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(54) **Coiled tubing with an electrical cable for a down-hole pumping system and methods for manufacturing and installing such a system**

(57) A method for manufacturing electrical power cable within coil tubing (12) by integrating the installation of the electrical power cable (13) with the manufacture of the coil tubing (12). The present invention includes an electrical power cable (13) with sufficient thermal insulation to withstand the temperatures associated with the tubing manufacturing process. Following

installation of the cable assembly in the coil tubing (12), the coil tubing (12) may be transported to an application site, and coupled to equipment, such as a submersible pumping system. The submersible pumping system may then be deployed by extension of the coil tubing (12) and cable assembly.

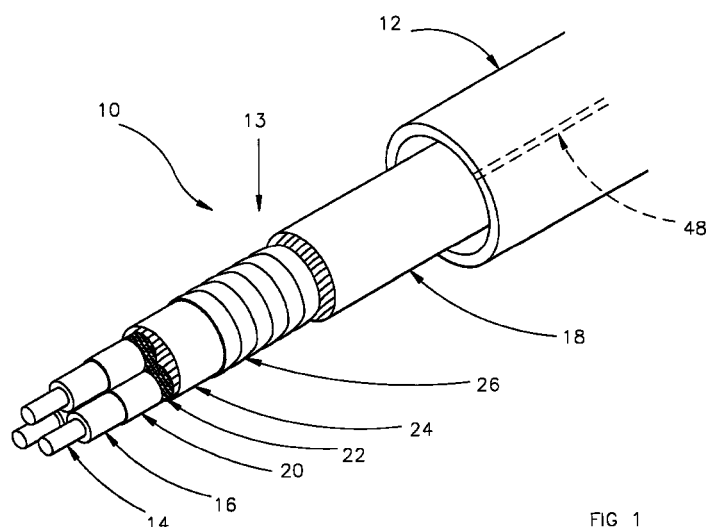


FIG 1

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Description

FIELD OF THE INVENTION

[0001] This invention relates generally to a system and method for installing electrical power cable into coil tubing used in deploying subterranean systems. More particularly, this invention relates to a method of integrating the installation of an electrical power cable within the coil tubing during the manufacturing process. The invention further relates to methods of deploying subterranean systems, such as electric submersible pumping systems, that utilize coil tubing containing an electrical power cable installed during the tubing manufacturing process.

BACKGROUND OF THE INVENTION

[0002] A number of applications exist wherein power or data signals must be supplied to remote sub-sea or subterranean locations, such as to drive, monitor or control underground equipment. For example, in the field of petroleum extraction and exploitation, it is commonplace to drill a wellbore. Minerals flow into the wellbore and are removed by pumping systems either situated at the earth's surface or submerged within the wellbore. In either case, it is often necessary to transmit electrical power or control signals to equipment situated in the wellbore to power or control operation of the downhole equipment.

[0003] Several methods have been employed for transmitting power and control signals to downhole equipment in wellbores. For example, various types of shielded cable are known and are currently available for transmitting significant levels of electrical power to submerged pumping systems of the type described above. The power cables may include multiple conductors, such as for three-phase operation, and are commonly shielded by a flexible, durable metallic casing or armor designed to reduce the risk of damage to the power conductors during deployment and use of the equipment. Control signals may be superimposed on power signals in certain applications, or may be transmitted via separate cables, radio telemetry, or other signal transmission techniques.

[0004] The submerged pumping systems often are deployed on tubing, and the power cable is attached alongside or through the center of the tubing. In an increasing number of applications, it is useful to place power cables within extended lengths of tubing extending between the earth's surface and a submerged pumping system, particularly in petroleum and other production wells. One particular type of tubing presently employed in such systems is coil tubing, which is available in extended lengths capable of being wound around a storage spool. The coil tubing and subterranean system are deployed into the well by unwinding the coil tubing from the storage spool. Lengths of tubing

may be spliced together, as required by the depth at which the submerged equipment is to be deployed. A difficulty arises, however, in the insertion of electrical power cables into the coil tubing. Presently, electrical power cable is installed in coil tubing by drawing the cable through extended lengths of tubing, often ten to twenty thousand feet long.

[0005] Significant disadvantages have been encountered in tensioning techniques, such as drawing, as the cable is drawn through the conduit, e.g. coil tubing. For example, high tension tensile forces are required to draw the cable into the tubing, owing to the weight of the cable and to frictional forces between the interior of the tubing and the exterior of the cable shielding. Such forces can result in damage to the cable during the installation process. Moreover, excessive tension in the cable can lead to stretching of the cable during installation. Residual strain resulting from such tension may then be stored along the cable, which remains unrelaxed prior to connection to the powered equipment. During subsequent operation, the residual strain can be relieved, leading to contraction of the cable and, in certain cases, interruption of electrical power between the submerged equipment and well-head equipment.

[0006] Several methods other than tensioning techniques have been used to install conductive cabling within coil tubing. Coil tubing has been manufactured around small wires using a long water cooled tube placed inside the coil tubing during the forming, welding, and annealing processes used to create the coil tubing. This method, however, was limited to small wires due to the limited clearance inside the water cooled tube. This technique does not work with electrical power cables, because these cables generally are too large to pass through the water cooled tube.

[0007] The cable injector is another manufacturing technique for installing electrical wiring. This technique uses high pressure to push the electrical wiring through the coil tubing. However, the cable injector method generally cannot be used for electric submersible pumping system power cables, because these cables are too stiff and heavy.

[0008] Finally, small pyrotenax cables which are stainless steel clad and mineral insulated have been installed in coil tubing during the manufacture of the coil tubing without the use of the cooling tube. However, these mineral insulated cables, which utilize a special high temperature mineral insulation, are extremely expensive, and not practical for use in delivering power to an electric submersible pumping system.

[0009] There is a need, therefore, for an improved technique for installing electrical power cable into coil tubing. In particular, there is a need for a technique allowing placement of an electrical power cable within coil tubing and the like over considerable lengths while addressing or avoiding the drawbacks of prior art techniques, e.g. damage to the cable or conduit and storage

of residual strain within the cable.

SUMMARY OF THE INVENTION

[0010] The present invention provides a method for manufacturing coil tubing containing an electrical power cable to respond to these existing needs. The method of the present invention integrates the installation of the electrical power cable into the coil tubing during the manufacturing process of the tubing. The method of manufacturing includes forming a strip of flat metal into tubing creating a linear seam along the tubing's length. The method further includes placing an electrical power cable along the metal strip during the forming process so that the electrical power cable becomes enclosed within the tubing. The method further includes welding the linear seam so that the tubing is fully enclosed and contains the electrical power cable. Additionally, the method may further include annealing the weld and a full body anneal of the coil tubing.

[0011] According to another aspect of the invention, a coil tubing system is provided for use in deploying an electric submersible pumping system. The coil tubing system includes an electrical power cable having a plurality of electrical conductors. The coil tubing system is further comprised of metal coil tubing which is wrapped around the electrical power cable. Additionally, the system includes at least one layer of thermal insulation material between the plurality of conductors and the coil tubing to protect the electrical conductors during the tubing manufacturing process.

[0012] According to another aspect of the invention, a method is provided for deploying subterranean systems requiring electrical power. This method includes forming coil tubing from a strip of metal. This method further includes integrating an electrical power cable within the coil tubing during the formation of the coil tubing. The method also includes connecting the subterranean system to the coil tubing and the electrical power cable. The method further includes deploying the subterranean device into a subterranean environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The invention will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

Figure 1 is a perspective view of coil tubing containing an electrical power cable, according to a preferred embodiment of the present invention.

Figure 2 is a schematic representation of a manufacturing process for coil tubing containing an electrical power cable, according to a preferred embodiment of the present invention; and

Figure 3 is a front elevational view of a subterra-

nean system for deploying an electrically powered device utilizing coil tubing containing an electrical power cable, according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] Referring generally to Figure 1, a coil tubing and electrical power cable system 10 is illustrated according to a preferred embodiment of the present invention. System 10 may be comprised of a variety of components, however, it typically includes at least a coil tubing 12 and an electric submersible pumping system (ESP) power cable 13. ESP power cable 13 includes a plurality of electrical conductors 14, e.g. three conductors, an electrical insulation layer 16 disposed about each conductor 14, and a thermal insulating barrier 18 disposed about the plurality of conductors 14. Thermal insulation layer 18 protects the conductors 14 and other materials within power cable 13 from exceeding their temperature limits during formation of system 10, including welding and subsequent annealing of coil tubing 12. Layer 18 may comprise one or more of fiberglass cloth or tape, aramid fiber cloth or tape, polyimide tape, PEEK, epoxy or EPDM.

[0015] As illustrated, ESP power cable 13 typically includes other components. For example, a tape 20 may be wrapped about each insulation layer 16 to act as additional thermal protection for the underlying electrical conductors 14 and electrical insulation 16. A braid 22 also may be disposed about each tape layer 20 to provide added support. An elastomeric jacket 24 may be used to enclose conductors 14 and to provide additional sturdiness and protection for the underlying electrical conductors 14. Additionally, an armor layer 26 preferably is disposed over jacket 24 to provide even stronger additional protection for the underlying electrical conductors 14. Preferably, armor layer 26 is made of a metal material. The insulating barrier 18 is disposed over or radially outward of armor layer 26 to provide added insulation from heat generated during manufacturing of system 10.

[0016] Referring generally to Figure 2, a schematic view of a manufacturing process for system 10 is illustrated according to a preferred embodiment of the present invention. The manufacturing process permits the integration of ESP power cable 13 into coil tubing 12 during the formation of coil tubing 12.

[0017] An exemplary manufacturing process for the combination of coil tubing 12 and electrical power cable 13 may comprise a variety of steps. However, the manufacturing process typically includes a tube forming mill 40 which forms tubing from strip metal 42 stored on a strip metal roll 44. The tube forming mill 40 is comprised of a series of rolls 46. A first series of rolls 46A initially are encountered by the strip metal 42 and begin to bend the edges of the strip upward, gradually forming a "U"

shape. Additional rolls 46B and 46C bend the metal strip around a longitudinal axis until the tubing is almost completely enclosed except for a longitudinal seam (see sealed longitudinal seam 48 in Figure 1).

[0018] The electrical power cable 13 is installed within the tubing 12 in the tube forming mill 40 during the formation process from strip metal to tubing. ESP power cable 13 may be stored on electrical power cable accumulator 50 and fed to forming mill 40 as needed. The installation of the electrical power cable 13 may occur at any stage of the tube forming process before the tubing has become too enclosed to receive ESP power cable 13. Electrical power cable 13 is fed along strip metal 42 as it is bent about the longitudinal axis. For example, after the strip metal has been rolled into a "U" shape the cable may be placed against the U-shaped metal strip, e.g. just prior to roll 46B. The additional series of rolls then bend the U-shaped metal around the ESP power cable 13, thus installing the electrical power cable within the tubing. Once the electrical power cable 13 has been enclosed

[0019] within the coil tubing 12 the tubing is ready to be completely enclosed by seam welding along the longitudinal seam at a seam welding station 52. One possible method of welding the seam is a high-frequency induction method. In the high-frequency induction method, heat for welding the edges of the seam together is generated by resistance to the flow of an induced electrical current produced by an encircling coil and concentrated at the edges by an internal ferrite or called an impeder. The heat is confined to a narrow band along the edges of the formed strip and reaches temperatures of 2200 to 2600 °F. A special set of insulated rolls squeeze the edges of the tubing together along the seam, while the tubing edges are at fusion temperature, to produce the seam weld.

[0020] After seam welding station 52 the tubing 12 is ready to be seam annealed at seam annealing station 54. The tubing is exposed to a slightly lower temperature than seam welding, approximately 1650°F. After the annealing station, the tubing is then cooled in a cooling bath at a cooling bath station 56.

[0021] There are several more steps that may be desirable to complete the manufacturing process. Additional sets of rolls 58 can be used to accurately size the tubing to its final dimensions. The combined tubing 12 and ESP power cable 13 is then subjected to a full body annealing at body annealing station 60 which heats the tubing to approximately 1,100 to 1,400 °F for approximately one minute. This is the period of greatest threat to the underlying electrical conductors 14, because there is more than just a brief localized exposure to high temperatures at the seam, but rather a longer exposure around the circumference of the tubing 12. The conductors can be exposed to a temperature of greater than 900 °F for just under one minute if not uniquely insulated as described with reference to ESP power cable 13. If there is an insufficient thermal barrier between the

electrical conductors 14 and the heat, the conductors can be damaged or destroyed. Insulating barrier 18 in combination with jacket 24, insulation layer 16 and the other layers, provides thermal insulation between coil tubing 12 and conductors 14 to protect the integrity of conductors 14 during the full body annealing stage.

[0022] Subsequently, the tubing is sent through another cooling bath at a cooling bath station 62 where it is slow cooled before it is ultimately coiled onto a storage reel 64, as a completed product, i.e. system 10.

[0023] The manufacturing process for the integrated coil tubing and electrical power cable of system 10 may include additional steps. For example, the seam welding process typically produces a small amount of weld flash on both the inside and the outside of the tube. The weld flash on the outside diameter of the tubing may be removed by an external weld flash remover at station 66 preferably disposed between seam welding station 52 and seam annealing station 54. The flash removal is accomplished by a carbide cutting tool contoured to the diameter of the tube being produced. The weld flash on the inside diameter may be controlled in height or removed with a contoured tool inside the tubing. The weld seam is immediately reheated by a narrow induction head to recrystallize the weld's heat affected zone to match the grain structure of the base metal.

[0024] Additionally, the tubing may be subjected to non-destructive eddy current testing at test station 68 to ensure weld and tubing quality. Station 68 preferably is disposed between rolls 58 and full body annealing station 60.

[0025] Referring generally to Figure 3, a front elevational view of a system and method of deploying a subterranean system 70, e.g. an electric submersible pumping system, is illustrated according to a preferred embodiment of the present invention. Deployment of the ESP is accomplished with the combined coil tubing 12 and ESP power cable 13 of the integrated system 10.

[0026] The method comprises rolling system 10, integrated as described above, onto a storage reel 72. The storage reel 72 is installed as part of a deployment system 74 which is capable of positioning the desired subterranean device in the wellbore by reeling the coil tubing on or off of the storage reel. The deployment system also includes an electrical power source 76 that is connected to one end of the ESP power cable disposed within the coil tubing 12 to provide electrical power to the subterranean system 70. The deployment system 74 may be mounted on a truck or on a skid for deployment offshore. The deployment system also includes a guide 78 to direct the coil tubing into a wellbore 80.

[0027] Prior to deployment into wellbore 80 the subterranean system 70 is connected electrically to the electrical power cable 13 and physically to the coil tubing 12, as known to those of ordinary skill in the art. The subterranean system 70 may then be lowered into the wellbore by the deployment system 74. An operator can

position the subterranean system 70 as required in the wellbore by operation of the deployment system 74. Additionally, the operator can control the electrical power to the subterranean system 70 from the electrical power source 76.

[0028] Alternatively, integrated system 10 can be utilized in applications where it is submerged in water. For example, the system can be laid along the ocean floor or a lake bed to provide power to production equipment.

[0029] It will be understood that the foregoing description is of preferred embodiments of this invention, and that the invention is not limited to the specific forms shown. For example, a variety of coil tubing sizes and materials may be utilized, the order of the manufacturing process steps may be altered or steps may be added or deleted depending on the particular application, and various power cables/constructions can be utilized. For example, one or more layers of polyimide insulating material can be combined with a secondary layer of EPDM. Also, a thicker layer of elastomeric jacket can be used to provide a sacrificial layer of material, e.g. a standard jacket having a thickness of approximately 0.060 inches can be replaced with a jacket of approximately 0.20 inches to provide greater thermal protection. These and other modifications may be made in the design and arrangement of the elements without departing from the scope of the invention as expressed in the appended claims.

Claims

1. A method of manufacturing coil tubing containing an electrical power cable, comprising:
 - forming a strip (42) of metal into a coil tubing (12) having a linear seam;
 - placing an ESP power cable (13) along the strip (42) of metal during forming such that the electrical power cable (13) becomes enclosed within the coil tubing (12); and
 - welding the linear seam to enclose the ESP power cable (13).
2. The method as recited in Claim 1, further comprising annealing the coil tubing (12).
3. The method as recited in Claim 2, further comprising wrapping the coil tubing (12) onto a reel (64).
4. The method as recited in Claim 2, further comprising forming the ESP power cable (13) with a plurality of electrical conductors (14) and placing at least one layer of thermal insulation (16, 18, 20) between the ESP power cable (13) and the coil tubing (12) sufficient to protect the conductors (14) during the

welding and annealing steps.

5. The method as recited in Claim 4, wherein placing at least one layer includes placing a layer (18) of EPDM.
6. The method as recited in Claim 4, wherein placing at least one layer includes placing a layer (18) of arimid fibre cloth tape.
7. The method as recited in Claim 4, wherein placing at least one layer includes placing a layer (18) of fibreglass material.
8. The method as recited in Claim 4, wherein placing at least one layer includes placing a layer (18) of PEEK.
9. The method as recited in Claim 4, wherein placing at least one layer includes placing a layer (18) of polyimide tape.
10. A coil tubing system for use in deploying an electric submersible pumping system, comprising:
 - an electrical power cable (13) having a plurality of electrical conductors (14);
 - a coil tubing (12) wrapped about the electrical power cable (13); and
 - at least one layer (16, 18, 20) of thermal insulation disposed between the plurality of electrical conductors (14) and the coil tubing (12) and having sufficient thickness to protect the electrical conductors (14) during annealing of the metal coil tubing (12).
11. The coil tubing system as recited in Claim 10, wherein the coil tubing (12) comprises a metal coil tubing (12).
12. The coil tubing system as recited in Claim 10, wherein the thermal insulation comprises EPDM.
13. The coil tubing system as recited in Claim 10, wherein the thermal insulation comprises a PEEK layer.
14. The coil tubing system as recited in Claim 10, wherein the thermal insulation comprises an insulative tape.
15. The coil tubing system as recited in Claim 10, wherein the electrical power cable (13) includes a layer (26) of armour and the at least one layer (18) of thermal insulation is disposed radially outward from the layer (26) of armour.

16. A method of deploying a downhole subterranean system requiring power, comprising:

forming a coil tubing (12) from a strip (42) of metal;

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integrating an electrical power cable (13) within the coil tubing during forming;

connecting the downhole, subterranean system to the coil tubing (12) and the electrical power cable (13); and

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deploying the downhole, subterranean system into a subterranean environment.

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17. The method as recited in Claim 16, wherein forming includes bending the strip (42) of metal into a generally tubular shape to form a longitudinal seam.

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18. The method as recited in Claim 17, further comprising welding the strip (42) of metal along the seam.

19. The method as recited in Claim 18, further comprising annealing the tubing.

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20. The method as recited in Claim 19, wherein annealing includes annealing the tubing for approximately 1 minute and at a temperature of approximately 1,100 to 1,400°F.

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21. The method as recited in Claim 16, wherein deploying includes deploying an electric submersible pumping system in a wellbore.

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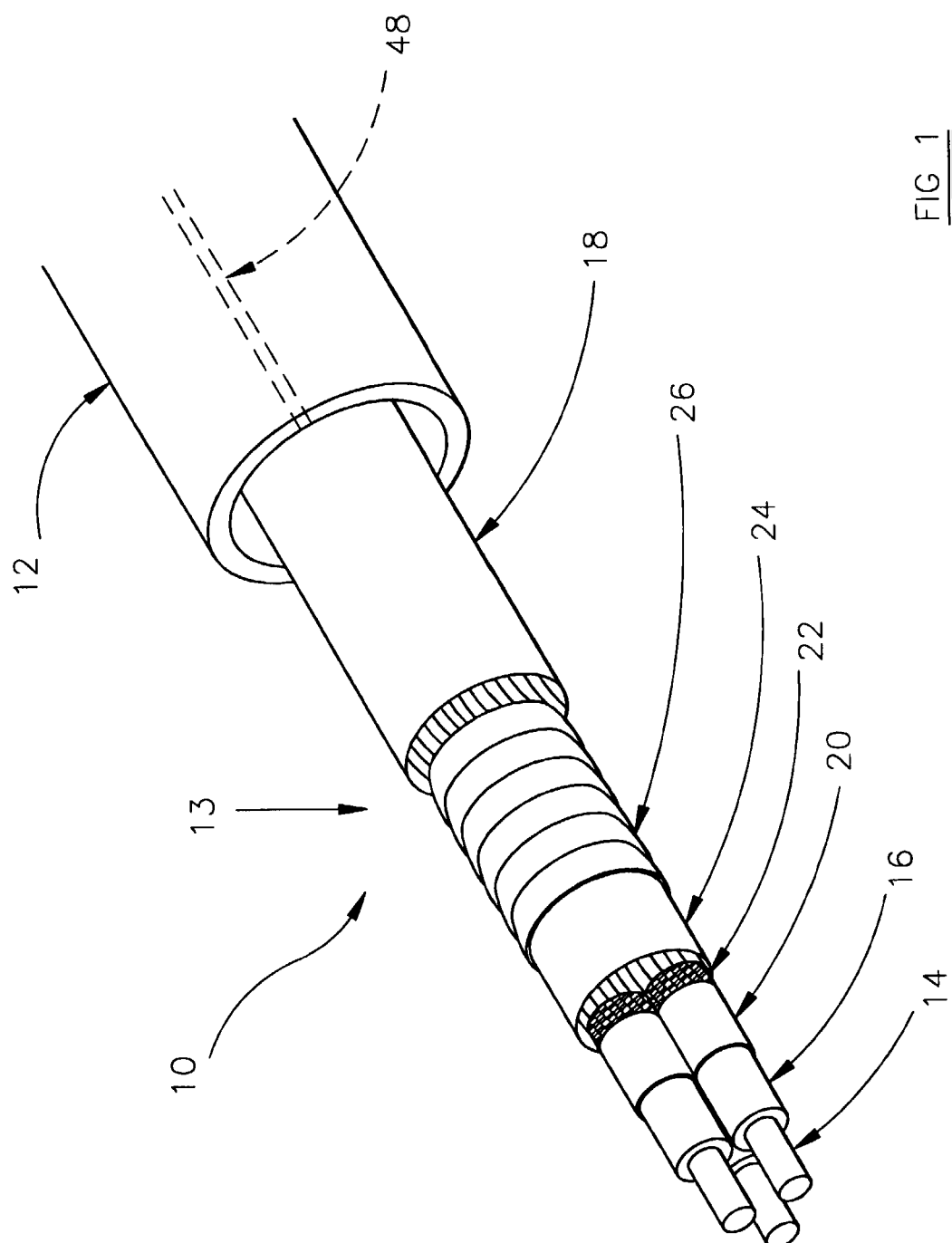


FIG 1

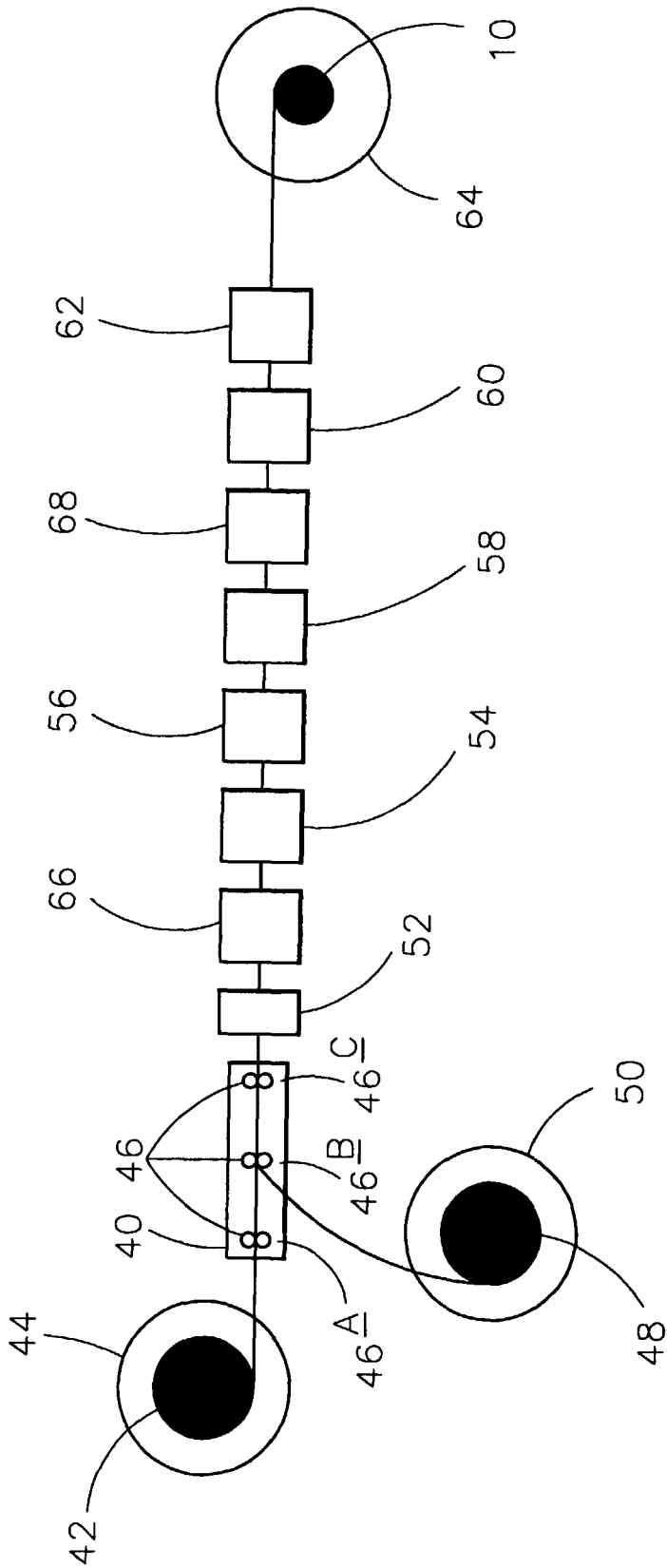


FIG 2

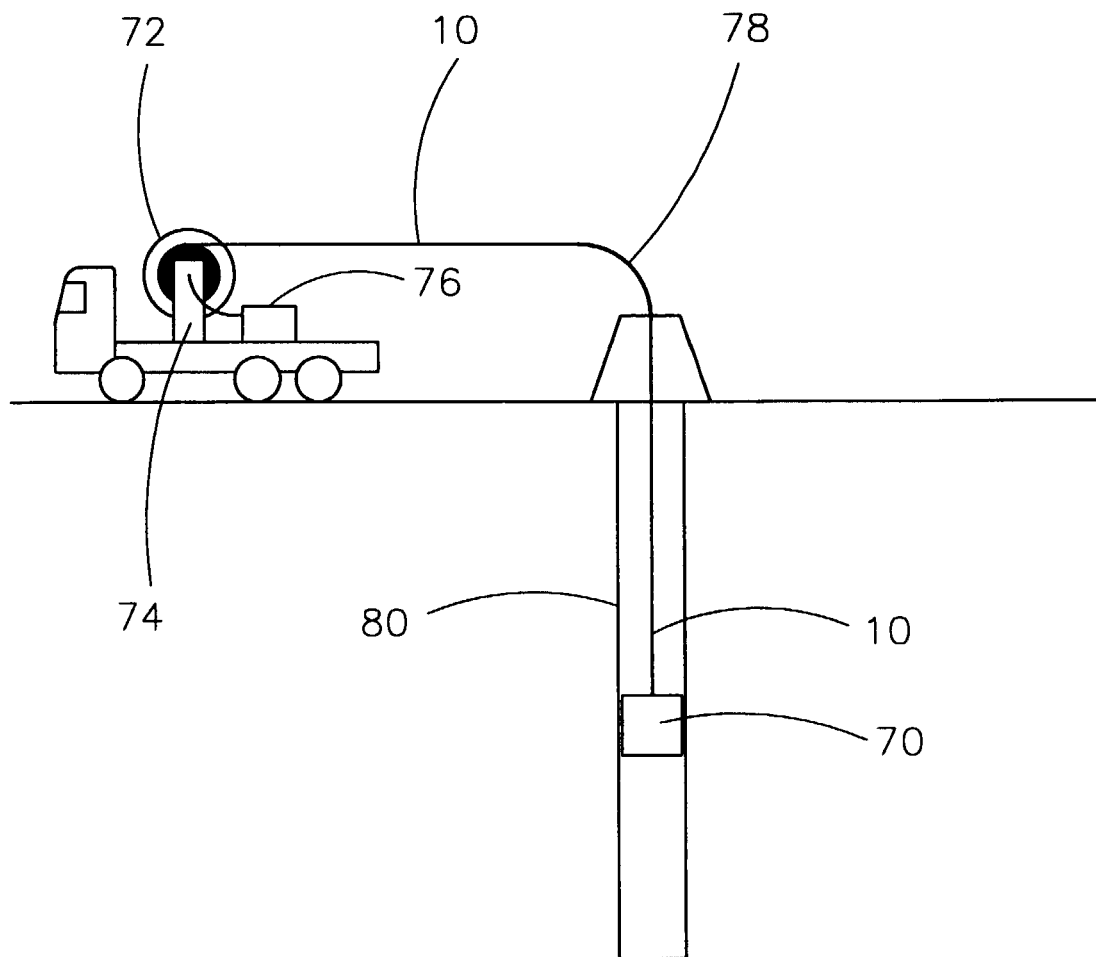


FIG 3