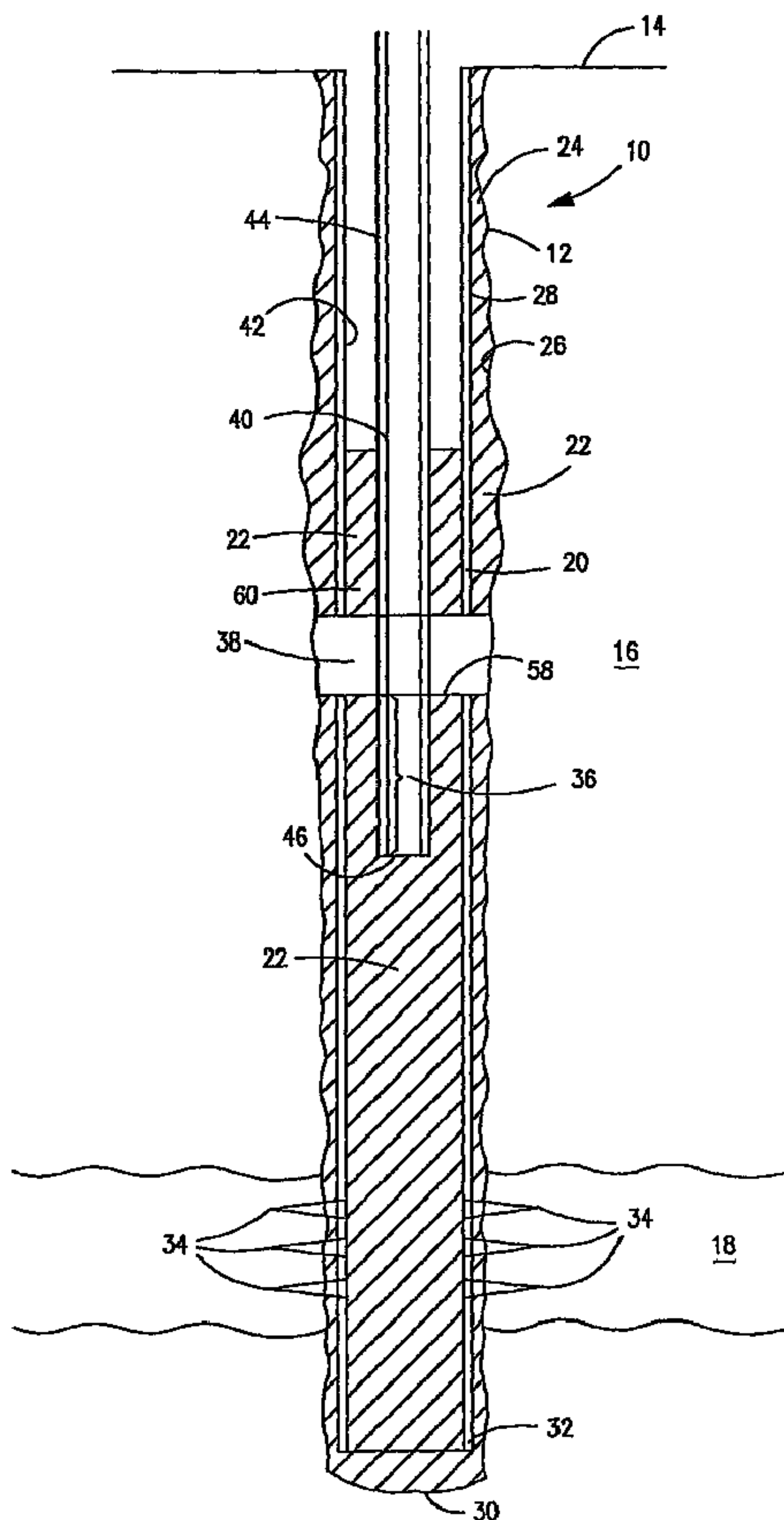




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A method for the detection of a fluid leak from a plugged well extending from a surface of the earth to penetrate a subterranean formation which contains fluid by logging a collection chamber positioned in the plugged well.

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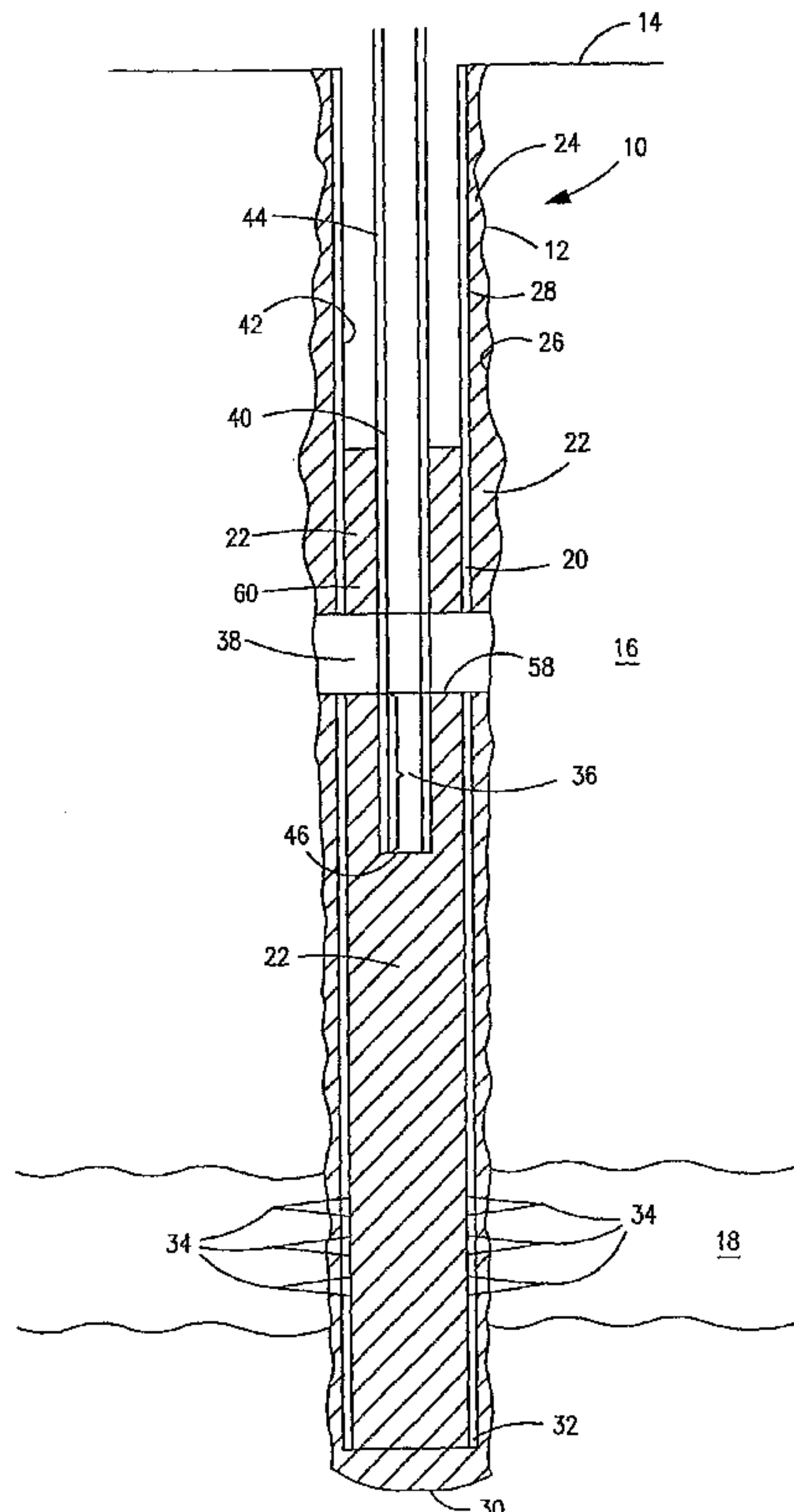
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[Continued on next page]

(54) Title: METHOD FOR DETECTING FLUID LEAKAGE FROM A SUBTERRANEAN FORMATION

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**METHOD FOR DETECTING FLUID LEAKAGE  
FROM A SUBTERRANEAN FORMATION**

5 **FIELD OF THE INVENTION**

[0010] The present invention relates to a method for the detection of fluid leaks from plugged wells extending from a surface of the earth to penetrate a subterranean formation containing fluid.

**BACKGROUND OF THE INVENTION**

10 [0011] Increasing attention has been directed in recent years to minimizing release of gases and liquids (fluids), which are considered to be atmospheric pollutants, into the atmosphere. Such fluids may comprise gases, such as carbon dioxide, light hydrocarbons, hydrogen sulfide, sulfur oxides, nitrogen oxides, halogens and the like, along with or in aqueous or hydrocarbonaceous solutions, hydrocarbons, contaminated  
15 water, airborne particulates and the like. Many such materials are naturally present or are injected into subterranean formations during the production of hydrocarbons, the disposal of unwanted fluids and the like. When the production or disposal operations are completed, the wells used to penetrate such formations are typically cemented shut to prevent the release of these fluids into the air, overlying aquifers, or the like as leakage  
20 from wells penetrating subterranean formations.

[0012] Such formations may contain carbon dioxide having a density of less than 1 (one) as a result of naturally-occurring in situ carbon dioxide, from use of the well as a carbon dioxide injection/disposal well, from use of the well as either an injection or a production well in a carbon dioxide enhanced oil recovery process, and the like. There  
25 are a variety of reasons why subterranean formations containing carbon dioxide are desirably isolated so that the carbon dioxide does not flow into the atmosphere. The most commonly used technique for isolating such formations is plugging the wells penetrating the formation containing carbon dioxide. This is most commonly accomplished by cementing the wells shut.

30 [0013] Of continuing concern is whether the cement plug, or other plugging material, has fully plugged the well and whether it continues to block the flow of fluids, such as carbon dioxide, from flowing upwardly through the well into the atmosphere. Should leaks occur, the source of leaks into the atmosphere can be through or around the cement plugging, which cements the casing in place in the wellbore, or through or

around the cement plugging the inside of the casing, which is typically used to case the well from the earth's surface to or through the carbon dioxide-bearing formation(s). Minute quantities of fluid leakage over long periods of time can erode the cement used to seal the well and result in larger leaks.

5           [0014] Various techniques have been used in the past for carbon dioxide measurement. These techniques include near infra red or other light absorption techniques and the like for the detection of carbon dioxide in flowing gas streams. However, such techniques are not effective for the detection of very minute quantities of carbon dioxide released on a continuing basis. Accordingly, an improved method for  
10 detecting fluid leakage from plugged wells has long been sought.

#### SUMMARY OF THE INVENTION

[0015] The present invention comprises a method for the detection of a fluid leak from a subterranean formation containing fluid by logging a collection chamber positioned in the plugged well above the subterranean formation.

15           [0016] According to the present invention, a method is provided for detecting a fluid leak from a plugged well extending downwardly from a surface of the earth and penetrating a subterranean fluid-containing formation by forming a collection chamber across a cross sectional area of the plugged well above the fluid-containing formation, sealingly positioning a tubing to extend through the collection chamber and to the  
20 surface, and passing a fluid detecting apparatus through the tubing and at least partially through the collection chamber to detect fluid in the collection chamber.

[0017] The invention further comprises a method for detecting a fluid leak from a plugged well extending from a surface of the earth and penetrating a subterranean formation containing fluid, the well comprising a wellbore containing a casing extending  
25 through an impermeable zone and being cemented in the wellbore by cement positioned in an annulus between the outside of the casing and the inside of the wellbore by forming a collection chamber in fluid communication with the inside of the casing and the cement in the annulus above the formation containing fluid; sealingly positioning a tubing to extend through the collection chamber and to the surface; and, passing a fluid detecting  
30 apparatus through the tubing and at least partially through the collection chamber to detect fluid in the collection chamber.

[0018] The invention also comprises a method for detecting a fluid leak from a plugged well extending downwardly from a surface of the earth and penetrating a subterranean fluid-containing formation, the method comprising forming a collection

chamber across a cross sectional area of the plugged well above the fluid containing formation, positioning a cap member across an upper end of the collection chamber, sealingly positioning a tubing to extend from the surface to operatively engage the cap member, and passing a fluid detecting apparatus through the tubing above the cap member to detect fluid in the collection chamber.

[0010] In each of these embodiments, carbon dioxide may be a principal fluid of interest.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG 1. is a schematic diagram of a wellbore extending from an earth surface through a subterranean fluid-bearing formation and including a collection zone according to the present invention;

[0012] FIG 2 and FIG 3 are alternate schematic embodiments of methods for plugging a well penetrating a fluid-containing formation;

[0013] FIG 4. is a schematic diagram of an alternative embodiment of the present invention;

[0014] FIG 5 is a further schematic diagram of a further embodiment of the present invention;

[0015] FIG 6 is a schematic diagram of a further embodiment of the present invention; and,

[0016] FIG 7 is a schematic diagram of another embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

[0017] In the description of the Figures, the same numbers will be used throughout to refer to the same or similar components.

[0018] While leakage of a wide variety of fluids may be detected by the present invention, carbon dioxide is a pollutant of particular interest. Therefore the invention will be discussed by reference to carbon dioxide unless otherwise stated, although the invention is not limited to detection of carbon dioxide leaks.

[0019] In FIG 1, a well 10 is shown and comprises a wellbore 12 extending from a surface 14 through an overburden 16 and penetrating a carbon dioxide-containing

formation 18. Well 10 includes a casing 20, which is cemented in place by cement 22 and which could be used to produce fluids from formation 18. In FIG 1 the casing extends to near a bottom 30 of wellbore 12 and ends at a lower end 32 of the casing. Typically fluids recovered from formation 18 could comprise hydrocarbons alone, hydrocarbons in combination with aqueous fluids, hydrocarbon gases, carbon dioxide, hydrogen sulfide, sulfur oxides and the like. Alternatively, well 10 could be used to inject carbon dioxide, aqueous surfactants or the like into formation 18 for the recovery of hydrocarbons or the like. Alternatively, carbon dioxide or other fluids could be injected into formation 18 for disposal of the carbon dioxide or other fluids up to a selected limit.

[0020] Well 10, as shown in FIG. 1, has been plugged to prevent the escape of carbon dioxide from formation 18. Cement 22, as shown, is typically used to position casing 20 in wellbore 12 by positioning the casing in the wellbore and thereafter injecting cement into an annulus 24 between an outside 28 of casing 20 and an inside 26 of wellbore 12. This cement desirably fills annulus 24 between the outside 28 of casing 20 and the inside 26 of wellbore 12. This cement is positioned with the objective of preventing the movement of fluids between the outside of casing 28 and the inside of wellbore 26. Well 10, as shown, has been perforated in formation 18 by perforations 34 to permit the flow of fluids into or from formation 18 during use of well 10.

[0021] Well 10, as shown, has been plugged with cement 22 to a top 58 of a cement layer which ends at a collection chamber 38, which is formed across a cross sectional area of wellbore 12. The collection chamber is positioned to collect carbon dioxide or other fluids which may flow upwardly from formation 18 through cement 22 inside casing 20 or up annulus 24. These fluids are allowed to accumulate in collection chamber 38 and the collection chamber is periodically tested to determine whether fluid has moved into collection chamber 38. Well 10 is sealed above collection chamber 38 by additional cement in the annulus 24 and in a second annulus 60 between an inside 42 of casing 20 and an outside 44 of a tubing 40 which is positioned to extend from surface 14 downwardly through well 10 through collection chamber 38 and for a selected distance 36 below collection chamber 38. Tubing 40 ends at a lower end 46 of the tubing.

[0022] By the operation of the present method a selected time is allowed to pass with any fluids which may be migrating upwardly through well 10 being collected in collection chamber 38. Thereafter a fluid detecting apparatus is passed downwardly

through tubing 40 and through collection chamber 38. The space 36 below collection chamber 38 is desirable to permit operation of the fluid detecting apparatus. The carbon dioxide (fluid) detecting apparatus may be one of a variety of logging tools, such as a pulse neutron logging tool, a neutron logging tool, an acoustic logging tool, a resistivity logging tool with a wireline, memory, downhole battery, fiber optics, radio transmission, pressure sensing, temperature, or other data transmission system. Such systems and tools are considered to be capable of detecting the presence of carbon dioxide or other fluids in collection chamber 38, especially when calibrated by the use of known carbon dioxide concentrations in chambers such as collection chamber 38. Some of these systems, or other systems as known to the art, may be used to detect the presence and optionally the composition of fluids other than carbon dioxide. A key criterion is the ability to detect the presence of any fluid in the collection chamber without regard to its composition since leakage of any fluid upwardly from the well normally requires remediation unless the cement above the collection chamber is effectively containing the fluids.

[0023] Desirably collection chamber 38 includes particulate matter such as sand, gravel or the like (not shown) which is desirably of a composition different than the materials making up formation 18. This enables the logging tool to more accurately detect the zone which comprises the collection chamber as the log is passed upwardly and downwardly through tubing 40. By these techniques the presence of carbon dioxide or other fluids can be detected. Since collection chamber 38 is sealed by cement above the collection chamber, the collection chamber accurately collects any carbon dioxide or other fluids moving upwardly through well 10 by concentrating any collected fluids in collection chamber 38. The use of the particulate material in chamber 38 also facilitates the calibration of the logging tool to detect carbon dioxide in combination with the specific particulate material used. Wide variations in the particulate material used are possible, as known to those skilled in the art.

[0024] In FIGs 2 and 3, alternate methods for plugging formation 18 are shown. In FIG 2, formation 18 is an open hole completion through formation 18 and has been plugged by placing cement in the open hole area as well as in the casing above the open hole area. Cement has been used to close annulus 24 as discussed above.

[0025] In FIG 3, a sleeve 48 has been positioned over formation 18 with cement then being positioned behind sleeve 48 to close formation 18, with cement then being positioned inside sleeve 48 and casing 20. Annulus 24 has typically been plugged previously with cement as discussed above. A wide variety of plugging completions are



considered to be known to those skilled in the art and all are suitable for use in the method of the present invention.

5 [0026] In FIG 4, an alternate method for forming collection chamber 38 is shown wherein the collection chamber is placed in an impermeable formation 50 positioned in the overburden 16. By use of this formation, perforations 52 can be placed through casing 20 and extended into formation 50 from which no fluids are produced. The perforations provide a flow path for any fluids which may be moving upwardly through annulus 24 from formation 18. Similarly, fluids which are moving upwardly through the cement inside casing 20 also accumulate in collection chamber 38 and are measured, as discussed previously, by the use of logging tools in tubing 40. Desirably, the lower end 10 46 of tubing 40 is sealed by either the use of a fabricated sealing member across lower end 46 of tubing 40 or by its position in cement inside casing 20. The detection of the carbon dioxide in FIG 4 is accomplished in the same way as in FIG 1. One additional difference in FIG 4 is that packers 54 and 56 are used to position cement in well 10 above collection zone 38, as known to those skilled in the art.

[0027] In FIG 5, a further embodiment of the present invention is shown wherein packers 62 and 64 are used to position cement above and below a collection chamber 38. The use of packers for such an application is well known to those skilled in the art and the carbon dioxide is detected in collection chamber 38, as discussed in conjunction with FIG 1. FIG 5 shows the use of the method of the present invention in an uncased well.

20 [0028] In FIG 6, an alternate embodiment of the present invention is shown wherein a collection chamber 38 is positioned across a cross section of a well 10. Collection chamber 38 includes a funnel or cap member 66 positioned to allow lighter components collected in collection chamber 38 to rise to a top of funnel 66. Funnel 66 is closed at its top end and is in operating engagement with tubing 44 so that logging measurements of fluids trapped in collection chamber 38 are accomplished through the bottom of tubing 44 and a top of funnel 66.

25 [0029] In FIG 7, a further embodiment is shown wherein a collection chamber is positioned between the outside of the casing and the inside of the wellbore. In this embodiment, a cavity is formed by milling or the like through the casing and the cement surrounding the casing in the wellbore to produce a collection chamber 38. The collection chamber is then completed by positioning a sleeve 68, which may be of any suitable sleeve material, expandable casing material or the like, to sealingly separate the collection chamber from the inside of the casing. The chamber then collects gases, other

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light vapors or fluids which may be rising through the cement closing the annulus between the outside of the casing and the inside of the wellbore. The presence of carbon dioxide is readily detected by passing a logging tool down the casing and through the area of the collection chamber to determine whether carbon dioxide has collected in the collection chamber.

[0030] In the embodiment of FIG 7, the well may be produced during the period when fluids are collecting in the collection chamber by a tubing positioned through the casing and extending to the vicinity of formation 18. The tubing may be removed as desired to pass a logging tool through the casing to determine whether fluids have collected in chamber 38. Production or injection through a tubing may then be resumed or alternatively the tests of chamber 38 for carbon dioxide or other fluids may be conducted when it is convenient to remove the tubing for production or injection reasons. In any event, this embodiment allows the detection of fluids which may be escaping from a fluid-containing formation through the annular space between the outside of the casing and inside of the wellbore. It will be understood that with this and other embodiments, that not only may a fluid-containing formation 18 be penetrated by the well, but other formations from which hydrocarbons or other materials are produced or into which other materials are injected may be penetrated by the well. In other words, the fluid-containing formation may lie above, below or between formations into which fluids are injected or from which fluids are produced. Such formation characteristics are well known to those skilled in the art. In view of the current concern about carbon dioxide in the atmosphere, it is desirable to be able to determine whether carbon dioxide is being lost from a carbon dioxide-containing formation into the atmosphere through the annular space or through plugged wells as discussed above.

[0031] A wide variety of configurations is possible within the scope of the present invention for the detection of leaks from a plugged well. In such embodiments, it is necessary that a collection chamber be positioned to intercept all sources for leaks of fluids upwardly through well 10 from formation 18. These fluids are then detected by the use of a logging system through tubing 40 or through an end 44 of tubing 40. Logging techniques such as those generally used in oil wells are effective for logging through tubing 44. The presence of particulate matter in the collecting chamber enables the use of the particulate material to produce a signal unique to the particulate material in the collection chamber.

[0032] Further, the material may be selected to act as an absorbent, to a certain extent, of the fluids produced upwardly through well 10. The logging detection of fluids passed upwardly through well 10 is anticipated to be done relatively rarely unless a substantial leak is suspected or detected. The use of the collection chamber permits the use of logging techniques to determine whether leakage is occurring and to determine the magnitude of the leakage over periods of time.

[0033] As discussed above, typically wells may be completed either open hole, i.e., with no casing, and produced open hole via tubing or otherwise as known to those skilled in the art. Such completions are relatively rare with cased completions and particularly at least partially cased completions being more frequently used. The method of the present invention is useful with either type of well and requires that a collection chamber be positioned across the cross-sectional area of the well in the path of the migration of fluids upwardly from formation 18. A variety of configurations can be used, as known to those skilled in the art. Further the completion of wells of the configurations discussed above is readily accomplished by those skilled in the art by techniques such as, two-phase cementing, gravel packs, packers, external casing packers and a variety of other known cementing and completion techniques.

[0034] The specific method selected for the formation of the collection chamber in the well is not considered to constitute a portion of the present invention, which is directed to the use of the collection chamber in determining whether fluid is escaping from the fluid-containing formation below the collection chamber.

[0035] While the present invention has been discussed primarily with emphasis on the detection of carbon dioxide leaks, which is of considerable interest in view of recent concerns about global warming, it should be understood that the present invention is equally useful for the detection of the migration of fluids upwardly through cement inside the well casing or outside the casing between the outside of the casing and the inside of the wellbore. Fluids which may be detected and which may migrate upwardly from a subterranean formation include materials such as gases, such as light hydrocarbons, carbon dioxide, hydrogen sulfide, sulfur oxides, nitrogen oxides, halogens and the like, either alone or in aqueous or hydrocarbon solutions. Further hydrocarbons, particulates which may be suspended in fluids and the like may also migrate upwardly through these areas. A variety of other contaminants may also be encountered and generally the present invention is effective to detect the migration of any such materials which can be collected in an open space in the cement.

[0036] The determination of the composition of these materials is possible as discussed particularly with respect to carbon dioxide with known oil field logging techniques. It may not be possible in all instances to distinguish between materials such as hydrogen sulfide and carbon dioxide or between methane and carbon dioxide and the like. A main objective of the present invention, however, is the detection of migration of any fluids from the subterranean formation. If any fluids are migrating upwardly from the subterranean formation, it is a potential problem at the surface if leakage of the fluids occurs. Obviously, hydrocarbons, water (which is typically brine if leaking from a subterranean formation), any of the gaseous components previously mentioned or the like are environmental problems if they escape from the wellbore onto the surface. The detection of leakage of any of these fluids is cause for concern and workover or remedial attention. If it can be definitely established that the cement above the collection zone is preventing the migration of these fluids to the surface, than it may not be necessary to perform a remedial workover. However, in the event fluids have migrated upwardly through the cement to the level of the collection chamber, it is a clear warning that remedial work may be necessary to prevent migration of fluids from the subterranean formation to the surface.

[0037] The present invention is operative to detect the leakage of such fluids and in many instances may permit the detection of the composition of the fluids, but in all instances is operative to detect the presence of the fluids. While it may be desirable to know the composition of the escaping fluids, it is of paramount importance that the detection of leaking fluids is accomplished.

[0038] The detection of the composition of the escaping fluids may enable determination of which formation is leaking fluids or the like. In other instances, the composition of the fluids may be of little interest once it has been determined that fluids are accumulating.

[0039] While the present invention has been described by reference to certain of its preferred embodiments, it is pointed out that the embodiments described are illustrative rather than limiting in nature and that many variations and modifications are possible within the scope of the present invention. Many such variations and modifications may be considered obvious and desirable by those skilled in the art based upon a review of the foregoing description of preferred embodiments.

**WHAT IS CLAIMED IS:**

1. A method for detecting a fluid leak from a plugged well extending downwardly from a surface of the earth and penetrating a subterranean fluid-containing formation, the method comprising:
  - a) forming a collection chamber across a cross sectional area of the plugged well above the fluid-containing formation;
  - b) sealingly positioning a tubing to extend through the collection chamber and to the surface; and,
  - c) passing a fluid detecting apparatus through the tubing and at least partially through the collection chamber to detect fluid in the collection chamber.
2. The method of claim 1 wherein the well comprises a wellbore containing a casing extending from the surface through the fluid-containing formation.
3. The method of claim 2 wherein the casing is cemented in place in the wellbore.
4. The method of claim 2 wherein the well has been plugged by filling at least a portion of the casing above the fluid-containing formation with cement.
5. The method of claim 4 wherein at least a portion of an annulus between an inside of the casing and an outside of the tubing is sealed with cement.
6. The method of claim 1 wherein the apparatus is a logging system capable of detecting fluid in the collection chamber through the tubing.

7. The method of claim 1 wherein the fluid comprises carbon dioxide.
8. The method of claim 1 wherein the apparatus comprises at least one of a pulsed neutron logging system, a neutron logging system, an acoustic logging system and a resistivity logging system.
9. The method of claim 1 wherein the plugged well is an open hole well.
10. The method of claim 1 wherein the collection chamber contains a particulate material.
11. A method for detecting a fluid leak from a plugged well extending from a surface and penetrating a subterranean formation containing fluid, the well comprising a wellbore containing a casing extending through an impermeable zone and being cemented in the wellbore by cement positioned in an annulus between an outside of the casing and an inside of the wellbore, the method comprising:
  - a) forming a collection chamber in fluid communication with the inside of the casing and the cement in the annulus above the formation containing fluid;
  - b) sealingly positioning a tubing to extend through the collection chamber and to the surface; and,
  - c) passing a fluid detecting apparatus through the tubing and at least partially through the collection chamber to detect fluid in the collection chamber.
12. The method of claim 11 wherein the casing and cement in the annulus between the outside of the casing and the inside of the wellbore are perforated to provide fluid communication from the annulus to the collection chamber.

13. The method of claim 11 wherein the well has been plugged by filling at least a portion of the casing above the formation containing fluid with cement.

14. The method of claim 11 wherein the apparatus is a logging system capable of detecting fluid in the collection chamber through the tubing.

15. The method of claim 11 wherein the fluid comprises carbon dioxide.

16. The method of claim 11 wherein the apparatus comprises at least one of a pulsed neutron logging system, a neutron logging system, an acoustic logging system and resistivity logging system.

17. The method of claim 11 wherein the collection chamber contains a particulate material.

18. A method for detecting a fluid leak from a plugged well extending downwardly from a surface of the earth and penetrating a subterranean fluid-containing formation, the method comprising:

- a) forming a collection chamber across a cross sectional area of the plugged well above the fluid containing formation;
- b) positioning a cap member across an upper end of the collection chamber;
- c) sealingly positioning a tubing to extend from the surface to operatively engage the cap member; and,
- d) passing a fluid detecting apparatus through the tubing and into operative engagement with the cap member to detect fluid in the collection chamber.

19. The method of claim 18 wherein the well is a cased well.
20. The method of claim 18 wherein the collection chamber contains a particulate material.
21. The method of claim 18 wherein the fluid comprises carbon dioxide.
22. A method for detecting a fluid leak from a plugged well extending from a surface and penetrating a subterranean formation containing fluid, the well comprising a wellbore containing a casing extending through an impermeable zone and being cemented in the wellbore by cement positioned in an annulus between an outside of the casing and an inside of the wellbore, the method comprising:
  - a) forming a collection chamber in the annulus above the formation containing fluid; and,
  - b) passing a fluid detecting apparatus through the casing and at least partially through the collection chamber to detect fluid in the collection chamber.
23. The method of claim 22 wherein the fluid comprises carbon dioxide.
24. A method for detecting a fluid leak from a subterranean formation containing fluid by logging a collection chamber positioned in a plugged well above the subterranean formation.
25. The method of claim 24 wherein the fluid comprises carbon dioxide.



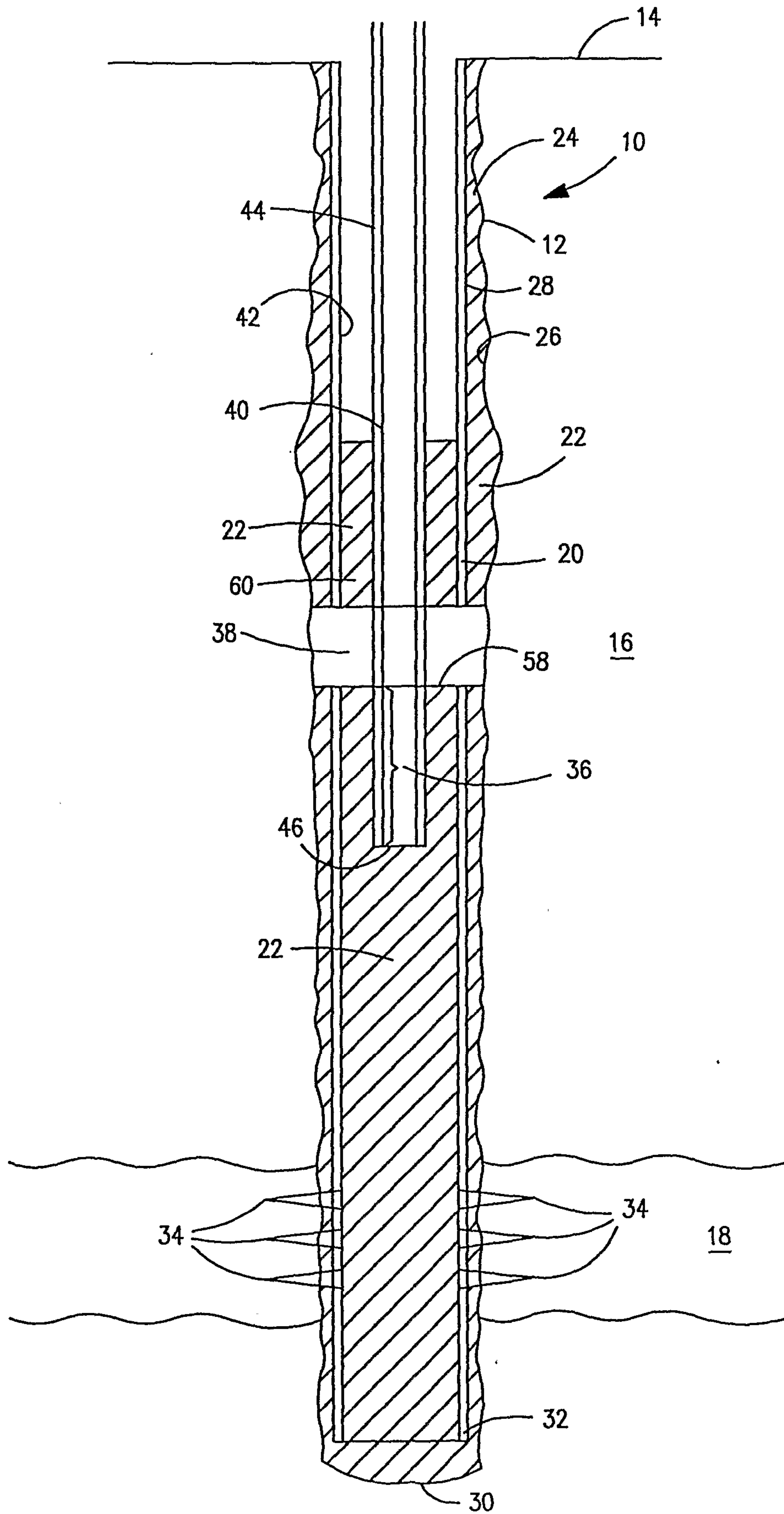
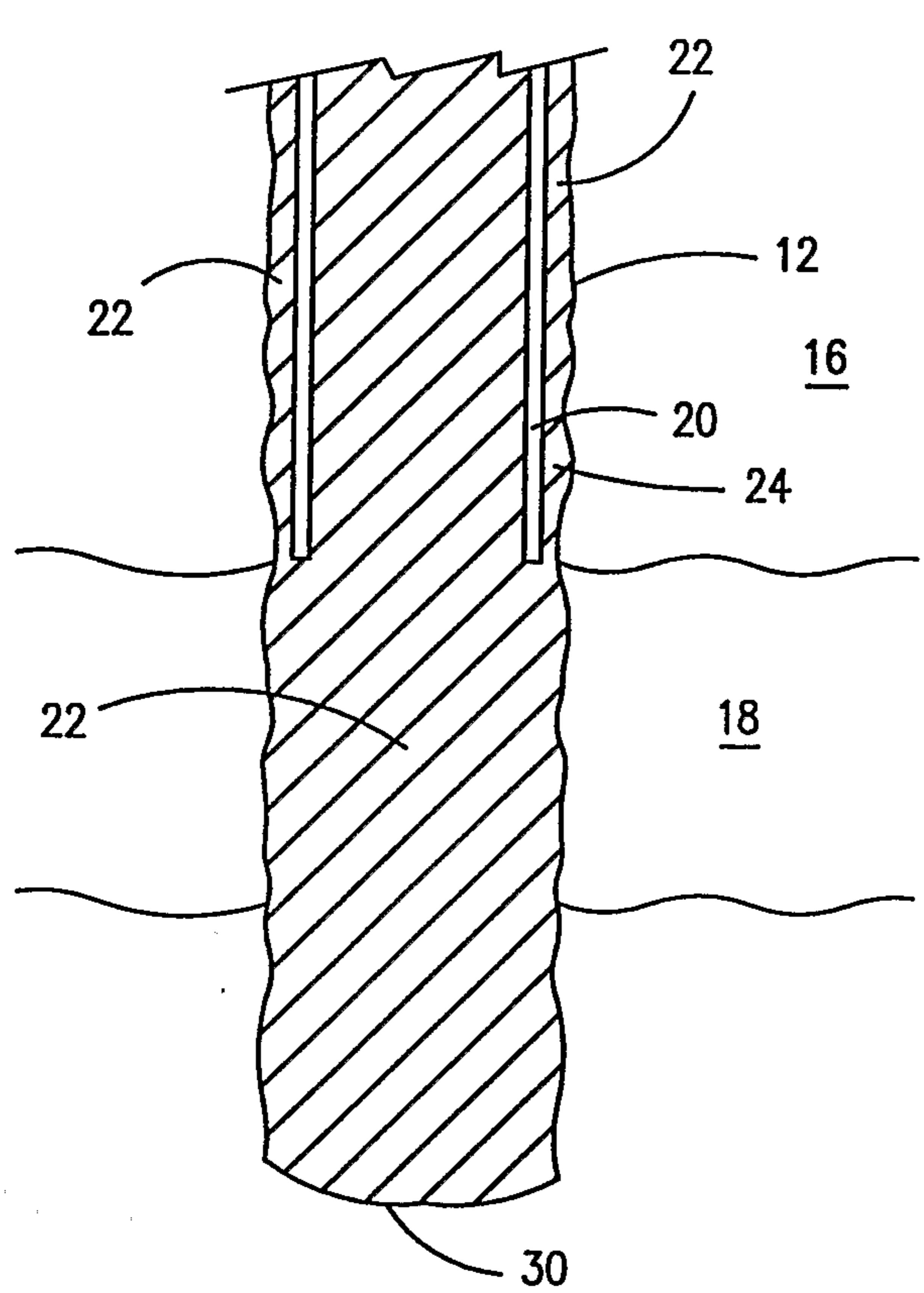
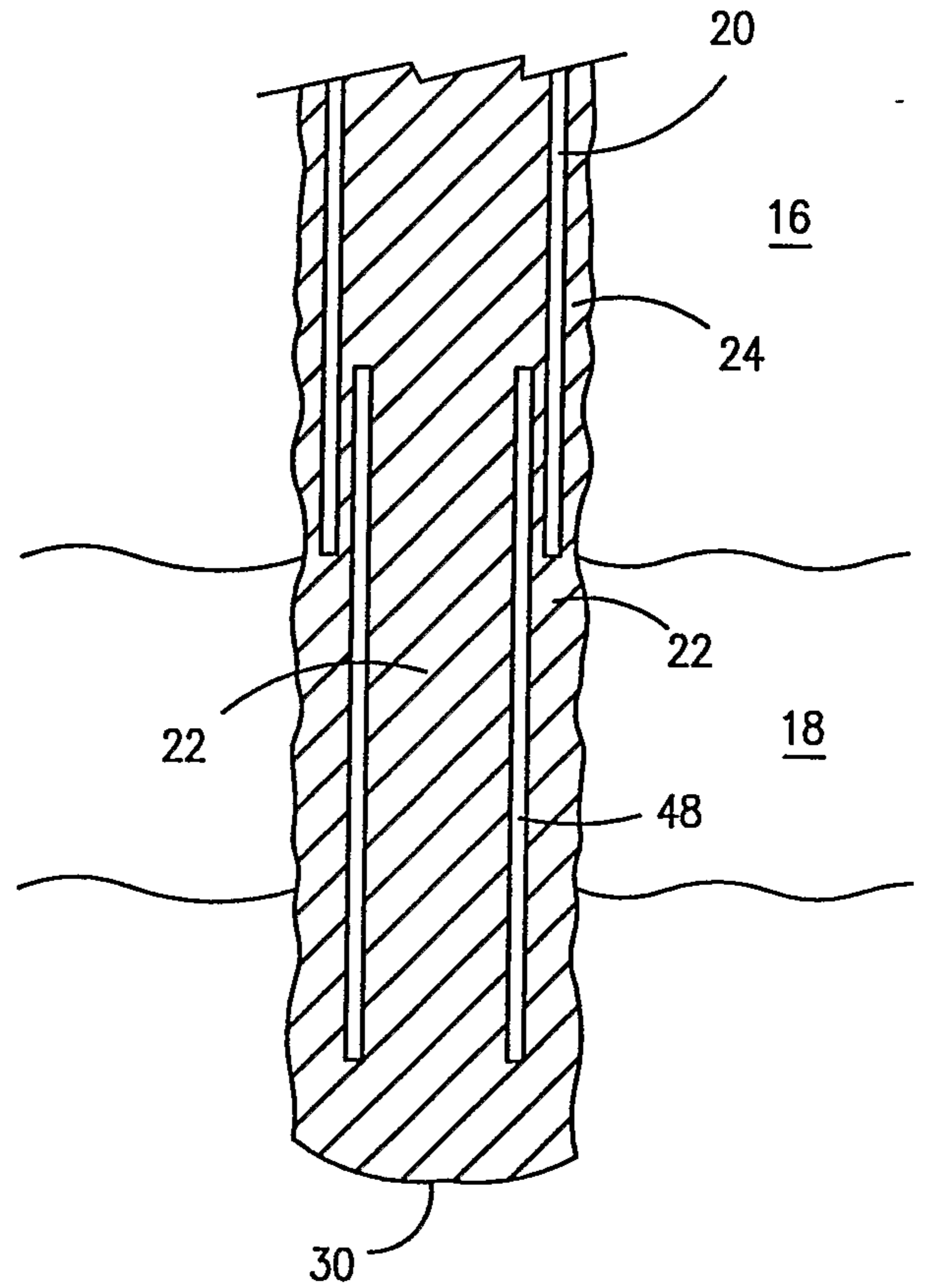


FIG. 1



**FIG. 2**  
PRIOR ART



**FIG. 3**  
PRIOR ART

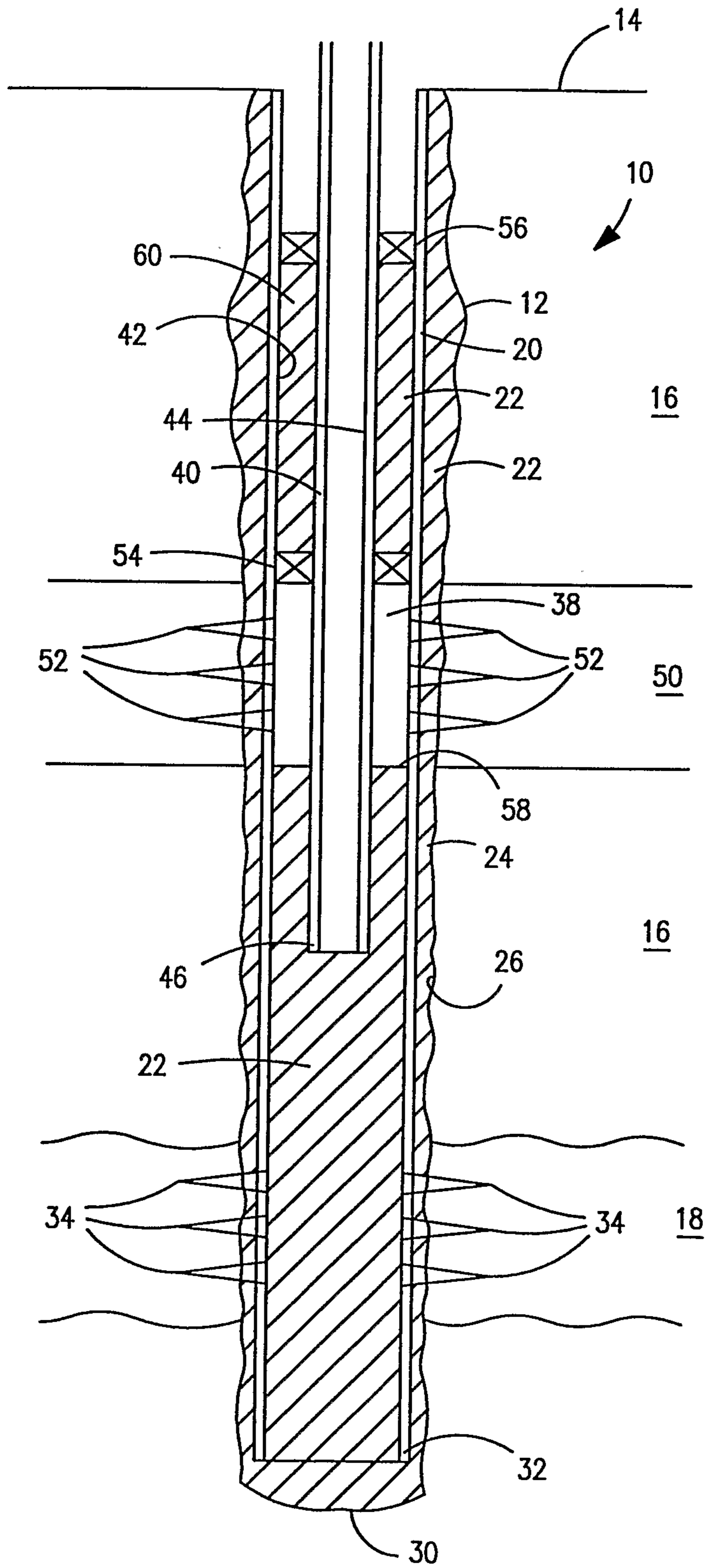
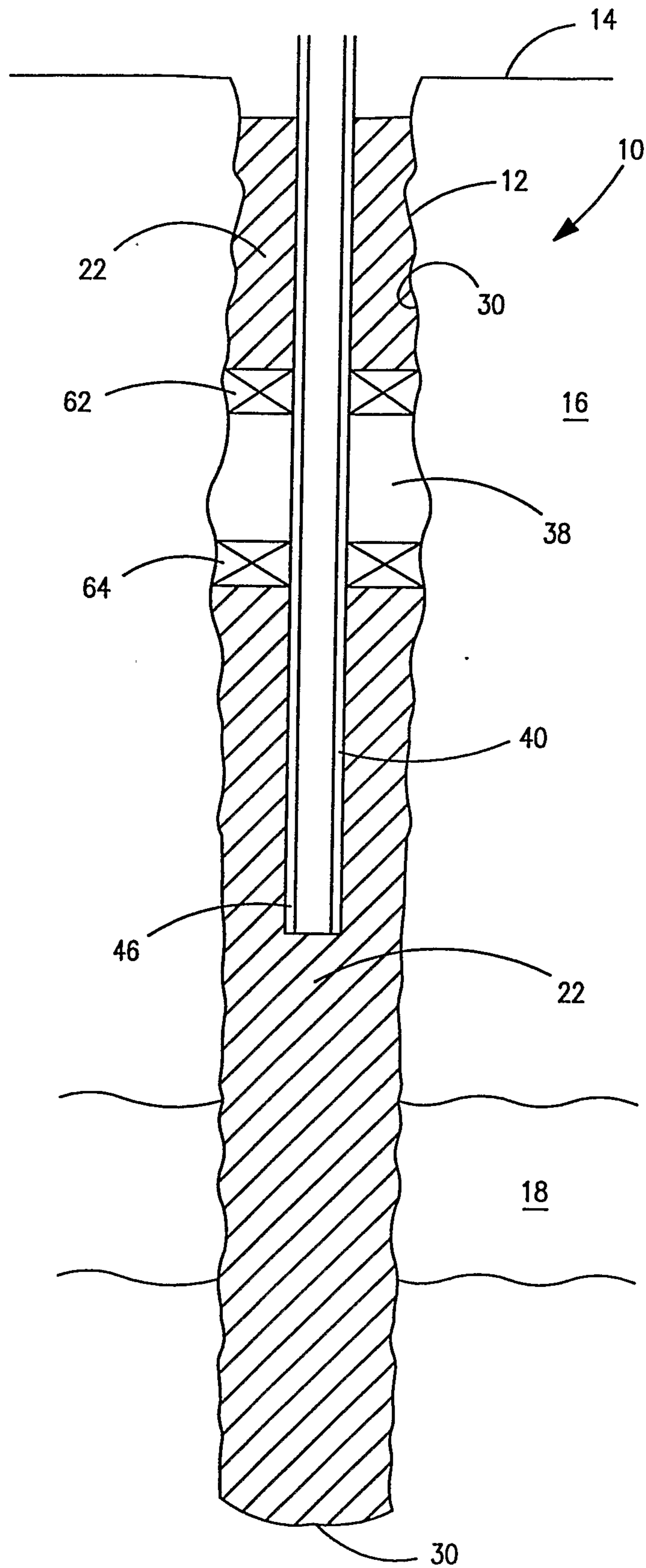
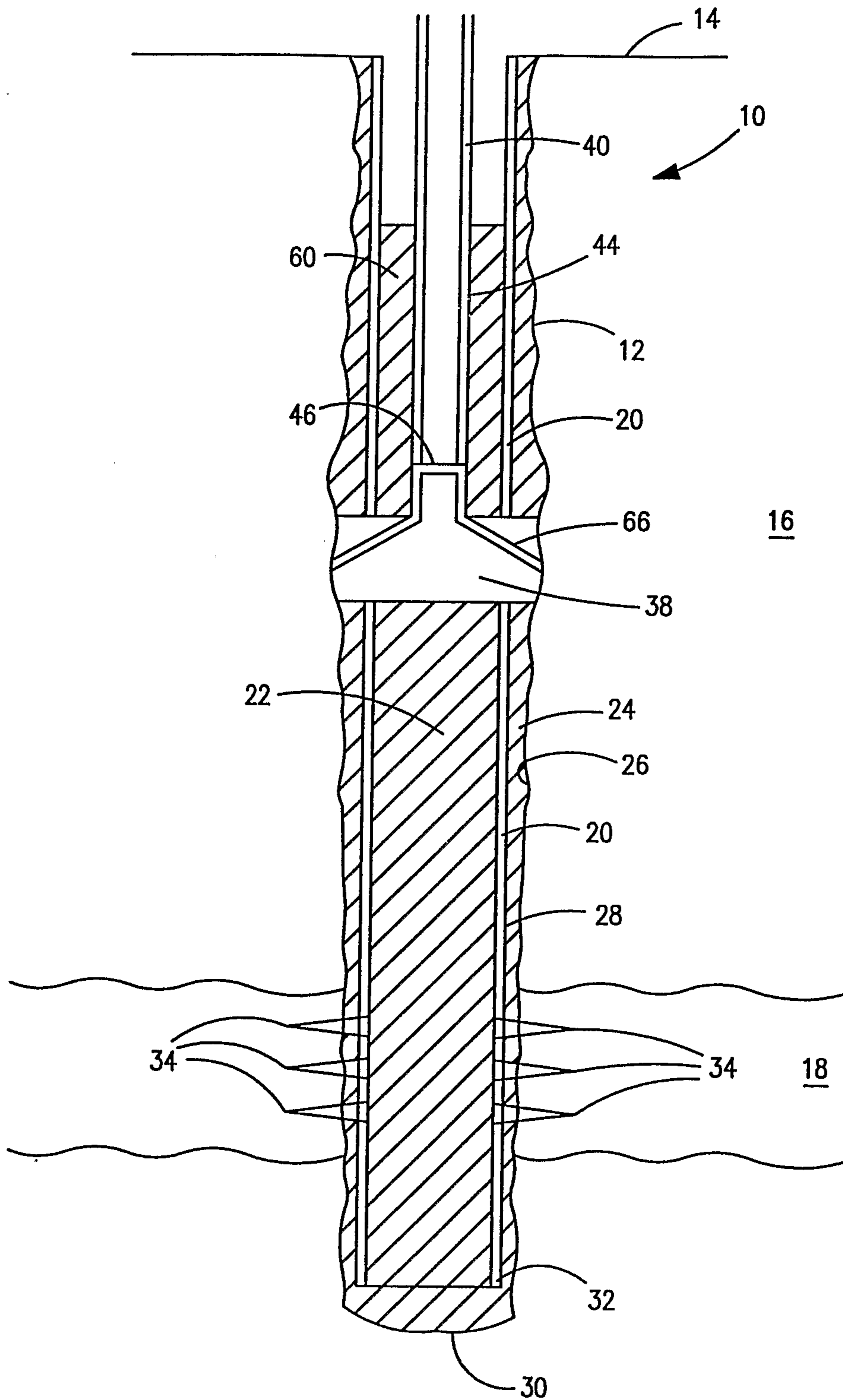


FIG. 4

**FIG. 5**



**FIG. 6**

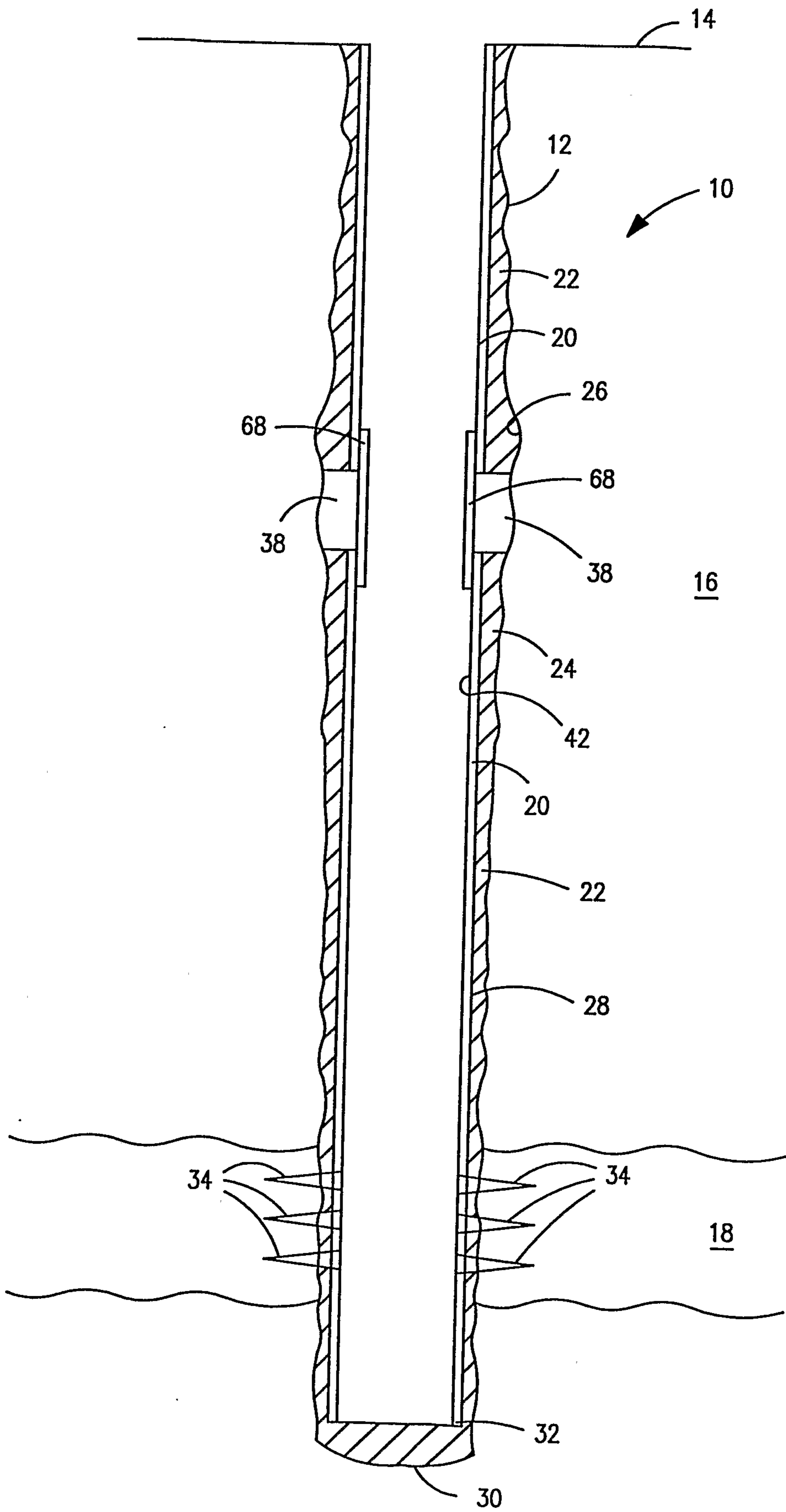


FIG. 7

