The invention provides a Christmas tree for a wellbore, comprising a plurality of modules, each module including at least one module opening, the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous passage through the housing, said continuous passage being adapted to be connected to the wellbore; a retrievable valve insert arranged in the module opening; and control means coupled to the module to control the valve insert between a closed position and an open position.
CHRISTMAS TREE AND METHOD

[0001] The invention relates to Christmas tree for a wellbore and to a method of retro-fitting a Christmas tree with safety valves.

[0002] Hydrocarbon wellbores are typically provided with a so-called Christmas tree at surface. Said Christmas tree may contain one or more valves to close a fluid channel in the event of emergency or for other reasons like maintenance or repair. The Christmas tree is typically arranged on a wellhead. In general the Christmas tree is arranged above ground level. Off-shore, the tree would be at the sea bottom and on shore on land. The Christmas tree may conventionally comprise a header connected of a solid block of material, wherein a predetermined number of valves and fluid connections is included, such as gate valves having a slide slideable transverse to a bore. Said slide may be manually, hydraulically or pneumatically operated.

[0003] Safety valves arranged below the wellhead are usually arranged at a depth of 100-150 meters below ground level. These safety valves are in the field frequently indicated as sub surface safety valves (SSSV). Known sub surface safety valves are provided as an elongate tubular component which is inserted in the production tubing as tubing retrievable or wire retrievable. In case of tubing retrievable, the component is provided at its upper end and lower end with connection means, like screw thread, for attachment to an upper and lower part, respectively, of the production tubing so that the lower production tubing part, tubular component and upper production tubing part form a continuous string. In order to retrieve a tubing retrievable component, the whole tubing has to be withdrawn from the wellbore up to the component surfaces. Components may be retrievable by wireline, wherein the tubular component is inserted as a plug into the production tubing, and fixed to the inner wall of the production tubing. Fixing may include a landing nipple provided inside the production tubing and a lock mandrel having keys provided on the outside of the tubular component. For retrieving a wireline retrievable component, a wire provided with a so called jar is lowered into the production tubing, the wire or jar is coupled to the component, the component is disengaged from the production tubing and subsequently retrieved by withdrawing the wire together with the connected component from the production tubing.

[0004] During the lifetime of the well, it may be desirable to change the setup of the wellbore as described above. For instance, additional tubing may be introduced in the wellbore to enable the injection of a treatment fluid or a velocity string to limit the diameter of the production tubing. The treatment fluid may for example be a soap-like substance to lower the surface tension of water in the well to limit liquid loading.

[0005] In practice, changing the setup of a producing wellbore is quite complicated, as the additional tubing has to be introduced through the Christmas tree, which has to be removed. The additional tubing has to be very flexible to allow insertion into the wellbore and to allow passage through the sub surface safety valve. Passage of the surface safety valve is in general achieved by introducing the additional tubing at a level lower than the surface safety valve or by first temporarily removing the surface safety valve, introducing the additional tubing, connecting the additional tubing to a side port below the surface safety valve and replacing the temporarily removed surface safety valve. This is all quite complicated and time consuming.

[0006] The invention aims to improve the flexibility of a producing wellbore.

[0007] According to a first aspect, the invention provides a Christmas tree for a wellbore, comprising a plurality of modules, each module including:

[0008] at least one module opening;

[0009] a retrievable valve insert arranged in the module opening, the retrievable valve insert being provided with at least one fluid passage; and

[0010] control means coupled to the module to control the valve insert between a closed position and an open position of the at least one fluid passage;

[0011] the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous conduit though the housing, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore.

[0012] The Christmas tree of the invention having retrievable valve inserts simplifies making changes to the wellbore setup. With a conventional tree, the entire tree would have to be removed and safety measures for well control must be established before tubing in the well can be introduced or replaced. The Christmas tree of the invention allows to replace valve inserts to repair broken valves, allows to remove valve inserts and to insert tubing in or remove tubing from the wellbore. Tubing or replacement valve inserts may for instance be introduced via a lock mechanism which may be arranged on top of the Christmas tree. Time required to maintain or update the wellbore setup will be significantly reduced.

[0013] In an embodiment, the continuous conduit is a straight cylindrical channel. Also, the continuous fluid passage may be a straight cylindrical passage.

[0014] In another embodiment, the valve inserts of each module may include at least two parallel fluid passages, the at least two fluid passages of the subsequent modules constituting at least two parallel continuous fluid passages though the continuous conduit of the housing. Herein, each module may comprise at least two control means coupled to the module, each control means enabling the control of the valve insert between a closed position and an open position of one of the at least two fluid passages.

[0015] In an embodiment, the control means are releasably coupled to the valve insert of the respective module.

[0016] The valve inserts may be retrievable by wireline.

[0017] According to another aspect, the invention provides a method of building a Christmas tree for a wellbore, comprising the steps of:

[0018] providing a plurality of modules, each module including at least one module opening;

[0019] connecting the modules to each other to form a housing, the respective module openings forming a continuous conduit through the housing;

[0020] arranging a retrievable valve insert in the module opening of the modules, each retrievable valve insert being provided with at least one fluid passage, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore; and
[0021] Coupling control means to each module to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage.

[0022] The term “wellbore”, as used in the present application, may imply for instance “wellbore for the production of hydrocarbons”, but also “injection wellbore for pressurizing a sub-surface formation in order to force hydrocarbons to surface” and “storage wellbore for sub-surface storage of hydrocarbons”. The term “valve” may imply a valve arranged in the path of a fluid flow to enable interruption of said flow.

[0023] The invention will now be explained by way of example with reference to the accompanying drawings, wherein:

[0024] FIG. 1 shows a cross-section of an exemplary hydrocarbon wellbore, provided with a system for injecting a treatment fluid and a Christmas tree;
[0025] FIG. 2 shows a cross-section of an embodiment of a Christmas tree according to the invention;
[0026] FIG. 3a shows a cross-section of a safety valve assembly for use in combination with the Christmas tree of the invention, in blocked position;
[0027] FIG. 3b shows a cross-section of a safety valve assembly for use in combination with the Christmas tree of the invention, in flow position;
[0028] FIG. 4 shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;
[0029] FIG. 5 shows a cross-section of a wellbore provided with another embodiment of a Christmas tree of the invention;
[0030] FIG. 6 shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;
[0031] FIG. 7 shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;
[0032] FIG. 8 shows a cross-section of a wellbore provided with an embodiment of a Christmas tree of the invention;
[0033] FIGS. 9A-9B show cross-sections of embodiments of a velocity string insert for a hanger module of the Christmas tree of the invention;
[0034] FIG. 10 shows a cross-section of another embodiment of a Christmas tree of the invention;
[0035] FIG. 11 shows a cross-section of a wellbore provided with the Christmas tree of FIG. 10;
[0036] FIGS. 12A-12F show exemplary steps of a method to provide a Christmas tree according to the invention; and
[0037] FIG. 13 shows a cross section of yet another embodiment of a Christmas tree of the invention.

[0038] FIG. 1 shows a wellbore 1, comprising borehole 4 which has been drilled from surface 3 through a number of earth formation layers 5, 6, 7, 8 to a reservoir layer 9. The reservoir layer 9 comprises hydrocarbons, for example oil and/or gas. The wellbore 4 is lined with one or more casings 12A-12D and a liner 15 which is suspended from the casing 12C by means of a liner hanger 13. Casing 12A may also be referred to as conductor. Casing 12D may also be referred to as production casing. The liner 15 extends to the reservoir layer 9 and is provided with perforations 11 to allow fluid communication from the reservoir layer 9 to a production zone 10 of the wellbore 1.


[0040] A sub-surface safety valve assembly 17 (also called downhole safety valve 17) may be installed in the production tubing 14. The sub-surface safety valve 17 may be surface-controlled. The safety valve 17 may be located at a depth exceeding 50 m, for example at approximately 100 m. The safety valve 17 may close the production tubing 14, for instance in the event of an emergency. The safety valve 17 may be designed to be fail-safe, i.e. to automatically close the wellbore 4 in the event of failure or damage to the control equipment at surface. An annular space 25 is defined between the outer surface of the production tubing 14 and the casing 12D. A hydraulic control line 18 extends from surface 3 within the annular space 25 to the safety valve 17 to control the safety valve.

[0041] A packer member 24 may be arranged between the production tubing 14 and the liner 15 to substantially isolate the annular space 25 from the interior of the production tubing 14. The packer member 24 may comprise means for securing the packer member 24 against the wall of the liner 15, such as a slip arrangement, and means for establishing a reliable hydraulic seal to isolate the annular space 25. Said isolation means may for instance include an expandable elastomeric element or an inflatable packer. The portion of the production tubing 14 below the packer member 24 may be referred to as the tail.

[0042] The wellbore 1 may comprise a system for injecting a treatment fluid into the production zone 10, comprising a treatment fluid injection tubing 19 having an uphole supply end 20 and a downhole discharge end 21. The supply end 20 may be installed in or coupled to the Christmas tree 16.

[0043] The treatment fluid injection tubing 19 is arranged in the interior of the upper part of the production tubing 14, which upper part extends from the Christmas tree 16 to the safety valve 17. The treatment fluid injection tubing 19 passes the safety valve 17 and runs further downhole through the interior of the lower part of the production tubing 14 up to the discharge end 21 in the production zone 10. Thus, the treatment fluid injection tubing 19 extends below the safety valve 17 and below the packer member 24. The treatment fluid injection tubing 19 may be several kilometers long.

[0044] The inner diameter of the pipes may be less than 1 cm, preferably less than 0.5 cm. The inner diameter of the tubing 19 may be much larger than 1 cm as well, for example 2.5 cm or larger. The additional tubing 19 can be stiff or rigid. The lower end of the treatment fluid injection tubing 19 might comprise a treatment fluid injection valve 22.

[0045] The additional tubing 19 is described as a system for injecting a treatment fluid into the production zone 10. This is just an example of additional tubing which can be useful in a wellbore. Additional tubing 19 for other purposes is also conceivable. Tubing 19 might also serve as a guide to insert a measurement device, a tool, an inspection means (like a camera), or any other object to any level between the wellhead 2 and the production zone. Further, additional tubing might serve the purpose of taking a sample from any level between the wellhead and the production zone.

[0046] As shown in FIG. 2, an embodiment of a Christmas tree 16 may comprise an original tree 16a and an additional spool module 16b on top of the original tree 16a. The additional spool module 16b is part of a retro fit assembly comprising this spool module 16b and a valve assembly 40. The
spool module 16b enables to mount the valve assembly 40 in the tree part 16a by hanging off constriction 43.

[0047] The term `original tree` may imply a Christmas tree of an existing wellbore. The tree 16a may comprise a swab valve 31, a lower master valve 32 and an upper master valve 33. Controls (not shown) of the respective valves may include hand-controlled wheels extending to sides of the tree. In addition, the tree may comprise a kill wing valve 34 mounted on a kill wing port 38 and a flow wing valve 35 mounted on the flow wing port 39 for discharging production flow. The lower end of the original tree 16a may be mounted on the wellhead 2. The production tubing 14 may hang off a lower end of the tree or the wellhead 2.

[0048] The spool 16b may be mounted on the upper end of the tree 1a. The upper end of the spool 16b may be closed by a cap 36 provided with a pressure gauge 37. The cap 36 with pressure gauge 37 may previously have been mounted on top of the tree 16a.

[0049] The spool module 16b is provided with hanger nipples, for instance upper hanger nipple 41 and lower hanger nipple 42. The hanger nipples may include circumferential recesses formed in the inner wall of the spool module 16b. An internal surface of lower end of the spool module 16b may be provided with a constriction or seat surface 43.

[0050] The spool module 16b may be provided with a side port 45 and valve 44 to allow fluid flow to exit or enter the spool module 16b. Hydraulic ports 46, 47 provide a fluid passage for hydraulic fluid to allow control of a hydraulically operated device inside the spool module.

[0051] The valve assembly 40, shown in FIG. 2, may comprise an insert assembly comprising three parts: a lower insert part 51, an upper insert part 52 and a bull plug 53. In the drawing, parts 51, 52 and 53 are shown, in disassembled state, on the same vertical level with respect to the spool module 16b and tree 1a as they will have when mounted in the spool module and tree. The locking dogs 79 will engage in the landing nipple 42. The locking dogs 79 and landing nipple 42 will preferably lie on the same horizontal line.

[0052] The lower insert part 51 comprises for instance a massive body of steel having two longitudinal fluid passages. A first passage 54 may have a large diameter and a second passage 55 may have a smaller diameter. Both passages 54 and 55 have an open lower end 56, 57 and open upper end 58, 59. A spring biased flapper valve 60, 61 may be provided in one passage or in both passages. The flapper valves 60, 61 are shown in open position. In closed position the flapper valves 60, 61 will shut off the passages 54 and 55 completely to prevent fluid flow through the passages 54 and 55. A radial bore 62 provides a side port in the first passage 54.

[0053] The lower insert part 51 is optionally provided with hydraulic line 92. The hydraulic line 92 may be mounted into the spool 16b, 16c, the hydraulic line 92 will be connected with hydraulic port 47. Hydraulic line 92 can be used for operation of a wide range of devices, for example to operate one of the flapper valves 60, 61. The line 92 may also be used to operate a device arranged below the first insert part 51 inside the tubing 14. A hydraulically operated device may for instance be arranged near the downstream end of the wellbore.

[0054] To provide sealing, the lower insert part 51 may be provided with seals selected from the group of: one or more outer seals 65 extending all around the circumference of the lower end of the insert part; one or more outer seals 91 extending around the circumference of the upper end of the lower insert part; one or more inner seals 66 provided in the second passage; one or more inner seals 67 provided in the first passage above the bore 62; one or more inner seals 68 provided in the first passage below the bore; and one or more inner seals 93 provided in the first passage at the lower end of the first passage.

[0055] To mount the lower insert part 51 in the tree 16, the cap 36 may be removed and the lower insert is lowered into the spool module 16b until the downward facing support surface 63 engages the corresponding seat surface 43. Tie down bolts 69 may fix the lower insert part 51 in the spool module 16b. When the support surface 63 engages the mating seat surface 43, the lower end of the lower insert part 51 projects into the upper end of the production tubing. The lower end of the lower insert part 51 fits like a plug in the upper end of the production tubing 14. The outer seal 65 seals circumferentially against the inner side of the production tubing 14 to prevent fluid from bypassing between the outside of the insert assembly and the inside of the production tubing. A further tubing 84 might be connected to the lower port 57 of the second passage 55.

[0056] The upper insert part 52 may comprise a body part 71 supporting a first tube 72 and a second tube 73. To accommodate the first and second tube in slidable manner in the upper insert part, the upper insert part is provided with passages corresponding to the passages in the lower insert part. The diameter of the first tube 72 is smaller than or about equal to the diameter of the first passage 54 so that the first tube can slide vertically within the first passage. Correspondingly, the diameter of the second tube 73 is less than or about equal to the diameter of the second passage 55 so that the second tube can slide within the second passage 55. Both tubes 72 and 73 are connected to a common piston member 74. The first tube 72 has an upper end 77 and the second tube 73 has an upper end 78. The lower ends of both tubes 72, 73 are open. The piston member 74 is immovable with respect to the tubes 72 and 73. A spring 76 may bias the piston member 74 in upward direction, the blocking direction. In order to be able to pull the tubes 72 and 73 downward against the action of the spring 76, a hydraulic pressure chamber 55 may be provided adjacent to the piston member 74. Hydraulic medium can be introduced in or removed from the hydraulic pressure chamber via hydraulic port 46.

[0057] To mount the upper insert part 52 in the tree 16, the cap 36 may be removed and the upper insert is lowered into the spool 16b until the locking dogs 79 are radially aligned with the lower hanger nipple 42. The locking dogs 79 may be spring biased so that they automatically engage in the lower hanger nipple. In order to prevent disengaging of the locking dogs 79 from the lower hanger nipple, the locking dogs may be fixed to prevent them from withdrawing in radial inward direction. When the locking dogs engage in the lower hanger nipple, the first tube 72 projects into the first passage 54 and the second tube 73 projects into the second passage 55. The inner seal 66 seals circumferentially against the outer side of the second tube 73 and the inner seals 67 and 68 seal circumferentially against the first tube 72 to prevent fluid from bypassing between the inner side of the respective passage and the outer side of the respective tube.

[0058] During mounting of the upper insert part 52 in the tree 16, the second tube 73 will push the flapper valve 61 in the open position. The flapper valve 60 will however not be opened by the first tube as the flapper valve 60 is arranged lower. In case the flapper valve 60 would be arranged higher and/or in case the first tube would be longer, also the flapper
valve 60 would be opened when mounting the upper insert part 52 in the tree. Similarly, opening of the flapper valve 61 would not occur during mounting of the upper insert part in the tree, in case the flapper valve 61 would have been arranged lower and/or in case the second tube would be longer. In mounted condition, an outer seal 85 prevents bypass between the spool wall and the outside of the upper insert part 52.

[0059] FIG. 2 shows the tubes 72 and 73 pushed downwards in a flow position. Herein, the first tube 72 has pushed the flapper valve 60 open. In case the flapper valve 61 would have been arranged lower and/or the second tube would have been longer, also the flapper valve 61 would have been opened by the second tube 73. When the tubes are in the flow position, the radial aperture 80 in the first tube 72 is radially aligned with the bore 62 and the side port 39.

[0060] When the tubes are in the so-called flow position, production fluid can, as indicated with arrows 81 and 82, flow from the production tubing into the lower end of the first passage, into the lower end of the first tube, through the first tube 72, through the radial aperture 80, through the bore 62 into the side port 39 of the original tree 16a. The first passage 54 in the upper insert part 52 has a closed upper end, whilst the first tube 72 is preferably open at its upper end. Alternatively, the upper end 77 of the first tube might be closed, in which case the upper end 83 of the first passage 54 in the upper insert part 52 has preferably a venting opening.

[0061] Upon relieving the pressure in the pressure chamber 75, the piston member 74 and tubes 72, 73 will be pushed upwards by the spring 76 to the blocking position. In this blocking position, the flapper valve 60 will be closed and the radial aperture 80 will be in place against the inner wall of the first passage 54 so that no flow is possible.

[0062] A secondary fluid flow through the second passage 55 and second tube is possible both in the blocking position and in the flow position of the tubes 72, 73. This is due to the fact that in this configuration the flapper valve 61 is always open, that the second tube is open at both ends, and that the second passage is open at both ends 57 and 84. This secondary flow can leave or enter the tree via the side port 45 and may be controlled by a control valve 44. Taking into account that the second tube 73 and second passage 55 always allow flow, it is also possible to use these for introducing—for example by means of a wireline—instrument, tool, sensor or other device into the wellbore.

[0063] In order to prevent leakage of any fluid through the upper end of the spool 16b, a bulk plug 53 may be provided. This bulk plug 53 has locking dogs 86 for locking engagement in upper landing nipple 41 and an outer seal 87.

[0064] FIG. 3a shows the assembly in blocking position (the valves being closed) and FIG. 3b shows the assembly in flow position (the valves being opened). The safety valve assembly 17 of FIGS. 3a, 3b may be used as a safety valve assembly, either as a sub-surface safety valve or as a surface safety valve. A surface safety valve, including valve assembly 17, may be included in the Christmas tree of the present invention.

[0065] The safety valve assembly 17 may be configured as one unit, which may be installed in the production tubing 14 and/or in the Christmas tree 16. The safety valve 17 may be installed or retrieved by wireline. The safety valve 17 may be fixed inside the production tubing or Christmas tree using, for instance, a landing nipple formed in the internal surface of the production tubing or Christmas tree and locking dogs provided on the outer surface of the safety valve assembly 17.

[0066] The safety valve assembly 17 may comprise an insert assembly arranged in a cylindrical housing 100 which is except for passages to be described closed at its upper side 121 and lower side 122. The cylindrical housing 100 is provided with two passages, a first passage 101 and a second passage 103. Both passages extend from the lower end face of the housing 100 up to the upper end face of the housing 100. A tube is arranged in each passage. First tube 102 is arranged in the first passage 101 and second tube 103 is arranged in second passage 104.

[0067] A control compartment 123 is provided inside the housing 100. This control compartment comprises a spring 106, a piston member 105 and a hydraulic pressure chamber 107. The first and second tube 102 and 104 are both fixed to and immovable with respect to the piston member 105. The spring 106 pre-biased the piston member 105 in upward direction. The hydraulic pressure chamber 107 exerts a downward force onto the piston member 105 when it is filled with a hydraulic fluid—indicated by arrow 124—under a pressure sufficient to overcome the force of the pre-biased spring 106. In order to prevent leakage of hydraulic medium from the pressure chamber to the spring 106, a seal 114 may be mounted to the piston member 105 for sealing engagement with the inner wall of the control compartment 123.

[0068] The tubes 102 and 104 may be provided with one or more radial apertures 108 and 109, respectively. The lower ends 110 and 111 of both tubes are preferably closed. The upper ends 125 and 126 of both tubes (see FIG. 3b) are both open to allow passage of fluid.

[0069] A pressure equalizing line 119 may be provided in the lower part of the housing. The pressure equalizing line 119 debouches with its lower end into the internal 127 of the production tubing. In order to prevent pressure build up in the compartment containing the spring upon compression of the spring 106, the pressure equalizing line may debouch in the compartment containing the spring 106. Due to the lower end 110 of the first tube being closed, the first tube might experience large upward forces if the pressure in the internal space 127 of the production tubing increases. Correspondingly large hydraulic pressure in the pressure chamber 107 may be required to push the tubes downward. The hydraulic power required to push the piston member 105 and tubes 102, 104 downward may be reduced by providing the pressure equalizing line 119 with an equalizing port 121 debouching into the passage 101 at a location below the radial passage 108 when the first tube is in its blocking position. Above and below the equalizing port 121, a circumferential seal 117 and circumferential seal 118 are provided to define a pressure equalizing space around the first tube 102. When the first tube 102 is pushed downwards, the equalizing line 119 provides fluid communication between the internal 127 of the production tubing and the internal of the first tube 102 as soon as the radial aperture 108 passes the upper seal 117. As a result, the upward pressure acting on the closed lower end 110 of the first tube is compensated for.

[0070] Outer seals 112 and 113 are provided on the outside of the housing 100. The seals extend around the housing 100 and seal against the inner wall of the production tubing to prevent bypass of hydrocarbon fluid (gas and/or liquid) around the insert assembly 17. To prevent bypass around the tubes 102 and 104 through the passages 101 and 103, respectively, several inner seals 115, 116, 117 and 118 may be provided.
The first passage 101 communicates at both ends with the inner space 127, 129 of the production tubing 14. The second passage 103 is at both ends sealingly connected to a further tubing 84, which extends through the production tubing. The diameter of the second tube 104 will consequently be smaller than the diameter of the additional tubing 84. It is noted that depending on circumstances, the second tube 104 can also be absent or might have an open bottom end. Absence of the second tube 104 or an open bottom end of tube 104, allows the additional tubing to be used easier as guide channel for an instrument, sensor, tool or other device to be brought deep into the wellbore. Note however, that, although less easy due to the radial passage 109, this guide function can also be provided in the presence of the second tube 104 having closed end 111.

The safety valve assembly 17 functions as follows. FIG. 3A shows the blocked position, in which there is no flow communication between the upper end and the lower end of the insert assembly. In the blocked condition, the spring exerts a pre-tension force directed in upward direction in order to keep the piston member and tubes in blocked position. Starting from the blocked position, hydraulic fluid is supplied (indicated by arrow 124) to the hydraulic pressure chamber 107. The fluid forces the piston member 105 and tubes 102 and 104 downward to the flow position, shown in FIG. 3B.

In the flow position, hydrocarbons (gas and/or liquid) can flow through radial apertures 108 into the first tube 102, flow upward through the first tube 102 and leave the first tube 102 to enter the production tubing 14 at a location above the insert assembly 100. Similarly, a treatment fluid or other fluid can be passed in the opposite direction through the insert assembly when the piston member 105 and tubes 102 and 104 are in flow position. Treatment fluid may arrive through additional tubing 84 at the upper end of the insert assembly 100. The fluid enters the second tube 104 through its open upper end 126, passes through the second tube 104 downwards and leaves the second tube 104 through the radial aperture(s) 109 to continue downwards through the part of the additional tubing 84 extending below the insert assembly 100. To keep the insert assembly 100 in the flow position, the increased pressure in the pressure chamber 107 is to be maintained. To close the safety valve assembly 17, the hydraulic pressure in the pressure chamber is released (reduced) and the spring 106 will push the piston member 105 and tubes 102, 104 to the blocked position shown in FIG. 3A. This functions as a failsafe mechanism.

As shown in FIGS. 4 and 5, a Christmas tree 160 according to the invention may comprise a number of modules 162, 164, 166, 170. Each module is provided with a module opening 172. The modules are connected to each other to form a housing 174. The module openings 172 together form a continuous conduit 180. Preferably, the continuous conduit 180 is a straight, cylindrical opening.

One or more retrievable inserts 182, 184, 186, 190 may be arranged in the module openings of the respective modules. The retrievable inserts are provided with at least one fluid passage 192. The respective fluid passages 192 of the subsequent inserts are connected to each other, forming a continuous fluid passage 194. Retrievable inserts 182, 186 and 190 as shown in FIG. 4 are valve inserts. Retrievable insert 184 can be regarded as a junction insert, providing for instance one or two fluid passages 196 extending sideways and connecting to the kill wing port 38 and/or the flow wing port 39 respectively (See FIG. 2). The kill wing port and the flow wing port may be connected to corresponding fluid conduits. The ports 38, 39 may be closed or opened using kill wing valve 34 and flow wing valve 35 respectively. Said valves may be located outside of the housing 174, as shown in FIG. 2.

Control means 202, 206, 210 are coupled to the modules to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage. In the closed position of the valve insert the fluid passage is blocked, whereas in the open position fluid may pass through the fluid passage of the valve insert. The control means may be releasably coupled to the valve inserts. In one embodiment, the control means may be a key or a key comparable to a key would couple to and control a lock. When an insert has to be replaced, the control means are released from the corresponding inserts to allow replacement of one or more inserts. Afterwards, the control means can be re-coupled to the respective insert.

The valve inserts 182, 186, 190 may include a ball valve. A ball valve includes a spherical disc disposable in the fluid channel to control the flow through the valve. The sphere has a hole, or port, through the middle so that when the port is in line with the fluid passage of the valve, flow is enabled. When the valve is closed, the hole is perpendicular to the fluid passage of the valve, and flow is blocked. The control means may include a wheel 212, handle or lever to control the valve’s position. Alternatively, the valve insert may include a butterfly valve, plug valve, or similar quarter turn valves.

The control means may be manually operable. For the manual control, the control means may comprise a wheel 212 (FIG. 5). Alternatively, the control means may include a motor, which may be remotely operated and/or automatically operated by a control computer (not shown).

In a practical embodiment, the modules may replace the valves of a conventional Christmas tree as follows:

- module 162: Swab valve;
- module 164: Flow wing valve and Kill wing valve;
- module 166: Upper master valve;
- module 170: Lower master valve.

At an upper end, the fluid passage 194 of the Christmas tree 160 may be covered by a cover 214. Preferably, the cover is a lock or floodgate, to allow the passage of material such as tools, tubing, and valve inserts into and out of the wellbore, while enabling to shut in the wellbore to maintain control of the well. The cover may include upper and lower closures 215 and 217.

At a lower end, which may be connected to the wellbore 1, the Christmas tree 160 may be covered by a cover 214. Preferably, the cover is a lock or floodgate, to allow the passage of material such as tools, tubing, and valve inserts into and out of the wellbore, while enabling to shut in the wellbore to maintain control of the well. The cover may include upper and lower closures 215 and 217.

At a lower end, which may be connected to the wellbore 1, the Christmas tree 160 may be covered by a cover 214. Preferably, the cover is a lock or floodgate, to allow the passage of material such as tools, tubing, and valve inserts into and out of the wellbore, while enabling to shut in the wellbore to maintain control of the well. The cover may include upper and lower closures 215 and 217.

In a practical embodiment, shown in FIG. 4, control connection 224 may allow the introduction of foam in the wellbore 1 via the treatment fluid injection tubing 19. Control connection 226 may enable the hydraulic control of the downhole safety valve 17. Control connection 228 is closed.

In another practical embodiment, shown in FIG. 5, the control of the downhole safety valve 17 via the connection
226 may have failed. The hanger module of the invention enables to change the control of the safety valve 17 and re-establish control of the safety valve 17 using control connection 224, for instance using hydraulics. Control connection 228 is closed.

[0089] In yet another practical embodiment, shown in FIG. 6, a velocity string 240 has been introduced in the production tubing 14. The inner diameter of the velocity string is smaller than the inner diameter of the production tubing, and serves as a remedial treatment to resolve liquid-loading problems. As the reservoir pressure in a gas well depletes, there may be insufficient velocity to transport all liquids up the wellbore. In time these liquids accumulate and impair production. Installing a velocity string reduces the flow area and increases the flow velocity to enable liquids to be carried from the wellbore. Velocity strings are commonly run using coiled tubing as a velocity string conduit.

[0090] The Christmas tree of the invention may allow to inject the velocity string 240 via the conduit 180 or via fluid passage 194. I.e., the velocity string may be inserted in the wellbore through the Christmas tree 160. An upper end of the velocity string may hang off a hanger nipple or similar device in the hanger module 220. Alternatively, the velocity string may be connected to a string insert, which may be inserted in the tree 160 instead of the lower insert 352 (FIG. 12C). An outer surface of the velocity string may be provided with a packer element 244. A fluid channel 242 inside of the velocity string may be provided with a surface controlled safety valve 246. The packer element 244 may be hydraulically inflated and controlled via the connection 224. The safety valve 246 may be hydraulically controlled via connection 224.

[0091] In an improved embodiment, shown in FIG. 7, the velocity string may be provided with a controllable valve 248 to allow opening and closing a fluid passage between the internal fluid channel 242 of the velocity string and an annular space 250 between the velocity string and the production tubing 14. Thus, the reduction of the flow area of the production tubing may be continuously controlled between the area of the production tubing and the area of the velocity string. The controllable valve 248 may include a slidable sleeve door (SSD). The valve 246 may be controlled via hydraulics, for instance via control 226.

[0092] Another improved embodiment, shown in FIG. 8, the packer element 244 includes a valve 254. The valve 254 opens or closes a fluid passage between the section of the annulus 250 above and below the packer 244. The valve 254 may be a gas lift valve, allowing the injection of gas via the control opening 228 into the annulus 250 and into the production zone 10 of the wellbore 1. The injected gas provides a gas-lift system, providing production energy by injecting gas into the production fluid column, thereby reducing the hydrostatic pressure and enabling improved reservoir production.

[0093] FIGS. 9A, 9B show respective embodiments of an upper end of the velocity string 240. Said upper end is for instance provided with a cylindrical head 260 and a support shoulder 262. The support shoulder 262 functions to hang the velocity string in the hanger module 220. An outer surface of the head 260 may be provided with one or more seal rings 264. Also, the head 260 may be provided with fluid passages 266, 268 to connect to control openings 224, 228 of the hanger module respectively.

[0094] As shown in FIGS. 10 and 11, the inserts of the modules 162-170 may be provided with multiple fluid passages, to form for instance two parallel continuous fluid passages 194, 294. Each module may be provided with multiple control means, one control mean for each fluid passage. The primary fluid passage 194 may include the control means as described above. In addition secondary control means 302, 306, 310 may control the secondary fluid passage 294.

[0095] In a practical embodiment, the primary fluid passage 194 may be connected to the annulus 250 (FIG. 11). The secondary fluid passage 294 may be connected to the velocity string 240. Downhole valves 246, 254 can be controlled via, for instance, control line 224. A downhole end of the velocity string 240 may be provided with a downhole pump 320. The pump 320 may be powered and controlled, for instance using hydraulics or electricity, via power line 322 which may be connected to the control opening 228 of the hanger module 220. The pump 320 may be replaced using wireline. Gas may be produced via the annulus 250 and the primary fluid passage 194. Hydrocarbon fluids may be produced via the velocity string 240 and the secondary fluid passage 294. The gas may leave the Christmas tree via primary flow wing valve 35A. The fluids may leave the Christmas tree via the secondary flow wing valve 35B.

[0096] The Christmas tree of the invention may be constructed as shown in FIGS. 12A to 12F.

[0097] In a first step (FIG. 12A), modules 162 to 170 are connected. The modules may be connected to hanger module 220. Herein, the respective openings of the modules together form continuous conduit 180. The modules 162, 166, 170 are provided with lateral control openings 342, 346, 350 respectively to allow the connection of control means. The module 164 may be provided with kill wing port 38 and/or flow wing port 39.

[0098] For initial production, an insert 352 having a fluid passage 192 is introduced by wireline 354 (FIGS. 12B, 12C). Said insert 352 may later be retrieved, for instance by wireline, and replaced with another insert carrying a velocity string, as described above with reference to, for instance, FIG. 6.

[0099] Subsequently, a second insert 356 is introduced by wireline 354 (FIG. 12D). Said second insert 356 may be a valve insert, suitable for lower master valve module 170.

[0100] In a next step, corresponding control means 210 may be connected to the module 170 (FIGS. 12E, 12F). The module may be provided with a notch 360 to receive the control means. An end of the control means is provided with an extension 362, which fits into the notch 360 of the valve insert for the control thereof between an open and a closed position.

[0101] The other modules of the Christmas tree may be assembled in a similar way. Also, the tree may be disassembled in reverse order.

[0102] In an embodiment, two or more of the retrievable inserts of respective modules may be combined to form an integral insert. The respective inserts of the integral retrievable insert may be inserted and retrieved in the housing 174 together.

[0103] FIG. 13 shows an embodiment wherein the valve inserts 182, 186 and 190 and the junction insert 184 are combined to form a single insert 380. The integral insert 380 may be inserted or retrieved from the housing, allowing to replace the valve inserts 182, 186, 190 all at once.

[0104] An internal surface of the housing 174 may be provided with placement means to arrange the insert in a predetermined position. The placement means may comprise
grooves, landing nipples, one or more shoulders 382, 384, 386, or a combination thereof. The insert 380 may be provided with ridges or insert shoulders 388, 390, 392, having a shape corresponding to the respective housing shoulder.

[0105] The Christmas tree element 160, described above with reference to FIGS. 4 to 13, may be combined with the Christmas tree element 16 as described with reference to FIGS. 2 and 3.

[0106] For instance, the Christmas tree element 160 may be connected to the top side of one of the Christmas tree elements 16a and 16b, providing in effect two Christmas trees. Alternatively, element 16a may be similar to the Christmas tree element 160 as described above. The element 16b may be connected to the top side of the Christmas tree element 160. When required, the retrievable valve element 51 or the entire valve assembly 40 may be inserted in the Christmas tree at some stage during the lifetime of the well to create multiple fluid lines through the tree, for instance for foam injection.

[0107] The description above describes exemplary embodiments of the present invention. Many modifications therein are conceivable within the scope of the appended claims. Features of respective embodiments may for instance be combined.

1. A Christmas tree for a wellbore, comprising a plurality of modules, each module including:
   - at least one module opening;
   - a retrievable valve insert arranged in the module opening, the retrievable valve insert being provided with at least one fluid passage; and
   - control means coupled to the module to control the valve insert between a closed position and an open position of the at least one fluid passage;
   - the modules being connected to each other to form a housing, the respective module openings being connected to form a continuous conduit through the housing, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore.

2. The Christmas tree of claim 1, wherein the continuous conduit is a straight cylindrical channel.

3. The Christmas tree of claim 1, wherein the continuous fluid passage is a straight cylindrical channel.

4. The Christmas tree of claim 1, wherein the valve inserts of each module include at least two parallel fluid passages, the at least two fluid passages of the subsequent modules constituting at least two parallel continuous fluid passages though the continuous conduit of the housing.

5. The Christmas tree of claim 4, each module comprising at least two control means coupled to the module, each control means enabling the control of the valve insert between a closed position and an open position of one of the at least two fluid passages.

6. The Christmas tree of claim 1, wherein the control means are releasably coupled to the valve insert of the respective module.

7. The Christmas tree of any of claim 1, comprising a hanger module for hanging tubing into the wellbore.

8. The Christmas tree of claim 7, wherein the hanger module is provided with at least one hydraulic connection, adapted to be connected to hydraulic activating means.

9. The Christmas tree of claim 8, wherein one hydraulic connection is connected to hydraulic activating means to control a downhole valve.

10. The Christmas tree of claim 1, wherein the valve insert of a respective module is retrievable by wireline.

11. The Christmas tree of claim 1, comprising a junction module, the junction module comprising a kill wing port and/or a flow wing port being provided with corresponding kill wing valve and/or flow wing valve respectively, and a retrievable junction insert.

12. The Christmas tree of claim 11, wherein the retrievable junction insert is connected to at least one valve insert of a valve module to form an integral retrievable insert.

13. A method of building a Christmas tree for a wellbore, comprising the steps of:
   - providing a plurality of modules, each module including at least one module opening;
   - connecting the modules to each other to form a housing, the respective module openings forming a continuous conduit though the housing;
   - arranging a retrievable valve insert in the module opening of the modules, each retrievable valve insert being provided with at least one fluid passage, the respective fluid passages of the valve inserts being connected to form at least one continuous fluid passage, said continuous fluid passage being adapted to be connected to the wellbore;
   - coupling control means to each module to control the valve insert in the respective module between a closed position and an open position of the at least one fluid passage.

14. The method of claim 13, wherein the continuous conduit is a straight cylindrical channel.

15. The method of claim 13, wherein the control means are releasably coupled to the valve insert of the respective module.

16. The method of claim 13, comprising the steps of:
   - connecting a hanger module to the housing for hanging tubing into the wellbore;
   - hanging tubing off the hanger module into the wellbore; and
   - connecting hydraulic activating means to a hydraulic connection of the hanger module to control a downhole valve.

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