HORIZONTAL VERTICAL DEEPWATER TREE

BACKGROUND OF THE INVENTION

The present invention is directed to a christmas tree for a subsea hydrocarbon production system. More particularly, the invention is directed to a tree which combines the ease of retrieval associated with vertical christmas trees with the ease of power feedthrough associated with horizontal christmas trees.

Vertical christmas trees ("VXT's") with fail safe closed ("FSC") barrier valves in the vertical bore are not compatible with hanging off elements in the top of the tree. Horizontal christmas trees ("HXT's") are not easy retrievable, as the tubing hanger is suspended in the tree.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention, there is provided a subsea hydrocarbon production system which comprises: a tubing hanger which is positioned at an upper end of a well bore, the tubing hanger including a tubing hanger production bore; a tubing string which extends from the tubing hanger into the well bore and is fluidly connected to the tubing hanger production bore; a christmas tree which is positioned above the tubing hanger and which comprises: a production bore which is fluidly connected to the tubing hanger production bore; a production outlet which is connected to the production bore; a first barrier element which is positioned in the production outlet; and a first closure device which is positioned in the production bore above the production outlet; wherein access from above the christmas tree through the production bore does not require passage through a barrier element; a hydraulic submersible pump which is positioned in the tubing string, the pump including a fluid power conduit which is connected to a downhole equipment hanger that is secured to the production bore above the production outlet and below the first closure device; and a pump conduit having a first end which is connectable to a source of pressurized fluid and a second end which is connected to production bore below the first closure device and above the downhole equipment hanger; wherein with the first closure device closed, pressurized fluid is communicated through the pump conduit, the production bore and the fluid power conduit to activate the pump.

According to a second aspect, there is provided a subsea hydrocarbon production system which comprises: a tubing hanger which is positioned at an upper end of a well bore, the tubing hanger including a tubing hanger

production bore; a tubing string which extends from the tubing hanger into the well bore and is fluidly connected to the tubing hanger production bore; a christmas tree which is positioned above the tubing hanger and which comprises: an axially extending tree production bore which is connected to the tubing hanger production bore; a laterally extending production outlet which is connected to the tree production bore; a first barrier element which is positioned in the production outlet; and a second barrier element which is positioned in the tree production bore below the production outlet; a downhole equipment device which is positioned in the tubing string and is connected to a suspension string which in turn is connected to a downhole equipment hanger; wherein the downhole equipment hanger is landed in one of the tubing hanger production bore or the tree production bore below the second barrier element.

In accordance with one embodiment of the present invention, a subsea hydrocarbon production system is provided which comprises a tubing hanger which is positioned at an upper end of a well bore, the tubing hanger including a tubing hanger production bore; a tubing string which extends from the tubing hanger into the well bore and is fluidly connected to the tubing hanger production bore; and a christmas tree which is positioned above the tubing hanger and which comprises a production bore which is fluidly connected to the tubing hanger production bore; a production outlet which is connected to the production bore; a first barrier element which is positioned in the production outlet; and a first closure device which is positioned in the production bore above the production outlet. In this manner access from above the christmas tree through the production bore does not require passage through a barrier element.

In accordance with one embodiment of the invention, the subsea hydrocarbon production system comprises a second closure device which is positioned in the production bore above the first closure device such that the first and second closure devices provide two pressure barriers between the well bore and the environment during the production mode of operation of the christmas tree. In this embodiment, the second closure device may comprise a tree cap or a wireline plug. In another embodiment of the invention, the subsea hydrocarbon production system comprises a third closure device which is positioned in the production bore below the production outlet.

may be landed in the tubing hanger production bore and the tubing hanger may comprise a number of axially extending bypass flow ports which permit the passage of fluid around the downhole equipment hanger.

Thus, it may be seen that the christmas tree as per embodiments of the present invention addresses the following needs in the subsea hydrocarbon production industry: the need for easy retrieval, as the tubing hanger is landed in the wellhead or tubing head, not the christmas tree; the need for the possibility of hanging off elements in the tree through active barriers (i.e., barriers which are designed to be routinely actuated either manually or by remote control) in the vertical production bore; the need for the possibility of a power and/or utility feedthrough to downhole equipment, such as an electrical submersible pump ("ESP"), as in conventional HXT's; and the need for the possibility of increasing the bore diameter without having to increase the weight of the tree (i.e., the size of FSC valve actuators).

The inventive christmas tree increases the functionality of today's VXT's and provides a larger bore alternative to HXT's. The added functionality allows for the use of larger completions (e.g., 9-5/8") with minimum or no impact on tree weight itself. The proposed tree configuration also facilitates the use of a power and/or utility feedthrough and a suspension string for downhole equipment, such as submersible pumps.

The christmas tree as per embodiments of the present invention comprises the following technical features: a tubing hanger suspended in a wellhead or a tubing head; an installable/retrievable downhole equipment hanger located in the vertical bore above or below the lateral production outlet; a power and/or utility feedthrough in the tree cap or radially through the tree or tubing head; actuated barrier elements (as that term is defined below) positioned in the production outlet, as in an HXT; actuated barrier elements having a size which is independent of the bore size of the vertical production bore; and optional closure devices (as that term is defined below) in the production bore above and/or below the production outlet (e.g., in a similar location as the PMV in a VXT).

Existing enhanced horizontal tree ("EHXT") systems are typically very costly to repair because, e.g., they require a mobile offshore drilling unit ("MODU") to pull the completion to enable the tree to be recovered for repair.

In contrast, the christmas tree as per embodiments of the present invention can be installed on wire on a wellhead or a tubing head to minimize the cost associated with using mobile drilling rigs.

Also, the christmas tree as per embodiments of the invention is especially suitable where the need exists for hanging off elements extending down into the well, as the active actuated barrier elements are located in the production outlet, similar to an HXT.

For the foregoing, it may be seen that the christmas tree as per embodiments of the present invention offers the following benefits. The tree may facilitate vertical well access in large bore completions in a safe and cost effective manner. The tree may comprise a closure device in the vertical production bore below the production outlet which allows produced fluids to pass during normal production operations but can be closed in case of failure of a primary barrier element. The tree can accommodate additional closure devices in the form of non-conventional tree valves, such as coiled tubing strippers or variable bore pipe rams, thus facilitating the migration of some of the functionally that would exist in a well control package into the tree itself. This becomes practical because the tree is retrievable for maintenance without pulling the completion, particularly when downhole barriers are employed as intervention barriers, for example a combination of a surface controlled subsurface safety valve ("SCSSV") and a surface controlled formation isolation valve ("SFIV"). The tree makes conventional tree weight and size less dependent on completion size by positioning the FSC barrier devices in the production outlet instead of the vertical production bore. Thus, the tree eliminates the need for large FSC barrier device actuators in the production bore. The tree facilitates power and/or utility feedthrough and the suspension of cable deployed downhole equipment, e.g., ESP's, in VXT-type subsea completions. The tree allows operators maximum flexibility, as downhole equipment can be installed at any time during the production mode of operation of the tree, and also allows them to standardize on a tree type whether they intend to deploy downhole equipment or not. Thus, the same tree can be used, thereby simplifying procurement and optimizing project cycle times. The tree provides the ability to add additional downhole functions into the completion, thus allowing multilaterals and downhole surveillance technologies, like fiber optic

distributed temperature sensing, to be employed. The tree allows a downhole equipment hanger to be located in several locations in the vertical bore, e.g., below the closure devices in the vertical bore, between the closure devices, or above the closure devices.

The following are some of the main features of the christmas tree as per embodiments of the present invention. The tree provides improved well access because it only contains closure devices in vertical production bore. The closure devices in the vertical production bore may be replaced with barrier elements to ensure well control functionality as part of a shut-down or well control philosophy. These barrier elements may be fail safe closed. One or more of the closure devices in the vertical bore, which are typically designed for use only during well intervention, can be "unconventional" valves for a tree, such as a ball valve, a coiled tubing stripper valve or a pipe or wireline ram, to facilitate well intervention and optimize the well access system. Traditionally this functionality would only exist in the well control package as a component that is added to the tree during a well intervention, but this results in high pressure well fluids being controlled in a large diameter bore, thus making the solution impractical as pressures continue to rise, and weight being moved further up from the wellhead, thus creating larger bending moments. This concept of merging tree and well access/control functionality becomes important for tree systems above 15k PSI. The tree facilitates the retrofit of downhole equipment in an existing tree without having to pull the tree and add electrical connections when the feedthrough is made through the tree cap. Traditionally, ESP's are deployed in horizontal subsea trees in which the electrical connectors for the ESP must be installed when the completion is run and the tubing hanger is latched in. The tree makes conventional tree weight and size less dependent on completion size by eliminating the need for large FSC barrier element actuators in the vertical production bore and providing well access through barrier elements or closure devices. The tree provides means for accommodating downhole equipment which is suspended from a downhole equipment hanger positioned in the vertical production bore or in the tubing hanger. The tree allows for the use of electric, optic and fluid connections. These connections may be wet mate, dry mate or even wireless, and they may extend through the tree cap or radially through, e.g.,

the tree. The tree is cost effective; it can be installed on wire without the use of a MODU and without the need to pull barrier elements, such as plugs, in the tree. The generally lateral production outlet can be formed in a number of possible locations, whereas in a horizontal tree it is typically located near the tubing hanger. Circulation lines can be fitted to the tree to facilitate circulating out of fluids trapped between closure devices, as is done with a subsea intervention system, or pressure testing between closure devices. In this way, the tree further integrates functionality that is normally provided by a well control package into the tree, thereby facilitating intervention. An intervention workover control system ("IWOCS") can be integrated between the tree and the well control package to thereby minimize the number of umbilicals in the water, thus simplifying integrated operation and allowing well control (valve actuation) operations to be conducted either (roughly) over the top of the well, as is typical, or from the host facility in the event the tree is tied back to a host through a production control umbilical or other communication to a remote location.

These and other embodiments and advantages of the present invention will be made apparent from the following detailed description, with reference to the accompanying drawings. In the drawings, the same reference numbers may be used to denote similar components in the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a representation of an exemplary prior art vertical christmas tree;

Figure 2 is a schematic representation of a first embodiment of the christmas tree of the present invention;

Figure 3 is a schematic representation of a second embodiment of the christmas tree of the present invention;

Figure 4 is a schematic representation of a third embodiment of the christmas tree of the present invention;

Figure 5 is a schematic representation of a fourth embodiment of the christmas tree of the present invention;

Figure 6 is a schematic representation of a fifth embodiment of the christmas tree of the present invention;