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(54) IMPROVEMENTS IN OR RELATING TO UNDERWATER WELLS

(71) We, FMC CORPORATION a corporation organised and existing under the laws of the State of Delaware, United States of America, of 1105 Coleman Avenue, San Jose, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to underwater wells and more particularly to underwater oil or gas wells.

The great and often irreparable harm to the environment, the great danger of loss of life, and the potentially great economic loss in terms of escaping petroleum or natural gas that can and have occurred when an offshore oil or gas well is damaged for example by storms, or surface vessels, have given rise to the development of safety equipment for use in preventing such occurrences. For this purpose, there has been proposed means for automatically closing the well when damage occurs to the wellhead structure, such means being in the form of remotely controllable valves in the production tubing strings at a subsurface level, such as at the ocean floor or mudline. These valves are arranged to remain open when subjected to fluid under predetermined pressure, and to automatically close when this fluid pressure drops below a certain point, such as when the surface structure is damaged or carried away by a storm, or ship collision, etc.

These previously proposed valves are subject to disadvantages that reduce their efficiency. For example, the flow passages are materially less than the size of the bore in the tubing strings, and thus the volume of fluid that can be carried through the installation is significantly reduced. Another problem with certain previously proposed installations is that they require taking the well out of production for an undesirably long period of time in order to service or replace the valves, such servicing procedures involving either pulling all the tubing strings from the well, or using a wire line technique, both of which are expensive in terms of time and equipment. Further, it is sometimes necessary that an oil string, at least two sizes larger than is required to accommodate just the tubing strings, be used in order to also accommodate the valves, thereby requiring the other casing strings to be larger and resulting in much more expense.

According to one aspect of the present invention, there is provided a method of remotely completing an underwater well having at least one casing string, said method comprising the steps of connecting a riser to the casing to provide a continuous, fluid-tight, conduit from the casing to the surface, feeding at least one tubing string through the riser and supporting the string in the well adjacent the lower end of the riser, feeding a tubing extension equipped with a tubing flow control valve into the riser, and releasably connecting the tubing extension into fluid-tight flow communication with the tubing string, whereby the tubing flow control valve can be withdrawn from the well for servicing or replacement without also removing or otherwise disturbing the tubing string from its set condition in the well.

According to another aspect of the invention, there is provided an underwater well comprising a well casing, a riser extending upwardly from the casing to the surface of the water, a tubing string extending into the casing and supported adjacent the upper end of the casing, and a tubing extension, incorporating a fluid control valve, extending through the riser and being releasably connected to the tubing string whereby the extension and valve can be withdrawn without disturbing the tubing string.

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The invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings in which:

Figures 1-6 schematically illustrate the sequential steps of completing an underwater well with dual tubing strings according to the present invention;

Figure 7 is a fragmentary side elevation of a well;

Figure 8 is a longitudinal section, to an enlarged scale, of the lower portion of the well;

Figure 9 is a section similar to Fig. 8, showing the state of completion after a master bushing and first tubing string have been incorporated in a tie-back adapter, and prior to release of a running string from the master bushing;

Figure 10 is a section similar to Fig. 9, showing the state of completion after a second tubing string has been incorporated, and prior to removal of the running string from the upper end of the coupling;

Figure 11 is a section similar to Figs. 9 and 10, showing the state of completion after the second tubing string has been locked in place in the master bushing and just prior to removal of the tie-down ring running string; and

Figures 12A and 12B together form a longitudinal section of the completed well.

Figs. 1-6 of the drawings show, in sequence, the several steps involved in effecting a dual completion in an offshore well 20 that has an inner casing 22 supported at the ocean floor or mudline 24 by a hanger 26, which in turn is supported in an outer casing hanger 27. The first step involves running and connecting a tie-back adapter 28 with a riser 30 into the hanger 26. The riser 30, which extends from the tie-back adapter 28 to the water surface 31, is then cut off at the level of the platform production deck 32, and a blow-out preventer system 34 installed. At this point, the tie-back seals, the riser and the blow-out preventer stack can be tested in the usual manner with a cup (not shown) run on drill pipe into the casing 22 below the hanger 26.

As illustrated in Fig. 2, a first or long tubing string 36 and a master bushing 38 to which it is connected are then run by means of a tie-back string 40, and the master bushing locked in place in the tie-back adapter 28. The master bushing 38 is connected to the tie-back string 40 so that the string can be released from the bushing by rotating the string to the right. Accordingly, once the master bushing 38 has been set in the tie-back adapter 28, right-hand rotation is imparted to the tie-back string 40 until it is released from the master bushing, and the string is then withdrawn.

As shown in Fig. 3, a second tubing string 42 is then run and landed in the master bushing 38 by means of a tie-back string 44. Like the connection between the string 40 and the master bushing 38, the string 44 is connected to the second tubing string 42 in such a manner that right-hand rotation will disconnect it. Thus, following the landing of the second tubing string 42 in the master bushing 38, the tie-back string 44 is rotated to the right, releasing it from the string 42, and then withdrawn.

Figure 4 illustrates the next step in this method, that of locking down the second tubing string 42 into the master bushing 38. This step can be accomplished by running a tie-down ring (Fig. 11) on the end of a string of drill pipe 46 into the master bushing and securing it thereto. The running string 46 is then released from the tie-down ring and withdrawn.

With both tubing strings 36,42 now effectively locked into the tie-back adapter 28, each string is then completed to the surface by a tubing extension containing a remotely controllable, full opening valve adjacent its lower end. As illustrated in Fig. 5, the first tubing string 36 is continued to the surface by running a tubing extension 48, containing a flow control valve 50, and releasably interconnecting the extension and the tubing string through the bushing 38, as by means of a tie-back mechanism 52. Next, and as illustrated in Fig. 6, the second tubing string 42 is completed to the surface by releasably connecting a tubing extension 54, having a flow control valve 56, to it by a tie-back mechanism 58. If it is desired to suspend the tubing extensions 48,54 in tension, the blow-out preventer stack 34 can then be picked up off the tubing head 59, tension applied to the extensions, and split tension rings or the like installed. A tree can then be mounted at the surface in the conventional manner.

Thus, following the foregoing method, the well 20 can be completed with dual tubing strings 36,42 each of which is locked down and supported at the mudline 24, and realeasable tubing string extensions 48,54 from the mudline to the surface located wellhead. Since the flow control valves 50,56 are in the tubing string extensions 48,54 rather than in the master bushing 38 or the tubing strings 36,42 these valves can be removed from the well for servicing or replacement simply by releasing and pulling the tubing string extensions, leaving the tubing strings secured in place in the bushing at the ocean floor. In order to maintain the well 20 in control while the valves 50,56 are removed, conventional back pressure valves (not shown) are run through the tubing string extensions 48,54 and the valves 50,56 into the master bushing 38 and secured

thereto, and when the tubing string extensions are reinstalled these flow control valves are removed. Furthermore, because of the placement of the valves, there is no problem in completing a well that has been drilled and lined with standard size casing.

Accordingly, the foregoing method results in a well completion that provides full opening valves for controlling the flow in each tubing string on or near the ocean bottom, and facilitates quick and easy removal of these valves for servicing or replacement without having to remove the tubing strings or otherwise relinquish control over the well. This means that a considerable savings in time and expense can be realized as compared with when it is completed by other techniques, and it also provides the highly desirable safety feature of automatic closure of the well's tubing strings at the ocean floor or at another level below the level at which damage due to storms or collisions by ships, could occur in the event of damage to or malfunction of the well structure above that level.

The foregoing method is entirely compatible for use with ball or other various types of remotely controllable valves currently available in the industry for use in tubing strings. Surface control of these valves can be achieved by maintaining hydraulic fluid under pressure in the annulus 90 between the tubing extensions 48,54 and the riser 30, or by running hydraulic lines from the surface through this annulus down to the valves. In either case, should the pressure of the fluid drop below a predetermined level, such as if the surface equipment is damaged by a storm, ship, etc., the valves will automatically close and will remain closed until sufficient pressure in the fluid control system is reestablished.

Although it should be understood that apparatus of various types can be used to carry out the foregoing described well completion method, a preferred apparatus which has been found highly successful in this regard is illustrated in detail in Figs. 8-12. In these Figures the apparatus is shown in conjunction with a well that has been lined with casing that is suspended from a location at or near the ocean floor or mudline 24, and with the innermost casing string 22 (Fig. 8) secured to a casing hanger 26. The hanger 26 is of the type described in United States Patent Specification No. 3,420,308, having a resiliently expandible and contractable hanger ring 60 that releasably secures the hanger 26 to an outer casing hanger 27. The tie-back adapter 28 is provided at its lower end with external right hand threads 28a that mesh with internal right hand threads 26a at the upper end of the casing hanger 26, so that the tie-back adapter and the riser 30 to which it is threaded can be run and connected into the hanger 26 by rotation of the riser to the right. Annular seals 62 are provided between the tie-back adapter 28 and the hanger 26, and the blow-out preventer stack 34 together with the tubing head 59 are mounted on top of the riser 30 at the level of the surface production platform 32.

An annular shoulder 28b in the lower portion of the tie-back adapter 28 provides a landing and support surface for the master bushing 38, and a releasable locking system 64, such as outwardly biased locking dogs, functions to releasably secure the bushing into the tie-back adapter. Annular packings at 65 provide a fluid tight barrier between the bushing 38 and the adapter 28.

The first tubing string 36 is threaded into the lower end of the master bushing 38, in alignment with the bushing's bore 38a that continues the flow passage from the tubing string 36. Near the upper end of the bore 38a is an annular groove 38b that serves as the housing for an inwardly biased segmented nut 66 that constitutes the female portion of a tie-back system for releasably connecting the tie-back string 40 to the master bushing 38. The male portion of this tie-back system comprises an adapter 68 attached to the lower end of the tie-back string 40. The lower outside diameter of the adapter 68 is provided with left-hand buttress-type threads which have a negative rake angle, to lock the adapter to the segmented nut 66 when the adapter is stabbed into it. Thus, the connection between the tubing extension 40 and the master bushing 38 is achieved simply by stabbing the adapter 68 into the position shown in Fig. 9, and release of the string 40 is achieved simply by rotating it to the right while simultaneously lifting on it.

As shown in Fig. 10, the second tubing string 42 is threaded into the bottom of a tubing coupling 70, and the tie-back string 44 is releasably connected to the upper end of the coupling 70 by the same type of tie-back mechanism as that between the string 40 and the master bushing 48. This mechanism includes an adapter 72 on the lower end of the string 44, and a segmented nut 74 in an annular groove 70a in the tubing coupling's bore 70b. The tubing coupling 70 has an annular shoulder 76 that lands on an annular shoulder 78 in the bore 38f of the master bushing 38, and the coupling is sealed to the bushing by an annular seal system 80. Thus, once the second tubing string 42 has been run and set in the master bushing 38 by the tie-back string 44, the string 44 can be released by simultaneous right-hand rotation and lifting, and then withdrawn.

In order to lock down the second tubing

string 42 into the master bushing 38, a lock down ring 82 (Fig. 11) is run by means of a tool 84 on the running string 46, and threaded into the upper end of the master bushing 38 until it comes to rest against the upper end of the tubing coupling 70. The running tool 84 is connected to the lock down ring 82 by left hand threads 84a, so that once the ring is set in the master bushing 38 continued right hand rotation of the running string 46 and tool 84 will unthread the tool from the ring, thereby facilitating its withdrawal. It will be seen, therefore, that at this stage of the method both tubing strings 36,42 are secured in a fluid tight manner to the master bushing and the bushing is locked down and packed off into the tie-back adapter 28. Thus, the well is now ready for completion to the surface.

Completing the tubing string 36,42 to the surface with the illustrated equipment is accomplished by running and setting a tubing extension 48 (Figs. 12A and 12B) into the master bushing 38, and another tubing extension 54 into the tubing coupling 70. As shown in Fig. 12B, the lower end of the tubing extensions 48,54 terminate in male tie-back adapters 52,58 respectively, that stab into the segmented nuts 66,74 respectively, of the tie-back mechanisms. Likewise, the tubing extensions 48,54 can be released from their connections to the bushing 38 and coupling 70 by lifting on them while also rotating them to the right.

A flow control valve 50 is positioned just above the male adapter 52 in the tubing extension 48, and another flow control valve 56 is positioned in the tubing extension 54 just above the level of the adapter 58. Valves suitable for use at these locations are known; these valves are maintained in an open position by fluid pressure which can exist either in the annular space 90 between the riser 30 and the tubing extensions 48,54 or by fluid under pressure carried to the valves by means of conventional hydraulic lines (not shown). When this fluid pressure is below that pre-established to maintain the valves in the open condition, the valves will automatically close and will remain closed until the requisite amount of pressure is reestablished.

The upper ends of the tubing extensions 48,54 can be supported by any of several conventional and well known means, including the tubing head 59 and related equipment such as that illustrated in Fig. 12A. In this illustrated arrangement, the upper ends of the tubing extensions 48,54 are secured to tension hanger couplings 92 that are held in place in a tension hanger bushing 94 by split tension rings 96.

Although in the foregoing arrangement both tubing valves are withdrawn from the well for servicing or replacement, it will, of course, be understood that either one of the valves may be withdrawn alone, leaving the other valve in place, and then reinstalled (or a new valve installed in its place) as might be desired. In other words, the operator can service or replace just one of the tubing valves, rather than having to withdraw both valves. This feature affords savings, both in time and equipment.

Further, the method described can be carried out fully from the surface, i.e., no assistance from divers at the ocean floor is required. This is especially important where the well has been drilled at an offshore location too deep for diver access, as is becoming more frequently the case.

WHAT WE CLAIM IS:—

1. A method of remotely completing an underwater well having at least one casing string, said method comprising the steps of connecting a riser to the casing to provide a continuous, fluid-tight, conduit from the casing to the surface, feeding at least one tubing string through the riser and supporting the string in the well adjacent the lower end of the riser, feeding a tubing extension equipped with a tubing flow control valve into the riser, and releasably connecting the tubing extension into fluid-tight flow communication with the tubing string, whereby the tubing flow control valve can be withdrawn from the well for servicing or replacement without also removing or otherwise disturbing the tubing string from its set condition in the well.

2. A method according to claim 1 including the step of locking down and packing off the tubing string to establish a fluid-tight seal between the tubing string and the casing.

3. A method according to claim 1 wherein two tubing strings are passed through the riser, and wherein two tubing extensions, each including a tubular flow control valve, are fed through the riser and are releasably connected to the two tubing strings, one extension being associated with each tubing string.

4. A method according to claim 3 wherein the first tubing string is connected at its upper end to a master bushing which is inserted and locked down with said first tubing string, and wherein the second tubing string includes a tubing coupling which is inserted into the master bushing and locked down therein.

5. A method according to claim 4 wherein the second tubing string is locked down into the master bushing by feeding and connecting locking means to said master bushing.

6. A method according to claim 3 including the step of feeding tubing string

string 42 into the master bushing 38, a lock down ring 82 (Fig. 11) is run by means of a tool 84 on the running string 46, and threaded into the upper end of the master bushing 38 until it comes to rest against the upper end of the tubing coupling 70. The running tool 84 is connected to the lock down ring 82 by left hand threads 84a, so that once the ring is set in the master bushing 38 continued right hand rotation of the running string 46 and tool 84 will unthread the tool from the ring, thereby facilitating its withdrawal. It will be seen, therefore, that at this stage of the method both tubing strings 36,42 are secured in a fluid tight manner to the master bushing and the bushing is locked down and packed off into the tie-back adapter 28. Thus, the well is now ready for completion to the surface.

Completing the tubing string 36,42 to the surface with the illustrated equipment is accomplished by running and setting a tubing extension 48 (Figs. 12A and 12B) into the master bushing 38, and another tubing extension 54 into the tubing coupling 70. As shown in Fig. 12B, the lower end of the tubing extensions 48,54 terminate in male tie-back adapters 52,58 respectively, that stab into the segmented nuts 66,74 respectively, of the tie-back mechanisms. Likewise, the tubing extensions 48,54 can be released from their connections to the bushing 38 and coupling 70 by lifting on them while also rotating them to the right.

A flow control valve 50 is positioned just above the male adapter 52 in the tubing extension 48, and another flow control valve 56 is positioned in the tubing extension 54 just above the level of the adapter 58. Valves suitable for use at these locations are known; these valves are maintained in an open position by fluid pressure which can exist either in the annular space 90 between the riser 30 and the tubing extensions 48,54 or by fluid under pressure carried to the valves by means of conventional hydraulic lines (not shown). When this fluid pressure is below that pre-established to maintain the valves in the open condition, the valves will automatically close and will remain closed until the requisite amount of pressure is reestablished.

The upper ends of the tubing extensions 48,54 can be supported by any of several conventional and well known means, including the tubing head 59 and related equipment such as that illustrated in Fig. 12A. In this illustrated arrangement, the upper ends of the tubing extensions 48,54 are secured to tension hanger couplings 92 that are held in place in a tension hanger bushing 94 by split tension rings 96.

Although in the foregoing arrangement both tubing valves are withdrawn from the well for servicing or replacement, it will, of course, be understood that either one of the valves may be withdrawn alone, leaving the other valve in place, and then reinstalled (or a new valve installed in its place) as might be desired. In other words, the operator can service or replace just one of the tubing valves, rather than having to withdraw both valves. This feature affords savings, both in time and equipment.

Further, the method described can be carried out fully from the surface, i.e., no assistance from divers at the ocean floor is required. This is especially important where the well has been drilled at an offshore location too deep for diver access, as is becoming more frequently the case.

WHAT WE CLAIM IS:—

1. A method of remotely completing an underwater well having at least one casing string, said method comprising the steps of connecting a riser to the casing to provide a continuous, fluid-tight, conduit from the casing to the surface, feeding at least one tubing string through the riser and supporting the string in the well adjacent the lower end of the riser, feeding a tubing extension equipped with a tubing flow control valve into the riser, and releasably connecting the tubing extension into fluid-tight flow communication with the tubing string, whereby the tubing flow control valve can be withdrawn from the well for servicing or replacement without also removing or otherwise disturbing the tubing string from its set condition in the well.

2. A method according to claim 1 including the step of locking down and packing off the tubing string to establish a fluid-tight seal between the tubing string and the casing.

3. A method according to claim 1 wherein two tubing strings are passed through the riser, and wherein two tubing extensions, each including a tubular flow control valve, are fed through the riser and are releasably connected to the two tubing strings, one extension being associated with each tubing string.

4. A method according to claim 3 wherein the first tubing string is connected at its upper end to a master bushing which is inserted and locked down with said first tubing string, and wherein the second tubing string includes a tubing coupling which is inserted into the master bushing and locked down therein.

5. A method according to claim 4 wherein the second tubing string is locked down into the master bushing by feeding and connecting locking means to said master bushing.

6. A method according to claim 3 including the step of feeding tubing string

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lock down means through the riser after the first and second tubing strings have been inserted, said lock-down means serving to releasably secure said second tubing string in the well.

7. A method according to any one of claims 3 to 6 wherein the tubing extensions are releasably secured at their upper end portions to a surface-located tubing support means connected to the riser.

8. A method according to claim 7 wherein the tubing extensions are hung in tension from the tubing support means.

9. A method of completing an offshore underwater well from a remote, water surface location, said well containing at least one casing string extending downwards from the ocean floor, said method comprising the steps of feeding a riser, having a connector means at its lower end, to the well and connecting the riser to the casing, feeding a first tubing string, connected at its upper end portion to a master bushing, into the well, and locking said master bushing in said connector means, feeding a second tubing string, connected at its upper end portion to a tubing coupling, through the riser and the master bushing and supporting said tubing coupling in said master bushing, feeding a lock-down means to the master bushing and locking down the second tubing string and the tubing coupling, feeding a first tubing extension, including a tubing flow control valve, through the riser and releasably securing the tubing extension to the master bushing in flow communication with the first tubing string, and feeding a second tubing extension, including a tubing flow control valve, through the riser and releasably securing the second tubing extension to the tubing coupling in a flow communication with the second tubing string, whereby the tubing flow control valves can be individually disconnected from the tubing strings and removed from the well for servicing or replacement while the tubing strings remain undisturbed in the well.

10. A method according to claim 9 including the step of suspending the tubing extensions from a tubing head mounted on the riser at a surface location.

11. A method according to claim 10 wherein the tubing extensions are suspended in tension from the surface located tubing head.

12. A method according to claim 9 wherein the master bushing is automatically locked down and packed off in the connecting means.

13. A method according to any one of claims 9 to 12 wherein the connector means comprises a tie-back adapter which is fed with the riser and connected into the casing in fluid-tight relationship therewith.

14. A method according to any one of claims 9 to 13 wherein the lock-down means comprises a lock-down ring threaded to the master bushing to lock the second tubing string into said bushing.

15. An under-water well comprising a well casing, a riser extending upwardly from the casing to the surface of the water, a tubing string extending into the casing and supported adjacent the upper end of the casing, and a tubing extension, incorporating a fluid control valve extending through the riser and being releasably connected to the tubing string whereby the extension and valve can be withdrawn without disturbing the tubing string.

16. An underwater well substantially as hereinbefore described with reference to the accompanying drawings.

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