehole (i.e., between the outer casing and the subterranean ground environment surrounding the casing). The graphite content is preferably an amount sufficient to provide a thermal conductivity of at least 3.0 Btu/hr-ft-F.

In another aspect, in order to further promote conductive heat transfer, it is also preferred concerning the novel casing used in the low thermal resistance ground heat exchange system that the casing be a thin-walled casing wherein : (a) the casing is preferably formed by embedding fiber or surrounding fiber in a thermosetting resin by applying the thermosetting resin composition to the fiber (e.g., by wetting the fiber in a thermosetting resin bath) and then winding the wetted fiber around a mandrel; (b) the large diameter cylindrical casing has a ratio of outer diameter to inner diameter that is less than 1.1; (c) the casing end cap is equipped with holes to allow a rope or wire to be threaded through the end cap to facilitate lowering the casing assembly into

the bore; (d) the end cap is equipped with a check valve and cement float shoe to facilitate grouting by pumping down the casing; (e) flow ports with cumulative cross sectional area greater than cross sectional area of center channel are provided in or at a distal end portion of the center channel near the center channel outlet; and/or (f) the  
5 outer casing is constructed in segments of 15-30 feet with male threads at one end and female threads at the other end. If desired, the thermosetting resin composition can optional also include other additives such as, e.g., a standard wetting and dispersing agent to facilitate dispersion of the resin fillers and wetting out of the fiber and/or an air release additive to reduce entrapped air bubbles to increase heat transfer.

10 In another aspect, the backfill grout slurry dry base preferably comprises (a) at least 70 parts by weight (more preferably from about 75 to about 85 parts by weight) natural flake graphite, the natural graphite preferably having a particle size of less than 200 mesh, and (b) from about 15 to about 30 parts by weight (more preferably from about 25 to about 15 parts by weight) bentonite or Portland cement. However,  
15 by way of example, one alternative backfill slurry dry mix composition can comprise at least 70% by volume amorphous graphite, synthetic graphite, or coke and from about 2% to about 5% by volume calcium sulfate with the remaining volume being made up of sodium bentonite.

In another aspect, there is provided a grout slurry composition for conductive  
20 heat transfer applications, the grout slurry composition consisting essentially of: (a) a grout dry base composition consisting essentially of from about 70 to about 85 parts by weight natural flake graphite and from 30 to about 15 parts by weight of bentonite, Portland cement, or a combination thereof, and (b) an amount of water in the range of from about 8 to about 12 gallons for each 50 pounds of the grout dry base  
25 composition. The natural flake graphite preferably has a particle size effective for causing the natural flake graphite to remain in suspension in the grout slurry composition during use without any dispersant or other suspension assisting agent being present in the grout slurry composition.

In another aspect, it is also preferred concerning the novel low thermal  
30 resistance ground heat exchange system that: (a) the smaller diameter cylindrical drop tube have a ratio of outer diameter to inner diameter of at least 1.2 to mitigate thermal short circuiting; (b) the standoffs employed each have three loops constructed from one continuous wire and that the standoffs be open so that they can be clipped

onto the drop tube; (c) an ultrasonic horn be pulled up the casing to instantly set the grout in the wellbore; and/or (d) the graphite enhanced cement mixture be used to provide structural support for the building piers and thermal conductivity for the ground heat exchanger.

5           The larger diameter cylindrical casing formed by the present invention minimizes thermal resistance and has sufficient crush and burst tolerance to be installed in depths of up to 500 ft or more. The novel cylindrical casing also resists corrosion when buried in the ground or when exposed to anti-freeze. In addition, the novel cylindrical casing preferably weighs less than 1 pound per foot and is preferably  
10 equipped with male and female threads for easy field assembly. Further, the above described thermosetting resin composition additives increase the thermal conductivity of the cylindrical outer casing. Also, the hole provided in the casing end cap allows a rope or wire to be threaded therethrough for lowering the assembled casing into the borehole. However the hole is formed and positioned such that it does not prevent the  
15 end cap from sealing the end of the casing.

          In another aspect there is provided a grout slurry composition for conductive heat transfer applications comprising: (a) a dry base premixed composition consisting of from about 70 to 85 parts by weight natural flake graphite and from about 30 to  
20 about 15 parts by weight bentonite and (b) water in an amount of not more than 12 gallons for each 50 pounds of the dry base premixed composition. The natural flake graphite has a particle size of not greater than 200 mesh. The dry base premixed composition and water are preferably present in concentrations such that the grout slurry composition has a solids content of at least 35% by weight based upon the total weight of the grout slurry composition. In addition, the grout slurry composition  
25 preferably also comprises a thinning agent present in an amount such that the grout slurry composition is pumpable.

          In another aspect there is provided a grout slurry composition comprising: from about 70 to about 85 parts by weight natural flake graphite; from about 30 to about 15 parts by weight of bentonite; water in an amount effective such that the grout  
30 slurry composition has a solids content of at least 30% by weight based on the total weight of the grout slurry composition; and a thinning agent. The thinning agent is preferably sodium chloride, potassium chloride, or a combination thereof and is present in the grout slurry composition in an amount effective such that the grout

slurry composition is pumpable. The grout slurry composition more preferably has a solids content of at least 35% by weight solids and most preferably has a solids content of at least 40% by weight solids.

In another aspect there is provided a method of installing a casing of a  
5 subterranean ground heat exchange system. The method comprises the steps of: (a) placing the casing in a borehole; (b) forming a treated water by adding a thinning agent to water; (c) adding the treated water to a dry base composition to form a grout slurry; and (d) placing the grout slurry in an annulus between an interior wall of the borehole and an outer wall of the casing. The dry base composition consists  
10 essentially of from about 70 to about 85 parts by weight natural flake graphite and from 30 to about 15 parts by weight bentonite. The treated water is added to the dry base composition in an amount such that the grout slurry formed in step (c) has a solids content of at least 30% by weight based on the total weight of the grout slurry. The thinning agent is added to the water in step (b) in an amount effective to allow the  
15 grout slurry to be placed in the annulus in accordance with step (d) by pumping. The grout slurry more preferably has a solids content of at least 35% by weight and more preferably has a solids content of at least 40% by weight. The thinning agent is preferably sodium chloride, potassium chloride, or a combination thereof. In one embodiment, the grout slurry formed in step (c) and placed in the annulus by pumping  
20 in step (d) consists solely of the dry base composition, the water, and the thinning agent.

In another aspect there is provided an improvement for a subterranean ground heat exchange apparatus of the type comprising a casing extending underground, an internal delivery conduit extending into the casing, and a supply and return header  
25 mounted at an upper end of the casing for supplying a heat transfer fluid into the internal delivery conduit and for receiving the heat transfer fluid as it returns to the supply and return header via a return flow annulus between the internal delivery conduit and an interior wall of the casing. The improvement comprises an inventive supply and return header comprising: a housing having a closed top and a vertically  
30 extending outer wall which surrounds an interior of the housing, the closed top defining an upper end of the supply and return header; a supply port for the heat transfer fluid provided through the vertically extending outer wall; a return port for the heat transfer fluid provided through the vertically extending outer wall; and an

interior supply conduit. The interior supply conduit includes a first portion thereof which extends into the interior of the housing from the supply port and has a bend which is positioned in the interior of the housing for directing the heat transfer fluid downwardly. The interior supply conduit also includes a second portion thereof  
5 which extends downwardly from the bend for delivering the heat transfer fluid to the internal delivery conduit of the ground heat exchange apparatus.

In another aspect, the inventive supply and return header used in the inventive improved ground heat exchange apparatus preferably has a height effective such that, when the inventive header is mounted on the upper end of the casing, the upper end of  
10 the supply and return header will not be more than 10 inches (more preferably not more than 8 inches, even more preferably not more than 7 inches, and most preferably not more than 6 inches) above the upper end of the casing.

In another aspect, there is provided a rubber or plastic drop tube that has ribs disposed along its outer surface to create flow vortices and induce flow turbulence in  
15 the annulus and cause the thermal boundary layer to restart along the casing inner wall.

In another aspect, there is provided a drop tube that resists corrosion and decomposition when exposed to antifreeze.

In another aspect, there is provided a drop tube that has a thermal conductivity  
20 value of less than 0.2 Btu/hr-ft-°F to reduce thermal short circuiting.

In another aspect, there is provided a plastic or corrosion resistant metal standoff to maintain alignment between the drop tube and inner casing wall to prevent low flow zones.

In another aspect, there is provided a procedure wherein standoffs are placed  
25 in the drop tube corrugation valleys to prevent vertical movement along the drop tube.

In another aspect, there is provided a drop tube with a smooth inner surface to minimize pressure drop along the center channel.

In another aspect, there is provided a drop tube that has an outer diameter such that the cross sectional area of the annulus is preferably equal to or greater than that of  
30 the inner channel in order to minimize pressure drop in the annulus.

In another aspect, there is provided a drop tube having holes in or at the bottom end portion thereof to provide flow channels should the bottom end of the drop tube come in contact with the casing end cap. The holes preferably have a

combined area equal to or greater than the center channel area to minimize pressure drop.

In another aspect, there is provided a slurry backfill composition that has thermal conductivity of preferably greater than 3.0 Btu/hr-F and permeability of preferably less than  $1 \times 10^{-7}$  cm/s.

In another aspect, there is provided a grout composition that has a set time greater than one hour and that does not significantly dissipate in geologies with significant ground water flow.

In another aspect, there is provided a grout composition that will not contaminate the environment.

Further aspects, features and advantages of the present invention will be apparent to those of ordinary skill in the art upon examining the accompanying drawings and upon reading the following Detailed Description of the Preferred Embodiments.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a vertical, partially cut-away view of an embodiment **10** of a mechanical assembly including an outer casing **12**, an end cap **14**, a ribbed drop tube **16** with standoffs **18** and flow ports **20**, and a header **22** for connecting the tube center channel **24** to a supply line and connecting the annular channel **26** between the tube **16** and the inner wall **28** of the casing **12** to a return line.

FIG. 2 is a cutaway cross-sectional view of the mechanical assembly **10** as seen from perspective 2-2 shown in FIG. 1.

FIG. 3 illustrates the thermal resistance (fluid boundary layer **2**, casing **4** and slurry backfill **6**) between the bulk fluid **5** in the annular channel of a concentric geothermal exchange assembly and the earth **8**.

FIG. 4 illustrates an embodiment of an inventive process for forming the inventive casing **12** wherein fibers **30** wetted with thermosetting resin composition **32** are wound on mandrel **34**.

FIG. 5 shows an embodiment of the inventive casing **12** with male threads **36** and female threads **38**.

FIG. 6 is a partially cutaway sectional side view illustrating the mechanical assembly **10** installed underground in a vertical borehole **11**. FIG. 6 also illustrates

the drop tube **16** having a ribbed outer surface **40**, a smooth inner surface **42**, and standoffs **18** attached between ribs **44**.

FIG. 7 shows an embodiment of an inventive standoff **18** used in accordance with the present invention.

5 FIGS. 8A and 8B are exterior and a cutaway elevation views of a concentric ground heat exchange assembly **102** using a prior art supply and return header **112**.

FIG. 9 is a schematic elevational cutaway side view of the upper end of an inventive concentric ground heat exchange assembly **200** having an embodiment **202** of the inventive supply and return header installed on the upper end thereof.

10 FIG. 10 is an exterior elevational side view of the inventive supply and return header **202**.

FIG. 11 is a bottom perspective view of a socket-to-thread adaptor **204** used for attaching the inventive supply and return header **202** to the upper end of the ground heat exchange assembly casing **206**.

15 FIG. 12 is a perspective view of the inventive supply and return header **202** having the socket-to-thread adaptor **204** installed thereon.

FIG. 13 is an upper perspective view showing the socket-to-thread adaptor **204** received on and chemically bonded to the upper end of the casing **206**.

20 FIG. 14 is a cutaway vertical view of a concentric ground heat exchange assembly using an alternative embodiment of the inventive supply and return header **202**.

FIG. 15 is a cutaway vertical view of an alternative cast embodiment **302** of the inventive supply and return header.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

25 A bore **11** of desired size, preferably measuring between about 5 to about 8 inches in diameter, is drilled vertically into the earth to a depth between from about 100 to about 500<sup>+</sup> feet. The inventive mechanical assembly **10** shown in FIGS. 1 and 2 is installed in the borehole **11** and then the borehole **11** is backfilled with an aqueous grout slurry **15** preferably comprising natural flake graphite and a binding material  
30 such as bentonite or Portland cement. Alternatively, by way of example, amorphous graphite, bentonite, and calcium sulfate could be used. As is illustrated, the pressure boundary of the mechanical assembly **10** preferably comprises an outer (i.e., a larger

diameter) cylindrical casing **12** capped at the bottom by an end cap **14** and at the top by a header **22** equipped with a supply port **23** and a return port **25**.

A ribbed drop tube **16** of smaller diameter is inserted inside the casing **12** and aligned concentrically with (i.e., substantially centralized in) the casing **12** to create a center flow channel **24** and an annular flow channel **26**. The supply port **23** connects the center flow channel **24** to a supply line and the return port **25** connects the annular flow channel **26** to a return line. The working fluid, which is preferably water or a water and antifreeze mixture, enters the mechanical assembly from the supply line, through the supply port **23**, and travels down the center channel **24**. The working fluid exits the center channel **24** through the drop tube outlet **21** at the lower end (i.e., distal end) of the drop tube **16** and through the flow ports **20**. The flow ports **20** provide an alternative flow path in case the drop tube bottom outlet **21** comes in contact with the bottom of the casing. The working fluid then travels upward through the annular flow channel **26**, then through the return port **25**, and exits the mechanical assembly **10** to the return line.

Heat is exchanged between the earth **8** (i.e., the underground environment surrounding the casing **12**) and the bulk fluid **5** flowing in the annular channel if a temperature gradient exists between the fluid **5** and earth **8**. The bulk fluid **5** rejects heat (i.e., is cooled) when the temperature of the bulk fluid **5** is greater than the temperature of the earth **8**. The bulk fluid **5** absorbs heat (i.e., is heated) when the temperature of the bulk fluid **5** is less than the temperature of the earth **8**.

As illustrated in FIG. 3, the heat exchanged between the earth **8** and the bulk fluid **5** flowing in the annular channel **26** must travel through three thermal resistances: the fluid boundary layer resistance **2**; the casing resistance **4**; and the slurry backfill (grout) resistance **6**. To reject heat from the bulk fluid **5**, the heat flows through the fluid boundary layer to the casing inner wall **28**, then through the casing **12** and then through the slurry backfill **15**. For the bulk fluid **5** to absorb heat, the heat flows through the slurry backfill **15**, then through the casing **12** and then from the casing inner wall **46** to the bulk fluid **5** through the fluid boundary layer. The present invention provides practical materials and methods to reduce all three thermal resistances, thereby allowing greater heat exchange per unit length of the mechanical assembly **10** for a given temperature gradient. The present invention also provides a

practical method to reduce thermal short circuiting between the center channel **24** and annular channel **26**.

As illustrated in FIG. 4, the present invention provides a novel conduit which is well suited for use as the outer cylindrical casing **12** for the system pressure boundary. However, the inventive conduit **12** is also well suited for use in other conductive heat transfer applications and can be formed in any desired cross-sectional shape. The inventive casing **12** is preferably formed by embedding fiber **30**, or surrounding fiber **30**, in a thermosetting resin by first wetting the fiber in a thermosetting resin bath **32**, or otherwise applying the thermosetting plastic composition to the fiber **30**, and then winding the wetted fiber **30** around a mandrel **34**. The fibers **30**, preferably made of glass, carbon or aramid (most preferably fiberglass direct-draw roving), impart directional strength to the material while the thermosetting resin **32** bonds the fibers **30** together and transfers stress between the fibers **30**. The thermosetting plastic composition **32**, which is preferably comprised of an epoxy base resin and an amine or anhydride curing agent, polymerizes to a permanently solid state upon the application of heat. An example of a preferred epoxy system is a two-part system comprising (a) an epoxy resin (e.g., FR-240 Epoxy Part A from Smith Fibercast or Dow DER 383 diglycidylether of bisphenol A) and (b) methylene dianiline or other curing agent (e.g., FR-204 Epoxy Part B from Smith Fibercast).

The thermosetting plastic composition **32** used for forming the inventive casing preferably comprises at least 1.5% (more preferably at least 2%) by weight, based on the total weight of the thermosetting plastic composition, of at least one additive such as graphite, aluminum flake, aluminum powder, aluminum oxide, aluminum nitride, boron nitride, silicon carbide, Raney nickel, silver-coated nickel or silver-coated copper to enhance thermal conductivity. As will be understood by those in the art, the resin mixture may also optionally contain other typical additives such as, for example, standard wetting and dispersing agents to facilitate dispersion of the resin and fillers and wetting out of the fiber and air release agents to reduce entrapped air bubbles.

The thermal conductivity additive used in forming the inventive casing conduit **12** is preferably aluminum powder. The thermal conductivity additive is most preferably a medium grade, dedusted, leafing aluminum flake powder having a <sup>+325</sup>

mesh retention of not more than 2%. Although, pound for pound, carbon is more thermally conductive, it has been discovered in accordance with the present invention that the filament winding epoxy loading characteristics of aluminum powder, particularly when using the preferred medium grade powder, are of such a surprisingly superior and unexpected nature that much higher loadings of the aluminum powder providing greater thermal conductivities are achieved. Moreover, even at such high loadings, a desirably thin-walled yet unexpectedly strong pipe is produced and the viscosity of the epoxy system remains relatively low, thus speeding the pipe manufacturing process. Further, the aluminum powder additive is also readily available at reasonable cost.

The amount of the aluminum powder additive used in the thermosetting epoxy composition will preferably be in the range of from about 1.5 to about 8% by weight (more preferably at least 2% and most preferably about 2.6%) based on the total weight of the thermosetting epoxy composition **32**. In addition, the thermosetting epoxy system composition will preferably further comprise an amount of an epoxy resin (i.e., the epoxy system Part A component) in the range of from about 77.8% to about 67.2% by weight and an amount of a curing agent (i.e., the epoxy system Part B component) in the range of from about 20.7% to about 17.8% by weight, all based on the total weight of the thermosetting epoxy composition.

In forming the casing **12**, the wetted fibers **30** are preferably wound to produce a casing or other conduit **12** with a ratio of outer diameter to inner diameter of less than 1.1 in order to minimize thermal resistance, while still maintaining sufficient crush pressure (75 psi or more) and burst pressure (300 psi or more) for (a) vertical deployment to a depth of up to 300 ft. in conjunction with the use of the inventive backfill slurry preferably blended to a specific gravity of 1.4 or less and (b) vertical deployment up to 300 to 400 feet, or even up to 500<sup>+</sup> feet, when preferably using a backfill slurry with a specific gravity of 1.3 or less. The inventive casing is preferably less than 1 pound per foot for diameters up to 3.5 inches and does not corrode in soil or antifreeze environments.

As shown in FIG. 5, the casing **12** is preferably fashioned into manageable segments of about 15 to about 30 feet in length with one end having male threads (spigot end) **36** and the other end having female threads (bell end) **38**, making the

casing **12** easy to assemble. An epoxy adhesive is preferably placed on the male threads **36** during assembly to ensure a good mechanical seal.

Concerning the wall thickness of the inventive conduit **12**, the wetted fiber **30** is more preferably wound on the mandrel **34** such that the ratio of the outside diameter to the inside diameter of the conduit **12** is not more than 1.055, most preferably not more than 1.04, with a collapse pressure of at least 75 psig. When used as a casing, the dimensions of the inventive conduit **12** will preferably be such that (a) the interior flow passageway **24** of the conduit **12** will be at least 9 inches in circumference and will more preferably be about 3.366 inches or more in diameter based upon the use of a 3.366<sup>+</sup> inch diameter forming mandrel **34** and (b) the conduit wall **52** will have a thickness of not more than 0.12 inch, more preferably not more than 0.085 inch and most preferably not more than 0.065 inch, while maintaining a collapse pressure of at least 75 psig.

As shown in FIG. 1, the present invention provides an end cap **14** that is preferably pressure molded from chopped fiber and thermosetting resin. A hole **54** through the end cap **14**, preferably measuring approximately 0.5 inches in diameter, is provided to allow connection for a rope or wire **53** to facilitate lowering the casing assembly into the borehole **11**. The end cap hole **54** is provided in such a manner as to not interfere with the casing seal provided by the end cap **14**. The end cap **14** is preferably secured to the bottom casing segment using epoxy adhesive.

As illustrated in FIG. 6, the present invention provides an inner cylindrical ribbed drop tube **16** that is preferably made from HDPE, PVC, or EPDM (i.e., a terpolymer elastomer produced from ethylene-propylene diene monomer) or any other rubber or plastic that is chemically resistant to common antifreeze additives such as methanol, ethanol, ethylene glycol and propylene glycol and that preferably has a thermal conductivity value less than 0.2 Btu/hr-ft-F. The drop tube **16** is a smaller diameter conduit which includes a series **58** of discrete, spaced apart, radial ribs **44**, said series **58** of ribs **44** extending along the exterior of the drop tube **16** such that the radial ribs **44** project into the flow annulus **26** formed between the exterior of the drop tube **16** and the interior wall **28** of the casing **12**. The radial ribs **44** are preferably circular in shape as shown in FIG. 2 and are preferably sized and spaced apart as shown in FIG. 1 such that, for each adjacent pair of ribs **44**, the ratio of the peak-to-

peak rib spacing **60** to the radial peak rib height **62** is in the range of from about 1.2:1 to about 3:1.

The ratio of the drop tube outer diameter (as measured between the ribs **44** at the point **64** of minimum tube thickness) to drop tube inner diameter will preferably be at least 1.2 to reduce thermal short circuiting between the center fluid delivery channel **24** of the drop tube **16** and the annular channel **26**. The drop tube outer diameter is preferably sized such that, at the point **64** of the minimum tube thickness, the cross sectional area of the annular flow channel **26** is greater than the cross sectional area of the center channel **24** in order to minimize pressure drop along the annular channel **26**.

The drop tube **16** is preferably a corrugated plastic or rubber tube. Such tubing is typically available on spools which makes it particularly convenient for installation and use in the inventive application. Because of the length of the tubing, few connections are needed for a given application. However, where necessary, sections of the corrugated tubing can be connected together mechanically using, e.g., plastic or stainless steel barbed connectors that are reinforced by applying bands on either end of the connection.

The drop tube inner surface **42** will preferably be smooth to reduce pressure drop along the center channel **24**. The ribs **44** are preferably disposed along the outer surface of the drop tube **16** perpendicular to the longitudinal axis **68** of the drop tube **16** to create flow vortices **70** and induce flow turbulence in the annulus **26** and cause the thermal boundary layer to restart along the casing inner wall **28**. However, the nature of the ribs **44** is such that the same turbulent flow conditions will not exist adjacent the drop tube **16** in the valleys **72** between the ribs, thus further reducing thermal short circuiting by not promoting the disruption of the fluid boundary layer on the exterior of the drop tube **16** at the points **64** of minimum tube thickness. The ribs **44** will preferably have a pitch in the range of from about 80 to about 90 degrees in order to assist in preventing the ribbed tube **16** from becoming deformed during shipping, packing, and installation.

As seen in FIG. 1, flow ports **20** are preferably provided at the lower end of the drop tube **16** to allow the fluid to exit the center channel **24** should the drop tube outlet **21** become blocked by the casing bottom. This may occur as the drop tube **16** elongates over time. The cumulative area of the flow ports **20** will preferably be

greater than the cross sectional area of the center channel **24** to minimize pressure drop across the flow ports **20**. The flow ports may be drilled through the side wall at the bottom portion of the drop tube **16** near the lower end **21**. Alternatively, an insert **76** with flow ports **20** can be inserted into the drop tube outlet **21**.

5 As illustrated in FIGS. 2, 6, and 7, the present invention provides plastic or corrosion resistant metal standoffs **18** that are clipped onto the exterior of the drop tube **16** between the ribs **44**, preferably providing three points of contact between the drop tube **16** and the inner wall **28** of the outer casing. The ribs **44** prevent vertical movement of the clips **18** along the drop tube **16**. The standoff contacts **78** are  
10 preferably in the shape of a loop, providing a rounded surface to minimize scoring of the inner casing wall **28** during insertion of the drop tube into the casing. The standoff **18** preferably has at least three contact loops **78**.

The present invention also provides a thermally conductive, low permeability slurry backfill that is made from environmentally safe materials. The slurry is  
15 preferably made by mixing a dry base mixture with water in sufficient quantity to produce a slurry with at least 25% solids by weight. The dry base mixture preferably comprises, and more preferably consists essentially of or consists of, (a) natural flake graphite, amorphous graphite, synthetic graphite, or coke, and (b) bentonite or Portland cement.

20 Graphite enhances the conductivity of the slurry and the insoluble graphite particles provide a barrier to slow the vertical flow of water. Sodium bentonite, which is environmentally friendly clay, hydrates to fill the interstitial spaces of the graphite particles, further reducing permeability to less than  $1 \times 10^{-7}$  cm/s. When using amorphous graphite, calcium sulfate, one of the more common minerals in  
25 sedimentary environments, preferably replaces 2-5% of sodium bentonite in the dry mixture to prevent dissipation of the backfill when the backfill is deployed in geologies with significant ground water flow.

In the case of amorphous graphite, the dry mix preferably comprises at least 70% amorphous graphite by volume with bentonite making up the remaining volume.  
30 Amorphous graphite, which is formed in the earth under intense heat and pressure, is inorganic, insoluble, and is virtually free of polyaromatics and metals.

In a particularly preferred embodiment, the inventive grout slurry comprises, and more preferably consists essentially of, (a) a dry base mix including, and more

preferably consisting essentially of, from about 70 to about 85 (most preferably from about 75 to about 80) parts by weight (pbw) natural flake graphite and from about 30 to about 15 (most preferably from about 25 to about 20) pbw bentonite, Portland cement, or a combination thereof and (b) an amount of water in the range of from  
5 about 8 to about 12 (most preferably from about 9 to about 11) gallons per each 50 pounds of the dry mix. The resulting slurry has a solids concentration in the range of from about 45% to about 30% (most preferably from about 40% to about 35%) by weight. If high ground water flow is present, the composition of inventive grout slurry can be changed to also include up to 25 pounds of sands and/or up to 5 pounds  
10 of gypsum per each 50 pounds of the dry mix.

To assist in maintaining the flake graphite in suspension without the use of any dispersants, polymers, or other suspension assisting agents which can detract from the desirable thermal properties of the grout, and to also permit the incorporation of higher concentrations of graphite for significantly higher thermal conductivity, the  
15 particle size of the flake graphite used in the preferred grout slurry composition is preferably not greater than 200 mesh (0.074 mm). In addition, the grout slurry is preferably pumped into the borehole **11** around the outside of the casing **12** using a nonshearing pump (e.g., a positive displacement or diaphragm pump) and a tremmie pipe. The occurrence of shearing during the pumping process alters the slurry particle  
20 size and can increase the slurry viscosity.

The inventive slurry composition has a set time greater than one hour allowing sufficient time for deployment. The slurry is pumped into the borehole **11** through a hose and the borehole **11** is preferably filled with slurry from the bottom up to prevent bridging and voids. In situ, the backfill provides a thermal path from the outer casing  
25 **12** to the borehole wall. The grout backfill most preferably includes a sufficient amount of the thermal conductivity enhancing additive to provide a thermal conductivity of greater than 3 Btu/hr-ft-F.

In a particularly preferred embodiment, the grout backfill used in the present invention is prepared for pumping into the borehole by (a) dissolving a thinning agent  
30 in water to form a dilute treated water solution and then (b) adding a dry mix of any type discussed above to the dilute treated water solution to form a pumpable grout backfill slurry. The dry mix preferably comprises, and more preferably consists essentially of or consists solely of a pre-blended mixture of (a) from about 70% to

about 85% by weight (more preferably about 70% to about 80% and most preferably about 75% by weight) natural flake graphite and (b) from about 30% to about 15% by weight (more preferably about 30% to about 20% and most preferably about 25% by weight) sodium bentonite. The natural flake graphite preferably has a particle size of not greater than 200 mesh and the sodium bentonite preferably has a particle size of not greater than 325 mesh, more preferably in the range of from 200 to 325 mesh.

The amount of thinning agent used in this embodiment for forming the dilute treated water solution is preferably an amount sufficient such that a pumpable slurry can be formed comprising, consisting essentially of, or more preferably consisting solely of (a) at least 30% by weight, more preferably from about 35% to about 45% by weight and most preferably about or at least 40% by weight of the dry mix and (b) not more than 70% by weight, more preferably from about 65% to about 55% by weight, and most preferably about or not more than 60% by weight of the dilute treated water solution.

The inventive grout slurry described above consisting solely of 75 parts by weight (pbw) natural flake graphite, 25 pbw sodium bentonite and sufficient water and NaCl thinning agent to provide a slurry solids content of at least 30% by weight will have a superior thermal conductivity when hardened. Moreover, the thermal conductivity of this inventive grout slurry will be further enhanced when blended to a slurry solids content of at least 35% by weight and will be even greater when blended to a slurry solids content of at least 40% by weight.

Examples of suitable thinning agents include, but are not limited to, sodium chloride, potassium chloride, and Aqua-Clear<sup>®</sup> PFD available from Baroid. If the thinning agent used is sodium chloride and/or potassium chloride, the dilute treated water solution will preferably comprise (and will more preferably consist essentially of and most preferably consist solely of) from about 8 to about 24 ounces by volume, more preferably from about 12 to about 20 ounces, of sodium chloride and/or potassium chloride per 9 gallons of water.

In the same way, Aqua-Clear<sup>®</sup> PFD will preferably be used in an amount of from about 5 to about 15 milliliters, more preferably from about 8 to about 10 milliliters, per 9 gallons of water. By way of example, the addition of 9 milliliters of Aqua-Clear<sup>®</sup> PFD per each 9 gallons of water provides a PFD concentration in the treated water of only 0.026% by volume.

In forming the preferred dry mix, the natural flake graphite and sodium bentonite components can be pre-blended in the appropriate ratio using a hopper and then poured into, e.g., 50 lb. sacks. By way of example, if no thinning agent is used, the addition of 12 gallons of untreated water to each 50 lb. sack of dry mix will  
5 produce a pumpable slurry having a solids content of about 30% by weight. In contrast, by using a thinning agent as discussed above, a pumpable slurry having a solids content of about 40% by weight can be produced using only 9 gallons of treated water per 50 lb. sack of dry mix.

As will be apparent, all slurry component ratios stated herein and in the claims  
10 relative to 50 lb. sack amounts of dry mix are equally applicable to slurry compositions containing less or more than 50 total pounds of dry mix. Thus, for example, the addition of 0.9 gallons of treated water to 5 lb. of dry mix is equivalent to and would be covered by any reference herein to the addition of treated water in an amount equivalent to 9 gallons of treated water per each 50 lbs. of dry mix.

15 When a preferred grout backfill slurry having a 40% solids context is pumped into the borehole outside of the casing, the slurry will settle in the annulus to a solids content of about 50% solids content after about six hours, thus greatly increasing the physical point-to-point contact between the grout carbon particles. This, in turn, provides a significantly enhanced level of thermal conductivity by allowing more  
20 phonons (infrared heat) to more easily move from one carbon particle to the next without having to jump across large insulating gaps formed of bentonite clay and bound water. Moreover, after about one month, the thinning agent will simply leach into the formation and the bentonite clay will swell by absorption of bound water to reduce the water permeability of the inventive grout backfill to near zero.

25 The thinning agent used in the present invention is preferably sodium chloride, potassium chloride, or a combination thereof, and is most preferably sodium chloride.

#### Example 1

A grout slurry was formed by adding 246 g of treated water (consisting of  
30 240g water and 6 g sodium chloride) to a dry mix consisting of (a) 120 g of natural flake graphite having a particle size passing (i.e., less than) 200 mesh and (b) 40 g of sodium bentonite having a particle size passing 325 mesh. The salt content of the treated water was thus 2.44% by weight (equivalent to about 1.88 lb. NaCl per 9 gallons of water) and the solids content of the slurry product composition was about

40% by weight. The slurry product was pumpable and had a specific gravity of 1.25. After setting overnight, a layer of water had begun to form on top of the slurry composition by the following morning.

#### Example 2

5 A grout slurry was formed by adding 152 g of treated water (consisting of 150 g water and 2 g sodium chloride) to a dry mix consisting of (a) 75 g of natural flake graphite having a particle size passing a 200 mesh screen and (b) 25 g of sodium bentonite having a particle size also passing a 200 mesh screen. The salt content of the treated water was thus 1.3% by weight (equivalent to 1 lb. of NaCl per 9 gallons  
10 of water) and the solids content of the slurry product composition was about 40% by weight. The slurry was more viscous, was not pumpable, was barely pourable, and had set up after one day. No water layer formed on the top of the composition.

#### Example 3

A grout slurry was formed by adding 154 g of treated water (consisting of 150  
15 g water and 4 g sodium chloride) to a dry mix consisting of (a) 75 g of natural flake graphite having a particle size passing a 200 mesh screen and (b) 25 g of sodium bentonite having a particle size passing 200 mesh. The salt content of the treated water was thus 2.6% by weight (equivalent to 2 lb. NaCl per 9 gallons of water) and the solids content of the slurry product composition was about 40% by weight. The  
20 slurry product was pumpable. After one day, the slurry was thicker, but still pourable, and 4 to 5 g of water had formed on the top of the composition.

These examples illustrate the effectiveness of the use of a thinning agent in accordance with the present invention for forming and delivering the inventive grout backfill composition. In regard to the use of sodium chloride, potassium chloride, or  
25 a mixture thereof as the thinning agent, these examples particularly show the effectiveness of treated water compositions preferably consisting of from about 1.5% to about 3% by weight, more preferably about 2.44% by weight of sodium chloride and/or potassium chloride to form pumpable inventive grout slurry compositions having very high solids concentrations and excellent heat transfer characteristics.

30 Aqua-Clear<sup>®</sup> PFD, available from Baroid, is a liquid, phosphate-free, dispersant which comprises from 30 to 60% anionic polyacrylamide. Aqua-Clear<sup>®</sup> PFD has a pH of 6.5 – 7.5, a specific gravity of 1.2 – 1.4 at 20°C, and is partially soluble in water. In contrast to the surprising new use thereof discovered in

accordance with the present invention, Aqua-Clear<sup>®</sup> PFD has heretofore only been used, to our knowledge, at a concentration of 0.2% by volume in water (i.e., almost an order of magnitude higher than the present invention) for (a) dispersing mud, sediment, and clay from producing formations and gravel packs and (b) reducing the viscosity and gel strength of drilling fluids.

An embodiment **202** of the improved supply and return header provided by the present invention is illustrated in FIGS. 9, 10, and 12. An embodiment **200** of an improved concentric ground exchange assembly having the inventive supply and return header **202** installed thereon is illustrated in FIG. 9.

The inventive supply and return header **202** comprises: an upper housing **208** which preferably has a cylindrical “can” shape with exterior threads **210** provided around the lower end portion thereof; a flat top plate **212** which seals the upper end of the housing **208** and defines the upper end of the header assembly **202**; a threaded inlet port **214** provided laterally through the vertical cylindrical wall **216** of the housing; a threaded outlet port **218** which is also provided laterally through the vertical cylindrical housing wall **216**, most preferably at a location in the range of from 90 to about 180 degrees from the inlet port **214**; and an interior feed conduit **220**. The interior feed conduit **220** extends horizontally from the inlet port **214** toward the interior center of the housing **208** to an internal elbow **225**. The internal elbow **225** directs the remainder of the interior feed conduit **220** vertically downward toward, and preferably through, the bottom end **221** of the cylindrical housing **208** for attachment to the inner conduit **222** of the concentric ground exchange assembly **200**.

Although other materials can be used, the header housing **208** and the interior feed conduit **220** are preferably formed of brass or stainless steel and are most preferably formed of 304 stainless steel. To absorb the tensile stress produced by the weight of the attached inner conduit **222** of the exchange assembly, the upper horizontal end **224** of the interior feed conduit **220** is preferably welded to the cylindrical wall **216** of the housing **208** at the inlet port **214**. Alternatively, or in addition, the upper horizontal portion **224** of the interior feed conduit **220** can be welded to the interior bottom surface of the housing top plate **212**. The lower end of the interior feed conduit **220** is preferably connected to the upper end of the exchange assembly inner conduit **222** using a coupling or other structure **230** having interior

threads which are received on corresponding threads **232** provided around the upper end portion of the exchange assembly inner conduit **222**.

The inventive supply and return header **202** is preferably secured on the upper end of the exchange assembly casing **206** using a socket-to-thread adaptor **204**.

5 Although other materials can also be used, the socket-to-thread adaptor **204** is preferably formed of fiberglass and includes: (a) an upper interior threaded portion **234** which is received on the lower exterior threaded portion **210** of the housing **208** and (b) a smooth cylindrical lower interior portion **236** which corresponds to and is received on the upper end of the casing **206**. The socket-to-thread adaptor **204** is  
10 preferably secured and hermetically sealed around the upper end portion of the casing **206** by chemically fusing the lower cylindrical interior portion **236** of the adaptor **204** directly to the exterior cylindrical wall of the casing **206** using an adhesive or other bonding material which is compatible with both the composition of the adaptor **204** and the composition of the casing **206**.

15 The socket-to-thread adaptor **204** is preferably formed by first mixing liquid epoxy resin, an aromatic amine hardener, and chopped glass strands in an industrial mixer to form a "prepreg." The prepreg mixture is then press molded under heat and pressure to form the finished part. An example of a commercially available fitting which is well suited for use in the present invention is a Fiber Glass Systems 29S  
20 threaded adaptor, preferably not having any hand lay-up overwrap applied on the molded body of the fitting.

The heat transfer working fluid feed line **238** and return line **240** are typically formed of a plastic such as high density polyethylene and extend horizontally underground toward and away from the ground exchange assembly header **202**.  
25 Consequently, as mentioned above, the feed line **238** and return line **240** are commonly referred to as "laterals." To accommodate the different expansion and contraction characteristics of the plastic laterals **238**, **240** and the preferred stainless steel header housing **208**, the feed and return laterals **238** and **240** are preferably secured to the header inlet and outlet ports **214** and **218** using connectors **242** and **244**.  
30 The connectors **242** and **244** are preferably formed of stainless steel and each has an externally threaded first end **246** which is threadedly received in the appropriate inlet or outlet port **214** or **218** and a threaded second end **248** to which the feed lateral **238** or return lateral **240** is threadedly connected. Adhesives are also preferably used for

sealing the connections between the connectors **242** and **244** and the inlet and outlet ports **214** and **218** and between the connectors **242** and **244** and the feed and return laterals **238** and **240**.

As an alternative to the use of a socket-to-thread adaptor **204**, it will be understood that cylindrical can housing **208** can be sized and the lower portion extended as needed to allow the housing itself to be placed on the upper end of the casing **206** and directly bonded thereto as illustrated in FIG. 14. In order to enhance the direct bond and seal between the housing **208** and the casing **206** in the embodiment of FIG. 14, a series of interior tiers **235** of decreasing diameter from the bottom up will preferably be formed in the lower portion of the can housing **208**.

An alternative embodiment **302** of the inventive supply and return header is depicted in FIG. 15. The inventive header **302** is similar to the inventive header **202** except that the inventive header **302** is a unitary cast structure. Examples of materials suitable for forming the inventive cast header **302** include, but are not limited to, stainless steel or a fiberglass composite. The inventive header **302** is preferably formed of 304 stainless steel.

The inventive cast header **302** comprises: an outer housing **308** preferably having a cylindrical can shape with a substantially flat upper end **312** and a smooth cylindrical or tiered (or grooved) lower end **310** sized to be received on, and chemically bonded directly to, the upper end of the casing **206**; an inlet port **314** projecting laterally from the vertical cylindrical wall **316** of the housing and optionally having threads cut in the interior thereof for threadedly receiving the inlet lateral or an inlet compression fitting; an outlet port **318** projecting laterally from the housing wall **316** and optionally having threads cut in the interior thereof for receiving the outlet lateral or an outlet compression fitting; and an interior feed conduit **320**.

The interior conduit **320** formed in the cast structure **302** comprises: (a) an upper portion which extends horizontally from the housing inlet **314** and has an internal elbow **325** at the distal end thereof and (b) a vertical discharge portion **327** which preferably extends from the internal elbow **325** through the bottom end of the outer housing **308**. Interior threads can also optionally be cut in the lower end portion **330** of interior conduit **320** for either directly threadedly receiving the upper end of

the inner conduit of the ground exchange system or threadedly receiving an attachment fitting for the ground exchange inner conduit.

As with the inventive header **202**, appropriate adhesives or other bonding agents will also preferably be used with the inventive cast header **202** to further seal, bond, and secure all of the threaded direct or threaded fitting attachments between the header **302** and the feed and return laterals and the ground heat exchange inner conduit.

In addition, it will also be understood that: (a) external rather than internal threads could alternatively be cut into the cast header **302** for use in some or all of the various threaded attachments, (b) rather than cutting threads in the cast header **302**, some or all of the various threaded attachments could alternatively be replaced with smooth, grooved, or tiered bore direct adhesive attachments, and/or (c) rather than bonding the header housing **308** directly on the upper end of the ground system casing, threads could alternatively be cut around the exterior of the cast header housing **308** for attachment to the upper end of the casing using a socket-to-thread adaptor in the same manner as described above for inventive header **202**.

In the inventive concentric ground exchange assembly **200**, as illustrated in FIG. 14, the casing **206** can be any type of casing suitable for use in ground exchange assemblies and will preferably comprise an string assembly of fiber reinforced composite casing segments as described above. The composite casing segments will preferably be formed of a thermoplastic material, most preferably epoxy, which is reinforced with fiberglass, carbon fiber, aramid fiber, or a combination thereof. In addition, the casing segments will preferably be formed by filament winding and will also preferably include at least 1.5% by weight of a thermal conductivity enhancing additive such as aluminum flake, aluminum powder, aluminum oxide, aluminum nitride, graphite, boron nitride, silicone carbide, Raney nickel, silver-coated nickel, silver-coated copper, or a combination thereof. An example of a commercially available adhesive material which is well suited for bonding the preferred fiberglass socket-to-thread adaptor **204**, the stainless steel housing **208**, or the cast stainless header **302** to a casing **206** of this type is WELDFAST<sup>®</sup> ZC-275 epoxy adhesive available from Fiber Glass Systems.

An example of a commercially available adhesive which is well-suited for use in sealing the attachment between the materially different HDPE inlet and return

laterals **238** and **240** and the stainless steel header connectors **242** and **244** is PLEXUS<sup>®</sup> MA830 methacrylate adhesive available from ITW PLEXUS.

The inner conduit **222** employed in the inventive concentric ground heat exchange assembly **200** can be any type of inner pipe or other conduit used in concentric ground heat exchange assemblies but, as discussed above, will preferably be a corrugated plastic or rubber drop tube having a continuous series of circular radial ribs **44**, **250** provided on the exterior thereof as illustrated in FIGS. 6 and 9. The corrugated inner drop tube **222** will most preferably be formed of high density polyethylene, PVC, or EPDM (i.e., a terpolymer elastomer produced from ethylene-propylene diene monomer).

Because the 90° bend **235** or **325**, which directs the horizontal flow from the feed lateral **238** into the vertical exchange assembly inner conduit **222**, is located within the housing **208** or **308** of the inventive supply and return header **202** or **302**, the height of the inventive supply and return header **102** can be as little as 5.25 inches or less, as compared to a typical height of from 16 to 20 inches or more for the prior art header **12** described above. This significantly reduces the amount of trenching and digging required for the assembly and installation of the inventive concentric ground exchange assembly **200**. In addition, the inventive supply and return header **202** or **302** provides a secure, hermetically sealed connection with the assembly casing **206** which eliminates the need for flanges, flange rings, bolts, nuts, washers, and gaskets. Further, the stainless steel materials preferred for use in forming the inventive supply and return header **202** or **302** are also commonly used with great success in other underground applications such as water wells and do not present any regulatory difficulties or concerns.

\* \* \* \*

Thus, the present invention is well adapted to carry out the objectives and attain the ends and advantages mentioned above as well as those inherent therein. While presently preferred embodiments have been described for purposes of this disclosure, numerous changes, adaptations, and modifications will be apparent to those of ordinary skill in the art. Such changes, adaptations, and modifications are encompassed within this invention as defined by the claims.

## CLAIMS

What is claimed is:

1. A grout slurry composition for conductive heat transfer applications comprising:
  - a dry base premixed composition consisting of from about 70 to about 85 parts  
5 by weight natural flake graphite and from about 30 to about 15 parts by weight bentonite and  
water in an amount equivalent to not more than 12 gallons of said water per each 50 pounds of said dry base premixed composition,  
said natural flake graphite having a particle size of not greater than 200 mesh.
- 10 2. The grout slurry composition of claim 1 wherein dry base premixed composition consists of said natural flake graphite and sodium bentonite.
3. The grout slurry composition of claim 2 wherein:
  - said dry base premixed composition consists of from about 75 to about 80  
15 parts by weight of said natural flake graphite and from about 25 to about 20 parts by weight of said sodium bentonite and  
said amount of said water is equivalent to an amount in a range of from about 8 to about 11 gallons of said water per each 50 pounds of said dry base premixed composition.
- 20 4. The grout slurry composition of claim 1 further comprising sand in an amount equivalent to not more than 25 pounds of said sand per each 50 pounds of said dry base composition.
- 25 5. The grout slurry composition of claim 1 wherein said natural flake graphite is present in said grout slurry premixed composition in an amount effective such that, when said grout slurry composition dries to form a set grout material, said set grout material will have a thermal conductivity of at least 3 Btu/hr-ft/°F.

6. The grout slurry composition of claim 1 wherein said dry base premixed composition and said water are present in concentrations such that said grout slurry composition has a solids content of at least 35% by weight based on the total weight of said grout slurry composition.
- 5 7. The grout slurry composition of claim 6 further comprising a thinning agent wherein:  
said thinning agent is sodium chloride, potassium chloride or a combination thereof  
said thinning agent is present in said grout slurry composition in an amount  
10 effective such that said grout slurry composition is a pumpable slurry.
8. The grout slurry composition of claim 6 wherein said thinning agent is present in said grout slurry composition in an amount equivalent to at least 8 ounces, by volume, of said thinning agent per each 9 gallons of said water.
9. The grout slurry composition of claim 8 wherein said dry base premixed  
15 composition and said water are present in said grout slurry composition in concentrations such that said grout slurry composition has a solids content of at least 40% by weight based on the total weight of said grout slurry composition.
10. The grout slurry composition of claim 1 further comprising a thinning agent comprising at least one anionic polyacrylamide, wherein:  
20 said dry base premixed composition and said water are present in said grout slurry composition in concentrations such that said grout slurry composition has a solids content of at least 35% by weight based on the total weight of said grout slurry composition and  
said thinning agent is present in said grout slurry composition in an amount  
25 effective such that said grout slurry composition is a pumpable slurry.
11. A grout slurry composition comprising:  
from about 70 to about 85 parts by weight natural flake graphite;  
from about 30 to about 15 parts by weight of bentonite;

- water in an amount effective such that said grout slurry composition has a solids content of at least 30% by weight based on the total weight of said grout slurry composition; and a thinning agent, wherein
- 5           said thinning agent is sodium chloride, potassium chloride, or a combination thereof and said thinning agent is present in said grout slurry composition in an amount effective such that said grout slurry composition is a pumpable slurry.
- 10   **12.**   The grout slurry composition of claim **11** wherein said amount of said water is effective such that said grout slurry composition has a solids content of at least 35% by weight based on the total weight of said grout slurry composition.
- 15   **13.**   The grout slurry composition of claim **12** wherein said amount of said water is effective such that said grout slurry composition has a solids content of at least 40% by weight based on the total weight of said grout slurry composition.
- 14   **14.**   The grout slurry composition of claim **12** wherein said natural flake graphite has a particle size of not greater than 200 mesh and said bentonite is sodium bentonite having a particle size of not greater than 325 mesh.
- 20   **15.**   The grout slurry composition of claim **14** wherein said grout slurry composition consists solely of said natural flake graphite, said sodium bentonite, said water, and said thinning agent.
- 25   **16.**   The grout slurry composition of claim **15** wherein said amount of said water is effective such that said grout slurry composition has a solids content of at least 40% by weight based on the total weight of said grout slurry composition.
- 25   **17.**   The grout slurry composition of claim **15** wherein said amount of said thinning agent is equivalent to at least 8 ounces by volume per each 9 gallons of said water.

18. A method of installing a casing of a subterranean ground heat exchange system comprising the steps of:
- (a) placing said casing in a borehole;
  - (b) forming treated water by adding a thinning agent to water;
  - 5 (c) adding said treated water to a dry base composition to form a grout slurry; and
  - (d) placing said grout slurry in an annulus between an interior wall of said borehole and an outer wall of said casing; wherein
- 10 said dry base composition consists essentially of from about 70 to about 85 parts by weight natural flake graphite and from about 30 to about 15 parts by weight bentonite,
- said treated water is added to said dry base composition in an amount such that said grout slurry formed in step (c) has a solids content of at least 30% by weight based on the total weight of said grout slurry, and
- 15 said thinning agent is added to said water in step (b) in an amount effective to allow said grout slurry to be placed in said annulus in accordance with step (d) by pumping.
19. The method of claim 18 wherein said thinning agent comprises at least one anionic polyacrylamide.
- 20 20. The method of claim 19 wherein said treated water is added to said dry base composition in an amount such that said grout slurry formed in step (c) has a solids content of at least 35% by weight based on the total weight of said grout slurry.
21. The method of claim 18 wherein said thinning agent is sodium chloride, potassium chloride, or a combination thereof.
- 25 22. The method of claim 21 wherein said treated water is added to said dry base composition in an amount such that said grout slurry formed in step (c) has a solids content of at least 35% by weight based on the total weight of said grout slurry.

23. The method of claim 22 wherein said dry base composition consists of:  
said natural flake graphite having a particle size of not greater than 200 mesh  
and  
sodium bentonite having a particle size of not greater than 325 mesh.
- 5 24. The method of claim 23 wherein said thinning agent is added to said water in  
step (b) in an amount equivalent to at least 8 ounces by volume per each 9 gallons of  
said water.
25. The method of claim 23 wherein said treated water is added to said dry base  
composition in an amount such that said grout slurry formed in step (c) has a solids  
10 content of at least 40% by weight based on the total weight of said grout slurry.
26. The method of claim 23 wherein said grout slurry formed in step (c) and  
placed in said annulus by pumping in step (d) consists solely of:  
said dry base composition;  
said water, and  
15 said thinning agent.
27. In an apparatus for subterranean ground heat exchange comprising a casing  
extending underground, an internal delivery conduit extending into said casing, and a  
supply and return header mounted at an upper end of said casing for supplying a heat  
transfer fluid into said internal delivery conduit and for receiving said heat transfer  
20 fluid as it returns to said supply and return header via a return flow annulus between  
said internal delivery conduit and an interior wall of said casing, the improvement  
comprising said supply and return header comprising:  
a housing having a closed top and a vertically extending outer wall which  
surrounds an interior of said housing, said closed top defining an upper  
25 end of said supply and return header;  
a supply port for said heat transfer fluid provided through said vertically  
extending outer wall;  
a return port for said heat transfer fluid provided through said vertically  
extending outer wall; and

an interior supply conduit including a first portion of said interior supply conduit which extends into said interior of said housing from said supply port and has a bend which is positioned in said interior of said housing for directing said heat transfer fluid downwardly and a second  
5 portion of said interior supply conduit which extends downwardly from said bend for delivering said heat transfer fluid to said internal delivery conduit.

**28.** The apparatus of claim **27** wherein the improvement further comprises said second portion of said interior supply conduit extending downwardly through a lower  
10 end of said housing.

**29.** The apparatus of claim **27** wherein the improvement further comprises a collar for mounting said housing on said upper end of said casing, said collar having an upper portion wherein a lower end of said housing is received and said collar having a lower portion wherein said upper end of said casing is received.

**30.** The apparatus of claim **29** wherein the improvement further comprises said collar being a socket-to-thread collar comprising interior threads in said upper portion of said collar for threaded attachment to corresponding exterior threads provided around said outer wall of said housing and said lower portion of said collar being a socket wherein said upper end of said casing is received for bonding said collar to an  
15 exterior upper end portion of said casing.  
20

**31.** The apparatus of claim **27** wherein the improvement further comprises said housing, said supply port, said return port, and said interior supply conduit being integrally formed as a unitary cast structure.

**32.** The apparatus of claim **27** wherein the improvement further comprises said  
25 closed top having a substantially flat upper exterior surface.

**33.** The apparatus of claim **27** wherein the improvement further comprises said supply and return header having a height effective such that, as mounted on said

upper end of said casing, said upper end of said supply and return header is not more than 10 inches above said upper end of said casing.

34. The apparatus of claim 27 wherein the improvement further comprises said supply and return header having a height effective such that, as mounted on said upper end of said casing, said upper end of said supply and return header is not more than 8 inches above said upper end of said casing.

35. The apparatus of claim 27 wherein the improvement further comprises said supply and return header having a height effective such that, as mounted on said upper end of said casing, said upper end of said supply and return header is not more than 7 inches above said upper end of said casing.

36. The apparatus of claim 27 wherein the improvement further comprises said supply and return header having a height effective such that, as mounted on said upper end of said casing, said upper end of said supply and return header is not more than 6 inches above said upper end of said casing.

37. The apparatus of claim 27 wherein the improvement further comprises said housing having a lower interior portion which is sized and adapted such that said upper end of said casing is received in said lower interior portion of said housing and said lower interior portion of said housing is directly bonded to an exterior upper end portion of said casing.

38. The apparatus of claim 37 wherein the improvement further comprises said lower interior portion of said housing comprising a plurality of interior tiers which are of decreasing diameters from a lower end of said housing upward.

39. The apparatus of claim 27 wherein the improvement further comprises a series of discrete, space apart, radial ribs extending along an exterior of said internal delivery conduit such that said radial ribs project into said return flow annulus.

40. The apparatus of claim 39 wherein the improvement further comprises said series of discrete, spaced apart, radial ribs having a ratio of peak-to-peak rib spacing to radial peak height in the range of from about 1.2:1 to about 3:1.

41. The apparatus of claim 39 wherein the improvement further comprises said  
5 internal delivery conduit being corrugated tubing.

42. The apparatus of claim 41 wherein the improvement further comprises said radial ribs being circular.

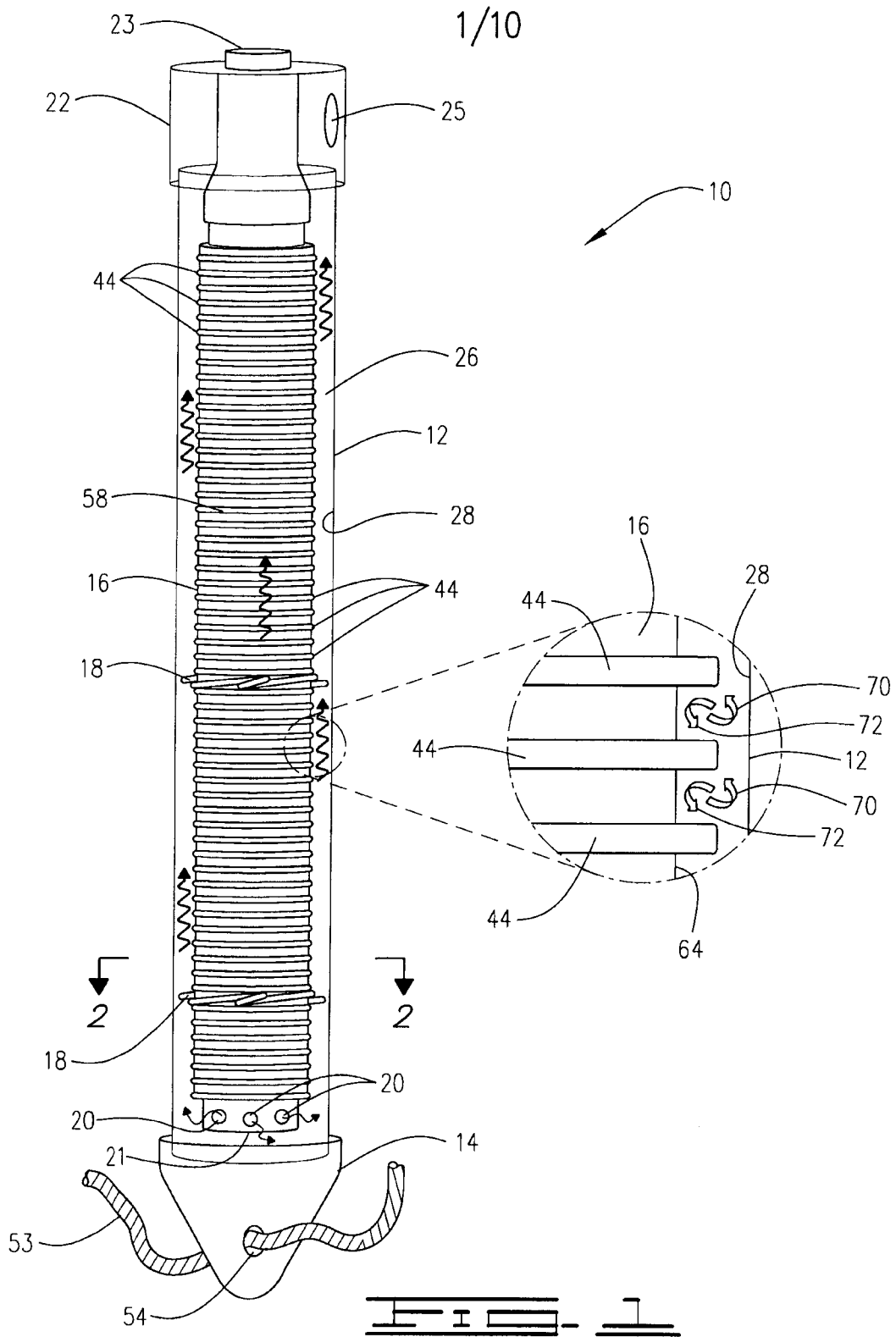
43. The apparatus of claim 27 wherein the improvement further comprises said casing comprising a string of filament wound pipe segments formed from a  
10 thermosetting plastic composition and a reinforcing fiber material wherein:

said reinforcing fiber material is fiberglass, carbon fiber, aramid fiber or a combination thereof;

said thermosetting plastic composition includes a thermal conductivity enhancing additive; and

15 said thermal conductivity enhancing additive is medium grade aluminum powder present in said thermosetting plastic composition in an amount of at least 1.5% by weight based on total weight of said thermosetting plastic composition; and

20 said filament wound pipe segments have an outside diameter to inside diameter ratio of not more than 1.055 and a collapse pressure of at least 75 psig.



2/10

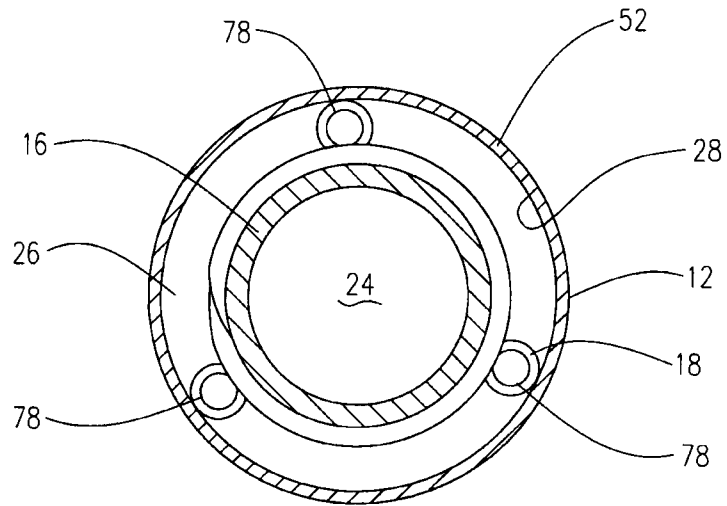


FIG. 2

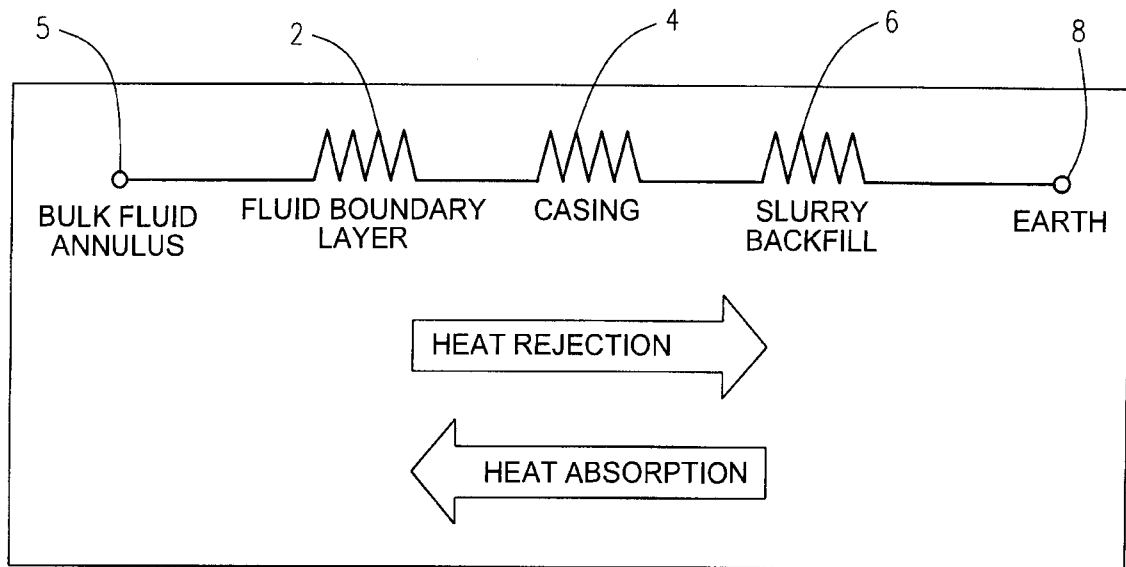


FIG. 3

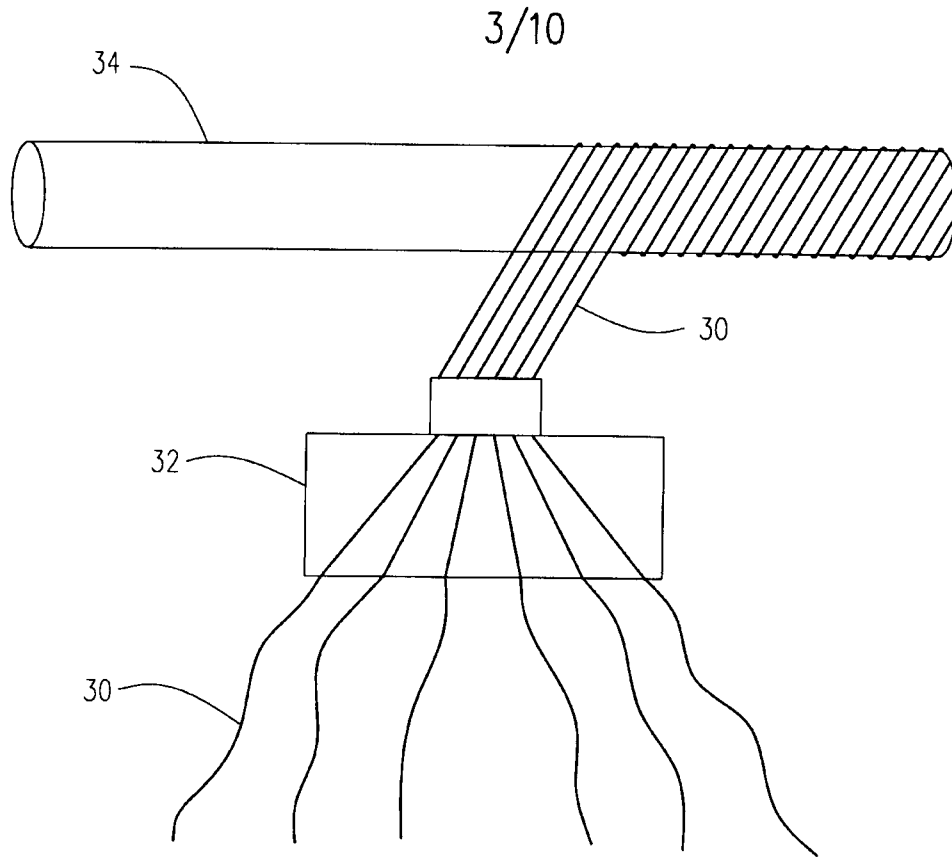


FIG. 4

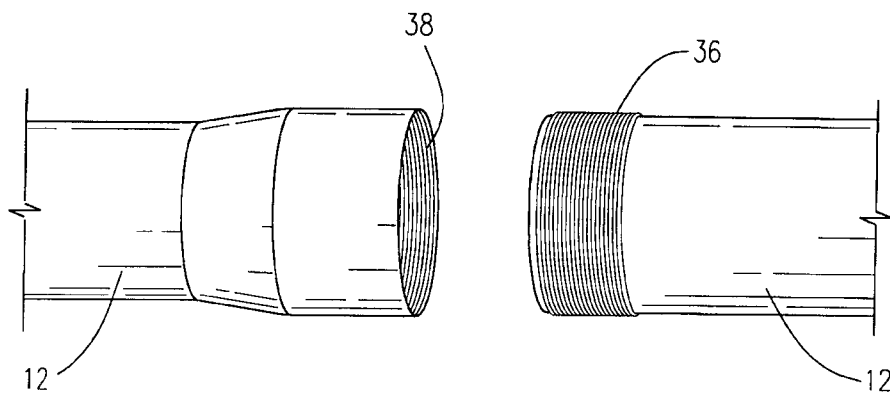


FIG. 5

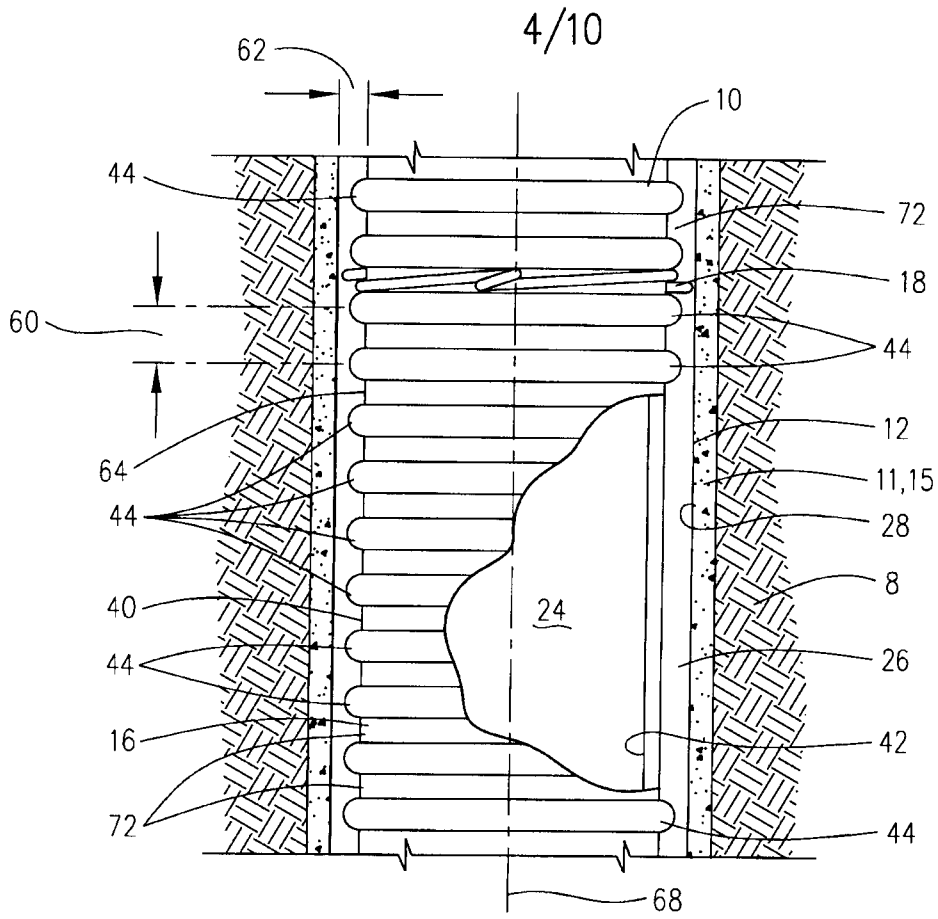


FIG. 6

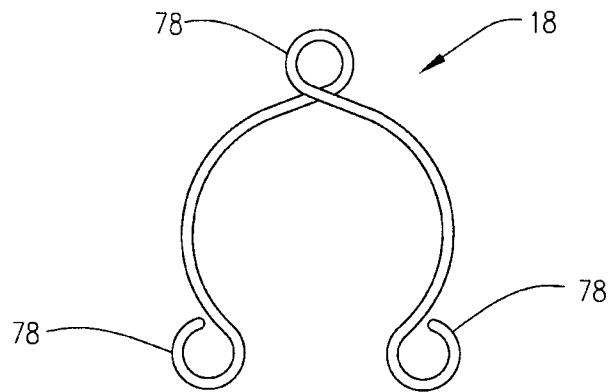
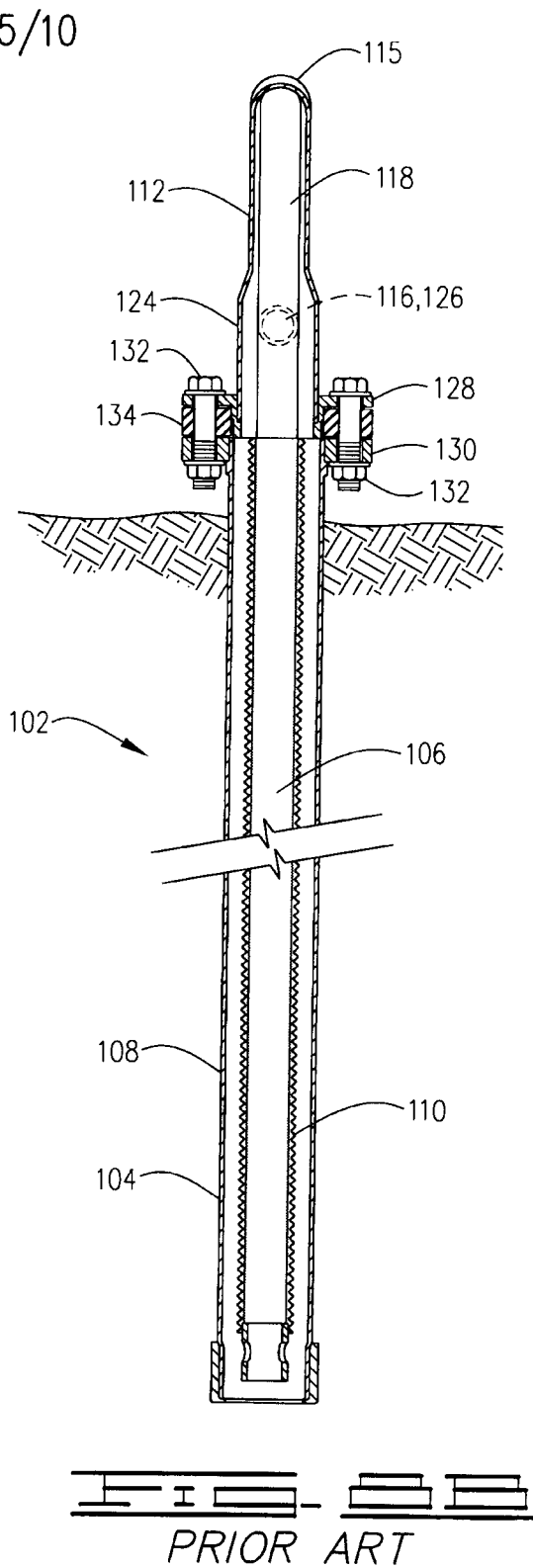
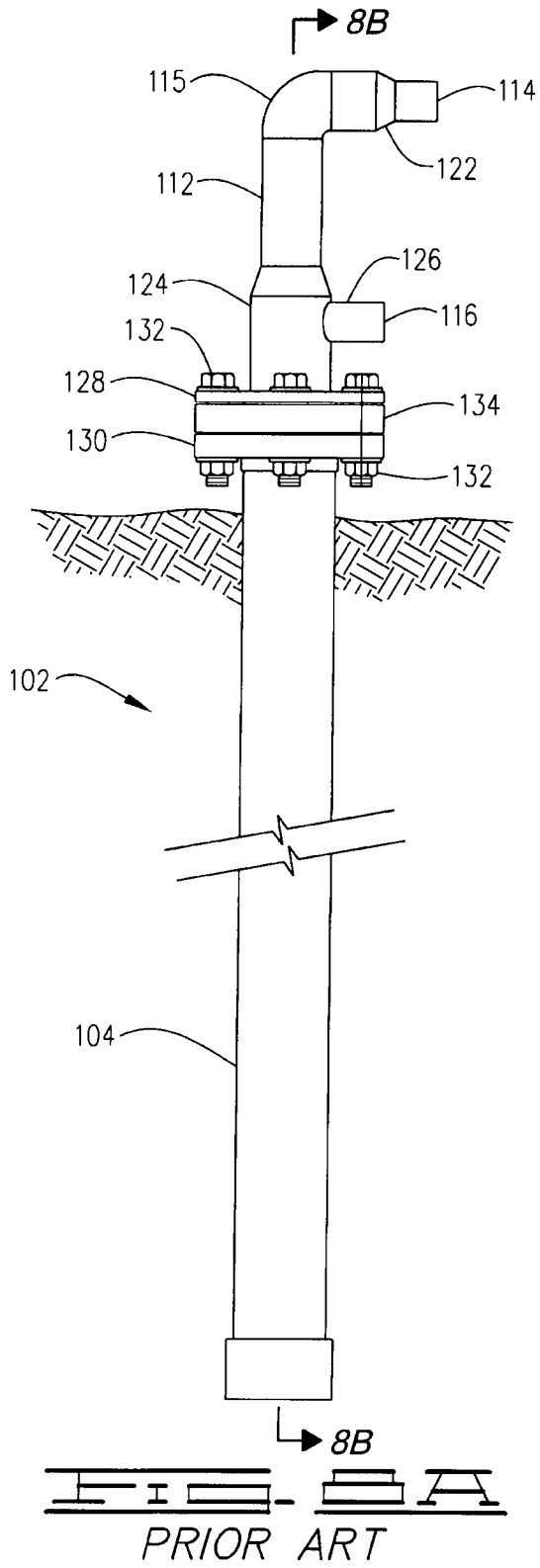
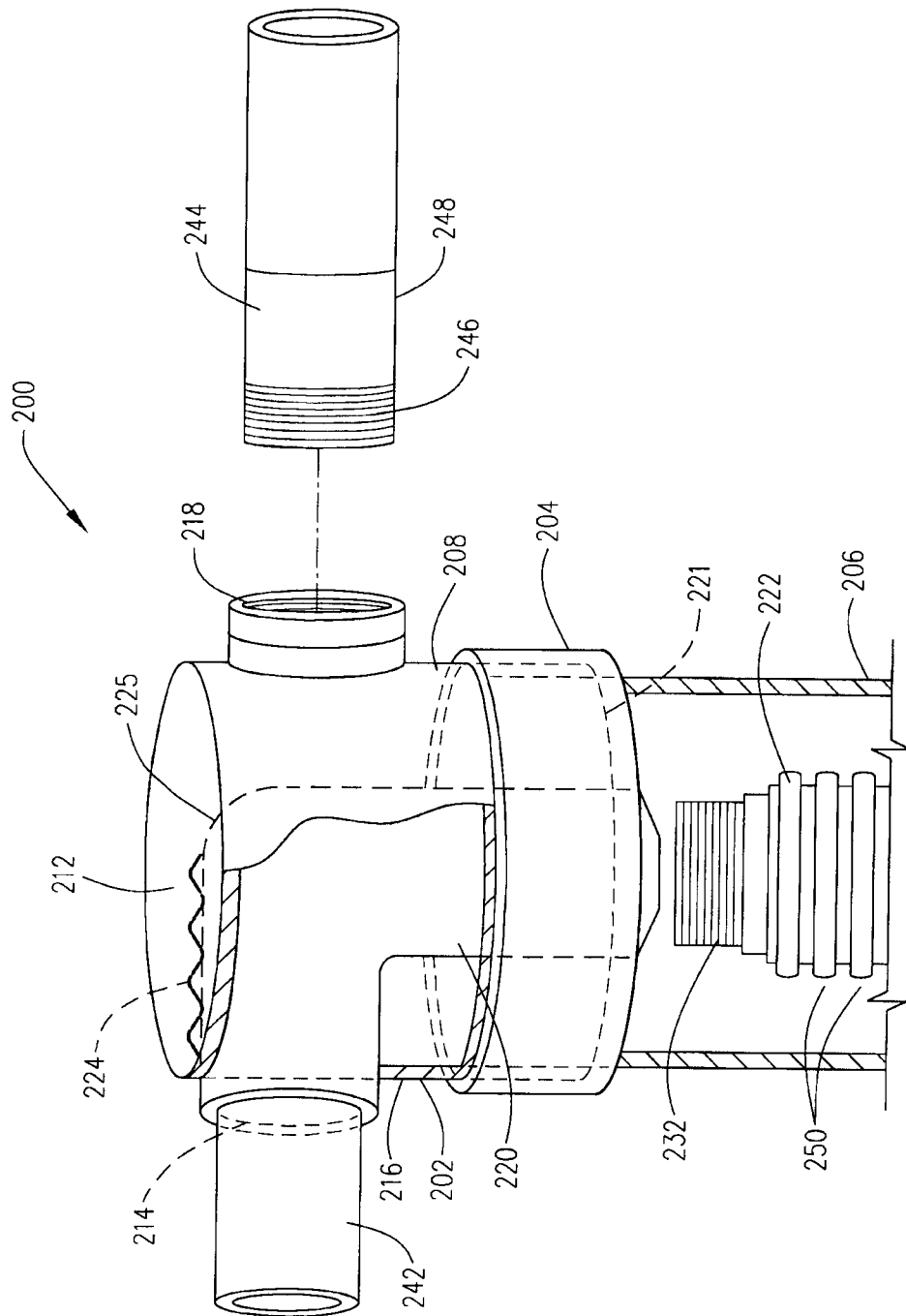
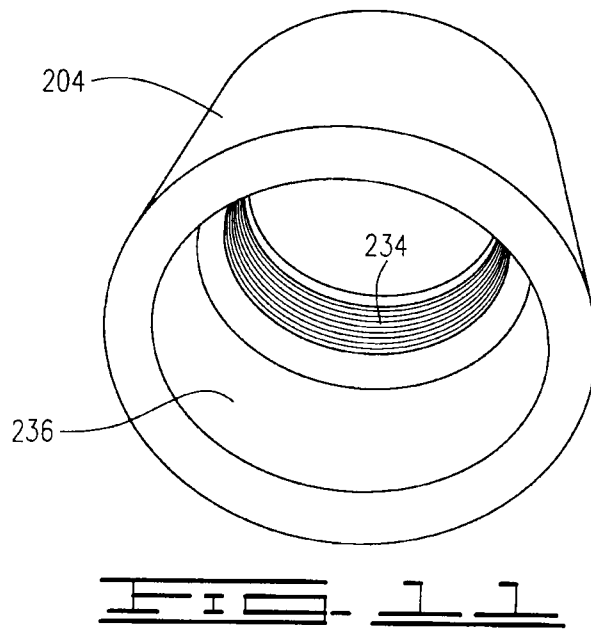
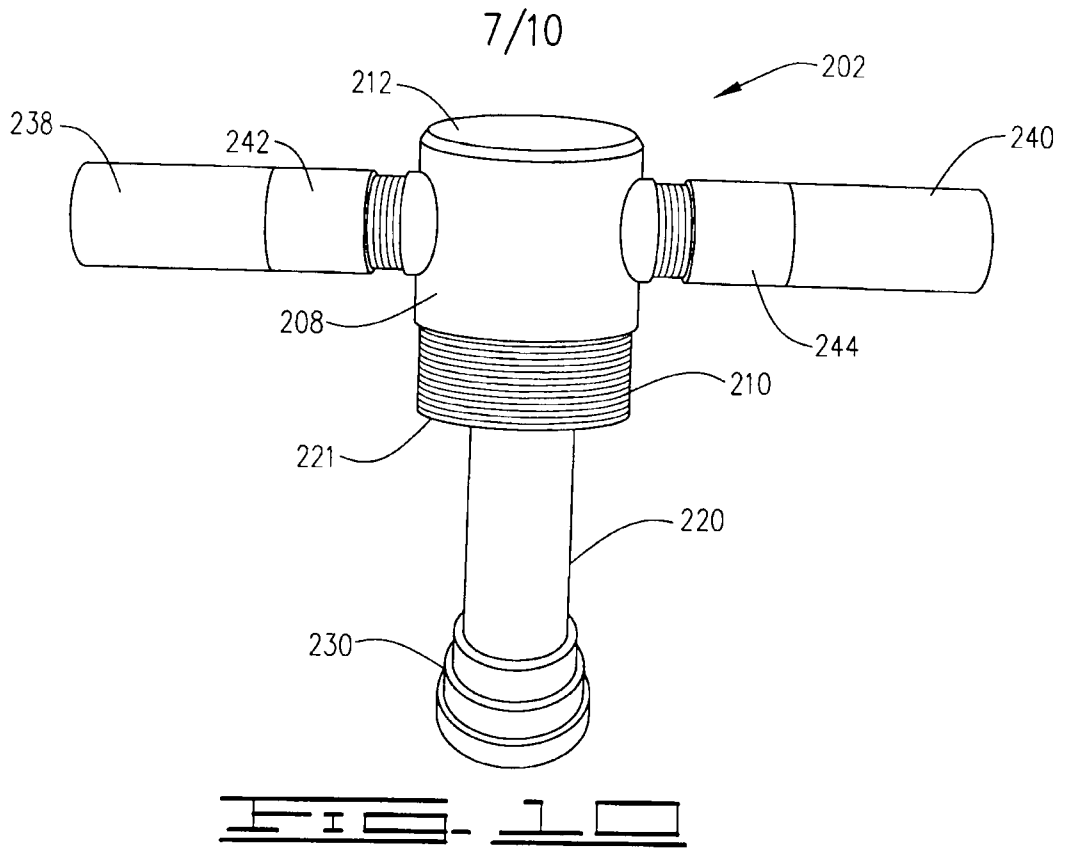


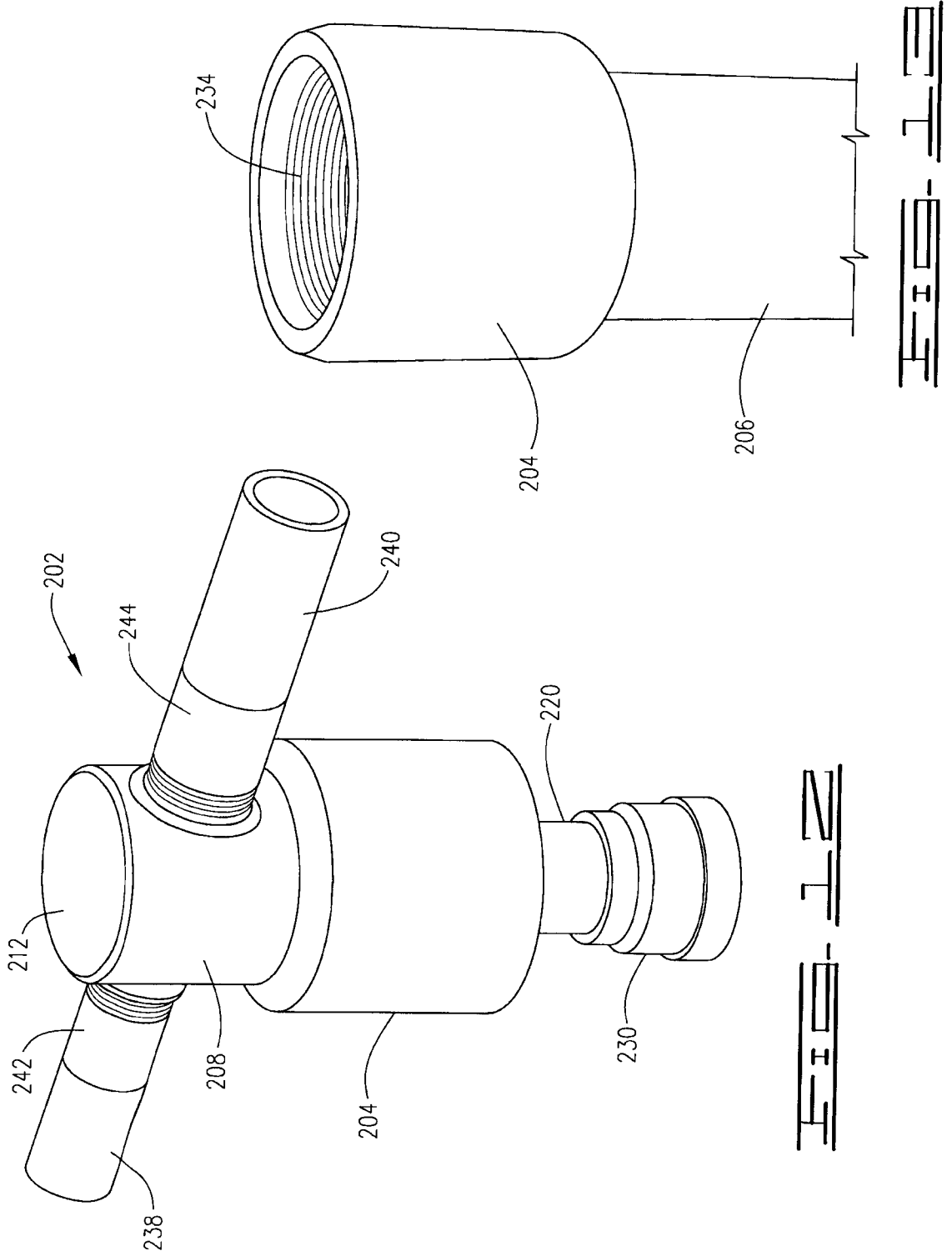
FIG. 7







8/10



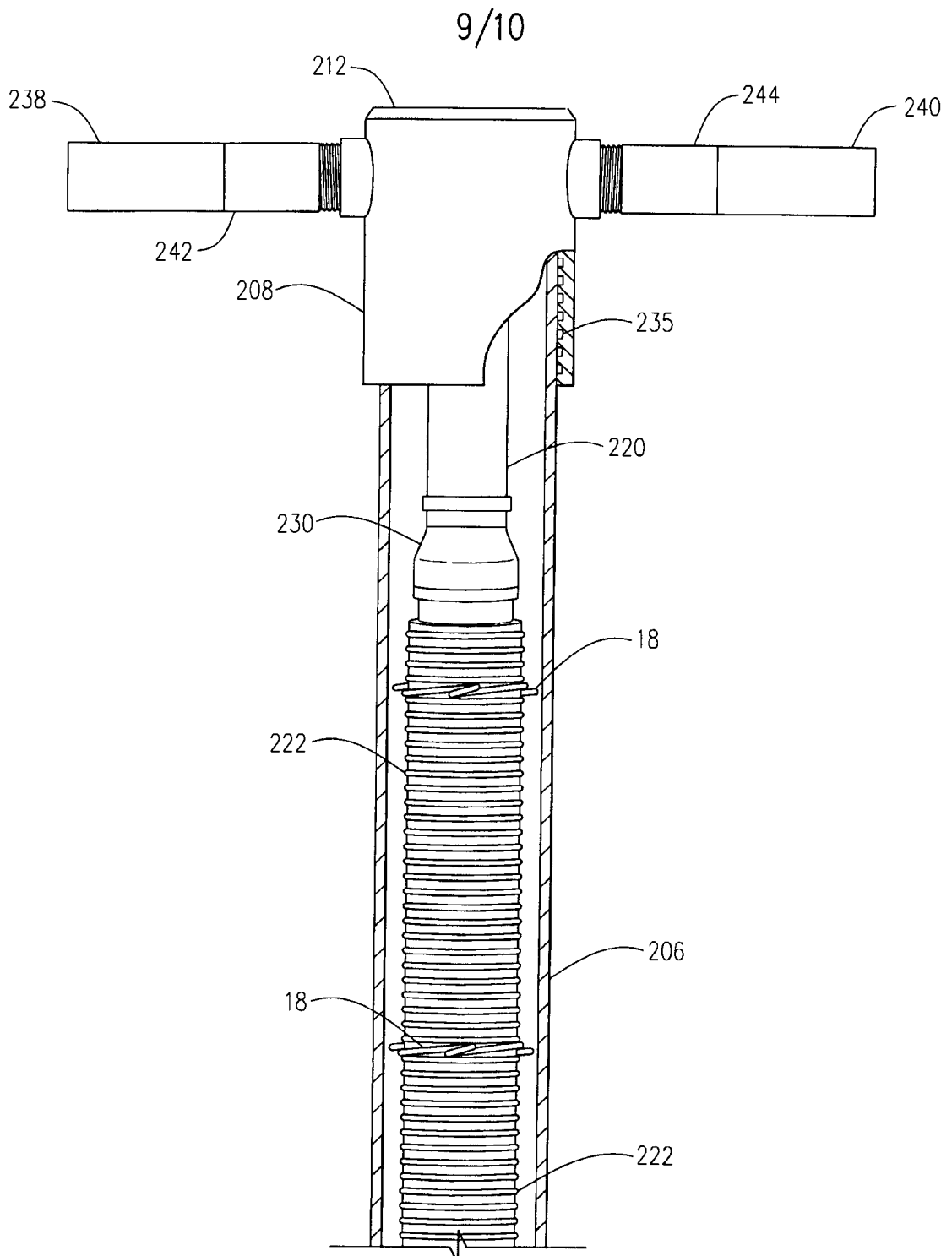
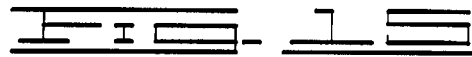
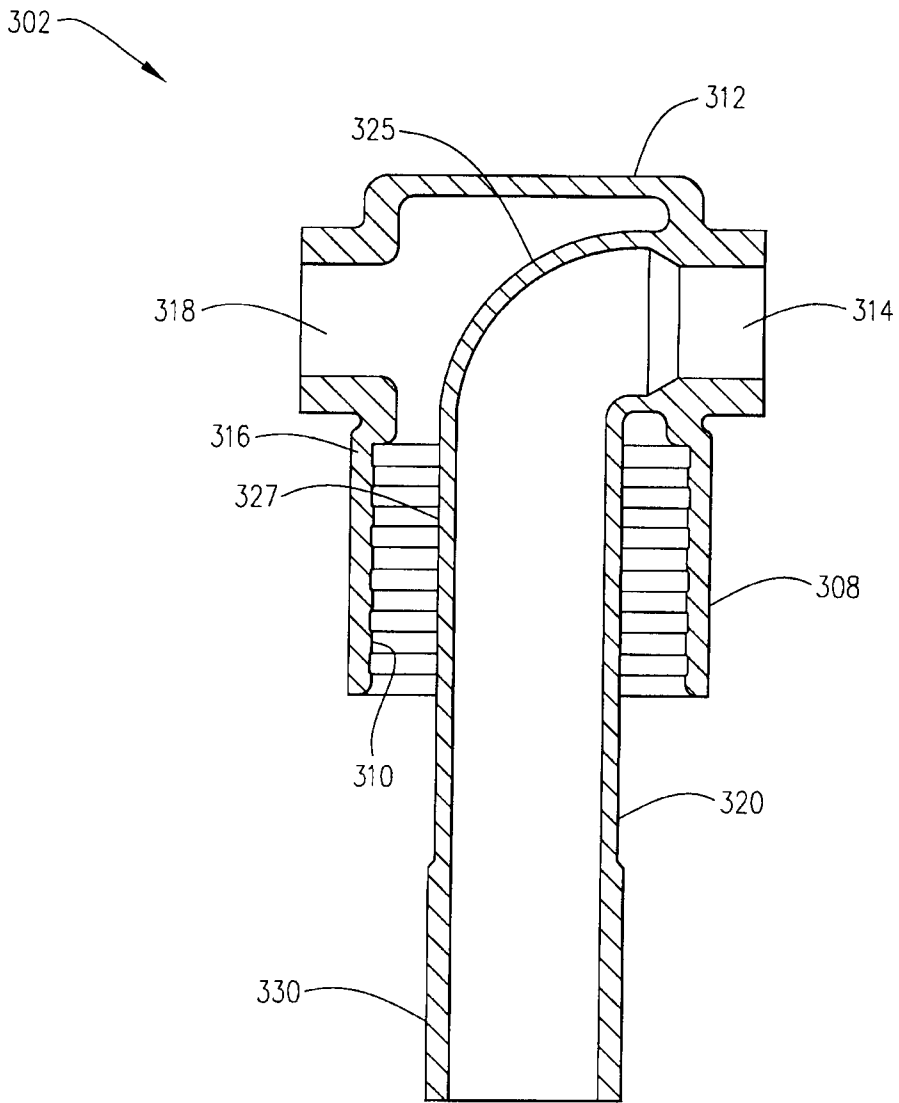


FIG. 14

10/10



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2010/026634

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C04B 14/00 (2010.01)

USPC - 106/638

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - C04B 14/00 (2010.01)

USPC - 106/638, 803, 805, 806; 166/293, 302

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
ECLA - C04B 28/10, 28/10M, 28/18B; C09K 8/05, 8/16, 8/46, 8/467 (2010.01)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Patbase, Google Patents

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 7,067,004 B2 (MATULA et al) 27 June 2006 (27.06.2006) entire document	1-26
Y	US 2007/0125274 A1 (MILLER) 07 June 2007 (07.06.2007) entire document	1-10, 14-17, 23-26
Y	US 6,251,179 B1 (ALLAN) 26 June 2001 (26.06.2001) entire document	4
Y	US 3,835,926 A (CLEMENT) 17 September 1974 (17.09.1974) entire document	7-9, 11-26
Y	US 4,654,085 A (SCHINSKI) 31 March 1987 (31.03.1987) entire document	10, 19-20

 Further documents are listed in the continuation of Box C.

## \* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;" document member of the same patent family

Date of the actual completion of the international search

22 June 2010

Date of mailing of the international search report

29 JUN 2010

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2010/026634

**Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

- 1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
- 2.  Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
- 3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:

See extra sheet.

- 1.  As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
- 2.  As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
- 3.  As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
- 4.  No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:  
1-26

**Remark on Protest**

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.

PCT/US2010/026634

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees need to be paid.

Group I, claims 1-26 are drawn to a grout slurry composition.

Group II, claims 27-43 are drawn to an underground casing.

The inventions listed in Groups I and II do not relate to a single general inventive concept under PCT Rule 13.1, because under PCT Rule 13.2 they lack the same or corresponding special technical features for the following reasons:

The special technical features of Group I, a grout slurry composition including flake graphite, bentonite, and a thinning agent, are not present in Group II; and the special technical features of Group II, an underground casing for ground heat exchange including multiple ports, delivery conduits, and a return header, are not present in Group I.

Since none of the special technical features of the Group I and II inventions are found in more than one of the inventions, unity is lacking.