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(54) **Methods of completing and producing a subterranean well and associated apparatus**

Verfahren zum Komplettieren und Produzieren einer Bohrung und zugehörige Vorrichtung

Methode et dispositif pour achever et faire produire un puits

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Description

[0001] The present invention relates generally to operations performed in subterranean wells and, in an embodiment described herein, more particularly provides apparatus and methods for completing and producing a subterranean well having multiple wellbores.

[0002] It is well known in the art of drilling subterranean wells to form a parent bore into the earth and then to form one or more bores extending laterally therefrom. Generally, the parent bore is first cased and cemented, and then a tool known as a whipstock is positioned in the parent bore casing. The whipstock is specially configured to deflect milling bits, drill bits, and/or other cutting tools in a desired direction for forming a lateral bore. A mill is typically lowered into the parent bore suspended from drill pipe and is radially outwardly deflected by the whipstock to mill a window in the parent bore casing and cement. Directional drilling techniques may then be employed to direct further drilling of the lateral bore outwardly from the window as desired.

[0003] The lateral bore may then be cased by inserting a tubular liner from the parent bore, through the window previously cut in the parent bore casing and cement, and into the lateral bore. In a typical lateral bore casing operation, the liner extends somewhat upwardly into the parent bore casing and through the window when the casing operation is finished. In this way, an overlap is achieved wherein the lateral bore liner is received in the parent bore casing above the window. In another type of lateral bore casing operation, the liner is completely received within the lateral bore and does not extend into the parent bore when the casing operation is finished.

[0004] The lateral bore liner is then cemented in place by forcing cement between the liner and the lateral bore. Where the liner extends into the parent bore, the cement is typically also forced between the liner and the window, and between the liner and the parent bore casing where they overlap. In this case, the cement provides a seal between the liner, the parent bore casing, the window, and the lateral bore. Where the liner does not extend into the parent bore, the cement provides a seal between the liner and the lateral bore.

[0005] Further operations may then be performed in completing and/or producing the well. For example, one or more tubing strings may be installed in the well to conduct fluids from formations intersected by the parent and lateral bores to the earth's surface, or to inject fluid into one or more of the formations. Unfortunately, these completion and/or production operations do not provide means whereby fluid flow through the tubing strings may be regulated in relatively close proximity to the formations and controlled from the earth's surface, in order to regulate rates of fluid flow from or into each of the formations, regulate the commingled proportions of fluids produced or injected into each of the formations, control rates of production or injection to comply with regulations affecting such matters, etc.

[0006] For example, a flow choke, inline orifice or other flow regulating device installed at the earth's surface is capable of influencing the rate of fluid flow through a single tubing string. However, when that tubing string conducts fluid produced from multiple formations or multiple intervals, the flow choke or inline orifice is not capable of regulating the proportional rate of fluid flow from each formation or interval. Of course, a separate flow choke or inline orifice may be provided for each formation or interval, but that would require a separate tubing string extending to the earth's surface for each formation or interval, which would be expensive and often impossible to achieve. Additionally, it is well known that wellbore storage effects make it much more desirable to regulate fluid flows in close proximity to the formations or intervals, rather than at the earth's surface.

[0007] As another example, flow regulating devices may be installed in the well, but past methods of accomplishing this have proved to be unsatisfactory. Most such flow regulating devices require intervention into the well to vary the rate of fluid flow therethrough, such as by shifting a sleeve using a shifting tool conveyed by wireline, slickline, tubing, etc. Others of such flow regulating devices obstruct the inner diameter of the tubing string in which they are installed.

[0008] From the foregoing, it can be seen that it would be quite desirable to provide a method of completing and/or producing a well which does not rely on flow regulating devices installed at the earth's surface, and which does not require intervention into the well to vary rates of fluid flow into or out of various formations or intervals, but which permits accurate and convenient regulation of fluid flow into or out of formations or intervals intersected by the well. It is accordingly an object of the present invention to provide such a method and associated apparatus.

[0009] In carrying out the principles of the present invention, in accordance with an embodiment thereof, a method is provided which permits a rate of fluid flow into or out of each formation intersected by a well to be regulated from the earth's surface. Furthermore, apparatus for facilitating performance of the method is also provided.

[0010] In broad terms, a method provided by the present invention results in a flow regulating device being installed within the well in relatively close proximity to each formation or interval intersected by the well for which it is desired to regulate the flow of fluids. The regulating devices may be remotely controllable from the earth's surface and may not require intervention into the well to vary rates of fluid flow therethrough.

[0011] In an embodiment of the invention described below, multiple tubing strings are installed in the well, with one of the tubing strings extending into a lower parent wellbore, and another of the tubing strings extending into a lateral wellbore. A flow regulating device is interconnected in the tubing string extending into the lateral

wellbore, and another flow regulating device is interconnected in yet another tubing string extending to the earth's surface. Fluid flow through the tubing string extending into the lower parent wellbore is directed to an annulus disposed radially between the upper parent wellbore casing and the tubing string extending to the earth's surface and axially between two sealing devices. The flow regulating devices may be remotely controllable.

[0012] In another embodiment of the present invention described below, apparatus is provided which interconnects the three tubing strings referred to above and eliminates the need for isolating the annulus between the two sealing devices. The apparatus includes a chamber into, or from which, fluid from one of the tubing strings is flowed. One of the flow regulating devices is also disposed within the chamber to regulate flow of that fluid into, or from, the tubing string extending to the earth's surface.

[0013] In yet another embodiment of the present invention described below, each tubing string extending into a wellbore intersecting a formation or interval into, or from which, fluid flow is to be regulated is provided with a flow regulating device interconnected therein. In this way, the rate of flow of fluid into or from each formation or interval may be independently controlled. The fluid flows may or may not be directed through separate tubing strings extending to the earth's surface, or commingled in one or more such tubing strings. Each flow regulating device may be remotely controllable.

[0014] In one aspect of the present invention, a releasable deflection device is provided which enables a tubing string to be deflected off of a deflection surface positioned at an intersection of a parent and a lateral wellbore, to thereby direct the tubing string into the lateral wellbore. In one embodiment described herein, the deflection device engages a tubular structure within the lateral wellbore and releases a relatively large diameter outer housing for displacement relative to the remainder of the tubing string.

[0015] According to one aspect of the invention there is provided a method of completing a subterranean well, the method comprising the steps of: interconnecting a first flow regulating device to first and second tubular strings; providing fluid communication between the first regulating device and a fluid chamber; and interconnecting a third tubular string to the fluid chamber.

[0016] The method preferably comprises the step of regulating fluid flow between the first tubular string and the third tubular string through the first regulating device. The regulating step is preferably remotely controlled.

[0017] The method preferably further comprises the step of regulating fluid flow through the second tubular string with a second flow regulating device interconnected to the second tubular string.

[0018] The method preferably further comprises the steps of sealingly engaging the second tubular string within a first wellbore portion of the well, and sealingly engaging the third tubular string within a second wellbore portion of the well, the second wellbore portion intersecting the first wellbore portion.

[0019] The step of providing fluid communication between the first regulating device and the fluid chamber preferably comprises enclosing the chamber and the first regulating device within a housing.

[0020] According to another aspect of the invention there is provided a method of completing a subterranean well having first, second and third wellbore portions, the third wellbore portion extending to the earth's surface, and the first, second and third wellbore portions intersecting, the method comprising the steps of: sealingly engaging a first tubular string including a first remotely controllable flow regulating device within the first wellbore portion; sealingly engaging a second tubular string within the second wellbore portion; and interconnecting the first and second tubular strings to a third tubular string including a second remotely controllable flow regulating device, the flow regulating device regulating fluid flow between the third tubular string and a fluid chamber in fluid communication with the second tubular string.

[0021] The first and second regulating devices are preferably remotely controllable via at least one line interconnected thereto.

[0022] The method preferably further comprises the step of operating the first regulating device to regulate fluid flow between the third tubular string and a formation intersected by the first wellbore portion.

[0023] The method preferably further comprises the step of operating the second regulating device to regulate fluid flow between the third tubular string and a first formation intersected by the second wellbore portion. Preferably, the method further comprises the step of commingling in the third tubular string fluid produced from the first formation with fluid produced from a second formation intersected by the first wellbore portion. The flow of the fluid produced from the second formation is preferably regulated by the first regulating device.

[0024] In an embodiment, the method further comprises the steps of: flowing a fluid between the third tubular string and a formation intersected by the second wellbore portion; regulating flow of the fluid with the second regulating device; and flowing the fluid into a housing enclosing the chamber, the housing being interconnected to the first, second and third tubular strings.

[0025] According to another aspect of the invention there is provided apparatus for completing a subterranean well, the apparatus comprising: first, second and third tubular strings; a housing interconnecting the first, second and third tubular strings, the housing including a fluid chamber in fluid communication with the third tubular string; a first flow regulating device, the first regulating device regulating fluid flow between the second tubular string and the first tubular string; and a second flow regulating device, the second regulating device

regulating fluid flow between the chamber and the first tubular string.

[0026] The first and second regulating devices are preferably remotely controllable.

[0027] In an embodiment, the apparatus further comprises a releasable deflection device operatively engaged with one of the second and third tubular strings.

[0028] The second tubular string preferably further includes a first sealing device interconnected between the first regulating device and the housing, and the third tubular string preferably further includes a second sealing device.

[0029] Preferably, at least one of the first and second sealing devices is remotely settable.

[0030] Reference is now made to the accompanying drawings, in which:

FIG. 1 is a schematic cross-sectional view through a subterranean well in which initial steps of a first embodiment of a method according to the present invention have been performed;

FIG. 2 is a schematic elevational view of a first embodiment of an apparatus according to the present invention;

FIG. 3 is a schematic cross-sectional view of the well of FIG. 1, in which additional steps of the first method have been performed, the first apparatus having been installed in the well;

FIGS. 4A-4B are a schematic cross-sectional views of another well in which a second embodiment of a method and a second embodiment of an apparatus according to the present invention have been utilized;

FIG. 5 is a schematic cross-sectional view of still another well in which a third embodiment of a method and a third embodiment of an apparatus according to the present invention have been utilized;

FIGS. 6A-6B are cross-sectional views of successive axial sections of a releasable deflection device according to the present invention, the device being shown in a configuration in which it is run into a wellbore;

FIGS. 7A-7D are cross-sectional views of successive axial sections of the releasable deflection device of FIGS. 6A-6B, the device being shown in a released configuration; and

FIG. 8 is a schematic cross-sectional view of yet another well in which a fourth embodiment of a method and a fourth embodiment of an apparatus according to the present invention have been utilized.

[0031] Representatively and schematically illustrated in FIGS. 1-3 is a method 10 of completing a subterranean well which embodies principles of the present invention. In the following description of the method 10 and other apparatus and methods described herein, directional terms, such as "above", "below", "upper, "lower", etc., are used for convenience in referring to the accompanying drawings. Additionally, it is to be understood that the various embodiments of the present invention described herein may be utilized in various orientations, such as inclined, inverted, horizontal, vertical, etc., without departing from the principles of the present invention.

[0032] FIG. 1 depicts a well in which initial steps of the method 10 have been performed. A parent wellbore 12 has been drilled and intersects a formation or interval of a formation 14. As used herein, the term "formation" is used to designate either a formation or a particular interval of a formation. Casing 16 is installed in the parent wellbore 12 and cemented in place. Perforations 18 are formed through the casing 16 and cement 20 to provide flowpaths for fluid between the wellbore 12 and the formation 14.

[0033] The method 10 will be described herein as it may be utilized in producing fluids from the well, such as by flowing fluid from the formation 14 to the earth's surface through the wellbore 12. However, it is to be clearly understood that a method performed according to the principles of the present invention may also be utilized in injecting fluids into one or more formations intersected by the well. Additionally, it will become readily apparent to one of ordinary skill in the art that a method performed according to the principles of the present invention may be utilized in simultaneously injecting fluids into one or more formations intersected by the well and producing fluids from one or more formations intersected by the well.

[0034] In the method 10, a lateral wellbore 22 is to be drilled so that it intersects the parent wellbore 12 at an intersection 24. For this purpose, a whipstock assembly 26 is positioned in the parent wellbore 12 and oriented so that an upper inclined deflection surface 28 formed on a generally tubular whipstock 30 is adjacent the intersection 24 and faces toward the lateral wellbore-to-be-drilled 22. The whipstock assembly 26 is anchored to, and sealingly engaged with, the casing 16 by means of a packer 32 attached to the whipstock 30. A tailpipe 34 or other tubular member, such as a conventional PBR, is attached to, and extends downwardly from, the packer 32. Alternatively, the tubular member 34 may be a mandrel of the packer 32.

[0035] It is to be understood that the whipstock assembly 26 may include other or different elements, or substitutions may be made for the representatively illustrated elements thereof, without departing from the principles of the present invention. For example, the whipstock 30 may include an axial bore 36 which is filled with a relatively easily drillable material. The tailpipe 34 may have a conventional plug installed therein prior to, and during, drilling of the lateral wellbore 22. Various whipstock assemblies and procedures for drilling lateral wellbores, which may be utilized in the method 10, are disclosed in our copending European patent application no. 97305217.8 entitled APPARATUS FOR COMPLETING A SUBTERRANEAN WELL AND ASSOCIATED

METHODS OF USING SAME and filed 14 July 1997, and another US copending patent application entitled METHODS OF COMPLETING A SUBTERRANEAN WELL AND ASSOCIATED APPARATUS and filed August 20, 1997.

[0036] With the whipstock assembly 26 positioned at the intersection 24, a series of cutting tools (not shown) are utilized to form an opening 38 laterally through the casing 16 and cement 20. The lateral wellbore 22 is then drilled outwardly from the parent wellbore 12 to intersect a desired formation 40. The formation 40 may be separate and isolated from the formation 14, or the formations 14, 40 may be portions of the same formation, etc. For example, in a water flooding operation, water may be injected into the formation 14, resulting in production of hydrocarbon fluids from the formation 40.

[0037] A liner 42 or other tubular structure is lowered through an upper portion 44 of the parent wellbore 12, through the opening 38, and into the lateral wellbore 22. The liner 42 is then cemented in place. However, it is to be understood that it is not necessary for the liner 42 to be installed in this manner in the method 10. For example, the liner 42 may extend upwardly through the opening 38, across the intersection 24 and into the upper portion 44 of the parent wellbore 12, as described in the incorporated copending applications.

[0038] Referring additionally now to FIG. 2, an apparatus 46 is representatively and schematically illustrated, which embodies principles of the present invention. The apparatus 46 is utilized in the method 10 for controlling the rate of fluid flow into, or out of, the formations 14, 40 intersected by the parent and lateral wellbores 12, 22. Although the apparatus 46 is depicted in FIG. 2 as it is completely assembled when installed in the well, it is to be understood that, in actual practice, the apparatus 46 may be assembled as it is installed in the well, it may be assembled in the well after its individual elements have been installed therein in separate subassemblies, etc.

[0039] The apparatus 46 includes three interconnected tubing strings 48, 50, 52. When the apparatus 46 is installed in the well, the tubing string 48 extends upwardly to the earth's surface. The tubing strings 50, 52, which may also be referred to as tailpipes, extend downwardly from the tubing string 48. The tubing string 50 extends into a lower portion 54 of the parent wellbore 12, and the tubing string 52 extends into the lateral wellbore 22, when the apparatus 46 is installed in the well.

[0040] The tubing string 52 includes a conventional plug 56, a remotely controllable flow regulating device 58, a packer or other sealing device 60 and a releasable deflection device 62. The deflection device 62 radially outwardly surrounds the packer 60, regulating device 58 and plug 56, and extends somewhat downwardly therefrom. The deflection device 62 is utilized to direct the tubing string 52 into the lateral wellbore 22 as the apparatus 46 is lowered into the well. It is configured so that it will deflect off of the deflection surface 28 toward the lateral wellbore 22, rather than passing through the bore 36 of the whipstock 30. The deflection device 62 releases for displacement relative to the remainder of the tubing string 52 after deflecting off of the deflection surface 28. Such release of the deflection device 62 may be performed upon receipt of a signal and/or fluid pressure on lines 64 interconnected thereto, in response to engagement with a structure in the lateral wellbore 22, in response to manipulation of the apparatus 46, or any other method. An apparatus which may be used for the deflection device 62 in the method 10 is described more fully hereinbelow in relation to FIGS. 6A-6B and 7A-7D.

[0041] The regulating device 58 may be a variable choke, which is responsive to signals and/or fluid pressures, etc. carried by lines 64 coupled thereto. Signals may be sent to the regulating device 58 by other methods, as well, such as by acoustic telemetry, electromagnetic waves, magnetic fields, mud pulses, etc. However, it is to be clearly understood that the regulating device 58 may be otherwise controlled for example, by manipulation of a latching or shifting tool engaged with the regulating device and conveyed on wireline, slickline, segmented tubing, coiled tubing, etc., by otherwise mechanically controlling the regulating device, by operating the regulating device with a Downhole Power Unit available from Halliburton Energy Services, etc.

[0042] Suitable regulating devices for use in the method 10 are described our copending European patent applications nos 98305750.6 and 98305764.7 entitled FLOW CONTROL APPARATUS FOR USE IN A SUBTERRANEAN WELL AND ASSOCIATED METHODS, each of which was filed 20 July 1998. Another suitable regulating device is the SCRAMS ICV available from Petroleum Engineering Services, Ltd. of The Woodlands, Texas. As representatively illustrated in FIG. 2, the regulating device 58 acts to regulate the rate of fluid flow through a sidewall portion of the tubing string 52, however, it is to be understood that the regulating device may alternatively regulate fluid flow axially therethrough, in which case the plug 56 may not be included in the tubing string 52.

[0043] The packer 60 may be another sealing device, such as a packing stack, seal element, etc. for sealing engagement with a seal surface, such as a PBR attached to the liner 42. A suitable packer for use in the method 10 is the remotely settable SCRAMS HF packer available from Petroleum Engineering Services, Ltd. This type of packer may be interconnected to the lines 64 and set within the liner 42, or other tubular structure, in response to signals and/or fluid pressures, etc. carried by the lines 64. Alternatively, the packer 60 may be a conventional hydraulically or mechanically settable packer having provision for passing the lines 64 therethrough. If remotely settable, the packer 60 may receive signals by acoustic telemetry, electromagnetic waves, mud pulses, or any other communication means.

[0044] A dual string packer 66 sealingly engages the tubing strings 50, 52. If the lines 64 are utilized to re-

motely control operation of the regulating device 58, packer 60 and/or the deflection device 62, the packer 66 may include provision for extending the lines 64 therethrough. The packer 66 is configured for sealingly engaging the casing 16 in the upper portion 44 of the parent wellbore 12 above the opening 38 when the apparatus 46 is installed in the well. The packer 66 may be hydraulically or mechanically set, and may be remotely set in response to signals and/or fluid pressures carried by the lines 64.

[0045] The tubing string 50 includes a packing stack 68 or other sealing device, a perforated sub 70 having openings formed radially therethrough and a plug 72. The packing 68 is configured for passing through the whipstock bore 36 and sealing engagement with the tailpipe 34. Alternatively, the packing 68 may be a packer configured for setting within the tailpipe 34, and may be remotely settable, as described above for the packer 60. It will be readily appreciated by a person of ordinary skill in the art that when the packing 68 is sealingly engaged within the tailpipe 34, fluid may flow from the formation 14, into a lower end of the tubing string 50, through the packer 66 and outward through the openings in the perforated sub 70.

[0046] The tubing string 48 includes a packer 74 or other sealing device and a remotely controllable flow regulating device 76. The packer 74 may be similar to the packer 60, except that it is configured for setting within the upper portion 44 of the parent wellbore 12. The regulating device 76 may be similar to the regulating device 58, and may be controlled by any of the means described above for controlling the regulating device 58.

[0047] A coupling device 78 couples the tubing string 48 to the tubular strings 50, 52. The coupling device 78 may be a conventional wye block and may include a vane or other member for directing tools, wirelines, coiled tubing, etc. from the tubing string 48 into a selected one of the tubing strings 50, 52. Of course, if access is desired to the tubing string 50, the plug 72 should be removed therefrom. A suitable wye block for use as the coupling device 78 in the method 10 is described in our copending European patent application no. 98304145.0 entitled WYE BLOCK HAVING A ROTARY GUIDE INCORPORATED THEREIN, filed on 26 May 1998.

[0048] Where such a directing member is included in the coupling device 78, it may be operated mechanically, hydraulically, in response to signals and/or fluid pressure carried by the lines 64, acoustic telemetry, electromagnetic waves, mud pulses, etc. The coupling device 78 may be controlled by any of those means described above for the regulating device 58.

[0049] The regulating device 76 operates to regulate the rate of fluid flow through a sidewall portion of the tubing string 48. In this way, fluid passing outwardly through the openings in the perforated sub 70, and into an annulus 80 formed radially between the tubing string 48 and the parent wellbore 12 when the apparatus 46 is installed in the well, may flow into the tubing string 48. Thus, as the apparatus 46 is representatively illustrated in FIG. 2, fluid flowing between the tubing string 48 and the tubing string 50 does not necessarily flow through the coupling device 78. Instead, it flows into the annulus 80, thereby bypassing the coupling device 78. Alternatively, the regulating device 76 may be included in the tubing string 50, similar to the manner in which the regulating device 58 is included in the tubing string 52, in which case the plug 72 and perforated sub 70 would not be included in the tubing strings 50 and flow between the tubing string 48 and the tubing string 50 would pass through the coupling device 78.

[0050] Referring additionally now to FIG. 3, the apparatus 46 is representatively illustrated as it is operatively installed in the well. The deflection device 62 has deflected the tubing string 52 into the lateral wellbore 22 as the apparatus 46 was lowered into the well. Thereafter, since the tubing string 50 is shorter than the tubing string 52, the tubing string 50 is inserted through the whipstock bore 36 and into the lower portion 54 of the parent wellbore 12. However, it is to be clearly understood that it is not necessary for the tubing string 50 to enter the lower parent wellbore 54 after the tubing string 52 enters the lateral wellbore 22, or for the tubing string 50 to be shorter than the tubing string 52.

[0051] The deflection device 62 has been released for axial displacement relative to the remainder of the tubing string 52 by engaging the deflection device with an upper PBR 82 attached to the liner 42 and applying an axially downwardly directed force to the deflection device by manipulation of the apparatus 46 from the earth's surface. As described above, however, release of the deflection device 62 may be accomplished by other methods.

[0052] When the deflection device 62 is released, the tubing string 52 extends further into the lateral wellbore 22. The packer 60, regulating device 58 and plug 56 enter the liner 42. When positioned therein as desired, the packer 60 is set so that it sealingly engages and anchors to the liner 42. The packer 60 may be set by any method, as described above.

[0053] It will be readily apparent to one of ordinary skill in the art that, with the packer 60 set in the liner 42 as representatively illustrated in FIG. 3, fluid (represented by arrows 84) may flow from the formation 40, inwardly through the regulating device 58, through the tubing string 52, through the coupling device 78, and through the tubing string 48 to the earth's surface. Of course, if it is desired to inject the fluid into the formation 40, the fluid 84 may flow in the opposite direction.

[0054] After the tubing string 50 has been inserted into the lower parent wellbore 54, the packing 68 sealingly engages the tubular member 34. If the packing 68 is a packer, it is set within the tubular member 34. Thereafter, the packers 66 and 74 are set within the upper parent wellbore 44, so that they sealingly engage and anchor to the casing 16. If the packers 60, 66, 68, 74 are remotely settable, as described above, they may be se-

quentially set by transmitting an appropriate signal to each of them and/or applying appropriate fluid pressure to each of them.

[0055] It will be readily apparent to one of ordinary skill in the art that, after the packers 66 and 74 are set and the sealing device 68 is sealingly engaged within the tubular member 34, fluid (represented by arrows 86) may flow from the formation 14, through the tubing string 50, outward through the perforated sub 70, into the annulus 80, inward through the regulating device 76 and through the tubing string 48 to the earth's surface. Of course, if an injection operation is to be performed, the fluid 86 may flow in an opposite direction. In the method 10 as representatively illustrated in FIG. 3, the fluids 84, 86 are commingled within the tubing string 48, but it is to be clearly understood that the fluids may be segregated from each other.

[0056] Thus has been described the method 10 and apparatus 46 which permits the rate of flow of the fluids 84, 86 to be regulated in close proximity to the formations 14, 40. The rates of each fluid flow may be conveniently varied as desired by remotely operating the regulating devices 76, 58. Additionally, proportional flow rates of the fluids 84, 86 may be controlled to thereby vary the proportions of the fluids commingled in the tubing string 48.

[0057] Referring additionally now to FIGS. 4A-4B, another method 90 embodying principles of the present invention is representatively and schematically illustrated. Elements of the method 90 which are similar to those previously described are indicated in FIGS. 4A-4B using the same reference numbers, with an added suffix "a".

[0058] The method 90 differs from the method 10 in part in that a tailpipe 92 that extends into the lower parent wellbore 54a includes the packer 60a, regulating device 58a and plug 56a, similar to that included in the tubing string 52a extending into the lateral wellbore 22a. The packer 60a is set in the tubular member 34a. In this manner, the perforated sub 70, plug 72 and separate annulus 80 are not utilized in the method 90. Thus, fluid 86a produced from the formation 14a flows into the regulating device 58a below the packer 60a and flows through the coupling device 78a into a tubing string 94, wherein the fluids 84a and 86a are commingled.

[0059] As discussed above, it is not necessary for the fluids 84a and 86a to be commingled. The packer 66a is shown in FIG. 4A in dashed lines to indicate that it is not necessarily or preferably utilized in the method 90 as representatively illustrated. However, it will be readily appreciated by a person of ordinary skill in the art that, if it is desired to segregate the fluids 84a and 86a from each other, the packer 66a may be installed and separate tubing strings (not shown) coupled thereto and extended to the earth's surface, in place of the coupling device 78a and tubing string 94. The packer 74a may be utilized if commingled flow in the tubing string 94 is desired.

[0060] FIGS. 4A-4B also show that the method 90 may be utilized to control fluid flow from additional wellbores and formations intersected by those wellbores. For example, an additional lateral wellbore 96 may be drilled above or below the lateral wellbore 22a extending outwardly from another opening 38a formed through the casing 16a and cement 20a, and intersecting another formation 100. Another tailpipe 98 including another set of the packer 60a, regulating device 58a and plug 56a may then be installed in a liner 42a in the lateral wellbore 96.

[0061] Fluid (represented by arrows 102) may then be flowed from the formation 100, inwardly through the regulating device 58a, and through the tailpipe 98. The fluid 102 may be commingled with the fluids 84a and 86a in a tubing string 104 extending to the earth's surface by providing another coupling device 78a interconnecting the tubing string 94, the tailpipe 98 and the tubing string 104. Alternatively, separate tubing strings may be provided for segregating the fluids 102, 84a and 86a, or any combination of them, as described above.

[0062] In FIGS. 4A-4B, the lateral wellbore 96 is depicted as being drilled above the lateral wellbore 22a. For this purpose, another whipstock assembly 26a is positioned in the parent wellbore 12, with its deflection surface 28a adjacent the intersection 24a of the parent wellbore and the upper lateral wellbore 96. The upper lateral wellbore 96 is then drilled in a manner similar to that used to drill the lower lateral wellbore 22a.

[0063] The tubing string 94 is segmented, so that a lower portion 160 of the tubing string 94 may be joined with an upper portion 162 thereof, after the upper lateral wellbore 96 has been drilled. For this purpose, the lower portion 160 includes a connector 164, which permits fluid communication between the upper and lower portions 160, 162, and also interconnects the lines 64a. The connector 164 may be of the type well known to those of ordinary skill in the art as a "wet connector". A suitable connector that may be used for the connector 164, with appropriate modification, is described in U.S. patent no. 5,577,925, entitled CONCENTRIC WET CONNECTOR SYSTEM.

[0064] Alternatively, the lower portion 160 may include a PBR at its upper end and the upper portion 162 may include an appropriate sealing device, such as a packing stack, at its lower end for sealing engagement with the PBR. In that case, interconnection of the lines 64a may be accomplished by one or more other conventional connectors. However, it is to be clearly understood that connection of the upper and lower portions 160, 162 of the tubing string 94 may be accomplished by any other means. For example, the tubular member 34a included in the upper whipstock assembly 26a could sealingly engage a PBR attached to the upper end of the lower portion 160, so that when the packer 60a is set in the tubular member, the upper portion 162 is in fluid communication with the lower portion 160.

[0065] With the lateral wellbore 96 drilled as described above, the tailpipe 98, upper portion 162 and

tubing string 104 are installed in the well. The tailpipe 98 may be deflected to enter the lateral wellbore 96 utilizing a deflection device, such as the deflection device 62a, or other means may be utilized to insert the tailpipe into the lateral wellbore. The upper portion 162 is inserted through the upper whipstock assembly 26a and connected to the lower portion 160. The packers 60a on the upper portion 162 and tailpipe 98 are set in the tubular member 34a and liner 42a, respectively. Fluids 84a, 86a and 102 may then be regulated to flow at desired rates of each into the tubing string 104 and therethrough to the earth's surface.

[0066] Referring additionally now to FIG. 5, another method 110 embodying principles of the present invention is representatively and schematically illustrated. Elements of the method 110 which are similar to those previously described are indicated in FIG. 5 using the same reference number, with an added suffix "b". The method 110 differs in substantial part from the previous methods 10, 90 in that a single tubing string 112 is utilized to regulate fluid flow from, or into, multiple formations 14b, 40b.

[0067] In the method 110, a liner 114 is installed extending into the lateral wellbore 22b, and remains partially received within the upper parent wellbore 44b. The liner 114 is cemented in place overlying the whipstock assembly 26b. Thereafter, an opening 116 is cut through a sidewall portion of the liner 114 to provide access to the lower parent wellbore 54b via the whipstock bore 36b.

[0068] The tubing string 112 includes two regulating devices 76b, 58b and two packers 74b, 60b. As representatively illustrated in FIG. 5, the regulating device 76b is interconnected between the packer 74b and the packer 60b, and the packer 60b is interconnected between the regulating device 76b and the regulating device 58b. However, it will be readily appreciated by a person of ordinary skill in the art that, for example, if a regulating device capable of regulating fluid flow axially therethrough is utilized in place of the regulating device 58b, it could be positioned between the packers 74b, 60b, and the plug 56b could be eliminated from the tubing string 112. Thus, other configurations of the tubing string 112 may be utilized.

[0069] The tubing string 112 is inserted through the opening 116, so that a lower portion thereof extends into the lower parent wellbore 54b. The packer 60b is set within the tubular member 34b and the packer 74b is set within the casing 16b in the upper parent wellbore 44b. As described above, if the packers 74b, 60b are remotely settable, they may be set sequentially and controlled from the earth's surface.

[0070] With the packers 74b, 60b set, the fluid 86b may flow from the formation 14b, inwardly through the regulating device 58b, and through the tubing string 112 to the earth's surface. The fluid 84b may flow from the formation 40b, through the liner 114, inwardly through the regulating device 76b, and through the tubing string 112 to the earth's surface, commingled with the fluid 86b. The regulating devices 76b, 58b may, thus, be utilized to independently regulate the rate of each of these fluid flows, and to control the proportions of the fluids 84b, 86b produced from the formations 14b, 40b. Of course, the flows of either or both of the fluids 84b, 86b may be reversed in an injection operation.

[0071] Referring additionally now to FIGS. 6A-6B, a deflection device 120 embodying principles of the present invention is representatively illustrated. The deflection device 120 may be utilized for the deflection device 62 in any of the methods described above wherein a deflection device is used. As described herein, the deflection device 120 is releasable upon engagement with a tubular structure and application of an axial force thereto, but it is to be clearly understood that the deflection device may be hydraulically, electrically, remotely, etc. released.

[0072] The deflection device 120 is shown in FIGS. 6A-6B in a configuration in which it is run into a well. It includes an engagement portion 122, one or more release members 124, a blocking device 126, an inner generally tubular mandrel 128 and an outer generally tubular housing 130. The outer housing 130 is shown radially outwardly surrounding a representative item of equipment, a packer 132, but it is to be clearly understood that the housing may overlie any item of equipment, or any combination of equipment desired, with appropriate modification to the housing.

[0073] The packer 132 is threadedly attached to the inner mandrel 128, and the inner mandrel is threadedly attached to a tubing string 134 extending upwardly therefrom. As depicted in FIGS. 6A-6B, the inner mandrel 128 is prevented from displacing axially relative to the housing 130, release members 124 and engagement portion 122 by the blocking member 126. The blocking member 126 is representatively a generally C-shaped member which is radially outwardly disposed to engage a sleeve 136 threadedly attached to the housing 130. The blocking member 126 is retained on the inner mandrel 128 by a retainer 138 threadedly attached to the inner mandrel. Thus, with the blocking member 126 disposed between and contacting the retainer 138 and sleeve 136, the inner mandrel 128 is prevented from displacing downwardly relative to the housing 130. Additionally, the inner mandrel 128 is shouldered up against a lower portion of the sleeve 136, thereby preventing the inner mandrel from displacing upwardly relative to the housing 130.

[0074] The housing 130 is configured so that it will deflect off of a deflection surface, such as the deflection surface 28. For this purpose, for example, the housing 130 may have a larger diameter than the bore 36 of the whipstock 30, or may be otherwise shaped to prevent its insertion through another member. The housing is threadedly attached to the release members 124, sleeve 136 and engagement portion 122 (the engagement portion and release members being integrally

formed as shown in FIG. 6A), thereby making up an outer assembly 140.

[0075] Preferably, the housing 130 extends downwardly past any items of equipment attached below the inner mandrel 128. In this manner, the housing 130 will contact any structure, such as a whipstock, prior to the equipment, and will permit the deflection device 120 to direct the engagement portion 122 toward, for example, a lateral wellbore. Fig. 6B shows an end cap 142 of the housing 130 through which an end sub 144 of the packer 132 extends, but it is to be understood that, when the deflection device 120 is utilized in the methods described above, it is preferred that the end cap 142 completely overlie any item of equipment connected below the inner mandrel 128.

[0076] The release members 124 are axially elongated and circumferentially spaced apart, so that they are resilient, that is, they may be radially inwardly deflected. Note that a radially inwardly extending projection 146 formed on each release member 124 is in radial contact with the blocking member 126. Thus, it will be readily appreciated that if the release members 124 are radially inwardly deflected, the blocking member 126 will also be radially inwardly displaced thereby, and the inner mandrel 128 will no longer be secured by the blocking member relative to the outer assembly 140. However, one or more shear pins 148 installed through the sleeve 136 and into the mandrel 128 will still releasably secure the inner mandrel 128 against axial displacement relative to the outer assembly 140.

[0077] The release members 124 also have radially outwardly extending projections 150 formed thereon. The projections 150 extend radially outwardly so that, when the deflection device 120 is inserted within an appropriate tubular structure, the projections 150 will engage the tubular structure and be deflected radially inward thereby. In the representatively illustrated embodiment of the deflection device 120, the projections 150 are configured to permit radially inward deflection of the release members 124 upon insertion of the deflection device 120 into a PBR attached to a liner in a lateral wellbore. It is to be clearly understood, however, that the release members 124 may be otherwise configured for engagement with other structures.

[0078] The engagement portion 122 is configured to engage the top of the PBR attached to the liner and prevent further insertion of the deflection device 120 into the liner. For this purpose, the engagement portion 122 has a radially outwardly extending flange 152 formed thereon, which has a greater diameter than the inner diameter of the liner PBR. However, it is to be clearly understood that the engagement portion 122 may be otherwise configured to engage a structure.

[0079] Referring additionally now to FIGS. 7A-7D, the deflection device 120 is representatively illustrated inserted into a PBR 154 attached to a liner 156. The PBR 154 and liner 156 may, for example, correspond to the PBR 82 and liner 42 of the method 10 as depicted in FIG. 3. The release members 124 have been radially inwardly deflected by radial contact between the projections 150 and the inner diameter of the PBR 154. Such deflection of the release members 124 has caused the projections 146 to radially inwardly displace the blocking member 126. Thus, when the deflection device 120 is inserted into the PBR 154, the blocking member 126 no longer secures the inner mandrel 128 against displacement relative to the outer assembly 140.

[0080] Thereafter, an axially downwardly directed force may be applied to the inner mandrel 128 to shear the shear pins 148 and permit the inner mandrel and any equipment 132 attached thereto to downwardly displace relative to the outer assembly 140. Such downwardly directed force may be applied by slacking off on the tubing string 134 at the earth's surface. An opposing force is applied to the outer assembly 140 by engagement of the engagement portion 122 with the top of the PBR 154, the flange 152 thereby preventing further downward displacement of the outer assembly 140. The packer 132 is now permitted to displace downwardly into the liner 156 and may be set therein, with the outer assembly 140 remaining within the PBR 154.

[0081] Referring additionally now to FIG. 8, another method 170 embodying principles of the present invention is representatively and schematically illustrated. Elements of the method 170 which are similar to those previously described are indicated in FIG. 8 using the same reference number, with an added suffix "c". The method 170 differs in substantial part from the previously described method 10, in that packers 74, 66 are not utilized to isolate an annulus 80 from the remainder of the upper parent wellbore 44 as shown in FIG. 3. Instead, the method 170 utilizes an apparatus 172, which includes a fluid chamber 174 interconnected to the tubing strings 48c, 50c, 52c.

[0082] The fluid chamber 174 is contained within an outer housing 176, representatively illustrated in FIG. 8 as a generally tubular enclosure having a generally rectangular cross-section. Each of the tubing strings 48c, 50c, 52c is sealingly connected to the housing 176, with the interior of the tubing string 50c being in direct fluid communication with the chamber 174, and the interiors of the tubing strings 48c, 52c being in fluid communication with the chamber 174 only via the regulating device 76c. It is to be clearly understood, however, that the housing 176 may be otherwise shaped, may be otherwise interconnected to the tubing strings 48c, 50c, 52c, and may be integrally formed with other items of equipment included in the apparatus 172 (such as the regulating device 76c).

[0083] The apparatus 172 is installed in the well in a manner similar to that described above for the apparatus 46 in the method 10. However, note that the tubing string 50c includes the packer 60c, which may be settable by application of fluid pressure thereto. Accordingly, the lines 64c are now extended to near the lower end of the tubing string 50c and interconnected to the packer

60c. Thus, when the apparatus 172 is positioned within the well as shown in FIG. 8, the two lower packers 60c and the upper packer 74c may be set sequentially or simultaneously by application of fluid pressure thereto. Of course, each of the packers 60c, 74c, or any combination of them, may be otherwise set.

[0084] When it is desired to produce the fluid 86 from the formation 14c, the regulating device 76c is opened. The fluid 86c may then flow from the formation 14c, into the lower end of the tubing string 50c, into the chamber 174, and inwardly through the regulating device 76c into the tubing string 48c. In an injection operation, the fluid 86c would flow in an opposite direction. The fluid 84c is produced or injected from or into the formation 40c in a manner similar to that described above for the method 10, flow of the fluid being controlled by the regulating device 58c.

[0085] It will, thus, be readily appreciated that the method 170 permits flow of each of the fluids 84c, 86c to be accurately, conveniently and remotely controlled. Such flow control is accomplished in close proximity to the formations 14c, 40c, thereby minimizing any wellbore storage effects, and is accomplished without requiring any intervention into the well to change the respective rates of flow of the fluids.

[0086] Of course, a person of ordinary skill in the art would find it obvious to make certain modifications, additions, deletions, substitutions and other changes to the various apparatus and methods described herein. Accordingly, the foregoing detailed description is to be clearly understood as being given by way of illustration and example only. It will be appreciated that the invention may be modified within the scope of the appended claims.

Claims

1. A method of completing a subterranean well, the method comprising the steps of: interconnecting a first flow regulating(76) device to first and second tubular strings (48,52); providing fluid communication between the first regulating device (76) and a fluid chamber (174); and interconnecting a third tubular string (50) to the fluid chamber (174).

2. A method according to Claim 1, further comprising the step of regulating fluid flow between the first tubular string (48) and the third tubular string (50) through the first regulating device.

3. A method according to Claim 2, wherein the regulating step is remotely controlled.

4. A method of completing a subterranean well having first (22), second and third (12) wellbore portions, the third wellbore portion (12) extending to the earth's surface, and the first (22), second and third (12) wellbore portions intersecting, the method comprising the steps of: sealingly engaging a first tubular string (52) including a first remotely controllable flow regulating device (58) within the first wellbore portion (22); sealingly engaging a second tubular string (50) within the second wellbore portion; and interconnecting the first (52) and second (50) tubular strings to a third tubular string (48) including a second remotely controllable flow regulating device(76), the flow regulating device (76) regulating fluid flow between the third tubular string (48) and a fluid chamber (174) in fluid communication with the second tubular string (50).

5. A method according to Claim 4, wherein the first (58) and second (76) regulating devices are remotely controllable via at least one line (64) interconnected thereto.

6. A method according to Claim 4 or 5, further comprising the step of operating the first regulating device (58) to regulate fluid flow between the third tubular string (48) and a formation (40) intersected by the first wellbore portion(22).

7. Apparatus for completing a subterranean well, the apparatus comprising: first (48), second (52) and third (50) tubular strings; a housing (176) interconnecting the first (48), second (52) and third (50) tubular strings, the housing (176) including a fluid chamber (174) in fluid communication with the third tubular string (50); a first flow regulating device (58), the first regulating device (58) regulating fluid flow between the second tubular string (52) and the first tubular string (48); and a second flow regulating device (76), the second regulating device (76) regulating fluid flow between the chamber (174) and the first tubular string (48).

8. Apparatus according to Claim 9, wherein the first (58) and second (76) regulating devices are remotely controllable.

9. Apparatus according to claim 7, further comprising a releasable deflection device (62) operatively engaged with one of the second (52) and third (50) tubular strings.

10. Apparatus according to claim 7, wherein the second tubular string (52) includes a first sealing device (60) interconnected between the first regulating device (58) and the housing (176), and the third tubular string (52) includes a second sealing device (60).

Patentansprüche

1. Eine Methode für das Komplettieren eines Unter-

grundbohrloches, wobei dieselbe die folgenden Stufen umfasst: das Verbinden eines ersten durchflußregulierenden (76) Geräts mit einer ersten und zweiten Rohranordnung (48, 52); das Erstellen einer Flüssigkeitsverbindung zwischen dem ersten durchflußregulierenden Gerät (76) und einer Flüssigkeitskammer (174); und das Verbinden einer dritten Rohranordnung (50) mit der Flüssigkeitskammer (174).

2. Eine Methode nach Anspruch 1, welche weiter die Stufe des Regulierens eines Flüssigkeitsflusses zwischen der ersten Rohranordnung (48) und der dritten Rohranordnung (50) durch das erste durchflußregulierende Gerät umfasst.

3. Eine Methode nach Anspruch 2, bei welcher die Regulierstufe ferngesteuert ist.

4. Eine Methode für das Komplettieren eines Untergrundbohrloches mit einem ersten (22), zweiten und dritten (12) Bohrlochabschnitt, wobei der dritte Bohrlochabschnitt (12) sich bis an die Erdoberfläche erstreckt, und wobei sich die ersten (22), zweiten und dritten (12) Bohrlochabschnitte durchschneiden, wobei die Methode die folgenden Stufen umfasst: das abdichtende Eingreifen einer ersten Rohranordnung (52) mit einem ersten fernsteuerbaren durchflußregulierenden Gerät (58) in den ersten Bohrlochabschnitt (22); das abdichtende Eingreifen einer zweiten Rohranordnung (50) in den zweiten Bohrlochabschnitt; und das Verbinden der ersten (52) und zweiten (50) Rohranordnungen mit einer dritten Rohranordnung (48) mit einem zweiten fernsteuerbaren durchflußregulierenden Gerät (76), wobei das durchflußregulierende Gerät (76) den Flüssigkeitsfluß zwischen der dritten Rohranordnung (48) und einer Flüssigkeitskammer (174) reguliert, welche in Flüssigkeitsverbindung mit der zweiten Rohranordnung (50) steht.

5. Eine Methode nach Anspruch 4, bei welcher das erste (58) und das zweite (76) durchflußregulierende Gerät über mindestens eine, mit denselben verbundene Leitung (64) fernsteuerbar sind.

6. Eine Methode nach Anspruch 4 oder 5, welche weiter die Stufe des Betreibens des ersten regulierenden Geräts (58) für das Regulieren des Flüssigkeitsflusses zwischen der dritten Rohranordnung (48) und einer Formation (40) umfasst, welche von dem ersten Bohrlochabschnitt (22) durchschnitten wird.

7. Gerät für das Komplettieren eines Untergrundbohrloches, wobei dasselbe Gerät das Folgende umfasst: erste (48), zweite (52), und dritte (50) Rohranordnungen; ein Gehäuse (176), welches die ersten (48), zweiten (52) und dritten (50) Rohranordnungen miteinander verbindet, wobei das Gehäuse (176) eine Flüssigkeitskammer (174) umfasst, welche mit der dritten Rohranordnung (50) in Verbindung steht; ein erstes durchflußregulierendes Gerät (58), wobei das erste regulierende Gerät (58) den Flüssigkeitsfluß zwischen der zweiten Rohranordnung (52) und der ersten Rohranordnung (48) reguliert; und ein zweites durchflußregulierendes Gerät (76), wobei das zweite regulierende Gerät (76) den Flüssigkeitsfluß zwischen der Kammer (174) und der ersten Rohranordnung (48) reguliert.

8. Gerät nach Anspruch 9, bei welchem die ersten (58) und zweiten (76) regulierenden Geräte fernsteuerbar sind.

9. Gerät nach Anspruch 7, welches weiter ein lösbares Ablenkgerät (62) umfasst, welches während des Betriebs in eine der ersten (52) und dritten (50) Rohranordnungen eingreift.

10. Gerät nach Anspruch 7, bei welchem die zweite Rohranordnung (52) eine erste Abdichtungsvorrichtung (60) umfasst, welche zwischen dem ersten regulierenden Gerät (58) und dem Gehäuse (176) angeschlossen ist, und wobei die dritte Rohranordnung (52) eine zweite Abdichtungsvorrichtung (60) umfasst.

Revendications

1. Procédé de conditionnement d'un puits souterrain, le procédé comprenant les phases d'interconnexion d'un premier dispositif régulateur de débit (76) pour la première colonne tubulaire (48) et la deuxième colonne tubulaire (52) ; d'assurer la communication fluide entre le premier dispositif régulateur (76) et une chambre à fluide (174) ; et d'interconnexion d'une troisième colonne tubulaire (50) avec la chambre à fluide (174).

2. Procédé selon la revendication 1, comprenant en outre les phases de régulation du débit de fluide ente la première colonne tubulaire (48) et la troisième colonne tubulaire (50) grâce au premier dispositif régulateur.

3. Procédé selon la revendication 2, dans lequel la phase de régulation commandée à distance.

4. Procédé de conditionnement d'un puits souterrain ayant une première (22), une deuxième et une troisième (12) parties de puits de forage, la troisième partie de puits de forage (12) s'étendant vers la surface terrestre, et la première (22), la deuxième et la troisième (12) parties de puits de forage se coupant,

la procédé comprenant les phases d'engagement hermétique d'une première colonne tubulaire (52) englobant un premier dispositif régulateur de débit à commande à distance (58) à l'intérieur de la première partie de puits de forage (22) ; d'engagement hermétique d'une deuxième colonne tubulaire (50) à l'intérieur de la deuxième partie de puits de forage ; et d'interconnexion de la première (52) et de la deuxième (50) colonnes tubulaires avec une troisième colonne tubulaire (48) comprenant un second dispositif régulateur de débit à commande à distance (76), le dispositif régulateur de débit (76) assurant la régulation du débit de fluide entre la troisième colonne tubulaire (48) et une chambre à fluide (174) en communication fluide avec la deuxième colonne tubulaire (50).

5. Procédé selon la revendication 4, dans lequel le premier (58) et le second (76) dispositifs régulateurs sont à commande à distance par le biais au moins d'une ligne (64) interconnectée à ceux-ci.

6. Procédé selon la revendication 4 ou 5, comprenant en outre les phases d'actionnement du premier dispositif régulateur (58) pour assurer la régulation du débit de fluide entre la troisième colonne tubulaire (48) et une formation (40) coupée par la première partie de puits de forage (22).

7. Appareil de conditionnement d'un puits souterrain, l'appareil comprenant : une première (48), une deuxième (52) et une troisième (50) colonnes tubulaires ; un logement (176) interconnectant la première (48), la deuxième (52) et la troisième (50) colonnes tubulaires, le logement (176) contenant une chambre à fluide (174) en communication fluide avec la troisième colonne tubulaire (50) ; un premier dispositif régulateur de débit (58), le premier dispositif régulateur (58) assurant la régulation du débit de fluide entre la deuxième colonne tubulaire (52) et la première colonne tubulaire (48) ; et un deuxième dispositif régulateur de débit (76), le second dispositif régulateur (76) assurant la régulation du débit de fluide entre la chambre (174) et la première colonne tubulaire (48).

8. Appareil selon la revendication 9, dans lequel le premier (58) et le second (76) dispositif régulateurs sont à commande à distance.

9. Appareil selon la revendication 7, comprenant en outre un dispositif déviateur amovible (62) engagé de manière opérationnelle avec l'une de la deuxième (52) et de la troisième (50) colonnes tubulaires.

10. Appareil selon la revendication 7, dans lequel la deuxième colonne tubulaire (52) englobe un premier dispositif de scellement (60) interconnecté entre le premier dispositif régulateur (58) et le logement (176), et la troisième colonne tubulaire (52) englobe un second dispositif de scellement (60).

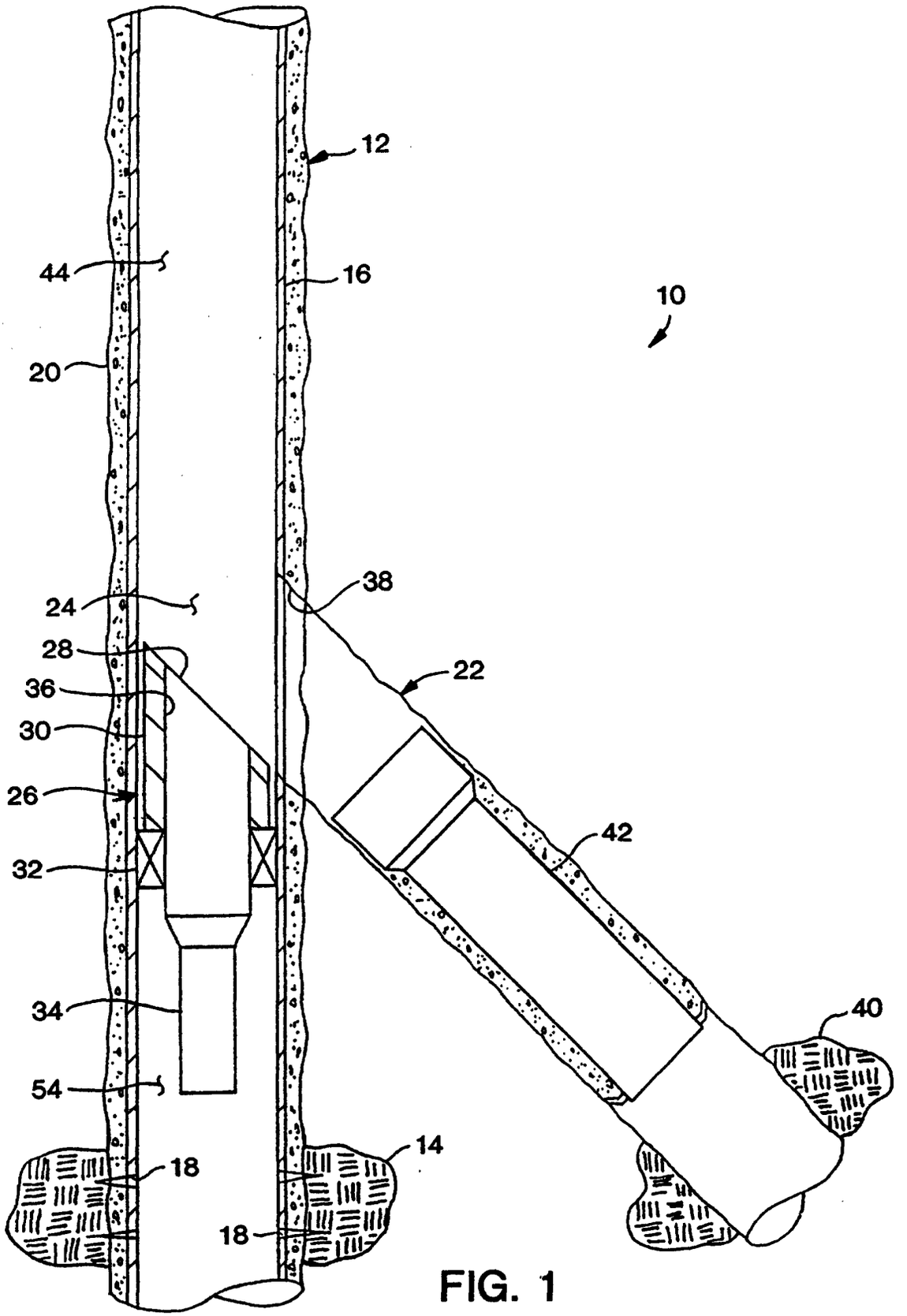


FIG. 1

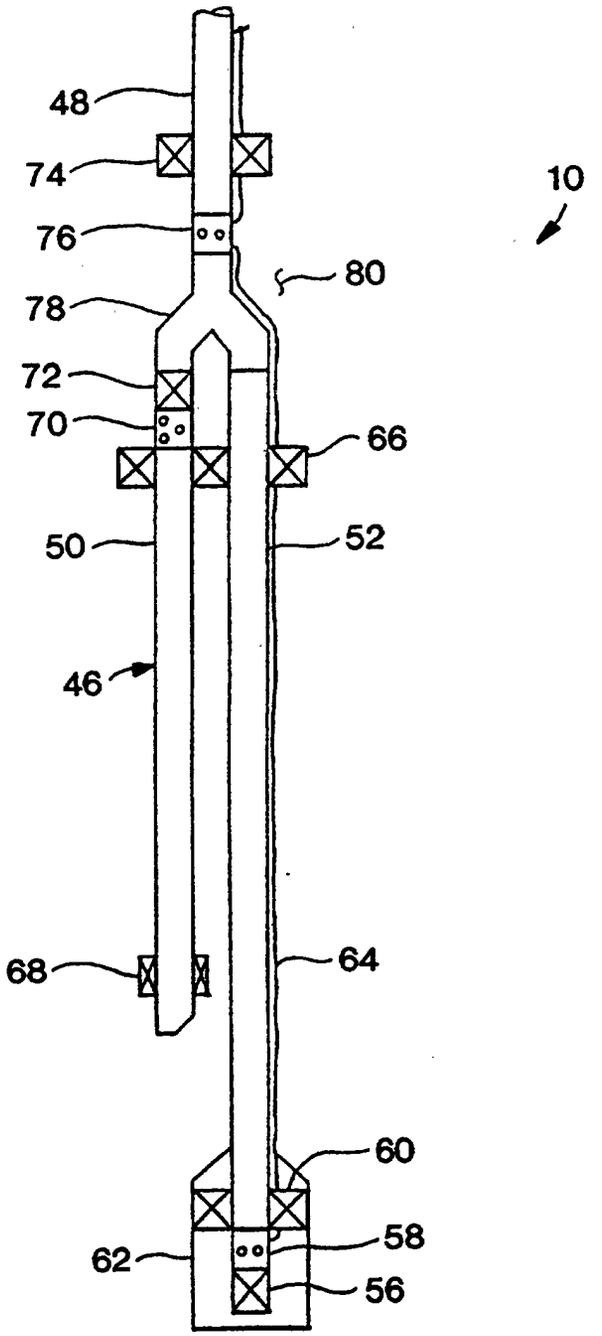


FIG. 2

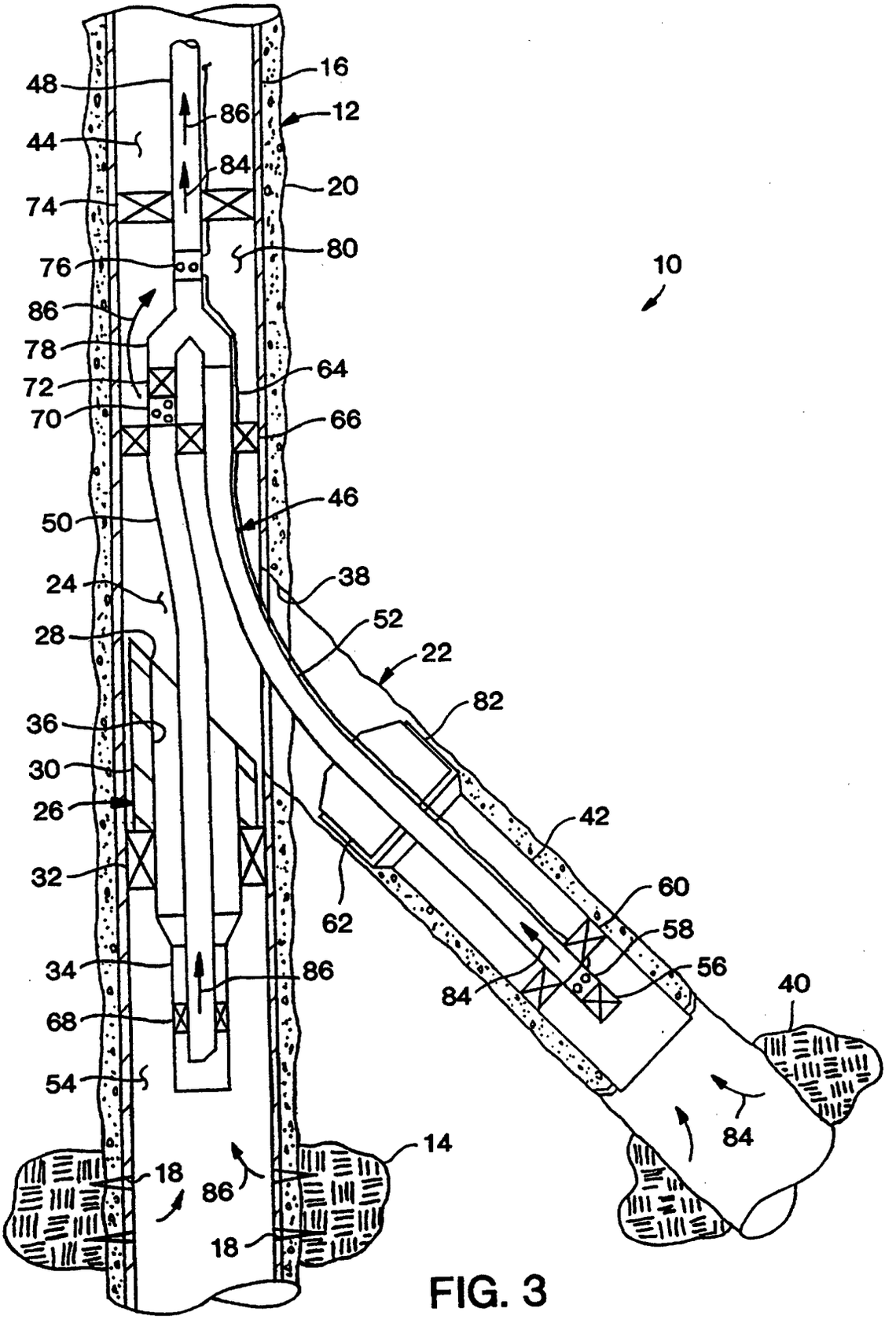

48
16
86
12
44
84
20
74
80
10
76
86
78
64
72
70
66
46
50
38
24
52
28
22
82
36
30
42
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58
62
56
34
86
84
40
68
54
84
14
18
86
18

FIG. 3

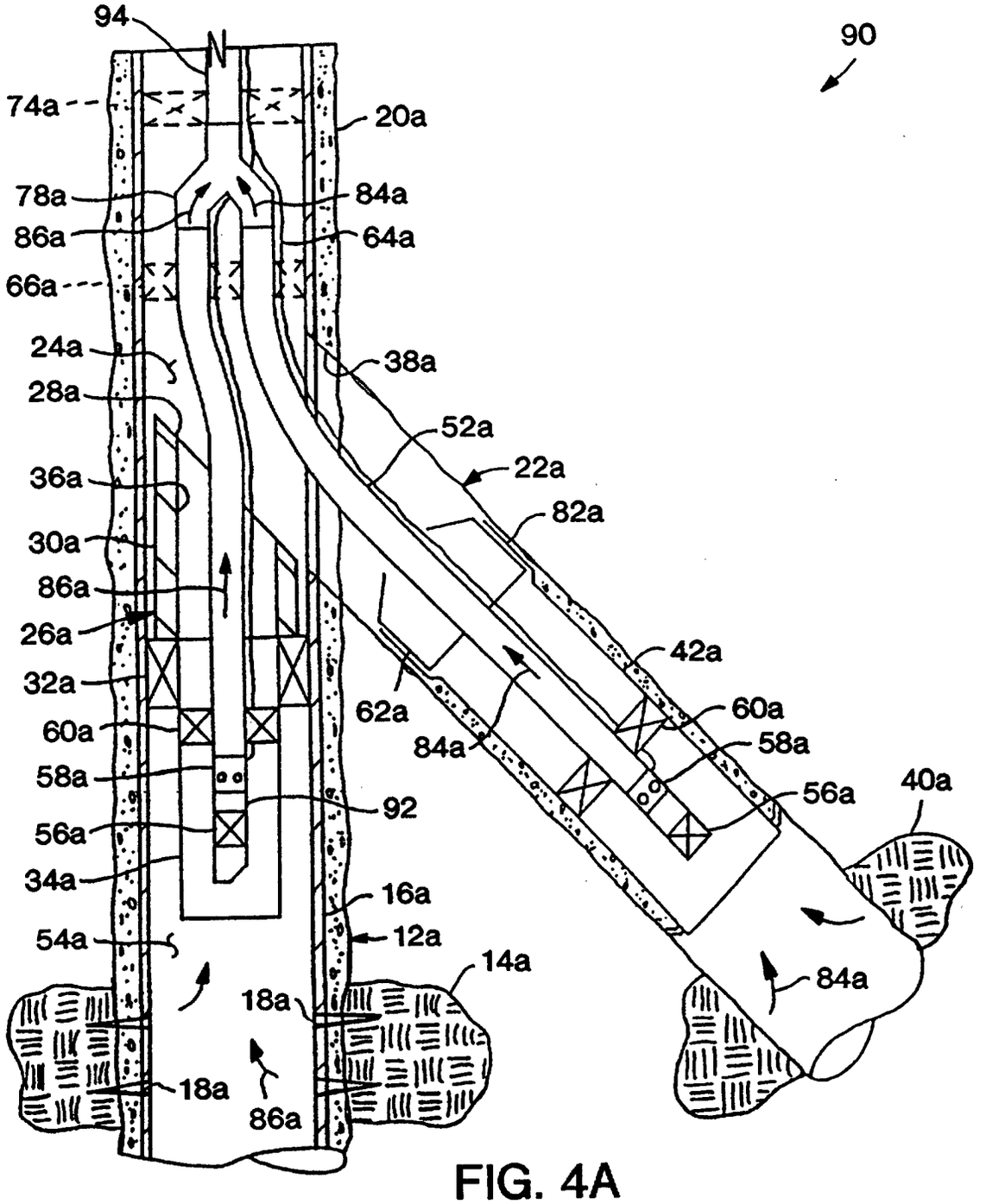

94
90
74a
20a
78a
84a
86a
64a
66a
24a
38a
28a
52a
22a
36a
82a
30a
86a
26a
42a
32a
62a
60a
84a
60a
58a
58a
56a
40a
92
56a
34a
16a
54a
12a
14a
18a
84a
18a
86a

FIG. 4A

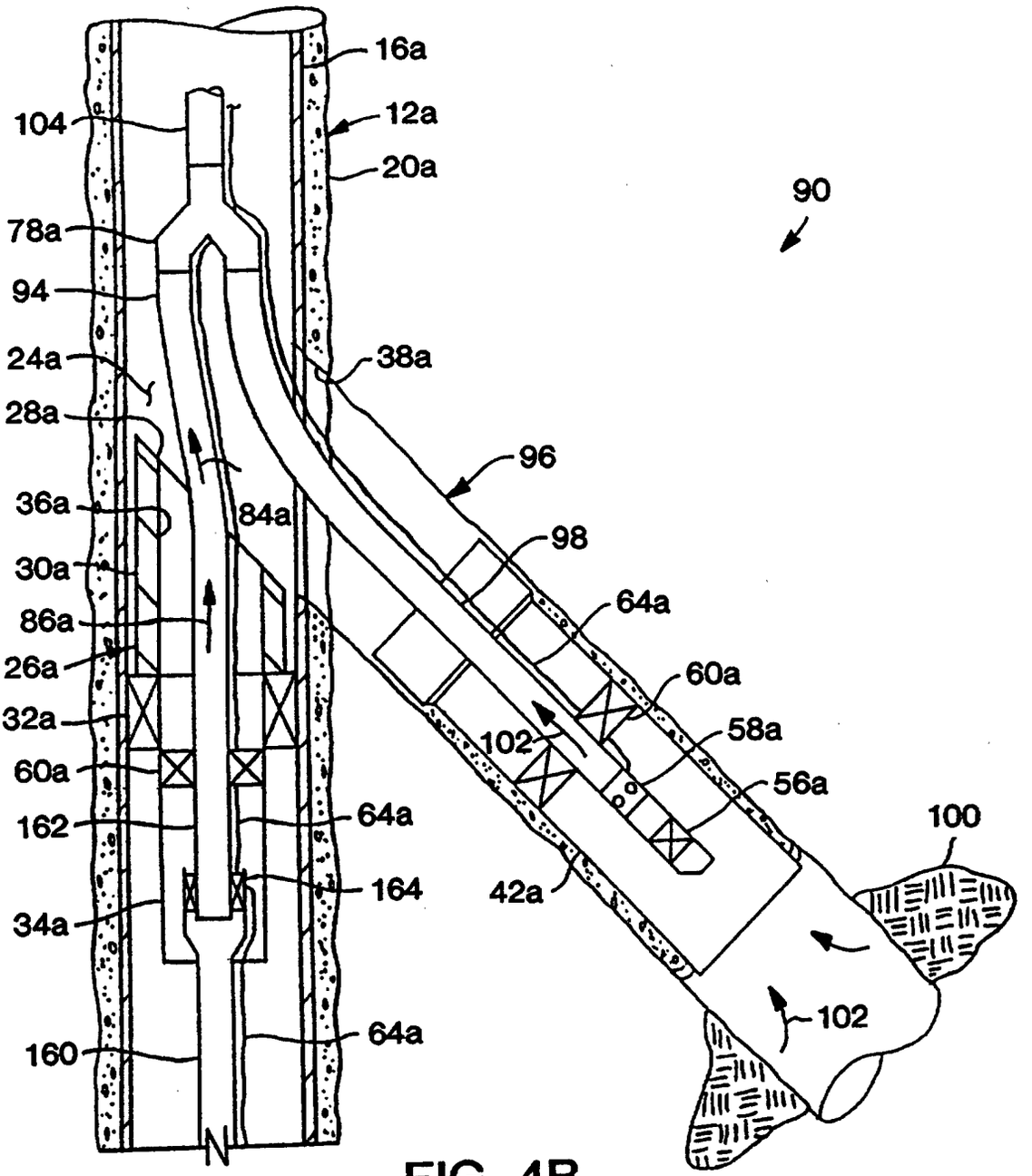

16a
12a
20a
104
90
78a
94
24a
38a
28a
96
36a
84a
98
30a
64a
86a
60a
26a
58a
32a
102
56a
60a
100
162
64a
164
42a
34a
102
64a
160

FIG. 4B

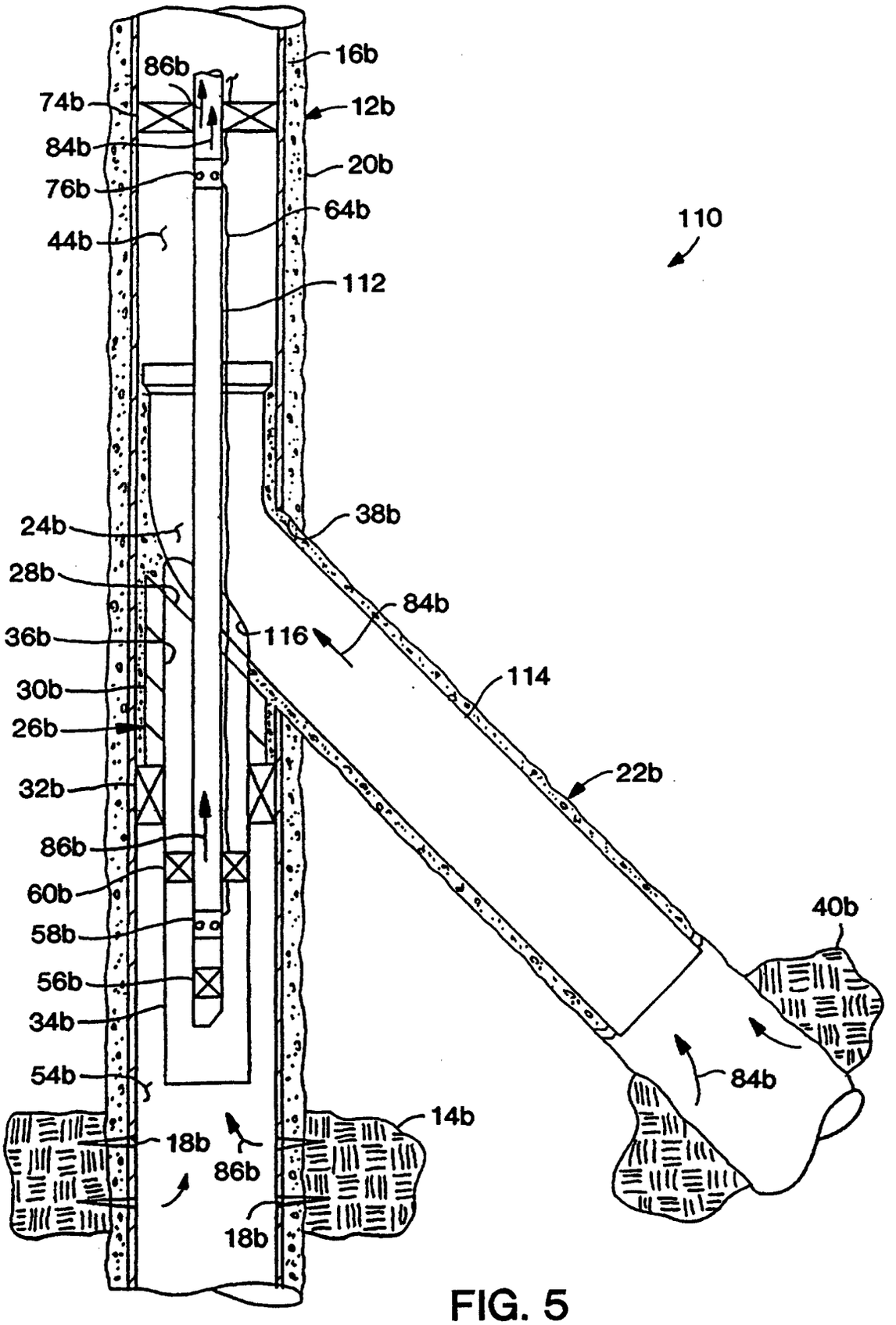

16b
86b
74b
12b
84b
20b
76b
64b
110
44b
112
38b
24b
28b
84b
36b
116
114
30b
26b
22b
32b
86b
40b
60b
58b
56b
84b
34b
54b
14b
18b
86b
18b

FIG. 5

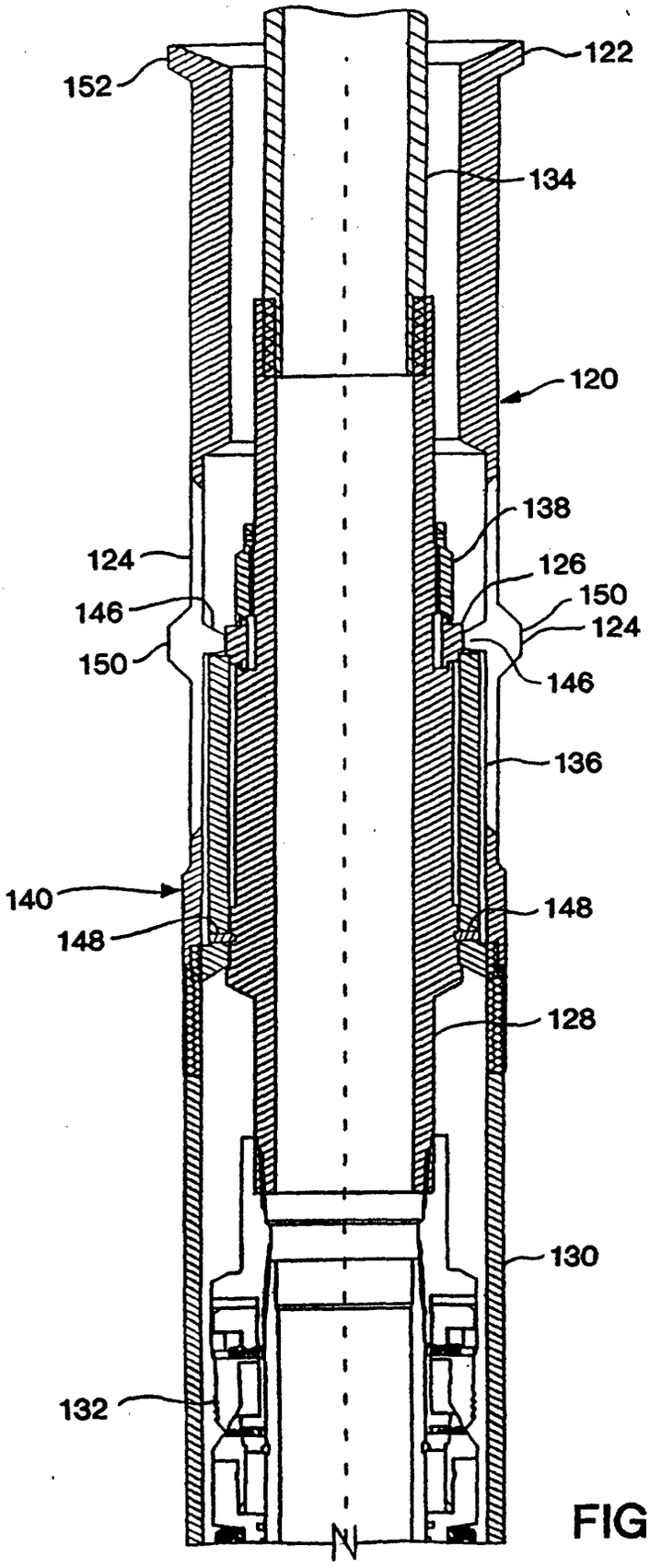

152
122
134
120
138
124
126
150
146
124
150
146
136
140
148
148
128
130
132

FIG. 6A

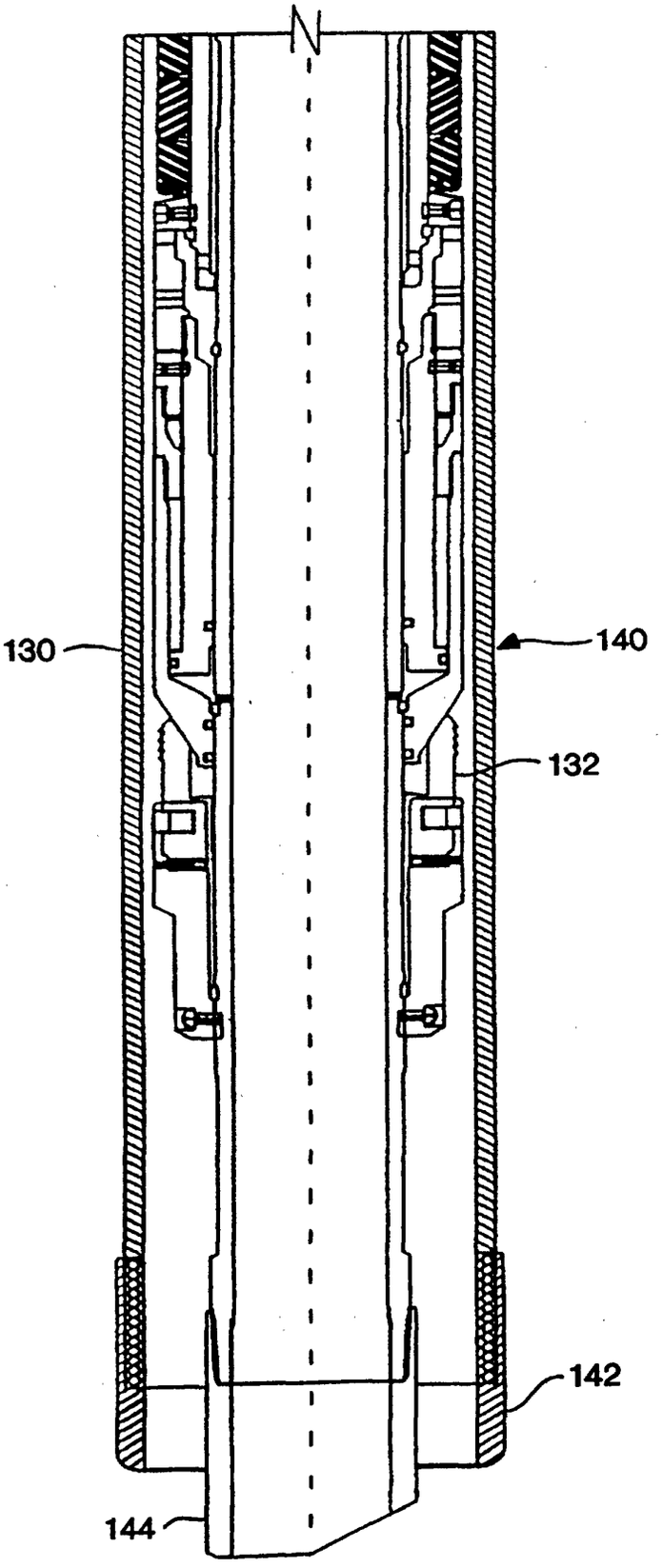


FIG. 6B

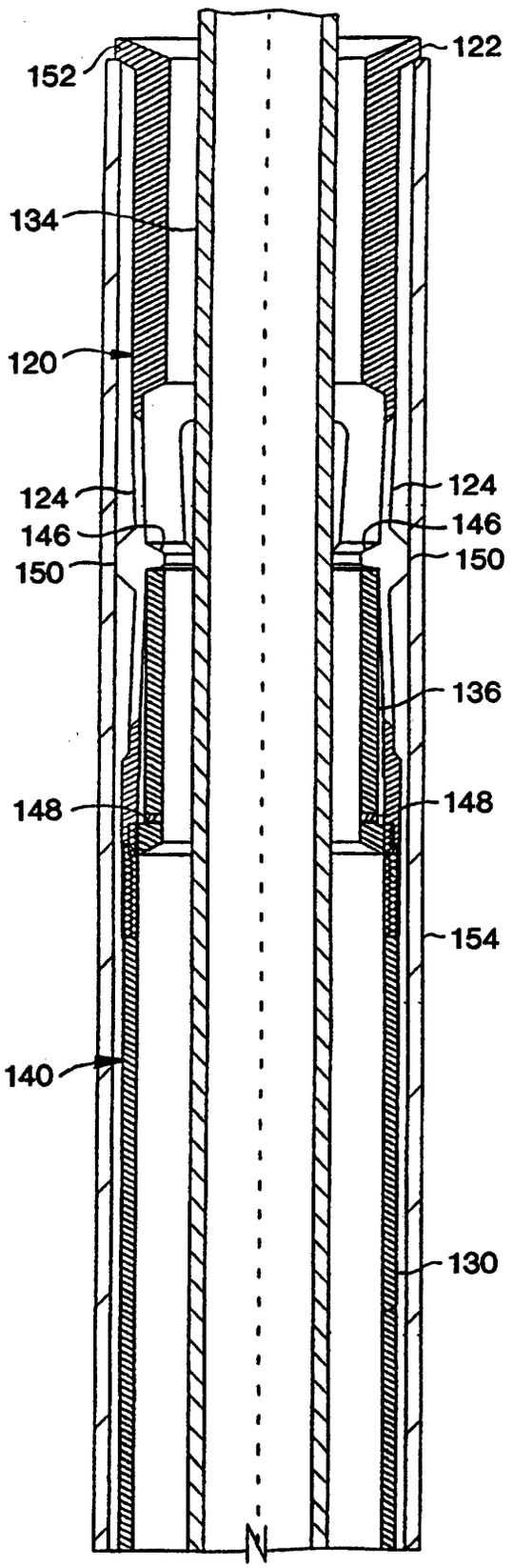

152
122
134
120
124
124
146
146
150
150
136
148
148
154
140
130

FIG. 7A

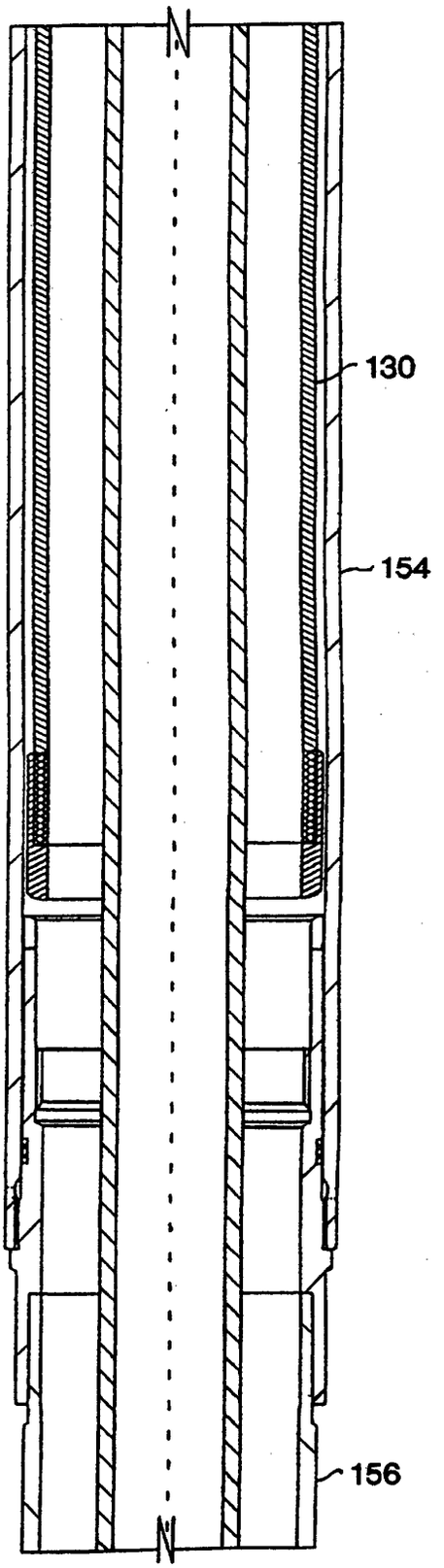

130
154
156

FIG. 7B

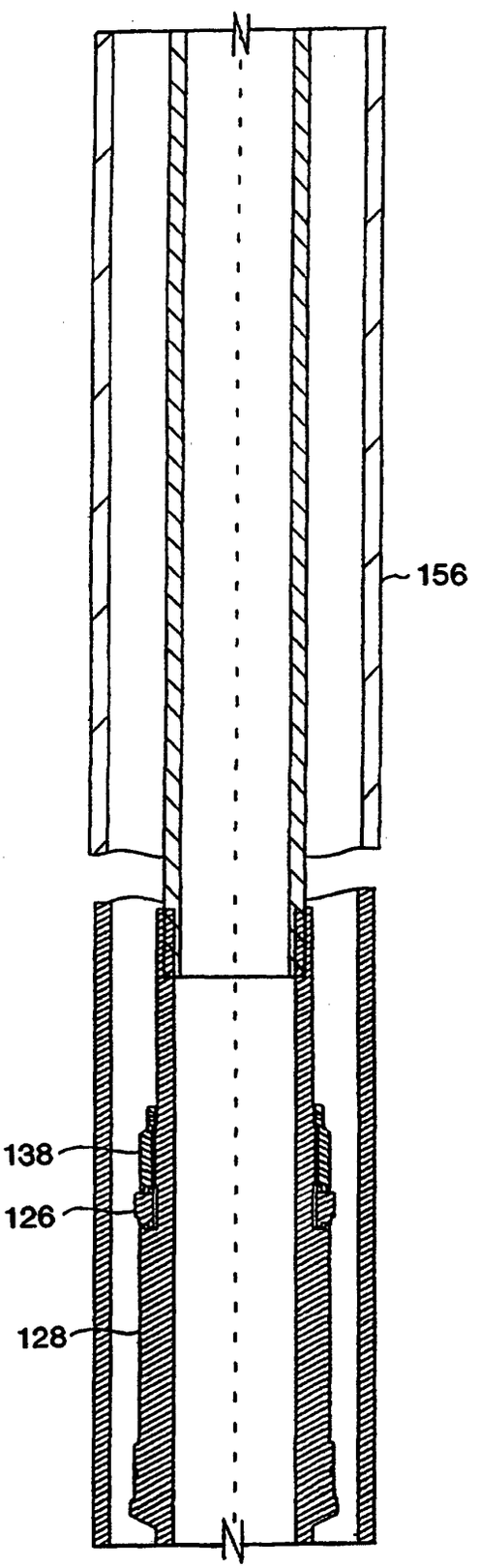


FIG. 7C

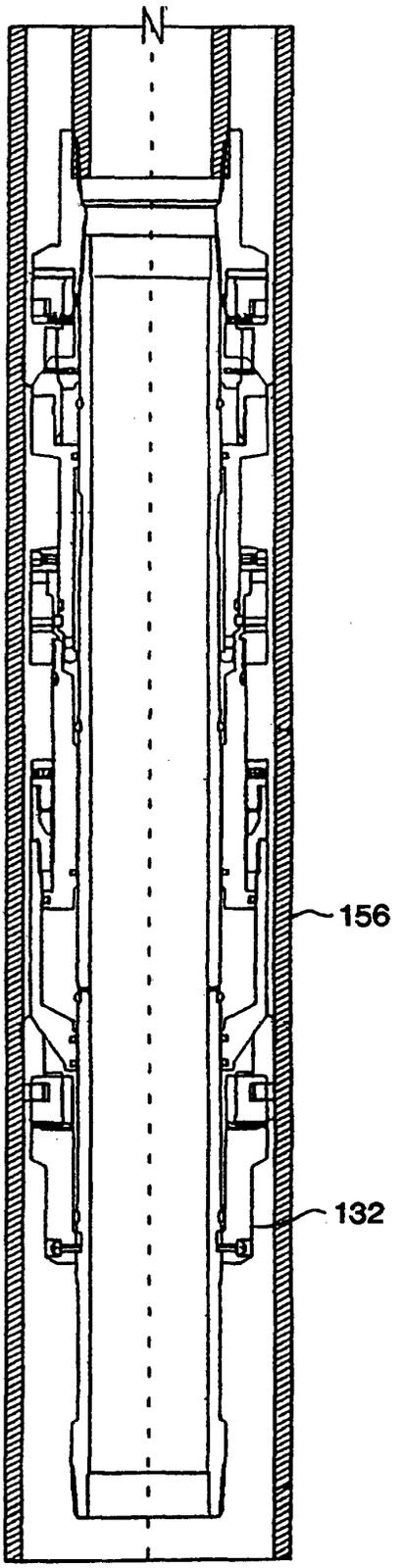


FIG. 7D

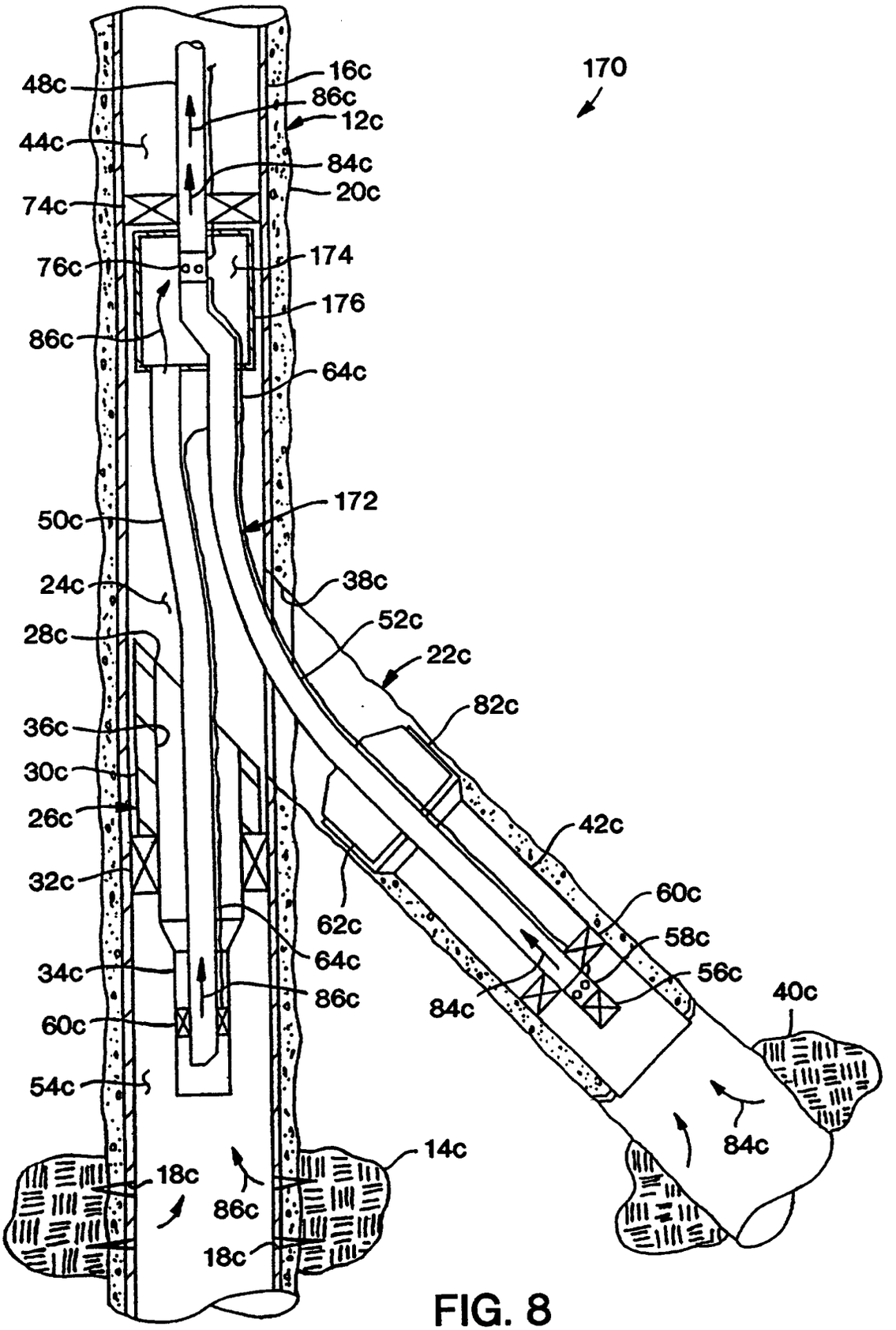

170
48c
16c
86c
12c
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84c
20c
74c
76c
174
176
86c
64c
172
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38c
52c
28c
22c
82c
36c
30c
26c
42c
32c
60c
62c
58c
64c
56c
34c
86c
84c
40c
60c
54c
14c
84c
18c
86c
18c

FIG. 8