Oct. 21, 1969 E. THUSE ET AL 3,473,605

UNDERWATER WELL COMPLETION APPARATUS

Filed June 12, 1967 5 Sheets-Sheet 1

FIG_2

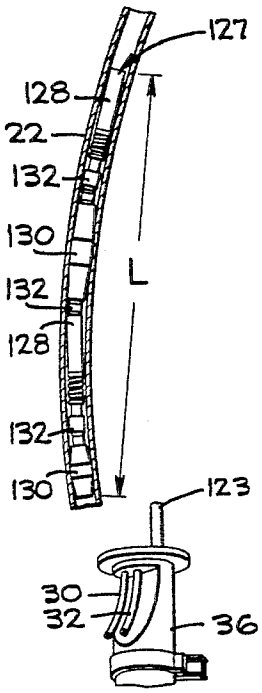
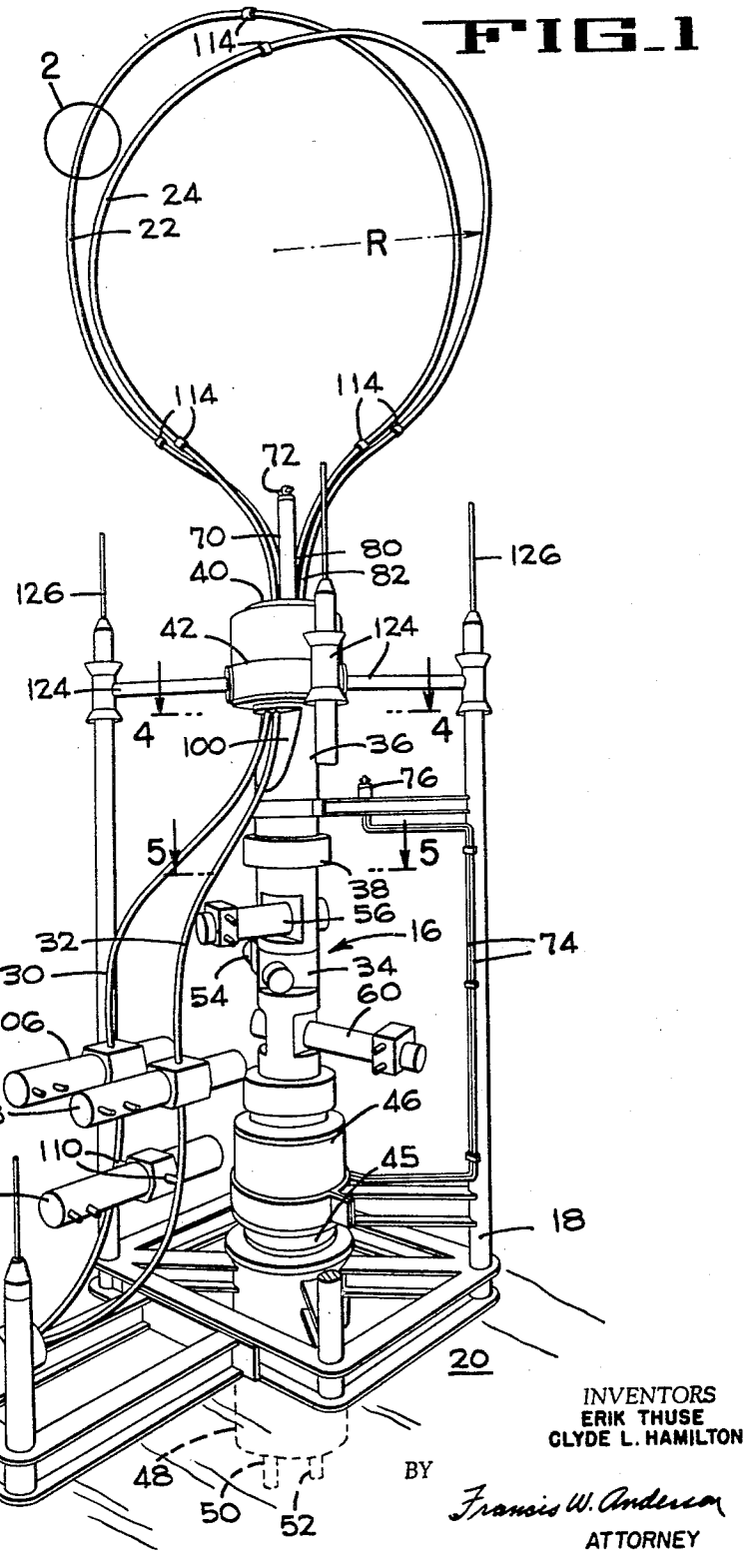


FIG_3

FIG_1



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UNDERWATER WELL COMPLETION APPARATUS

Filed June 12, 1967 5 Sheets-Sheet 2

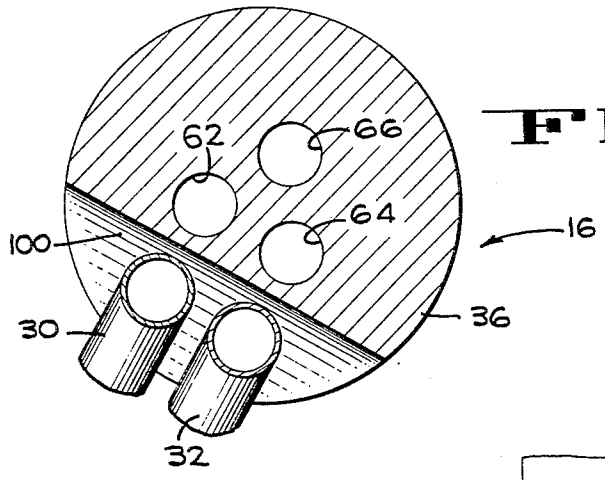

FIG_4

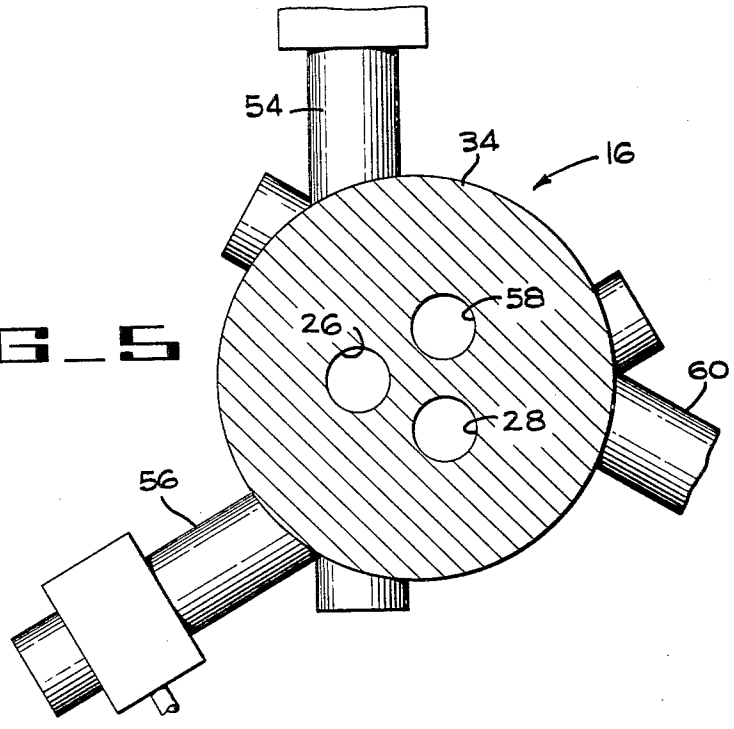

FIG_5

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UNDERWATER WELL COMPLETION APPARATUS

Filed June 12, 1967 5 Sheets-Sheet 3

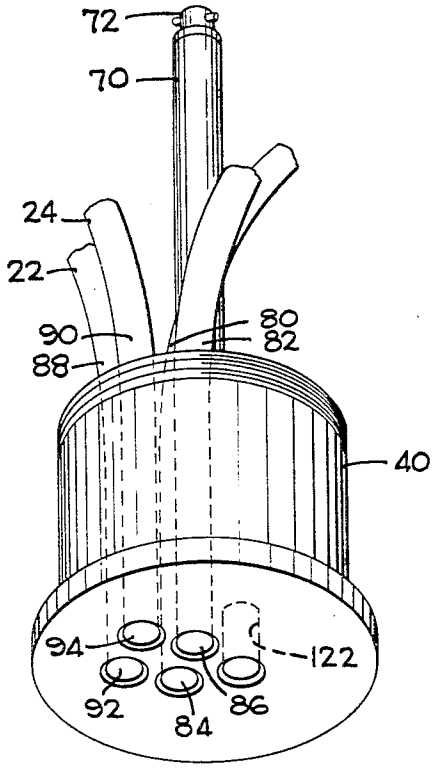


FIG_8

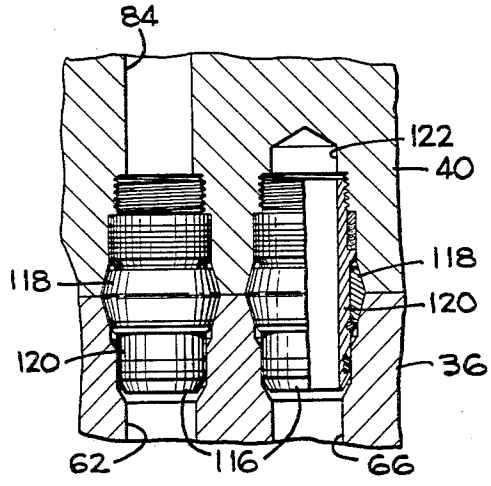


FIG_9

FIG_6

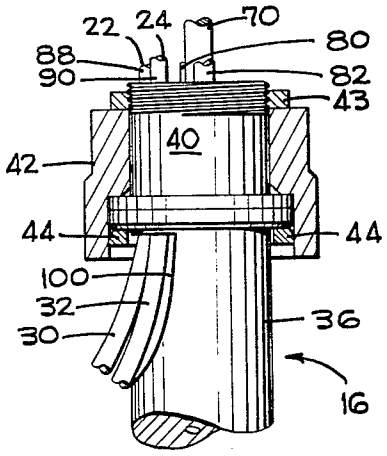
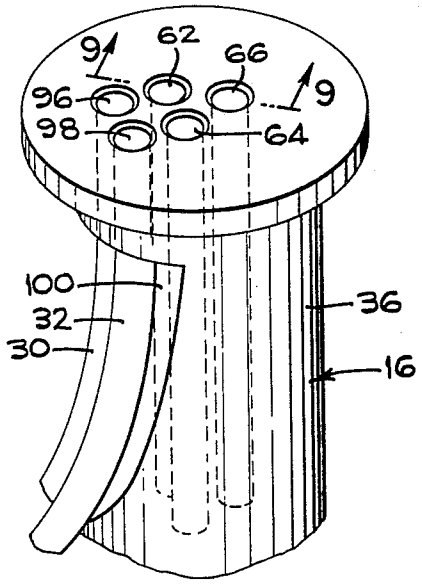


FIG_7



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UNDERWATER WELL COMPLETION APPARATUS

Filed June 12, 1967 5 Sheets-Sheet 4

FIG_10

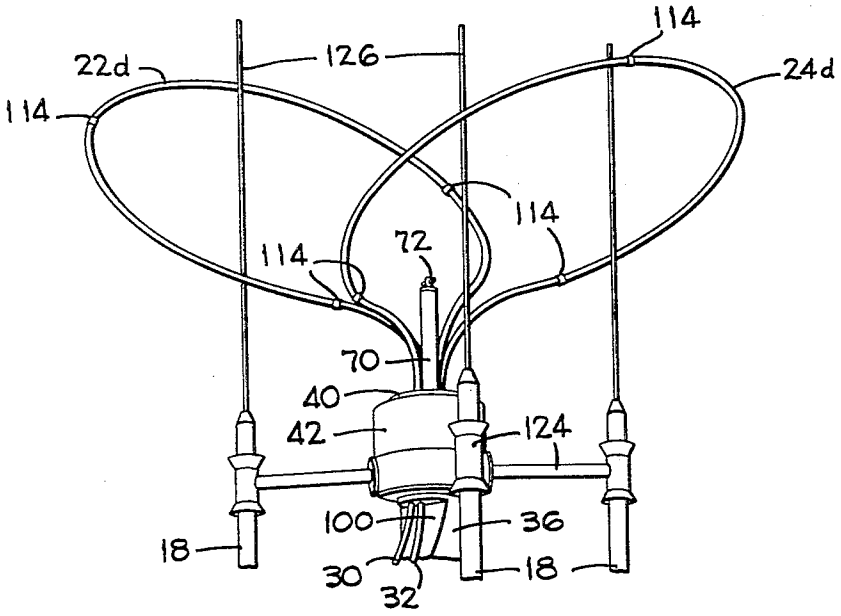
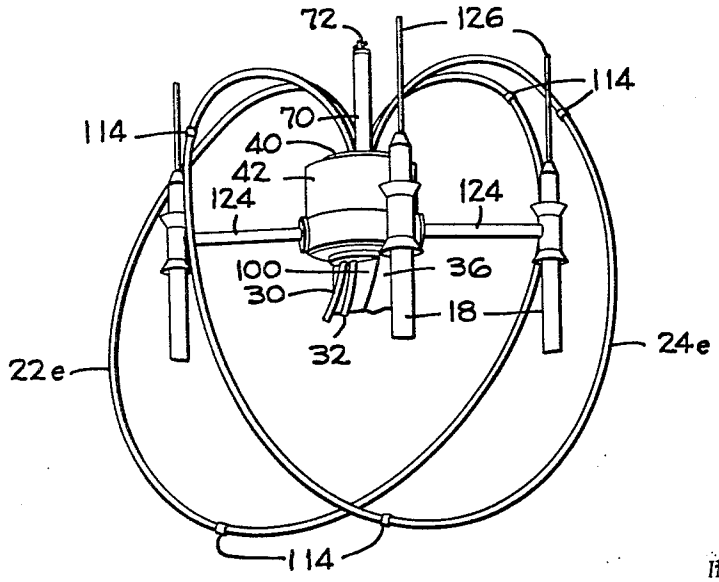


FIG_11



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UNDERWATER WELL COMPLETION APPARATUS

Filed June 12, 1967 5 Sheets-Sheet 5

FIG-14

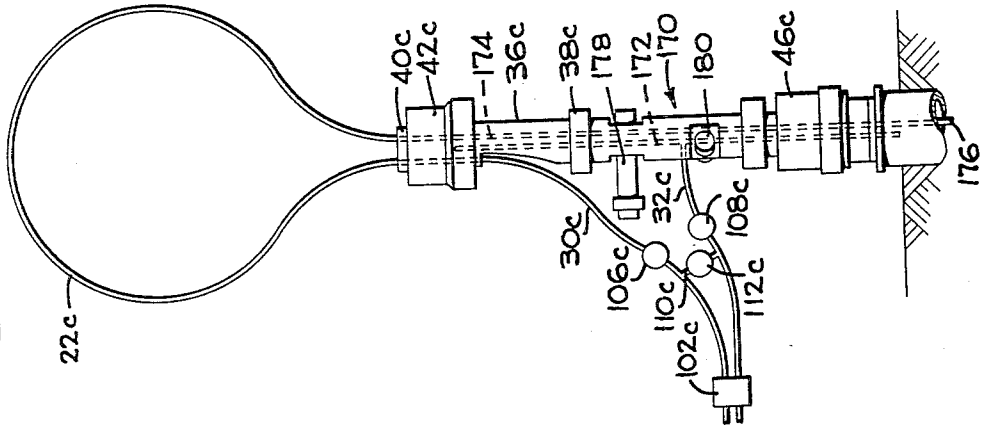


FIG-13

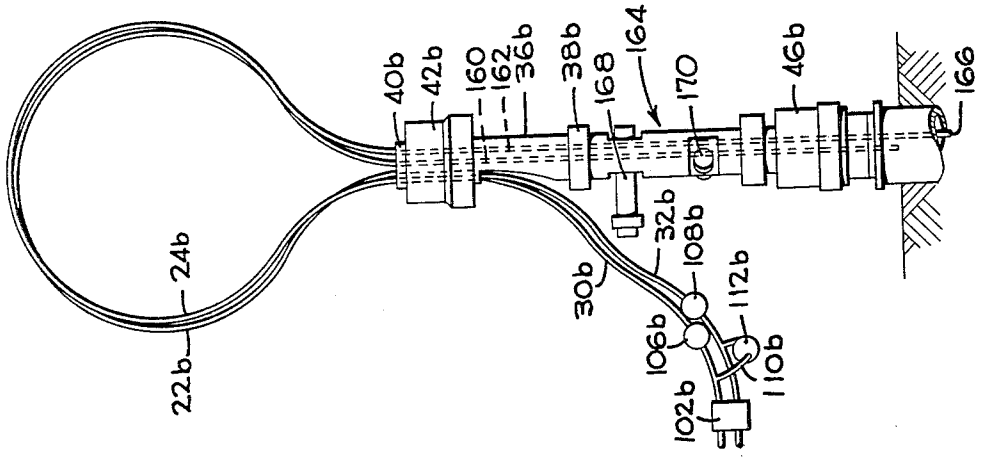
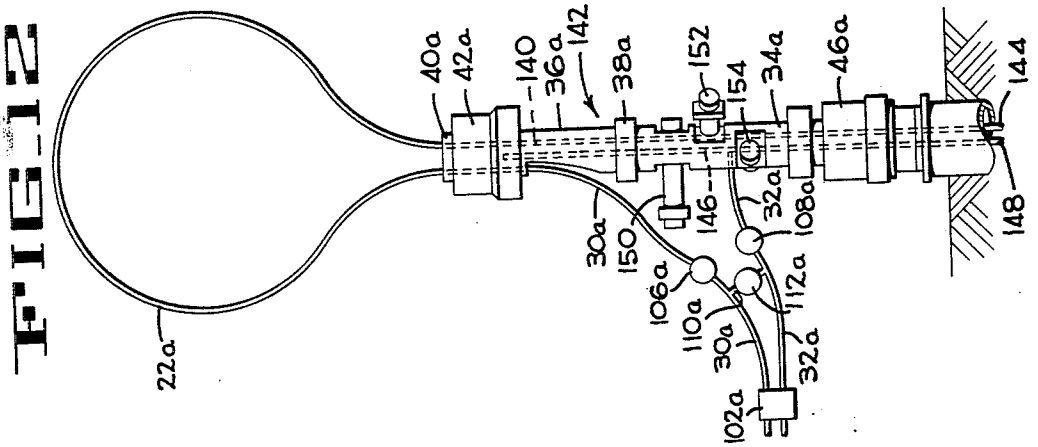


FIG-12



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United States Patent Office 3,473,605 Patented Oct. 21, 1969

3,473,605

UNDERWATER WELL COMPLETION APPARATUS

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Int. Cl. E21b 33/035; E21c 19/00
U.S. Cl. 166—.6 21 Claims

ABSTRACT OF THE DISCLOSURE

An underwater well completion apparatus including a remotely installable and controllable Christmas tree with straight-through bores to the production tubing and the well annulus, and at least one flowline that comes out of the removable top of the tree, loops back and returns through the top, and then exists downwardly and laterally from the upper part of the tree, simplifying vertical access into the tree and providing a passageway for pump-down tools.

BACKGROUND OF THE INVENTION

The field of art to which the present invention relates includes apparatus for use in completing oil and gas wells, and more particularly to wellhead apparatus for completing underwater wells. Further, the invention relates to that field of art including Christmas trees that provide straight-through vertical access to the production tubing and the well annulus, and to flowline loops for conducting pump-down tools for "through-the-flowline" well operations.

In recent years the interest in locating and producing undersea deposits of oil and natural gas has increased at such a remarkable rate that today this activity is world-wide in scope. Current procedures for underwater completion of wells into these deposits usually involve the installation of a Christmas tree on the wellhead at the ocean floor, and then connecting flowlines to the tree to conduct the produced fluids to a remote storage location. The tree should be designed to provide straight-through access to the well below it so that maintenance and other servicing procedures can be carried out from a ship or platform positioned above at the water surface. The well also should be accessible to pump-down tools that are circulated through the flowlines and the production tubing by hydraulic pressure to perform a variety of "through-the-flowline" well operations. A concise but highly informative article covering this development and the current status of technology in this field is entitled "Deep Water Completions Extend Technological Thresholds," beginning on page 103 of the November 1966 issue of Petroleum Engineer.

As explained in this article, in order to be able to use pump-down tools the passageways in the flowlines, and of course through the tree into the production tubing, must be either straight or curved with a minimum radius of approximately five feet, i.e., they cannot be sharply angled and any curve in their path cannot be tighter than any segment of a circle with a five foot radius, for the pump-down tools presently available will bind in a line with a curve of lesser size. To provide both straight-through vertical access and a properly curved flowline to the well bore, the Christmas tree customarily is made of one or more solid block valve assemblies having straight-through bores connecting to the production tubing and well annulus, and a generally Y-shaped spool on top of these assemblies. This Y-spool has a base or stem with straight-through bores connecting with the valve assembly bores, and lateral arms with bores gradually curving away from the stem bores and connecting with the flowlines. As in the conventional land-type Christmas tree, this type of

underwater tree has master valves, wing valves, and swabbing valves, the master valves located in the block valve assemblies, the wing valves in the "arms" of the Y-spool, and the swabbing valves in the Y-spool stem above the juncture of the curved and straight-through bores.

One of the problems with this tree lies in the fact that manufacturing the Y-spool, and especially machining the curved bores in the arms, is quite difficult and expensive. Another problem with such a Y-shaped system is that flowline diverters must be placed in the stem bores above their junctures with the curved arm bores, so that pump-down tools return from the well into the flowlines rather than into the upper part of the stem bores where they would lodge in the spool. These diverters must be accurately positioned in the stem bores so that they do not obstruct the flowlines and restrict passage of the pump-down tools, and in order to make such positioning possible the diverters and their bores must be manufactured to close tolerances. Furthermore, debris or other solid particles may be entrapped by these diverters and create flowline obstructions that the pump-down tools cannot pass.

With these and other problems in mind, applicants have invented a new type of underwater well completion apparatus that provides all of the desired functions and advantages of the above described Y-type apparatus without its aforementioned problems and disadvantages.

SUMMARY OF THE INVENTION

Generally considered, applicants' invention comprises a new type of Christmas tree and flowline assembly for underwater well completions, the tree providing straight-through access to the well bore for routine maintenance and work-over from a position above the well, and the flowline connected to the tree without a Y-spool and providing diverter-free passages for pump-down tools. The invention includes a new Christmas tree with vertical, straight-through bores extending from the well to the top of the tree's upper unit or outlet spool, and one or more flowlines that connect to these bores at the top of the spool, course in a loop and return into the spool's top, and then curve out of the spool towards the ocean floor. The flowlines are attached to a spoon cap which in turn is attached to the top of the spool with a connector so that vertical access to the well bore is accomplished by merely releasing this connector and lifting the spool cap and the flowline loops off the tree. No swabbing valves are needed in this new apparatus, and no flowline diverters are required since the flowlines connect directly to the vertical bores, rather than to curved lateral offshoots thereof. The result is a greatly simplified structure that is easier and less costly to manufacture, is easier to operate, and has less parts, yet provides the same functions and facilities available in other undersea systems.

BRIEF DESCRIPTION OF THE DRAWING

FIGURE 1 is a view in perspective of a version of the underwater well completion apparatus of the invention installed on a well at the ocean floor.

FIGURE 2 is a view in section, on an enlarged scale, of a portion of one flowline loop as indicated by the circle in FIGURE 1, showing diagrammatically an assembly of pump-down tools in the line.

FIGURE 3 is a view of the upper unit or outlet spool of the Christmas tree of FIGURE 1, with the spool cap and connector removed, and showing a riser or conductor to which a blow-out preventer or a lubricator can be attached in the conventional manner for workover from the surface.

FIGURE 4 is a view in section on an enlarged scale, taken along the line 4—4 of FIGURE 1 showing the bores through the outlet spool and the adjacent external flowlines.

FIGURE 5 is a view in section, on the same scale of FIGURE 4, taken along the line 5—5 of FIGURE 1, showing the bores in the Christmas tree body and the relative position of the master valves.

FIGURE 6 is a view in side elevation, and on an enlarged scale, of the upper portion of the outlet spool, the spool cap, and a connector holding the two together, with part of the connector broken away to better illustrate how the spool and cap fit together.

FIGURE 7 is a view in perspective, and on an enlarged scale, of the upper end of the outlet spool illustrating the relative positions of the flowlines and the bores.

FIGURE 8 is a view in perspective, and on the same scale as FIGURE 7, of the outlet spool cap showing the relative positions of the flowlines and the bores.

FIGURE 9 is a view in vertical section, and on an enlarged scale, taken on the line 9—9 of FIGURE 7 and as though the spool cap of FIGURE 8 were in place, showing one way of sealing the bores between the spool body and the cap.

FIGURE 10 is a view in perspective of another configuration in which the flowline loops of FIGURE 1 may course.

FIGURE 11 is a view in perspective of still another flowline loop configuration within the scope of the invention.

FIGURE 12 is a view in side elevation of another version of the underwater well completion apparatus of this invention having only one flowline loop, showing one of the flowlines connected through this loop and a bore in the Christmas tree to one tubing string in the well, and the other flowline connected to the other tubing string directly through the tree body and a bore therein.

FIGURE 13 is a view in side elevation of yet another version of the apparatus of this invention installed on a well with only one tubing string, showing one flowline connected through a flowline loop and a bore in the tree to the tubing string, and the other flowline connected through the other loop and another bore to the well annulus.

FIGURE 14 is a view in side elevation of still another version of the apparatus of this invention, also installed on a well with but one tubing string, showing one flowline connected to the tubing string through the single flowline loop and a bore in the Christmas tree, and the other flowline connected to the well annulus directly through the tree body and another of its bores.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In reference to the drawings, and particularly to FIGURES 1 and 4 through 8, one version of the underwater well completion apparatus of the present invention comprises a Christmas tree **16** surrounded by a permanent guide structure **18** that is positioned on the ocean floor **20**, and flowline loops **22**, **24** connecting the bores **26**, **28** (FIGURE 5) through the tree **16** to flowlines **30**, **32** that lead to a remote storage location (not shown). The Christmas tree **16** includes a body **34** surmounted by an outlet spool **36**, the two joined together by a connector **38**, and a spool cap **40** secured through a connector **42** to the top of the spool **36**. The tree **16** is mounted on a whellhead **45** through a connector **46** and, as indicated in dotted lines, the well in this particular illustration has a casing **48**, one production tubing string **50**, and an associated tubing string **52**. These strings **50**, **52** are connected in the conventional manner to bores **26**, **28** in the Christmas tree body **34**, and each bore is provided with a master valve **54**, **56**, respectively, for controlling the fluid flow through the bore. A third bore **58** in the Christmas tree body **34** connects to the well annulus, and this bore is likewise provided with a master valve **60**.

The outlet spool **36** contains bores **62**, **64** coaxial with the bores **26**, **28**, respectively, in the Christmas tree body **34**, and a bore **66** that is coaxial with the tree body's bore **58**. The bore pairs **62** and **26**, **64** and **28**, and **66** and **58** thereby provide straight-through access from the top of the spool **36** to the strings **50**, **52**, and the well annulus, respectively.

In the drawings the connector **42** between the spool body **36** and the spool cap **40**, and the connector **46** between the Christmas tree body **34** and the wellhead **45**, are illustrated as hydraulically actuated, although connectors with other means for remote control are also suitable for this function. As shown in FIGURE 6, the connector **42** is secured to the spool cap **40**, such as by a threaded nut **43**, and has locking devices, such as dogs **44**, that move radially inwardly in response to hydraulic pressure to grip the top of the spool body **36** and hold it and the spool cap **40** together. A basic type of hydraulic connector for this purpose is shown and described in detail in Eckert et al. copending U.S. patent application Ser. No. 294,844, filed July 15, 1963, and entitled "Well Apparatus" now Patent No. 3,325,190. Preferably the connector **42** receives hydraulic pressure through a system of interconnected hydraulic passages (not shown) in the spool cap **40**, the spool cap lift-off post **70**, and its fitting **72**. The connector **46** may receive its hydraulic pressure for actuation through conventional lines **74** and a terminal fitting **76**. The fittings **72**, **76** provide a means for connecting in a remote hydraulic pressure system to control the connectors **42**, **46** in the usual manner. These details are not critical to the invention, and are shown to aid in an understanding of how the entire underwater completion apparatus is operated.

It should be understood that mechanically actuated connectors, or connectors of other types that are remotely controllable also may be used between the spool body **36** and the cap **40**, and also between the tree body **34** and the wellhead **45**. Furthermore, where the wellhead is in shallow water, i.e., within the reach of divers, clamps or other types of connectors such as that at **38** can be used if desirable.

As best illustrated in FIGURE 8, the inner ends **80**, **82** of the flowline loops **22**, **24**, respectively, are connected to the bores **84**, **86**, respectively, in the spool cap **40**, and the outer ends **88**, **90** of the loops **22**, **24**, respectively, connect with the bores **92**, **94**, respectively, of the cap. The bores **92**, **94** are coaxial with bores **96**, **98**, respectively, in the upper end of the spool **36**. As shown in FIGURE 7, the flowlines **30**, **32** connect to the bores **96**, **98**, respectively, and extend therefrom downwardly and outwardly along the face **100** of the relieved side of the spool **36**. The flowlines **30**, **32** pass through a flowline connector **102** (FIGURE 1), illustrated herein as a remotely controllable hydraulic type with a hydraulic pressure fitting **104**, and then continue on to the remote storage facility (not shown). In the conventional manner each of the flowlines **30**, **32** has a wing valve **106**, **108**, respectively, for controlling the flow of fluid in that line, and these flowlines are connected by a cross-over line **110** with a valve **12** which provides a means to reverse the flow of fluid and back the pump-down tools out of the line.

Although each of the master valves **54**, **56** and **60**, as well as the two wing valves **106**, **108** and the cross-over valve **112**, are herein illustrated as hydraulically operated, electrically or other remotely controllable valves may be used in their stead if desired. Furthermore, in those shallow water locations where divers are able to descend to the tree, manually operated valves may be employed. Since valves of these types are well-known, and their details are not critical to this invention, their further description appears unnecessary.

In looping around to return to the spool cap **40**, the flowlines **22**, **24** are curved in arcs that have a radius R (FIGURE 1) of about five feet or more. The dimension of this radius is dependent upon the type of pump-down tool that will be sent through the flowline, and as of

the present date all known pump-down tools require a passageway with a radius of at least about five feet. However it is to be understood that the flowline loops may be of smaller radius if pump-down tools are developed to pass through them. In other words, the scope of the invention is commensurate with the radius restrictions of pump-down tools, and is not limited to a specific radius dimension.

As illustrated in FIGURES 1, 10 and 11, the configuration of the flowline loops may be varied to suit the requirements of the location of the well. Where there is adequate water depth so that they would not present a problem to navigation, the flowline loops may extend upwardly as illustrated in FIGURE 1. In this configuration, the loops 22, 24 may lie closely together with just sufficient space between them to permit access with well tools, hydraulic lines, etc. to th lift-off post 70. Where the well is in shallower water, the flowlines may be looped more horizontally as indicated by 22*d*, 24*d* in FIGURE 10, or even downwardly as at 22*e*, 24*e* in FIGURE 11. As a matter of fact, there is no restriction on the configuration of the flowline loops other than the radius of the curvature of the loops that must be maintained to accommodate the particular pump-down tools that are to be employed. The loops may be formed from segments of tubing connected by conventional connectors 114, as shown in the drawings, or each loop can be formed from a single piece of tubing if desired.

When the outlet spool 36 and the spool cap 40 are connected, the aforementioned respective pairs of coaxial bores are sealed at their junctures to provide fluid-tight integrity, such as by a conventional sealing device 116 (FIGURE 9). This sealing device 116 has a metal slip-ring seal 118 on a carrier 120 that is threaded into the spool cap 40, so that when the cap is removed from the spool the sealing devices 116 are removed at the same time. This sealing device 116 is further illustrated and described in the aforementioned Eckert et al. application Ser. No. 294,844, its details not being critical to this invention. Note that the bore 66 coming from the well annulus also is sealed to its corresponding bore 122 in the spool cap 40, the bore 122 in this version of the invention dead-ending in the cap 40 since the annulus is not connected to a flowline. Other types of well-known sealing devices and systems may be used in lieu of, or in addition to, the device 116 if desired.

As is evident from the foregoing, when the well is entered from above a pipe string with a hydraulic line is lowered and connected to the attachment 72 on the top of post 70, and the hydraulic connector 42 is actuated and released. The pipe string is then lifted, removing the connector 42, the spool cap 40, and the flowline loops 22, 24 from the top of the spool 36. This provides direct vertical access through the bores 62, 64 and 66 to the production tubing string 50, the associated tubing string 52, and the well annulus, respectively, to facilitate workover, etc., operations from the surface through a riser 123 (FIGURE 3) and blow-out preventers or lubricators (not shown) in the conventional manner. Since the spool cap 40 and the connector 42 are linked as by brackets 124 to the guide cables 126 running to the surface from the platform 18, reconnecting the cap and the flowline loops on the Christmas tree is a simple matter of merely lowering them back down the guide cables until the cap comes to rest on the spool, and actuating the connector.

The pump-down tools for use in this underwater well completion apparatus comprise an assembly of units interconnected through universal joint-type couplings to facilitate pivotal movement between the units. As illustrated diagrammatically in FIGURE 2, such an assembly 127 may be made up by interconnecting operating tools 128, which might be paraffin scrapers, valves of various types, regulators, etc., with piston units 130 that provides a seal between the unit and the wall of the passage in which the tools are positioned to function as driving members of the assembly. The length L (FIGURE 2) of the assembly 127 is unrestricted insofar as this invention is concerned, the only condition being that whatever tool or length is chosen will pass through a flowline loop with a radius R (FIGURE 1), the dimension of which is not less than the tightest arc into which the assembly 127 can be curved.

FIGURES 1–11 illustrate the employment of this invention on a well completed with a single production tubing string 50. In this version of the invention, a second or associated tubing string 52 is installed, and the two flowlines 30, 32 are connected to these strings 50, 52, respectively, through two flowline loops 22, 24, respectively, so that pump-down tools may be sent through either flowline 30, 32 and into either tubing string 50, 52. Of course, the two strings 50, 52 are connected down in the well, and usually in the approximate area of their lower ends, by a cross-over (not shown) to facilitate fluid circulation through these strings, and thus running pump-down tools in either string and returning them in the same string, all in the conventional manner. In a dual or other multiple completion system, more strings of tubing may be required, as well as flowline loops and flowlines, to provide adequate circulation systems for each of the flowlines and strings in which pump-down tools will be sent. Such equipment and facilities are also within the scope of this invention.

FIGURES 12, 13 and 14 illustrate diagrammatically three additional versions of the invention as described and illustrated above. In FIGURE 12, the flowlines 30*a*, 32*a* coming from the remote storage area travel through a flowline connector 102*a* and valves 106*a*, 108*a*, respectively, and then diverge. The flowline 30*a* continues through the spool 36*a* and its cap 40*a* into the single flowline loop 22*a* that connects through a vertical bore 140 in the Christmas tree 142 to the production tubing string 144. The flowline 32*a* enters the body 34*a* of the tree 142 directly to connect to a second vertical bore 146 that leads to the associated tubing string 148. This version is designed for use where "through-the-flowline" procedures are to be performed only on the production tubing string, hence a second flowline loop is unnecessary. In this version the Christmas tree 142 has a third vertical bore (not shown) running from the top of the tree to the well annulus, three master valves 150, 152, and 154 to control the flow in the three bores, and a cross-over 110*a* and valve 112*a* between the flowlines 30*a*, 32*a*, just as in the version of FIGURES 1–11. Furthermore, the remaining parts of the apparatus also are the same as in the FIG. 1–11 version, except that the bore 146 terminates in the spool cap 40*a* since there is no flowline loop for it to connect with above the cap.

In FIGURE 13 the underwater completion apparatus resembles that of FIGURES 1–11 in that it also has two flowlines 30*b*, 32*b*, a flowline connector 102*b*, flowline valves 106*b*, 108*b*, a cross-over 110*b* and a valve 112*b*, and two flowline loops 22*b*, 24*b* that connect with the flowlines 30*b*, 32*b* through the spool 36*b* and its cap 40*b*, and with two vertical bores 160, 162, respectively, in the Christmas tree 164. However, in the FIGURE 13 version the bore 160 communicates with the well annulus and the bore 162 connects to the production tubing string 166. There is no associated tubing string, and the Christmas tree 164 has only two vertical bores 160, 162 each with a master valve 168, 170. In this arrangement, circulation is obtained by using the well annulus as a cross-over between the production tubing string 166 and the lower end of the bore 160. Of course, pump-down tools can be run in both flowlines and flowline loops, the passageway formed by the flowline 30*b*, flowline loop 22*b*, and bore 160 being used primarily for completing the circulation through the other line-loop-bore passageway, and for accommodating pump-down tools to perform control operations on the well, such as setting a plug in the wellhead before removing the tree.

FIGURE 14 illustrates another version of the apparatus of this invention, similar in some respects to that of FIGURE 13 but differing in that the flowline 32c enters the body of the Christmas tree 170 directly and connects with the bore 172 that extends vertically from the spool cap 40c through the tree to the well annulus. Furthermore, this version has only one flowline loop 22c that connects the flowline 30c to the second vertical bore 174 in the tree, the bore 174 connecting at its lower end to a production tubing string 176. A pair of flowline valves 106c, 108c, a cross-over 110c and its control valve 112c, and a flowline connector 102c are also included in this version, and the tree 170 has a pair of master valves 178, 180 for controlling the flow in its bores. The well annulus is used to complete the circulation between the production tubing string 176 and the bore 172, as in the FIGURE 13 version, and pump-down tools are used only in the flowline 30c, etc., as in the FIGURE 12 version.

The upper connectors 42a, 42b, and 42c, the lower connectors 46a, 46b, and 46c, and the intermediate connectors 38a, 38b, and 38c, of the versions of FIGURES 12, 13 and 14, respectively, are analagous to their counterparts in FIGURES 1–11. Of course, the supporting structures, guides, etc. as shown in FIGURE 1 are also used in the versions in FIGS. 12–14, but have been left out of these figures for the sake of simplicity.

If desired, a second or even a third set of master valves can be included in any and all of the versions of this invention, merely by the addition of a second or third Christmas tree body, these bodies being connected together in the usual manner with connectors, clamps, bolted flanges, or the like.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from what is regarded to be the subject matter of the invention as set forth in the appended claims.

Having completed a detailed description of the invention so that those skilled in the art could practice the same, we claim:

1. An underwater well completion apparatus adapted for installation on a well having a casing and one or more tubing strings disposed therein, comprising:

(a) a Christmas tree assembly including a Christmas tree having a plurality of straight first flow passages extending vertically therethrough, flow control means in said Christmas tree to control fluid flow through at least one of said first flow passages, at least one second flow passage extending from the top of said tree to an exit between the top and bottom of said tree, and a removable cap for the top of said tree having at least one third flow passage and at least one fourth flow passage positioned so that when said cap is mounted on said tree said third flow passage is coaxial with one of said first flow passages and said fourth flow passage is coaxial with said second flow passage;

(b) a flowline assembly comprising a plurality of flowline passages, one of said flowline passages adapted for connection to said exit of said second flow passage, and a second flowline passage adapted for fluid communication with another of said first flow passages, thereby providing a plurality of flowline passages between said Christmas tree assembly and a remote location; and

(c) a flowline loop assembly mounted on the cap of said Christmas tree assembly and having at least one flowline loop passage with inner and outer ends, said inner end connecting to said third flow passage of said cap and said outer end connecting to said fourth flow passage of said cap, whereby said flowline passages, said second and fourth flow passages, said flowline loop passages, and said third and first flow passages, respectively, form a continuous fluid circulation system between said remote location and said well, and whereby removal of said cap provides vertical access straight through said first flow passages and said flow control means to said well.

2. The apparatus of claim 1 wherein there is one flowline loop with one flowline passage.

3. The apparatus of claim 1 wherein there are at least two flowline loops, each with a flowline passage.

4. The apparatus of claim 1 wherein said flowline loop assembly extends generally above said Christmas tree assembly.

5. The apparatus of claim 1 wherein said flowline loop assembly extends generally laterally from said Christmas tree assembly.

6. The apparatus of claim 1 wherein said flowline loop assembly extends generally downwardly from said Christmas tree assembly.

7. The apparatus of claim 1 including a cross-over passage between said selected tubing string and said first flow passage aligned with said well annulus.

8. The apparatus of claim 7 including a flowline cross-over passage between said flowline passages, and flow-control means in said flowline cross-over passage.

9. The apparatus of claim 1 wherein said Christmas tree includes a body and an outlet spool, said spool mounted on top of said body, and said cap mounted on top of said spool.

10. The apparatus of claim 9 wherein said outlet spool contains the upper portions of said first flow passages, and all of each of said second flow passages.

11. The apparatus of claim 10 wherein said exit of each of said second flow passages is positioned near the top of said spool.

12. The apparatus of claim 9 wherein said body is connected to said wellhead and said cap is connected to said spool by releasable connection means.

13. The apparatus of claim 12 wherein said releasable connection means are fluid actuated.

14. The apparatus of claim 12 wherein said releasable connection means are mechanically actuated.

15. An underwater well completion apparatus adapted for installation on a well having casing and tubing strings disposed therein, comprising:

(a) a Christmas tree assembly including a Christmas tree with a plurality of straight first flow passages extending vertically therethrough and at least one second flow passage extending from the top of said tree to an exit between the top and bottom of said tree, and a removable cap for the top of said tree with at least one third flow passage and at least one fourth flow passage positioned so that when said cap is mounted on said tree said third flow passage is coaxial with one of said first flow passages and said fourth flow passage is coaxial with said second flow passage;

(b) a tubing string assembly including at least two tubing strings, and at least one crossover passage between two of said strings;

(c) a flowline assembly comprising a plurality of flowline passages one of which is adapted for connection to said exit of said second flow passage and another of which is adapted for fluid communication with another of said first flow passages; and

(d) a flowline loop assembly mounted on the cap of the Christmas tree assembly and having at least one flowline loop passage interconnecting said third and said fourth flow passages,

whereby when said well completion apparatus is assembled and installed on a well with said tubing strings connected to said first flow passages a continuous fluid circulation system betwen said flowline assembly and said well is established, and removal of said cap provides a straight-through vertical access to said well.

16. The apparatus of claim 15 including a flowline cross-over passage between said flowline passages, and

flow control means in said flowline cross-over passage.

17. An underwater well completion apparatus adapted for installation on a well having casing and tubing strings disposed therein, comprising:

(a) a Christmas tree assembly including a Christmas tree comprising a body and an outlet spool, said spool mounted on top of said body, said Christmas tree having a plurality of straight first flow passages extending vertically therethrough and at least one second flow passage extending from the top of said tree to an exit between the top and bottom of said tree, and a removable cap for the top of said tree with at least one third flow passage and at least one fourth flow passage positioned so that when said cap is mounted on said tree said third flow passage is coaxial with one of said first flow passages and said fourth flow passage is coaxial with said second flow passage;

(b) a flowline assembly comprising a plurality of flowline passages one of which is adapted for connection to said exit of said second flow passage and another of which is adapted for communicating with another of said first flow passages;

(c) a flowline loop assembly mounted on the cap of the Christmas tree assembly and having at least one flowline loop passage interconnecting said third and said fourth flow passages; and

(d) means in said body to control the fluid flow in said passages,

whereby when said well completion apparatus is assembled and installed on a well a continuous fluid circulation system between said flowline assembly and said well is established and removal of said cap provides a straight-through vertical access to said well.

18. The apparatus of claim 17 wherein said means are remotely controllable.

19. A Christmas tree assembly especially suitable for use on an underwater well, comprising:

(a) a Christmas tree having at least one straight first flow passage extending vertically therethrough for providing communication with the well, and at least one second flow passage extending from the top of said tree to an exit between the top and bottom of said tree for providing communication to an external flowline;

(b) flow control means in the Christmas tree to control fluid flow through at least one of the first flow passages; and

(c) a removable cap above the flow control means and on top of the Christmas tree, said cap having at least one third flow passage coaxial with one first flow passage, and at least one fourth flow passage coaxial with one second flow passage;

whereby interconnecting a third and fourth flow passage establishes flow communication between said external flowline and said well, and removal of said cap provides straight through vertical access through said tree to said well.

20. A Christmas tree assembly according to claim 19 including at least one fifth flow passage interconnecting one third and one fourth flow passage in said cap.

21. A Christmas tree assembly according to claim 20 wherein the fifth flow passage comprises a flowline loop assembly connected to the cap.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,473,605 Dated October 21, 1969

Inventor(s) THUSE et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 17, before "downwardly" change "exists" to -- exits --; line 63, after "made" insert -- up --.
Column 2, line 43, before "cap" change "spoon" to -- spool --.
Column 4, line 58, after "valve" change "12" to -- 112 --.
Column 5, line 17, before "lift-off" delete "th" and insert -- the --.

Signed and sealed this 13th day of July 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
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WILLIAM E. SCHUYLER, JR.
Commissioner of Patents