FIG. 6
UNDERWATER WELL ENCLOSING CAPSULE AND SERVICE CHAMBER

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FIG. 19

FIG. 19A

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The present invention relates to underwater drilling methods and apparatus and, more particularly, to novel methods and apparatus permitting a separation of the drilling, producing, and servicing phases of underwater well construction and operation.

This is a continuation-in-part of our application Ser. No. 81,543, filed Jan. 9, 1961, and now abandoned.

The rapid depletion of the mineral resources underlying the earth's land masses and the growing demand for raw materials have led to an urgent quest to develop means for exploiting deposits beneath the floor of the sea and in other areas underlying water. A number of devices have been developed for this purpose, including notably the mobile platforms now in operation off the coasts of the United States mainland. However, conventional mobile platforms and similar apparatus have not provided a complete solution to the problem.

It is an object of the present invention, accordingly, to provide new and improved means for drilling, operating and servicing wells under the water.

A further object of the invention is to provide new and improved means for enclosing an underwater wellhead, keeping it dry, and enabling workmen to gain access to it for well maintenance.

Still another object of the invention is to provide means for lowering workmen to the wellhead for inspection and maintenance purposes.

Another object of the invention is to provide separate pieces of equipment to accomplish the drilling, operating, and servicing of underwater wells, including means for drilling a well, a watertight capsule for enclosing the wellhead, and personnel-carrying means for servicing the equipment at the wellhead at periodic intervals.

Another object of the invention is to make possible the replacement of conventional platforms by a small underwater capsule which is inexpensive and undisturbed by weather and shipping.

These and other objects are attained, in a first representative embodiment of the invention, by providing a submersible vessel which is outfitted with the accommodations of the well driller. Attached to the vessel's exterior surface is a watertight capsule adapted sealably to pass drilling and casing means. Drilling means are extended from the vessel through the capsule for drilling a well, and casing is inserted into the well and sealed to the capsule. When the well is completed, the capsule and the vessel are sealed off from each other and separated. The capsule remains on the floor of the sea enclosing the wellhead and keeping the equipment at the wellhead dry, and the vessel is available for drilling another well. At particular intervals a service chamber may be lowered to facilitate inspection and repair of the equipment at the wellhead. A line extending from the capsule to a float on the surface or a cabled transponder on the capsule facilitates relocation of the capsule.

A second embodiment of the invention has numerous features which adapt it particularly for shallow-water drilling. For example, means are provided for mounting blowout preventers above the water's surface.

A third embodiment of the invention, adapted particularly for drilling in great water depths, has many novel features including novel hold-down equipment for hold-

ing down underwater-well apparatus. The apparatus so held includes a plurality of submersible chambers mounted upon a wellhead in vertically-stacked relation on a floor underlying water.

For an understanding of further particulars of the invention, reference may be made to the following detailed description of three representative embodiments thereof and to the accompanying figures of the drawings, in which FIGS. 1–6 illustrate the first embodiment, FIGS. 7–13 the second, and FIGS. 14–22 the third. More particularly:

FIG. 1 is a perspective view, partially broken away, of a submersible vessel supported by a foundation pad on a floor underlying water and sealably attached to a watertight capsule in accordance with a first representative embodiment of the invention;

FIG. 2 is a detailed view in elevation (partly sectioned along the line 2—2 of FIG. 4) of the capsule as it appears when it is attached to the submersible vessel and has typical drilling equipment in place;

FIG. 3 is a detailed view in elevation (partly sectioned along the line 3—3 of FIG. 4) of the capsule as it appears after completion of the well, substitution of well-completion equipment for the drilling equipment, placement of a watertight hatch on the capsule, and departure of the submersible vessel;

FIG. 4 is a plan view, partially broken away, showing the construction of the capsule-hatch seal;

FIG. 5 is a diagrammatical representation of a service station being lowered from a tender to the capsule at the wellhead for the purpose of facilitating inspection or repairs in accordance with the invention;

FIG. 6 is a view in elevation, partially broken away, of the service chamber in position on top of the capsule and forming a watertight seal therewith;

FIG. 7 is a perspective view of apparatus for lowering a capsule support casing into a conductor pipe driven or otherwise placed into a shallow-sea floor in accordance with the invention;

FIG. 8 is a partly-sectioned elevational view of a drilling capsule particularly suited for drilling in relatively shallow water;

FIG. 9 is a partly-sectioned fragmentary elevational view of the mechanism by which the watertight integrity of the capsule shown in FIG. 8 is established along an annular junction of upper and lower halves of the capsule and by which the upper half is guided into seating relation with the lower half;

FIG. 10 is a partly-sectioned detailed elevational view of one form of adapter constructed in accordance with the invention;

FIG. 11 is a vertical sectional view of a wellhead and associated means constructed in accordance with the invention for handling a plurality of casings down into a well during a drilling operation and for supporting a plurality of upper casing extensions associated therewith;

FIG. 12 is a partly-sectioned elevational view of a production capsule particularly adapted for use in relatively shallow waters;

FIG. 13 is a partly-sectioned fragmentary elevational view of a hydraulic lifting device shown also in FIG. 12;

FIG. 14 is a diagrammatic view of an overall arrangement of capsule, adapter, separating equipment, production buoy, underwater storage tank, and other apparatus particularly adapted for use in connection with wells drilled in great depths of water;

FIG. 15 is a partly-sectioned elevational view of a conductor pipe and a foundation pad which are being prepared at great depth to receive a drilling capsule;

FIG. 16 is a partly-broken-away and partly-sectioned elevational view of a capsule enclosing a wellhead on
the floor of the sea, the structure being particularly adapted for use in drilling in great depths of water; FIG. 17 is a partly-sectioned elevational view of a deep-water capsule having well-completion valves in place and hydraulically-operated hold-downs from a superior chamber inserted in hold-down tubes attached to the capsule; FIG. 18 is a partly-sectioned elevational view of a novel adaptor for use with the capsule shown in FIG. 17; FIG. 19 is a partly-sectioned elevational view of separating apparatus mountable on the adaptor of FIG. 18; FIG. 19A is a fragmentary sectional view taken along the line 19A—19A of FIG. 19 and looking in the direction of the arrows; FIG. 20 is a diagram of novel electrohydraulic apparatus for operating hydraulic hold-down tubes, latching mechanisms and inflatable seals constructed in accordance with the invention; FIG. 21 is a partly-sectioned elevational view of a center-line elevator or submersible personnel chamber constructed in accordance with the invention; and FIG. 22 is a partly-sectioned elevational view of a production buoy constructed in accordance with the invention.

While for purposes of exposition the three embodiments are treated separately, various apparatus and methods described in connection with one embodiment may also be used in combination with apparatus and methods which are described as relating to another embodiment.

First embodiment: Drilling a well from a submersible vessel

In FIG. 1 a submersible vessel 10 is shown permanently secured to a foundation pad 11 at the bottom of the sea by remotely-controlled vertical adjustors 13. As many adjustors are used as may be necessary, and, in any event, other adjustors similar to the ones shown are located on the side of the vessel 10 opposite the side visible in the figure, so that the vessel 10 is provided with at least four "legs" formed in a manner hereinafter set forth to hold down the vessel 10 and to make all adjustments in its position when it arrives at the bottom.

The adjustors 13 are permanently attached to the vessel 10 and comprise cylinders 13a fitting salubriously about rams 13b slidably mounted therein. Ram extensions 13e which extend downwardly from the rams 13b and salubriously by the bottoms of the cylinders 13a to form the "legs," are secured to the pad 11 by ball-in-socket connections 13e or other (preferably universal) connections. Fluid lines 13d communicate with opposite ends of the cylinders 13a and extend to conventional apparatus (not shown) mounted within the vessel 10 for supplying a fluid to and exhausting it from the cylinders 13a, so that the ram extensions 13e may be remotely moved upwardly or downwardly to provide proper control of the position of the vessel 10.

A capsule 14 extending through a hole 15 in the pad 11 forms a watertight seal at its upper end with the vessel 10 by means of a mechanism indicated generally at 16, hereinafter described in detail, and at its lower end with a well casing 17.

Inasmuch as the pad 11 may settle during the drilling operation, it may be necessary to adjust the position of the vessel 10 with respect to the pad 11 by means of the adjustors 13 in order to preserve the seals at the pad 11 and the capsule 14. Relative vertical movement of the vessel 10 with respect to the pad 11 is readily effected by equal parallel movements of the adjustors 13. Limited horizontal movement of the vessel 10 with respect to the pad 11 is effected by certain unequal movements of the adjustors 13.

Lugs 18 help to establish the proper orientation of the capsule 14 with respect to the vessel 10 and thereby facilitate the forming of the seal by means of the mechanism 16. The lugs 18 are conveniently three in number and spaced at 120-degree intervals around the periphery of the capsule 14.

A traveling block 20 is used to lower a Kelly 21, a drill pipe (not shown in FIG. 1) and the casing 17 into the capsule 14 and sealably through sealing means such as locks (not shown) in the bottom thereof.

FIG. 2 shows in detail the structure of the capsule 14 and the equipment associated therewith during the drilling process. The top 22 of the wellhead 23, which is securedly mounted in an and tightly sealed to the capsule 14, supports a double collar gate 24 having a lower gate 25 and an upper gate 26. In accordance with the custom of the art, the collar gate 25 is fitted with pipe rams (not shown), while the collar gate 26 is fitted with blind rams (not shown). An annular preventer 27 is removably mounted on the double collar gate 24, and an extension spool 28 extends upwardly from the top 29 of the preventer 27 for engagement with a drill-through blowout preventer 31.

The drill-through blowout preventer 31 comprises a lower stationary body portion 32 and an upper or "stripper" portion 33, also stationary. While drilling is in progress, the Kelly 21 is slidable and rotatably attached to the stripper portion 33 and extends downwardly through the portion 32 for engagement with a drill pipe 34 which drives a drill bit (not shown) at its lower end.

In accordance with standard drilling practice, all of the blowout preventers, including any additional preventers mounted between the extension spool 28 and the preventer 31, are remotely controlled, and drill bits and casing are passed or locked through the preventers and into the floor of the sea.

 Mud return is provided for in the usual manner by an emergency high-pressure outlet 35 on the wellhead 23 which communicates through a valve 36 with a high-pressure mud-return line 37 and by a normal-pressure outlet 38 on the preventer 31 which communicates through a valve 39 with the high-pressure mud-return line 37 to form a combined-pressure mud-return line 40.

A closure plate 41, which is sealed to a flange 42 on the vessel 10 by means of bolts 43 and annular packing 44, prevents the entry of seawater into the interior of the vessel 10 in the event that the seal established by means of the mechanism 16 between the vessel 10 and the capsule 14 becomes ineffective during the drilling operation. A first opening 45 in the plate 41 is fitted with a removable gland 46 which forms a slidable seal about the spool 28. A second opening 47 in the plate 41 is fitted with a removable gland 48, which forms a seal about the high-pressure mud-return line 37. A manhole 49, the third and final opening in the plate 41, is provided with a cover 50, which is tightly sealable about its periphery to the plate 41.

The watertight seal between the vessel 10 and the capsule 14 is effected by a circular flange 42 on the vessel 10 and a mating flange 51 on the capsule 14 which are welded by the mechanism 16 referred to above. The mechanism 16 includes a level 52 for turning a shaft 53 at the end of which a pinion 54 engages a ring gear or annulus 55. The annulus 55 has a dovetail circular tongue 56 which fits within a dovetail circular groove 57 in the bottom of the vessel 10 so that the annulus can be freely rotated. When the annulus 55 is rotated, spaced-apart inwardly projecting lips 58 on the annulus engage spaced-apart outwardly projecting lips 59 formed around the circumference of the flange 51. The lips 58 and 59 are inclined to form portions of helices, so that the vessel 10 and capsule 14 are drawn tightly together when the annulus 55 is rotated in one direction and are disengaged from each other when the annulus is rotated in the opposite direction. Suitably placed packing or gaskets at 60, 61 and 62 ensure a watertight seal. A collar 63 on the shaft 53 main-
tains the vertical position of the shaft regardless of the pressure of the sea.

Thus it will be seen that drilling can be conveniently accomplished from the submerged vessel 10 by personnel who are not subjected to the hazards of working while exposed to the great pressures which prevail in the ocean depths.

After the drilling of the well is completed the well-drilling equipment is removed from the capsule 14, well-production equipment is in place, a hatch 64 is put onto the capsule 14, and the vessel 10 withdraws; see FIG. 3. The cementing of the casing 17 may be accomplished in a conventional manner.

The well completion equipment illustrated in FIG. 3 includes a "Christmas tree" 65 which has one or more master valves 66 and wing connections 67 and 68 which pass sealably through the capsule 14 for the delivery of oil. Wing valves 69 and 70, respectively, control the flow of oil through the wing connections 67 and 68 and sea valves 71 and 72 so that either of the wing connections can be closed off to facilitate the making of repairs.

The watertight integrity of the capsule 14 in the vicinity of the hatch 64 is maintained by a circular sealing flange 73 which mates with the sealing flange 51 on the capsule. The flanges are locked together by means of a wheel 74 which rotates a shaft 75 connected to rods 76. When the wheel 74 is turned the rods 76 are rotated about the axis of the shaft 75 so that their outer ends fit into slots 77. The slots 77 are inclined to form portions of helices, so that the hatch 64 and capsule 14 are drawn tightly together when the wheel 74 is rotated in one direction and are disengaged from each other when the wheel is rotated in the opposite direction. Packing 78 ensures a watertight seal. See also FIG. 4, which is a plan of the capsule 14 and hatch 64.

A downhaul cable 79, illustrated in FIGS. 3 and 5, extends vertically from the hatch 64 to the surface of the water, where it may be secured to a float (not shown) indicating the position of the well. The float may be distinctively marked to identify a particular well in a field. Alternatively, a transponder 79a on the capsule 14 may be used for this purpose. The transponder 79a may be coded to transmit an identifying signal on demand.

FIG. 5 shows a service chamber 89 guided in its descent from a tender 81 to the capsule 14 by the downhaul cable 79, which is taken up within the chamber 80 by a cable reel 82 (see FIG. 6). Cables 83 include air supply and exhaust hoses and light and communications lines. Anchor chains 84 and 85 hold the tender 81 in position during the descent of the chamber 80 (FIG. 5).

When the chamber 80 reaches the capsule 14, (FIG. 6), it is guided by the downhaul cable 79 and thebugs 88 so that it is properly oriented with respect to the capsule 14. A gasket 86 corresponding to the gasket 62 on the vessel 10 is compressed by the chamber 80 to form a temporary seal.

In FIG. 6 the chamber 80 is illustrated in position on top of the capsule 14. The chamber 80 comprises an upper compartment 87 and a lower compartment 88 divided by a deck 89. The upper compartment 87 is of a watertight construction, while the lower compartment 88 has a diving bell configuration: That is, it is enclosed on the top and around the sides but open at the bottom during the descent of the chamber 80.

The personnel who are to effect repairs within the capsule 14 make the descent in the compartment 87 (to which they gain access through an upper hatch 90 while the chamber 80 is on the surface) and are accordingly exposed to a pressure of only one atmosphere. The compartment 88 admits water at the bottom as the chamber 80 makes the descent. The water is, of course, unable to rise completely to the top of the compartment 88; it compresses into the upper portion thereof the air trapped therein, keeping it always at the pressure of the water at the depth at which the compartment 88 happens to be located.

A pump 91 is provided to expel the water from the compartment 88 through a valve 92 and into the sea after the chamber 80 is seated on the capsule 14. The air trapped within the compartment 88 simultaneously expands and fills all of the compartment except the part thereof which is now occupied by the upper portion of the capsule 14. Thus, with the removal of the water from the compartment 88, the pressure within the compartment is reduced to little more than one atmosphere. Venting the lower compartment 88 to the upper compartment 87 equalizes the pressures in the compartments.

If the chamber 80 is accidentally tipped while being lowered into the water, so that the compartment 88 prematurely fills with water, air is admitted into the compartment 88 after a temporary seal has been established between the chamber 80 and the capsule 14 by means of the packing 86 and during the time when the water in the compartment 88 is being pumped out into the sea in order to fill the vacuum which is created in the compartment 88 upon the removal of the water. The air to fill the vacuum is supplied from the compartment 87 or tanks (not shown) on board the vessel 10.

After the pressure in compartment 88 has been brought to the proper level, a hatch 94 in the deck 89 may safely be opened by means of a block and tackle 95, and the personnel within the compartment 87 may descend into the compartment 88. Here they may complete the formation of a watertight seal between a circular flange 96 (identical to the flange 42 on the vessel 10) and the flange 51 by means of a mechanism 97 (identical to the mechanism 16 on the vessel 10) in the manner described above, open the hatch 64 and descend into the capsule 14 for the purpose of making an inspection or effecting repairs. Upon completion of the inspection or repairs they may re-enter the compartment 88, replace the hatch 64 on the capsule 14, break the seal between the flanges 96 and 51 by means of the mechanism 97, re-enter the compartment 87, replace the hatch 94 in the deck 89, admit water into the compartment 88 to raise the pressure therein, and signal the personnel on the tender 81 that the chamber 80 is returning to the surface. A cable 98 is reeled in as the chamber 80 rises.

Second embodiment: Drilling a well in shallow water

FIGS. 7 through 13 illustrate an embodiment of the invention particularly adapted for use in drilling, completing, and producing from a well in shallow water. Water is deemed to be "shallow" for present purposes when drilling may be accomplished from a platform which is mounted on a floor underlying water but which extends above the water's surface.

FIG. 7 shows means for lowering casing into an under-water well. A conductor pipe 100 has been driven by conventional means into the floor of the sea to the point of refusal in preparation for drilling a well. An anchor pad 101, having casing-means-receiving means such as a center hole 102 large enough to pass over the conductor pipe 100, is lowered about the conductor pipe 100 in concentric relation thereto. Elongated guide means such as guide cables 103 attached to the anchor pad 101 on opposite sides of the hole 102 by conventional releasable end fittings 104 extend upwardly to a drilling rig (not shown) on the surface of the water. The drilling rig may be a conventional rig mounted on a platform resting on the bottom of the sea and rising above the water's surface.

A hole or well is drilled to a desired depth (which may be a thousand feet or so) below the lower end of the conductor pipe 100, so that the hole 102 is aligned with the well, and the conductor pipe 100 is then severed in the vicinity of the pad 101 at, say, a point 105, the upper portion being withdrawn to the drilling rig, where it may be stored for later use on another well. A capsule-support casing 107 also carried aboard the drilling rig is then
attached near its lower end 106 to a guide frame 108, which may comprise a structural cross brace 109 and guide sleeves 110. The guide cables 103 are passed through the guide sleeves 110, so that the guide frame 108 is slideable on the guide cables 103. The cables 103 guide the frame 108. The guide frame 108 is so formed that the lower end 106 of the casing 107 is aligned in the well as the frame and casing 108 are lowered from the drilling rig toward the anchor pad 101. Accordingly, the casing 107 is readily insertable into the interior 112 of the conductor pipe 100.

The connection 113 between the support casing 107 and the guide frame 108 may be a lashing of Manila line and is designed to break when the guide frame 108 encounters the upper edge 114 of the conductor pipe 100. The guide frame 108 may then be retrieved by cables or pennants 115—which may also be used for lowering the frame 108, though the casing 107 normally serves that purpose—and the guide cables 103 released from the releasable end fittings 104 by means of a conventional "overshot" (not illustrated) and lifted to the drilling rig. Alternatively, the lines 103 may be cut off close to the pad 101 by a conventional auxiliary cutting device.

FIG. 8 is a partly-sectional elevational view of a novel shallow-water drilling capsule 116 which comprises an upper substantially dome-shaped or bell portion 117 and a lower substantially bowl-shaped or base portion 118. The portions 117 and 118 are removably attachable in sealed relation to each other for forming a hollow watertight capsule. The base portion 118 is firmly and permanently attached to an underwater wellhead forging 119 which is in turn attached to the capsule support casing 107 and removably connected to a wellhead extension piece 120. The extension piece 120 communicates with an upper casing extension 122 and a set of blowout preventers 123 above the surface of the sea. Conventional ring joints 121 may be employed at suitable intervals between the extension piece 120 and the blowout preventers 123.

The wellhead extension 120 is slideable—for a purpose hereinafter set forth in connection with a description of the operation of the apparatus of the second embodiment of the invention—through a gland 124 adapted to prevent entry of water into the interior 125 of the capsule 116 when the capsule is submerged.

The capsule base 118 has cable-guide connections 127 which firmly hold cable-guide pipes 128 inserted therein. Capsule guides 129, rigidly mounted on the bell portion 117, are slideable over the cable-guide pipes 128 and cable 126 is adapted to guide the capsule portion 117 when it is raised from or lowered to the base portion 118. The capsule bell portion 117 is provided on one side thereof with a watertight man-lock chamber 130 having a hatch 131 at its upper end and a door 132 in common with the capsule 116. A service or personnel chamber may be designed to fit sealably over the hatch 131, thereby enabling workmen to open the hatch 131, enter the man-lock chamber 130, open the door 132, and enter the capsule 116. The upper end of the man-lock chamber 130 may be formed in such a way as to be capable of forming a seal with one of the service chambers disclosed in this application and illustrated in FIGS. 6 and 21. Alternatively, it may be conventionally designed to fit sealable with apparatus such as a United States Navy rescue chamber.

The annular downhaul cable 133 extends upwardly from the hatch 131 to a surface buoy 143 marking the location of the well. The service chamber preferably has positive buoyancy and makes the descent by means of apparatus designed to reel in the downhaul cable 133, such as the apparatus shown in FIG. 6.

FIG. 8 also shows an adaptor 134 releasably connected to the lower portion 117 of the capsule 116 on the side of the capsule opposite the man-lock chamber 130. Lines 157, 158 and 159 for fluid, power and compressed air, respectively, extend upwardly from the adaptor 134 to a drilling platform (not shown) resting on the floor and rising above the surface of the sea. The power line 158 may also include control lines as required. The purpose of the adaptor is to facilitate the connecting and disconnecting of various lines such as the lines 157, 158 and 159 to and from the capsule 116.

The wellhead extension piece 120 is fitted near its lower end with a stop ring 161 integral with the extension piece 120 and a drain valve 162 adapted to drain the interior of the extension piece 120. The stop ring 161 acts as a stop structure 163 when the wellhead extension 120 is moved upwardly to disengage the upper portion 117 of the capsule 116 from the lower portion 118 in order to shift from the drilling cycle to the production cycle as set forth below in connection with the description of the operation of the apparatus of the second embodiment of the invention.

FIG. 9 shows in detail a novel guide means for facilitating formation of a seal between the upper portion 117 and the base portion 118 of the capsule 116. A ring 135 made of rubber or other resilient material is retained in a groove 135' formed in a bell base ring or thickened rim portion 136 at the lower end of the bell 117 of the capsule 116. The ring 135 seals against a flanged rim or seal ring 137 at the upper end of the base portion 118 and integral therewith. Proper position of the upper portion 117 during the sealing operation is facilitated by means of a guide bracket 138 sloping upwardly and outwardly from an outer portion of the flanged rim or seal ring 137 and an adjustable biasing means such as a spring-operated centering device 139 mounted on an inner portion of the flanged rim or seal ring 137 and adapted to press against the inner side or face of the bell base ring 136. The spring-operated centering device 139 comprises a bracket 140 adjustably connected to the base seal ring 137, a spring 141 connected to the bracket 140, and a conventional strain gauge 142 for measuring the strain on the spring 141. The outer side or face of the bell base ring 136 is fitted with a chafing pipe or protector 144 which is interposed between the rim 136 and the guide bracket 138 and which co-operates with the guide bracket 138 and guides the upper portion 117 while it is being lowered onto and sealed to the base portion 118. Apparatus similar to that shown in FIG. 9 is spaced continuously or at suitable intervals about the periphery of the capsule 116 and is likewise employed on a capsule 213 (FIG. 12).

FIG. 10 shows in detail the construction of an adaptor 134' similar to the adaptor 134 of FIG. 8. The adaptor 134' is a two-ended generally tubular structure open at the top and bottom. The bottom end of the adaptor is adapted for watertight connection to a portion of a capsule enclosing an underwater wellhead, and the top end of the adaptor is adapted for watertight connection to a portion of a service chamber for servicing the capsule. Flanges 134a and 134b are formed around its lower and upper edges, respectively. The lower surface of the flange 134a is plane and sealably attachable by clamping means such as clamps 147 and annular packing 148 to the upper surface of a landing plate 149 integral with the upper portion 117 of the capsule 116. The annular packing 148 is retained in an annular groove 149 formed in the lower surface of the flange 134a. The upper surface of the flange 134b is also plane and is designed to be sealed to the lower end of a service chamber 146 by an annular packing 150 and hooking means such as hooks 151 in a manner well known in the art of submarine rescue. When so sealed at the top and bottom, the adaptor 134' forms with a generally bowl-shaped member 149a connected to the plate 149 a watertight extension of the lower end of the service chamber 146. The watertight integrity of the assembly is maintained at the lower end thereof by the generally bowl-shaped
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member 149a secured to the lower surface of the landing plate 149. A line 156a passes sealably through the member 149a and is communicated with a spacer 156.

The utility of the adaptor 134 is chiefly in facilitating the attaching and detaching of lines to and from under water well apparatus. In order to attach a line to underwater well apparatus in accordance with the invention it is necessarily merely to attach the line to an adaptor, attach the adaptor to a washpipe with a personnel-carrying chamber, lower the chamber and adaptor to underwater well apparatus, attach the adaptor and the line to the apparatus, and detach the chamber from the adaptor. In order to detach the line from the apparatus, it is necessarily merely to lower the chamber to the adaptor, attach the chamber to the adaptor, and detach the adaptor and line from the apparatus.

More particularly, to remove the adaptor 134 from the landing plate 149, in order, for example, to detach the line 156, the chamber 146 is lowered from the surface with the aid of a downhaul cable 152 and sealed the adaptor 134. The hooks 151 facilitate hold-down of the chamber 146 to the adaptor 134. The lower compartment 153 of the chamber 146 is evacuated of water and supplied with air at a pressure of about one atmosphere and a work crew within the chamber may slowly descend, close a valve 155 and remove the spacer 156 and the clamps 147. The workmen ascend into the upper compartment (not shown) of the chamber 146, flood the lower compartment 153, and allow the chamber 146 to return to the surface of the sea, carrying with it the adaptor 134.

The enumerated steps are performed in reverse sequence in order to attach the adaptor 134 to the landing plate 149.

Outer casing means constructed in accordance with the invention has an interior portion near its upper end tapering from a given inside diameter downwardly and inwardly to a smaller inside diameter. A hanger constructed in accordance with the invention for supporting additional casing means in an underwater well has an interior portion tapering from a given inside diameter downwardly and inwardly to a smaller inside diameter and an exterior portion tapering from a given outside diameter downwardly and inwardly to a smaller outside diameter. The hanger further has engaging means such as threaded portions for supporting casing means extending downwardly from the hanger into an underwater well and casing extensions extending upwardly from the hanger.

These and other features are illustrated in FIG. 11, which shows the wellhead forging 119 during a stage in the drilling operation. The wellhead 119 is, of course, attached to the base portion 118 of the capsule 116 in watertight fashion, as by welding. The lower end of the upper extension 120 is attached in watertight fashion to the upper end of the wellhead 119 by a ring clamp 166 and a gasket 165.

Within the wellhead 119 is a hanger 169 for the next smaller casing 170 and its associated upper casing extension 171. The hanger 169 has generally cylindrical inner and outer side walls which, however, taper inwardly and downwardly at their lower ends and of which the outer side wall tapers inwardly and upwardly at a point somewhat removed from its upper end. The upper end of the casing 170 is secured to the lower end of the hanger 169 by mating threads 172 formed on the inner walls of the hanger 169 and the outer walls of the casing 170. Similarly, the lower end of the casing extension 171 is secured to the upper end of the hanger 169 by mating threads 172' formed on the outer walls of the hanger 169 and the inner walls of the casing extension 171. A hanger 174, a casing 175 and an extension 176 are hung within the hanger 169. The hanger 174, casing 175 and casing extension 176 are similar to the hanger 169, casing 170, and casing extension 171, respectively, the chief difference being that the former are diametrically smaller so that the hanger 174 fits snugly within the hanger 169 and is supported thereby and the casing 175 and casing extension 176 fit within the casing 170 and casing extension 171, respectively, in spaced relation thereto. The hanger 169 supports the hanger 174 by virtue of the downwardly and inwardly tapering lower portions thereof and is itself supported by a similar taper of the inner walls of the upper portion of the wellhead 119. The casings extend to various depths, the depths being selected in a manner well known in the art.

The annuli 177a and 177b and the center bore 177c formed by the illustrated casings are connected to tubular members 247, 248 and 249 (FIG. 12) in the capsule 116 by passages 178, 179 and 180, respectively. That is, the passage 175 extends from the tubular member 247 in the capsule 116 to the annulus 177a between the wellhead 119 and the casing 170; the passage 179 extends from the tubular member 248 in the capsule 116 to the annulus 177b between the casing 170 and the casing 175; and the passage 180 extends from the tubular member 249 in the capsule 116 to the center bore 177c formed by the casing 175.

The passage 179 comprises a first segment 179a extending through the hanger 169 and a second segment 179b extending through the wellhead 119. An annular groove 179c formed about the circumference of the hanger 169 provides a fluid flow path between the segments 179a and 179b regardless of the relative angular orientations of the hanger 169 and the wellhead 119 about their vertical axes. Similarly, the passage 180 is divided into segments 180a, 180b and 180c extending through the hangers 174 and 169 and the wellhead 119, respectively, and an annular groove 180c formed about the circumference of the hanger 174 connects the segments 180a and 180b, while an annular groove 180b formed about the circumference of the hanger 169 connects the segments 180a and 180b.

The portions of the upper extension 120, 171 and 176 above the surface of the sea are joined rigidly together by steel annuli 190 and 191 to form the head of a strong column. As such each (and diametrically smaller) extension piece is put into place, the blowout-prevention equipment is shifted thereto in order to contain the well pressure within the extension having the smallest diameter. A blowout assembly 193 is shown mounted on the upper end of the extension 176 and attached thereto by a ring joint 195 or other suitable device.

The casing extensions 120, 171 and 176 have radial passages 196a, 196b and 196c respectively extending therein. The passage in the casing extension on which the blowout preventers are mounted (196c in FIG. 11) is plugged, the others being open to permit expansion and contraction of the structure forming the annular spaces 197 and 198 due to various causes. Annuli 197 and 198 between the extensions 120 and 171, and 171 and 176, respectively, are full of mud, or nearly so, during the drilling operation.

FIG. 12 shows novel apparatus constructed in accordance with the invention for use in completing a well and operating it during the production cycle. After completion of the drilling cycle, the upper portion 117 of the capsule 116 is removed, and a new upper portion or upper production-capsule bell portion 200 is installed on the base 118, forming a production capsule 212.

The upper production-capsule structure 200 is lowered from the surface of the sea by means of a drill string 201. A portion of which is attached by a safety joint comprising separable upper and lower members 202 and 203, respectively, the former of which is mounted on the lower end of the drill string 201 and the latter of which is integral with the production-capsule bell portion 200.

An adaptor 205 similar to the adaptors 134 and 134' (FIGS. 8 and 10) is attached to a crude line 206, power and control leads 207 and an air connection 208. The con-
connections are completed from the adaptor 265 to the capsule 212 by means of a crude discharge line 209, an air plug 210 and a power and control conductor 211, communicating respectively with the lines 206, 208 and 207 and sealably penetrating the upper portion 200 in a manner well known in the submarine art.

A man-lock chamber 214 similar or identical to the chamber 130 (FIG. 8) is attached to the bell portion 200, and the structure indicated generally at 213 is similar or identical to the corresponding structure shown in FIG. 9.

Above the landing plate 215 (which is similar or identical to the plate 149 shown in FIGS. 8 and 10) and rigidly connected thereto is a centerline landing plate 216. The centerline landing plate 216 is attached in a watertight manner to a lip 218 of an entrance cone 219, the latter being adapted to guide the upper safety member 202 into engaging relation to the lower safety member 203 (see also FIG. 13).

A hydraulic hoist 220, a hydraulic hoist line 221 supplying hydraulic fluid to the hoist 220 and having valves 222 and 224 and an accumulator 225 communicating with the lines 221 are mounted within the production-capsule bell portion 200. A hydraulic hoist supply line 226 having a valve 227 is connected to the hydraulic plant 221 and to the line 222. A valve 223 regulates flow of fluid to a drain line 229 which branches from the line 221.

The hydraulic hoist 220 supports a valve 231, a tee member 232 suspended from the valve 231, an annular blowout preventer 233 suspended from the tee 232, a ram-type wire blowout preventer 234 suspended from the blowout preventer 233, and a Christmas-tree forging 235 suspended from the blowout preventer 234. The Christmas tree 235 has a swabbing valve 236, a wing valve 237, an upper master valve 238 and a lower master valve 239 and is attachable to the wellhead 119 by a joint 241 which is preferably a ring joint. A fluid "kill" line 242 extending from the tee 232 to the well head 119 is adapted to force mud into the well under a pressure greater than that developed by the well, thereby halting the flow of oil or gas. A hydraulic control line 243 extends from a hydraulic power source 244 to the wellhead 119 and communicates with a conventional hydraulic control valve 245 adapted to control the operation of the kill line 242. The valves are controlled hydraulically or electrically in a conventional manner.

Tubular connections 247, 248 and 249 on the wellhead 119 communicate with the casing annuli 177a and 177b and the center bore 177c (FIG. 11) and are provided with pressure-reading devices 247a, 248a and 249a, respectively, which can be read by a person within the capsule and located elsewhere such as in a central control station or on the drilling rig.

A pump 251 attached to an interior wall of the upper portion 200 and fitted with a suction line 252 of which the lower portion 253 is flexible is adapted to pump out the bilges 256 of the capsule 212. A pump discharge line 254 is connected to the discharge line 209 through a valve 255. The line 209 discharges liquids to the drilling rig or to another desired station during the production cycle.

A power and control cable 258 forming an extension of the conductor 211 is connected to a switchboard 259.

Like the remaining equipment within the sometimes-flooded capsule 212, the cable 258 and board 259 are designed to withstand exposure to salt water and great hydrostatic pressure.

FIG. 13 illustrates the novel hydraulic hoist or lift 220 in detail. The hoist comprises hollow elongated cylinder means such as a ram chamber 263 orientable with its axis extending in a vertical direction and having an opening 263a at one end, a ram 266 slideable within the ram chamber 263 and forming a fluid-tight seal with the inside of the ram chamber 263, a ram extension 262 extending from the ram 266 and slideably through the opening 263a, the ram extension forming a fluid-tight seal with the opening, whereby an expansible and contractible fluid-tight annular enclosure 264 is formed between a portion of the inside of the ram chamber and a portion of the outside of the ram extension, and means such as the line 221 for supplying a fluid to and exhausting it from the enclosure.

The annular space 264 is sealed at its lower end by a ram packing 265 mounted in the inner wall of the chamber 263 and at its upper end by annular packing 267 mounted in an outer peripheral groove in the ram 266. Supplying hydraulic fluid to or exhausting it from the annular space or enclosure 264 respectively raises or lowers the ram 266 (lowering of the ram 266 is gravity- and sea-pressure assisted).

The hoist or lift 220 is mounted within the capsule 212 above and in spaced-apart relation to the well head 119, and the Christmas tree 235 and the apparatus associated therewith (FIG. 12) are collectively suspended from the lower end 269 of the ram extension 262 by means of a ring clamp 270 (FIGS. 12 and 13). Thus, after the bell portion 200 is properly positioned on the base portion 118, the assembly may be lowered to facilitate make-up of the ring joint 241, whereby hydraulic coupling of the Christmas tree 235 to the wellhead 119 is accomplished (FIG. 13). A retaining shoulder 274 is formed on an inner portion of the ram 266 (FIG. 13) to prevent a conventionally-mounted packer from backing upwardly out of the bore 273 of the ram extension 262 in response to the pressure generated within the bore 273 when the well is being halted.

FIG. 13 further shows a pair of screws 275 for mounting the hydraulic device 220 on the upper capsule bell portion 200. A thickened ring 275 is formed at the top of the bell portion 200. An annular flange 276 is rigidly attached as by welding to the ram chamber 263 and removable attached to the upper side of the ring 275 by bolts 277. A gasket 278 retained in an annular groove formed in the upper surface of the ring 275 establishes a seal between the ring 275 and the flange 276. The entrance cone 219 and the lower safety-joint member 203 are bolted or otherwise removably attached in a watertight fashion to an upper annular flange 279 formed at the upper end of the ram chamber 263. The flange 279, like the flange 276, is integral with the ram chamber 263.

A method of drilling and completing a well in shallow water and the operation of the apparatus of the second embodiment of the invention will now be described.

The conductor pipe 100 is driven or otherwise placed into the sea floor or other floor underlying water, and the anchor pad 101 is lowered about it as shown in FIG. 7. A hole or well is drilled to a desired depth below the lower end of the conductor pipe 100, and the conductor pipe 100 is severed at the point 105, the upper portion thereof being withdrawn to the drilling rig on the water's surface.

As the casing 107 is lowered into the hole prepared within the conductor pipe 100, the assembled drilling capsule 116 is attached to the casing 107 at the upper end thereof by a ring joint 121 (FIG. 8). The attaching of the capsule preferably takes place under the drilling rig. Further lowering of the casing 116 and of the capsule support casing 107 is effected by adding sections of the extensions 112 until the collar 208 rests upon the upper end 121. Above the collar 208 and the blowout preventers 123 are mounted above the water's surface, beneath the drilling rig, and stop the uppermost extension 122. During the drilling operation, all casings and tubing are preferably installed or set in the hole as illustrated in FIG. 11, the casings and tubing being lowered by means of their respective extension pieces, and cemented in the usual fashion.

Upon completion of the drilling and cementing operations (means of performing which are well known in the art and need not be described here), all of the extension pieces are removed. In the apparatus shown in FIG. 11, the removal of the extension pieces 171 and 176 is accomplished by unscrewing them from their respective
hangers 169 and 174. Conventional means are provided to prevent the well casing from "breaking out" anywhere except at the hanger connections. The extension piece having the smallest diameter is the first to be removed. Extension pieces having successively larger diameters are then removed, leaving only the wellhead extension 120 attached to the wellhead 119 by the ring joint 166.

The interior of the wellhead extension piece 120 is swabbed out to remove therefrom as much of the mud therein as possible (by means of conventional techniques, it is possible to avoid the need to "pull a vacuum" during the swabbing operation). Workmen then descend to the drilling capsule 116 in a service chamber, enter the capsule, open the valve 162 being held in its uppermost position by the extension 120 to the bilges 256, remove the ring joint clamp 166 (FIG. 11) to detach the extension 120 from the wellhead forging 119, and remove bolts 139a for securing lugs 139b integral with the bell base ring 136 to the seal ring 137 (FIG. 9).

Re-entering the service chamber, the crew return to the rig and lift the upper casing extension 122 and the wellhead extension 120 (FIG. 8) upwardly in order to clear the wellhead 119. By means of any suitable conduit remotely controlled in a conventional manner, the crew then files the capsule with cotton to nullify the suction force of the submergence pressure.

The upwardly-directed force on the extensions 120 and 122 raises them until the stop ring 161 abuts the stop-ring arresting means 163. A further lifting disengages the flooded drilling capsule bell portion 117 from the base portion 118. The bell portion 117 and the extensions 120 and 122 are raised to the surface of the water and hoisted aboard the drilling rig. The guides 129 integral with the bell portion 117 pass over the guide cables 126, thereby steadying the bell portion 117 during its ascent. All other lines from the bell portion 117 are reeled in at a rate sufficient to prevent fouling.

To complete the well and commence the production cycle, a second structure, the production bell 200 (FIG. 12), is lowered from the rig supported by an elongated rigid member such as the drill string 201 and guided by the cables 126. The drill string 201 may be suspended from a derrick on the drilling rig (not shown), and the cables 126 pass through cable guides 127 and direct the production bell 200 to a generally central position on the base structure 118. Exact centering is effected by the apparatus 212, similar or identical to that shown in FIG. 9.

During the lowering of the production bell 200, the Christmas tree 235 and the associated apparatus are suspended from the hydraulic lift device 220, the ram 266 (FIG. 13) being held in its uppermost position by a fluid delivered under pressure from the accumulator 225 through the line 221 (FIG. 12) to the annular space 264 (FIG. 13). To assist in holding the ram 266 in its upper position, chain slings (not shown) may be connected between pad eyes 222 on the bell structure 200 and pad eyes 225 integrated with the Christmas tree 235. When the Christmas tree 235 is held in its upper position, its lower flange 294 is preferably one or two feet above its companion flange 295 on the wellhead 119.

When the bell structure 200 is set in place the capsule 212 is pumped out by means of the pump 251, replacement volume of air at about one atmosphere being furnished from the drilling rig through the air line 210. The crew then descend from the drilling rig in a service chamber, enter the capsule 212 through the man-lock chamber 214, and secure the bolts 139a, thereby fastening the upper bell structure 200 to the base 118 mechanically. Sea pressure of course continues to force the upper structure 200 to the base structure 118, thereby ensuring the watertight integrity of the capsule 212.

With the upper and lower safety joint members 202 and 203, the crew removes the chain slings, if used, and lower the Christmas tree 235 until the flange

344 abuts the flange 295 (FIG. 12). To this end, the fluid in the ram chamber 263 (FIG. 13) is permitted to flow out through the line 221, the valves 232 and 233, and the drain line 229 (FIG. 12). The crew secure the flange 294 to the flange 295 by means of the ring joint 241, complete the connection of air, discharge and control lines, and return to the drilling rig.

The personnel on the drilling rig complete the well and place it in production in the fashion customary in the area, preferably by means of wire lines (not shown) extending through the drill string 201, the Christmas tree 235, and a safety valve 296. Crude oil or another well product flows through the safety valve 296, the master valves 239 and 235, the wing valve 237, and the crude lines 209 and 206 to a shore-based or other installation having facilities for collection.

The upper and lower safety joint members 202 and 203 are then disengaged and the drill string 201 is hoisted aboard the drilling rig. A small buoy is set out to mark the site of the well, and the drilling rig proceeds to its next location.

At any future time, the production capsule 212 may be visited by personnel in a service chamber attachable to the man-lock chamber 214 for the purpose of making inspection or repairs. The drill string 201 may be lowered from the surface and connection between the upper and lower safety joint members 202 and 203 re-established. Tools may be lowered from the surface through the drill string 201 for "work-over" of the well. Alternatively, when, for example, work is to be done on the hydraulic hoist 220, a center-line elevator may carry a work crew directly to the landing plate 216.

**Third embodiment: Drilling and operating a well in deep water**

FIGS. 14 through 22 show apparatus particularly adapted for use in drilling and operating wells in deep water.

FIG. 14 is a schematic drawing of an over-all arrangement of capsule, separating chamber, buoy, underwater storage tank and surface vessel particularly adapted for use in operating wells in great depths of water.

A reinforced poured-concrete foundation pad 300 bordered by a retaining skirt 30a is placed on the bottom of the ocean or other floor underlying water in order to mount an underwater wellhead and production equipment adjacent thereto. A conductor pipe 301 extends from a hole (not shown in FIG. 14) in the pad 300 into the floor of the ocean, and casing means 303 is inserted through the conductor pipe 301.

A foundation-pad cover 304 extends from the pad 300 to a capsule 305. Hold-down tubes such as the tubes 306 are held stationary with respect to the capsule 305 and are adapted in a manner hereinafter described to hold down various chambers sent down from the surface. Frusto-conical members or "entrance cones" 307 at the upper ends of the hold-down tubes 306 are adapted to guide apparatus such as hold-downs 308 into the hold-down tubes 306. An adaptor chamber 309 is designed to fit on the top of the capsule 305 and support at its upper end a separator chamber 310 bearing one or more separators 311 and one or more hold-down tubes such as the hold-down tube 312. The hold-down tube 312 has an entrance cone 313 adapted to receive a hold-down from, for example, a personnel carrier such as the one shown in FIG. 21.

Rigid guide members 314 (the nearer of which is broken away to allow a view of the farther) having portions 314a tapering upwardly terminate in guide cables 314b which are attached to a small marker buoy 315. The lower end of the guides 314 are secured by hold-down tubes 316 provided with entrance cones 317. The hold-down tubes 316 are held stationary with respect to the capsule 305.
One of the separators 311 is shown provided with means such as a rigid discharge line 318 which communicates with a flexible discharge line or trunk 319 for transporting a well product such as natural gas. A line 492 extending from the chamber 310 is also incorporated into the line 319 and may carry another well product such as oil. The lines 318 and 492 are separate from each other within the line 319. The gas and oil products at the well are, of course, initially mixed with each other but are separated from each other by the separators 311 if they are to be stored on the sea floor, as hereinafter more fully described. The upper end of the flexible discharge line or trunk 319 is coupled to a rigid connection 320 mounted in a production buoy 321 which is floatable on the water and supports the weight of the line 319. The oil entering the buoy 321 through the connector 320 is discharged through a quick-connect coupling 322 and a flexible discharge line 323 or other means for transporting a well product to a surface vessel such as a pickup tanker 324. The flexible discharge line 323 is supported by a cradle 325 suspended from a tackle 326.

The pickup tanker 324 conveniently may moor to the buoy 321 by means of a mooring line 327 and supplies power to pumping apparatus located on the bottom and preferably in the separator chamber 310 through a power cable 328 attached to the buoy 321 through a watertight connection 329. It also may collect oil or another well product from a storage tank 340 and the well itself.

During periods when they are not in use, the discharge, power and mooring lines 323, 325 and 327 may be carried aboard the tanker 324. In any event, they should be made in lengths sufficient to permit the tanker to remain at a safe distance from a flare 350 which may be lighted on the buoy 321 to oxidize waste gases.

A remote connector 333 is inserted into a cone 334 which is mounted in an oil discharge line 335 extending from the adaptor 309. A flexible discharge line 336 or other means for transporting a well product leads from the remote connector 333 to a remote connector 337 inserted into a cone 338 and a first aperture or port line 339 in the tank 340. Valve means shown in FIG. 19 and hereinafter described control the flow of the well product to and from the tank 340 and to the buoy 321.

The tank 340 is open to liquid flow to and from the sea through a second aperture or water pipe 341 disposed in spaced relation to the aperture 339. The pipe 341 is equipped with a strainer 342. The tank 340 has a shell 343 preferably of reinforced concrete, and its interior cavity 344 is adapted to contain crude oil 345 floating on sea water 346. Attached to the shell 343 in supporting relation thereto is a foundation pad 347 which also may act as ballast if required.

Workers skilled in the art will understand from the preceding description that, as the aperture 339 admits or exhausts a well product to or from the tank 340, the second aperture 341 automatically exhausts or admits an equal volume of water, so that the tank 340 is continuously under substantially equal interior and exterior pressures.

The tank 340 is lowered from the surface of the sea and located in proper relation to the capsule 305 by means of a conventional spacer or jig (not shown). The line 336 may then be attached to the remote connectors 333 and 337, which, guided by a conventional jig of construction similar to that of the one used in placing the tank 340 on the bottom, are inserted into the cones 334 and 338, respectively.

The tanker 324 makes periodic trips to the well site, where it collects oil from the tank 340 and from the separator chamber 310. The tanker 324 thus serves as a second well-product-storage or collection means.

FIG. 15 shows a preferred method of preparing the novel foundation pad 300. A framework or retaining skirt 300a and associated steel framework are provided with a center aperture, trunk or hole 358 adapted to pass casing means therethrough and drill-string-centering devices or members 359.

The frame 309a is adapted to be lowered to an undersea water floor and there to receive and mold a fresh-mixed setting compound such as cement to form the anchor pad 309. The centering devices or members 359 comprise a plurality of substantially U-shaped members each having its ends 359a and 359b attached to the walls of the aperture and a mid-portion 359c extending to a position displaced radially inwardly from the walls and adapted to abut the casing means. The devices or members 359 position the casing 301 in equally spaced-apart relation to the walls of the aperture 358 and may be spaced at substantially equal intervals about the aperture 358. By means of cables 363, the pad 300 is lowered about the conductor pipe 301, which has been forced into an uneven sea bottom 360 to the point of refusal. The lower edge of the skirt 300a typically penetrates the sea bottom 360 to some extent. In order to pour concrete within the skirt 300a, one or more means for depositing a freshly-mixed setting compound such as pipes or ducts 361 are attached to guides 362 which are slidably mounted on the lowering cables 363. The mouth 364 of the duct 361 is placed at or near the bottom of the cavity to be filled. Concrete or cement discharged into water from a mouth so placed sets into a hard mass, which will allow to fall a considerable distance through water becomes dispersed and fails to set. The depositing means or duct 361 may be raised and lowered, so that the distance moved by the setting compound from the depositing means 361 to a position of rest is adjustable. Generally, the depositing means 361 is raised gradually as the cementing operation progresses.

FIG. 16 shows the foundation pad 300 after its construction by the novel method described in connection with FIG. 15.

The conductor pipe 301 has been cut off in a manner similar to the manner in which the pipe 100 is cut off (FIG. 7). The cutting may be effected by any one of a number of means conventional in the drilling of oil wells. The conductor pipe above the point of severance is withdrawn to the surface and stored for future use on another well.

The crew on the floating surface rig make up a string of the capsule-support casing 303 having a length equal to the ground-penetration depth of the conductor pipe 301 or to the depth of the bottom of an additional hole 376 drilled below the bottom of the conductor pipe 301. The capsule-support casing 303 is guided into the conductor 301 with the aid of the cables 363. At a proper point along the length of the capsule-support casing 303, a hollow watertight capsule 305 is permanently attached thereto. A wellhead 378 is installed within the capsule interior 380 after the capsule 305 is in position on the ocean bottom. A lower safety joint 381 secures the upper end of the wellhead 378 to the lower end of a wellhead extension 382 having the lower part of an upper safety joint 383 attached thereto.

A protective skirt 384 integral with the extension 382 is adapted to prevent fouling of or other damage to the upper surfaces of the capsule 305 during the drilling operation.

On the outer surface 385 of the capsule-support casing 303 centering devices 386 are secured by welding or other suitable means.

After the capsule 305 and the capsule-support casing 303 have been properly centered in the hole, cement 390 is forced by conventional means as far as possible up into the annular space 388 between the conductor pipe 301 and the capsule-support casing 303. Inasmuch as the capsule-support casing 303 is generally short as compared to a string of casing progressing therethrough, the annular space 388 is typically filled throughout its entire length. Wires 387 attached to and extending circum-
ferentially of the capsule-support casing 303 improve the shear strength of the concrete 390. The load-carrying ability of the wellhead 378 is a function of the quality of the cement work even when, owing to a condition such as underconsolidation of the sea bottom 360, it is necessary to hang casing strings from a point below the wellhead 378 to minimize column load on the conductor pipe 301.

After the cementing operation has been completed and the water has been pumped out of the capsule 305, the capsule may be entered by a work crew who descend thereto in a personnel chamber.

The capsule 305 has a shell 391 designed to withstand the pressure of the sea at its intended location while maintaining within a pressure of one atmosphere. A base ring 389 or other suitable reinforcing member is attached to the shell 391 at its lower end, and a landing ring 392 on which chambers such as the protective skirt 384 land is attached to the shell near its upper end.

A latching groove 393 formed in or below an upper reinforcing ring or collar member 394 attached to the shell 391 above the landing ring 392 (see also FIG. 17) facilitates hold-down of a variety of chambers in a manner described more fully in connection with FIGS. 18, 19 and 20. A sealing neck 395 is formed at the upper end of the shell 391 and about an aperture 305a in the capsule 305. A similar sealing neck may be formed on the other submersible chambers illustrated in the third embodiment of the invention. The sealing neck 395 is hollow and generally cylindrical but has an end 395b which is "rolled home" or curved inwardly and an end 395c which flares into the walls of the capsule 305. All of the sealing necks are sealably insertable in mating openings formed in the lower portions of all the submersible chambers (except, of course, the capsule 305, protective skirt 384 and tank 340) of the third embodiment of the invention.

The collar member 394 is generally frusto-conical, its larger base 394a being nearer the end 395c of the neck 395 and its smaller base 394b being nearer the end 395b of the neck 395. Flat annular members 394c and 394d connect the bases of the collar member 394 to the neck 395. The groove 393 is between the neck 395 and the annular member 394c connecting the larger base 394a of the collar member 394 to the neck 395.

Hollow elongated tubular members such as hold-down tubes 306 (see also FIG. 14) are two of six identical tubes which are spaced at equal intervals about the periphery of the capsule shell 391 and permanently attached to the exterior thereof by means such as supports 306a. The hold-down tubes 306 are open at their upper ends, which are provided with hollow generally frusto-conical members 397 for holding-down apparatus into the tubes 306. The operation of the hold-down mechanism is described more fully in connection with FIG. 20.

The foundation pad cover 304 surrounding the shell 391 and abutting it comprises structural members 304a as required, a frusto-conical member or sheet 398 having its smaller base 398b connected to the capsule 305 and its larger base lowermost and connected to the anchor pad 300, and a skirt 399. Along its circumference, the skirt 399 is provided with a backing mesh 400 or other suitable means to facilitate proper union between the skirt 399 and the upper surface 401 of the reinforced-concrete pad 300. After the installation at the wellhead 378 is otherwise complete, the volume 402 bounded by the surface 401, the sheet 398, and the capsule 305 may be filled or partly filled with cement.

The rigid guide members 314, which serve as permanent guides, are then installed, and the cables 363 cut off or otherwise removed.

FIG. 16 also illustrates an assembly 409 of conventional cellular gates and blowout preventers mounted atop the upper safety joint 383. The assembly 409 is removed and replaced by similar equipment of different sizes as the drilling progresses.

A drill string 410 having a collar 411 and supporting a bit 412 is advanced to drill out a plug 413 formed during the cementing operation so as to effect any additional drilling which may be necessary.

After the placing and cementing of the capsule support casing 303, the drilling and the casing of the well proceed as though the well were on shore, except that, whenever it is necessary to work on the wellhead equipment, the wellhead is visited by personnel in a submersible, which may be, for example, of the type shown in FIG. 21.

FIG. 17 illustrates the capsule 305 during the production cycle. The capsule 305 is shown as unitary but may be divisible as the capsules 116 and 212 (FIGS. 8 and 12), of the second embodiment are. The capsule 305 has a dual-completion head facilitating the production of oil from two zones. The wellhead 378 is of the full-bore type, whereon all gauges are remote-reading and all valves are remote-actuated. Such gauges and valves are well known in the art and need not be further described here.

After the installation of a master valve 416, its remotely-controlled actuator motor 417, a flow-control valve 418 and its remotely-controlled motor 420, tubing 421, or other means for delivering a well product, is installed. The tubing 421 extends through the capsule 305 and sealably through a chamber 422, and is flanged into a flange 423 (only one of which is shown). A mixed well product such as oil and gas flows upwardly through the tubing 421. The capsule cover 422 has an access manhole 424 with a stuffing box 425 mounting an electrically-conducting means such as an electrical conductor 426. The conductor 426 is in electrically-insulated relation to the capsule 305. In order to confine the wellhead pressure to the capsule 305 and to simplify the pipe-fitting problem in other chambers, one or more flow-control valves such as the valve 418 are preferably located within the capsule 305 as shown.

On the exterior of the capsule 305 and attached to the capsule shell 391 are the hold-down tubes 306 having the conical entrance guides 307, as FIGS. 14 and 16 also show. The hold-down tubes 306 are adapted to receive hold-downs (from, for example, a superior chamber). The hold-downs 308 are tubes or hollow shafts vertically movable with respect to a superior chamber in a manner explained in connection with FIGS. 19 and 20. The hold-downs 308 have at their lower ends hydraulically-operated slips such as the slips 433, actuable in a manner hereinafter explained to prevent pulling down the hold-downs 308 with respect to the capsule 305. The capsule 305 may be provided with conventional storm chokes or down-hole valves for automatic down-hole shut-off.

A variety of hold-down tubes may be spaced at positions around a capsule or other chamber. The hold-downs of each type may be arranged at equal intervals around the periphery of the capsule. Thus, a different set of hold-down tubes may be disposed about the capsule for each of the chambers to be lowered to the capsule, each set of hold-down tubes being adapted to receive the hold-downs of a particular type of chamber.

Inasmuch as the exterior form of the groove 393, the ring 394 and the neck 395 is identical for all of the submersible chambers, any chamber can be attached to any other. The rolling home of the upper edge 395a of the capsule shell 391 and of the neck 395 facilitates the attachment of chambers above it.

FIG. 18 shows in detail—and from the side opposite that shown in FIG. 14—the next-to-lowest chamber shown in FIG. 14, the adaptor 399. Its function is to provide an area in which connections may be made with the capsule 305, the storage tank 346, and superior chambers. It is a hollow two-ended generally tubular member having a shell 446 open at the bottom to the sea until it is secured to a lower chamber such as the capsule 305. The adaptor 399 is designed to be lowered.
from the water's surface attached beneath a personnel chamber such as the one shown in FIG. 21 and to be connected to the capsule 305 by personnel within the chamber. Sealing members such as a plurality of annular seals 439 mounted within the adaptor 309 circumferentially of a hole or trunk 449 for receiving the neck (FIG. 17) are inflatable by personnel within the personnel chamber to establish a seal between the lower end of the adaptor and a sealing neck inserted therein.

The adaptor 309 has an interior configuration at its lower end substantially complemental to the sealing neck 395. More particularly, it is complemental to the sealing neck 395, the latching groove, sealing neck member 394, and the landing ring 392. Thus, the adaptor 309 can be lowered over the sealing neck 395 until a sealing ring 440 to which is attached a sealing gasket 441 is in firm contact with the landing ring 392 (FIGS. 16 and 17). Evacuation of water from the interior 443 of the adaptor 309 by any suitable means sets the sealing gasket 441 firmly. The sealing members 439 are then inflated to improve the seal between the adaptor 309 and the sealing neck 395.

A hatch 445 near the upper end of the adaptor 309 gives workers access to the interior 443 after it has been evacuated of water and filled with air at a pressure of about one atmosphere and therefore to the capsule 305.

The adaptor 309 thus functions as a sealed vessel, its watertight integrity being maintained by the shell 446, the gasket 441, an interior ring 448 welded to the shell 446 and to a seal-support trunk 449, sealing members 439, and either a superior chamber sealably encompassing the upper portion 471 or the hatch 445 and associated structure at the upper end of the adaptor 309.

Latching means such as the latch 451 spaced, preferably at equal intervals, peripherally about the members 439 near the shell 446 at the end thereof opposite the portion 471 are actuated manually by tightening a nut 452, thereby retracting a threaded shaft 453 through a stuffing box 454 and lifting a toggle 455. The latch 451 is pivoted by the moving toggle 455 about a pin 456 held stationary with respect to the shell 446. Thus, the latch 451 firmly engages the upper reinforcing ring 394 in the latching groove 393 (FIG. 17) and holds the adaptor chamber 309 to the capsule 305.

Flow lines or tubing 457a or other means for delivering oil or another fluid product are attached to the tubing 421 (see also FIG. 17) by make-up adaptors 459 and 460. The flow lines 457a and a line 457b (which carries oil either upwardly towards the tank 324 or downwardly towards the tank 340 in a manner herein described) are attached at their upper ends with remote-connector guide cones 474.

The storage discharge line 457b is coupled to the storage discharge line 335 through a stop valve 453 which prevents flow of sea water from the line 335 to the line 457b during installation and servicing. The line 335 is passed sealably through the shell 446 in a conventional manner. Electrically-conducting means such as an electrical connector 465 passed into the interior space 443 through a stuffing tube 468 while the adaptor 309 is on the surface is attached to the capsule electrical conductor 426 (see also FIG. 17). The connector 465 is in electrically-insulated relation to the adaptor 309. A bow 469 integral with the shell 446 and extending outwardly therefrom guards the electrical conductor 465 against damage by the personnel adaptors of superior chambers, and a similar bow 470 protects the storage discharge line 335.

The adaptor 309 is normally lowered and attached to the capsule 305 and thereafter left permanently. However, it can be removed by reversing the installation procedure described above.}

The upper portion 471 of the adaptor 309 comprises a landing ring, latching groove, reinforcing ring or collar member and sealing neck, all of which have the same configuration as the landing ring 392, latching groove 393, upper reinforcing ring 394 and sealing neck 395 of the capsule 305, so that a variety of additional chambers may be lowered and attached to the adaptor 309 or substituted therefor on the capsule 305.

FIG. 19 shows the separator chamber 310 in detail. The chamber 310 has a shell 476, a landing ring 477 integral with and extending inwardly from the lower end of the shell 476 and provided with a peripheral gasket 478, an interior ring 479 integral with and extending inwardly from the shell 476 at a point above the ring 477, and an annular inflatable seal trunk 480 extending upwardly from the inner end of the ring 479. The upper portion 524 of the separator chamber 310 is shaped identically to the sealing neck 395 and associated structure, and the interior configuration of the lower end of the chamber 310 is substantially complementary to the exterior configuration of the sealing neck 395 and the other sealing necks disclosed herein.

In a manner which in the light of the preceding disclosure will be understood by workmen skilled in the art, the lower part of the chamber 310 forms with the chamber 301 into which it is fitted, such as the adaptor 309, a watertight enclosure 481 which can be entered by workmen after it has been evacuated of water and supplied with air at a pressure of about one atmosphere and which therefore serves as a passage to the adaptor 309 and capsule 305. Entrance from the separately-closed upper compartment 482 of the chamber 310 to the watertight enclosure 481 is by way of a hatch 483 sealing an opening in the upper portion of the shell 476 and a ladder 484 extending from a point immediately beneath the hatch 483 downwardly into the space 481.

Mechanical locking of the chamber 310 to the adjacent lower chamber is performed by a number of peripherally-spaced latches such as the latch 485 similar in construction and operation to the latch 451 (FIG. 18), except that the latch 485 is remotely controllable by a hydraulic means including a ram extension 486 and a ram chamber or cylinder 487. The operation of the ram 486 and ram chamber 487 is set forth in connection with the description of FIG. 20.

One or more hollow watertight separators such as the separator 311 are mounted on the separator chamber 310. The separators 311 are provided with indicator trunks 521 which penetrate the chamber 310 in the manner shown. A liquid level indicator 522 may be incorporated into one of the indicator trunks 521.

Remote-connector devices 489 adapted to enter the remote-connector guide cones 474 of the adaptor 309 (FIG. 18) comprise tube latching mechanisms 490, extensor sleeves 491, inner tubular members such as pressure tubes 492 and 492a and tubing doublers 493 (only one of which is shown) and outer tubular members such as tubing supports 494. Given parts of the tubing supports 494 are attached to support means such as the shell 476 and support the weight of the remote-connector devices 489.

The attaching of the pressure tubes 492 and 492a and the tubing doublers 493 to the tubing supports 494 at points 496 displaced longitudinally of the tubular members 492, 492a and 494 from the points 496a of connection of the tubular members 494 with the shell 476 and from the points of connection of the latching mechanisms 490 within the guide cones 474 permits moderate lateral movement of the latching mechanisms 490 and their guidance within the cones 474 to a proper connection with lower tubes such as the flow lines 457a and 457b (see also FIG. 18). Thus, by providing freedom of movement, less accuracy in the fabrication of the connecting parts is required and successful remote coupling is facilitated.

Workmen skilled in the art will understand that a mixed well product such as oil and gas from an under-water well may be separated by the separator 311 attached to the chamber 310. Essentially, the apparatus FIG. 19.
comprises first tubing means for transporting a mixture of oil and gas from an underwater well from the chamber 310 to the separator 311, which separates the oil and gas, second tubing means for transporting the separated oil from the separator 311 back to the chamber 310, third tubing means extending from the chamber 310 to the surface, fourth tubing means extending from the chamber 310 to underwater storage means, and valve means connected to the third and fourth tubing means for selectively connecting the second tubing means to one of the third and fourth tubing means. Fifth tubing means may be extended from the separator 311 directly to the water's surface for discharging gas separated from the oil.

More particularly, a mixture of oil and gas rising from an underwater well in a line 457a (FIG. 18) rises through the line 492a (FIG. 19) with which the line 457a is connected and passes into the separator 311.

The oil and gas are separated in the separator chamber 311, the gas rising through the line 318 and a valve 318c (see also FIG. 14) and the oil returning to the chamber 310 through a line 492c. The gas is generally burned to form the flare 330 shown in FIGS. 14 and 22, and the oil is normally delivered to the tank 340 where it is stored until picked up by the tanker 324.

The line 492b communicates with the line 492 at a point between a normally-closed valve 492c and a normally-open valve 492d. A pump 492e, operated by a battery (not shown) during periods when the tanker 324 is not on station at the well and by power from the tanker 324 during periods when the tanker 324 is present, facilitates movement of the oil downwardly through the line 492 and the line 457b (FIG. 18) and through the lines 335 and 336 to the tank 340.

When the tanker 324 is on station at the well for the purpose of picking up oil from the tank 340, the valves 492c and 492d are both open, and the pump 492e is reversed to pump oil from the tank 340 through the lines 336 and 335 (FIGS. 14 and 18) and upwardly through the lines 457b and 492.

Simultaneously, oil which is being produced at the well and which rises in the line 457a and passes into the separator 311 and back through the line 492c can pass into the line 492, provided the oil is under sufficient pressure. A check valve 492f in the line 492b permits passage of oil from the line 492c to the line 492 but not in the reverse direction.

The latching mechanisms 490 are controlled by hydraulic operating lines 499 and 500 extending from the upper compartment 482 through the shell 476. The lines 499 and 500 are controlled by remote control by a small pump 554 (FIG. 20). The latching mechanisms 490 can thus be extended in a direction opposite to the direction of displacement of the points 496 from the points 496a to effect a fluid coupling between the tubing 492 and 492a on the one hand and the tubing 457b and 457a on the other.

As FIG. 19A shows, each of the extensor sleeves 491 has an annular inwardly-projecting shoulder 491a which fits tightly into the associated latching mechanism 490. Annular packing 491b in an inwardly-facing annular groove 491c insures a tight seal about the latching mechanism. Each latching mechanism 490 is formed with outward-facing annular shoulders 490a and 490b disposed respectively above and below the shoulder 491a. Annular packing 490c and 490d in outwardly-facing annular grooves 490e and 490f, respectively, insures a tight seal with the interior wall of the extensor sleeve 491. Cavities 499g and 499h are thus formed between the extensor sleeve 491 and the latching mechanisms 490. When a fluid such as oil is supplied to the cavity 499g through the line 500 and exhausted from the cavity 499h through the line 499 and exhausted from the cavity 499g through the line 500, the latching mechanism 490 is raised; conversely, when fluid is supplied to the cavity 499h through the line 499 and exhausted from the cavity 499g through the line 500, the latching mechanism 490 is lowered.

The same pump which pressurizes the lines 499 and 500 also powers a hydraulic hold-down assembly 501 (see also FIG. 14) which comprises hydraulic operating lines 502 and 503, a cylinder 504 rigidly attached to the chamber 310 and having a lower cavity 566 and an upper cavity 507, and the hold-down tube 306. The hold-down tube 306 is double acting, retraction being effected by a pressure equal to sea pressure in the lower cavity 506 acting against atmospheric pressure in the upper cavity 507.

The hold-down 306 has throughout its length a channel 509 through which hydraulic fluid is supplied to gear 511 for operating the internal slips 435. A generally conical nose 515 on the lower end of the slips 433 facilitates entrance of the slips 433 and the gear 511 into the frusto-conical entrance guide 307 of the hold-down tube 306.

The lower end of the cylinder 504 is closed by a gland 517 through which the hold-down 308 is extensible. When they are set by means of the hydraulic circuitry shown in FIG. 20, the internal slips 433 or other expandable securing means prevent upward movement of the slips 433 and thus prevent the hold-down tube 306 (see also FIGS. 14, 16 and 17).

The hydraulic circuitry shown in FIG. 20 is adapted to operate not only the hydraulic hold-down assembly 501 and the expandable securing means at the lower end thereof but also the latches 485 and the inflatable annular seal 534 (FIG. 19). The hold-down mechanism comprises the cylinder 504 having the lower cavity 506 and the upper cavity 507. The ram extension or hold-down 308 is free to move within the cylinder 504, and a ram 530 is sealed against the interior wall 531 of the cylinder 504 by a gasket 532 or other suitable device. Hydraulic pressure can be applied to the lower cavity 506 through the line 502 and to the upper cavity 507 through the line 503.

The conical nose 515 is located at the lower end of the ram extension or hold-down 308. The operating gear 511 for the slips 433 comprises a retractor cylinder 539 adapted to seal about and slide upon the outer surface of the ram extension or hold-down 308. Slip links 540 secure the lower portion of the retractor cylinder 539 to lugs 541 integral with the slips 433. The outer surfaces of the slips 433 are provided with horizontally-extending teeth or serrations 542 which, when in the lower, expanded, gripping or set position, engage the inner wall of the hold-down tube 306 and prevent upward movement of the hold-down 308 with respect to the hold-down tube 306.

In FIG. 20 the slips 433 are shown in the upper, contracted or retracted position. Movement of the slips 433 along ramps 543, which have outer surfaces inclined to a reference line, such as the axis of the hold-down 308, is guided by keys or slides 544, which may be, for example, T-shaped in cross section. A stop 545 provided with a peripheral sealing gasket 546 is integral with the ram extension 308 and serves as the bottom of the retractor cylinder cavity 547. A compression coil spring 548, or other biasing means, here shown in a position of maximum compression, abuts the lower face of the stop 545 and the upper surface 549 of the slips 433.

Hydraulic fluid is supplied to the retractor cavity 547 from the channel 509 drilled or otherwise formed in the ram extension 308 through an aperture 551 formed in a portion of the ram extension 308 lying within the retractor cylinder cavity 547.

Retraction of the internal slips 433 is effected by adjusting the pressures in the hydraulic operating lines 502 and 503 so that sufficient pressure is transmitted to the retractor cylinder cavity 547 to overcome the force of the coil spring 548 and force the slips 433 upwardly and inwardly along the ramps 543. By precisely balancing the pressures within the lower cylinder cavity 566 and the upper cylinder cavity 507, the hold-down or ram extension...
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308 can be made to "inch" or move slowly in either direction. To this end, throttling valves 552 and 553 are provided in the lines 502 and 563, respectively.

A suction line 555, a pump 554, a cylinder-supply line 556, a multiple-position valve 557, and the line 503 supply hydraulic fluid to the upper cavity 507. A meter 558 in the line 503 shows the value of the instantaneous fluid flow vector. The upper pressure regulating valve 559, the valve 557, and the upper atmospheric discharge line 559 discharging to a sump 560 or a regulated-pressure-discharge line 561 containing an adjustable relief valve 562 and also discharging to the sump 560 exhaust fluid from the upper cavity 507.

A submergence sea pressure line 564 and the line 502 supply fluid to the lower cavity 506. The line 502, the valve 564, the portion of the line 563 adjacent to the valve 564, a line 573a, and the portion of the line 561 between the junction of the line 561 with the line 573a and the point of discharge of the line 561 into the sump 560 form a first discharge system for discharging fluid from the lower cavity 506, and the line 502, the valve 564 and a regulated-pressure-discharge line 565 containing an adjustable relief valve 566 form a second. A portion of the regulated-pressure discharge line 561 is thus common to the upper and lower cylinder discharge systems.

In operating the mechanism shown in FIG. 20, it is necessary first to advance and engage the slips 433 and then to exert a downward holding force on the cylinder 504.

Let it be assumed that the annular area of the ram 539 exposed to the pressure in the lower cavity 506 is half as great as the area of the ram presented to the pressure in the upper cavity 507 and that initially the slips 433 are expanded and the fluid within the cavities 506 and 507 is at sea pressure. All of the movable parts shown in FIG. 20 are then at rest, inasmuch as the total force exerted on the ram 530 by the fluid in the upper cavity 507 is equal to the force exerted on the ram by the fluid in the cavity 506 plus the force exerted on the ram by the ram extension 308 as a result of sea pressure on the apparatus extending from the cylinder 504. If the pressure in the upper cavity 507 is increased to sea pressure plus 150 lbs. per sq. in. that in the lower cavity 506 to sea pressure plus 300 lbs. per sq. in., the ram 530 remains substantially at rest, because the products of (a) the increased pressures in the cavities 506 and 507 and (b) the areas on the ram 530 against which they respectively act are equal. However, the increased pressure in the upper cavity 507 is transmitted through the channel 509 and aperture 551 to the cavity 547 within the cylinder 539, raising the cylinder against the force of the compression spring 548 and retraction 433. A further increase in the upper cavity 507 advance the ram 530 and its associated parts including the slips 433 downwardly, keeping the slips 433 retracted.

The rate of the advance is determinable by the rate at which fluid is supplied to the upper cavity 507. In a preferred embodiment of the invention, the valve 564 adjusted for flow from the port 569 to the port 572, the relief valve 566 is set to open at 300 lbs. per sq. in. above sea pressure and the multiple-position valve 557 is adjusted for fluid flow from a port 567 in the valve 557 communicating with the line 556 to a port 568 in the valve 558 communicating with the line 503. Fluid is supplied by the pump 554 at a pressure greater than sea pressure plus 150 lbs. per sq. in. to the upper cavity 507, whereupon the holddown 568 and apparatus suspended therefrom advance the ram 539 and engage the slips 433. The position because of fluid pressure in the cavity 547. When the nose 515 has entered the cone 507 of the holddown tube 306 (see FIG. 14) and descended a suitable distance into the hold-down tube 306, the slips 433 may be set. In setting the slips, the throttling valve 553 is closed, the relief valve 562 is adjusted for fluid flow from a port 569 in the valve 566 communicating with the line 502 to a port 570 in the valve 564 communicating with the line 563, whereupon fluid escapes from the cavity 547 through the port 551 and the channel 509 and into the upper cavity 507. Fluid simultaneously escapes from the lower cavity 506, allowing the ram 530 to drop slightly under the combined influence of gravity and the coil spring 548. As the spring 548 expands it advances and sets the slips 433 in the manner previously described.

The throttling valve 553 is then opened, and the multiple-position valve 557 shifted for fluid flow from the port 568 to a port 571 in the valve 557 communicating with the line 556 in order to exert fluid force on the cylinder 506 effective to overcome the slight positive buoyancy of the chamber 310 or other chamber to which the cylinder 504 is attached. The chamber when thus seated may be sealed by the latches 485 and the annular seals 554 to the adapter or other object on which it is positioned.

Workmen skilled in the art will understand from the disclosure that a second set of slips (not shown) may be employed and the hydraulic-operating sequence adapted to lower a negative-buoyancy chamber to engage seals in a similar manner. The combination of two sets of slips oriented oppositely with respect to each other simplifies buoyancy control.

To disengage and retract the hold-down apparatus, the multiple-position valve 564 is shifted to permit fluid flow from the port 569 to a port 572 in the valve 564 communicating with the line 565 and through the line 566 and the valve 566, which remains set at sea pressure plus 300 lbs. per sq. in. The multiple-position valve 557 is adjusted to permit fluid flow from the port 567 to the port 568. Fluid is supplied to the upper cavity 507 at a pressure greater than sea pressure plus 150 lbs. per sq. in., thereby moving the hold-down assembly downwardly and retracting the slips 433 at a rate determined by the setting of the throttling valve 553.

To raise the hold-down 306 so that the nose 515 clears the entrance cone 307, the relief valve 562 in the line 561 is adjusted to sea pressure plus 150 lbs. per sq. in., the stop 573 in the line 573a is closed, the stop valve 574 in the line 561 is opened, the multiple-position valve 564 is adjusted for fluid flow from a port 575 in the valve 564 communicating with a line 562c to a port 576 in the valve 557 communicating with the line 566. Fluid is then supplied from the pump 554 at a pressure greater than sea pressure plus 300 lbs. per sq. in., thereby raising the ram 530 and while maintaining the slips 433 in the retracted position.

The ram chamber or cylinder 487, which controls the latches 485 (see also FIG. 19), is operated after the chamber 310 is properly seated by means of the hold-down mechanism described immediately above. To lock the latches 485, a multiple-position valve 578 is shifted for fluid flow from a port 579 in the valve 578 communicating with a line 563a which branches from the line 563 to a port 590 in the valve 578 communicating with a line 580a and from a port 581 in the valve 578 communicating with a line 581a to a port 582 in the valve 578 communicating with a line 582c. The line 580a communicates with a lower cavity 583 of the ram chamber or cylinder 487; the line 581a communicates with an upper cavity 584 in the chamber 487; and the line 582a discharges to the sump 560. The lower cavity 583 of the ram chamber or cylinder 487 is thus brought to sea pressure, while the upper cavity 584 is discharged to the sump 560 at atmospheric pressure. The ram or piston 577, which may have a peripheral sealing gasket 577a for forming a fluid-tight but slidable seal between the ram 577 and the interior wall of the ram chamber or cylinder 487, and the shaft or ram extension 486 rise, locking the latches 485 (FIG. 19) in a manner hereinbefore explained. Shifting the valve 578 for fluid flow
from the port 580 to the port 579 and from the port 582 to the port 581 reverses the operation, dropping the piston 577 and an ram extender 486 downwardly and releasing the latches 485 (FIG. 19) from the chamber below.

Inflation of annular seals 534 is effected by shifting a valve 585 for fluid flow from a port 586 in the valve 585 communicating with a line 563b to a port 587 in the valve 585 communicating with a line 586. The line 563b communicates at its end opposite the port 586 with the line 563, and the line 587c communicates at its end opposite the port 587 with a low-pressure cavity 591 of an intensifier 589. Fluid is therefore supplied at a lower, lower cavity 587c. The pressure in the low-pressure cavity 588 moves to the right as seen in FIG. 20 a ram assembly 590 having rams 590a and 590b respectively sidable within the low-pressure cavity 588 and a high-pressure cavity 591 of the intensifier 589 in sealed relation thereto. Fluid under high pressure is forced by a ram moving ram 590 from the high-pressure cavity 591 through a tube 592 and into an interior cavity 593 of the annular seal 534. The annular seal 534 is therefore inflated to help maintain the watertight integrity of the chamber 310 (FIG. 19). While in FIG. 20, only one seal sleeve is shown connected to the intensifier 589, it is obvious that a multiplicity of such seals may be so connected.

To deflate the seal 534, the valve 585 is shifted for fluid flow from the port 587 to a port 594 in the valve 585 communicating with a line 593. Sea pressure against the outer surface of the annular seal 534 then collapses the seal and forces the fluid within the interior cavity 593 back through the tube 592 and into the high-pressure cavity 591. The ram assembly 590 moves to the left as seen in FIG. 20, and the fluid within the low-pressure cavity 588 escapes through a line 595 to the sump 560, which is of course at atmospheric pressure. The valves 557, 564, 578 and 585 may be provided with solenoids or other apparatus facilitating remote control of the valves.

A reservoir 596 contains a hydraulic fluid 597 floating on a bed of sea water 598. A floating or otherwise moveable diaphragm 599 separates the hydraulic fluid from the water. The sea water 598 is supplied through a sea valve 600a and an intake line 600b which extends through the chamber shell 476 into the sea. Thus, a continuous supply of submergence pressure is assured without the use of a pump or other powered pressure source, the sealing and latching devices upon which the safe operation of the chamber to a large extent depends on being operated by sea pressure. The hold-down, latching, and sealing mechanisms herein described are therefore quite safe. For example, even if the lines 502 and 503 supplying fluid to the cylinder 504 should both be ruptured, sea pressure and the spring 548 would continue to keep the hold-downs in position; they would not release accidentally.

FIG. 21 illustrates the elevator 601 and personnel-carrying chamber 601. The center-line elevator 601 is adapted to be sealed to any of the submersible chambers shown in FIG. 14 (except, of course, the tank 340, though the tank could be so constructed as to be capable of receiving the chamber) and previously described, including the capsule 305. The elevator 601 has a lower diving bell compartment 602 and a hollow watertight upper compartment 603, the latter of which is continuously maintained at an interior pressure of approximately one atmosphere. Depth gauges, oxygen tanks, air-purifying equipment, ballast-pumping equipment, compressed air tanks for ballast blowing, and other equipment (not shown) similar to that with which U.S. Navy submarine rescue chambers are provided are carried aboard the elevator 601. The elevator is further adapted to carry a work crew and the equipment required to effect repairs to a wellhead.

The lower compartment 602 is provided with a generally bell-shaped shell 604, a landing ring 605 projecting inwardly from the lower end of the shell 604 and acting as a back-up ring for a peripheral guide groove attached to the lower face thereof, an interior ring 607 extending inwardly from the shell 604 at a plane above the plane of the ring 605, and an annular inflatable seal trunk 608 extending upwardly from the ring 607. Inflatable seals 609 are placed between the annular inflatable seal trunk 608 and a lower vessel neck such as the neck 534 on the chamber 310 (see FIG. 19). The lower compartment 602 is thus a watertight unit which may be evacuated of sea water and filled with air at a pressure of about one atmosphere and which personnel may enter.

The elevator 601 is lowered into position from the surface of the sea by means of a fall or cable 611 attached to lifting eyes 612. It is adjusted to final position by hydraulic hold-down apparatus such as the apparatus 613 similar to that shown in FIGS. 19 and 20.

The upper compartment 603 is provided with shell 614, an upper access hatch 615 sealably covering an opening in the upper end of the shell 614 and a lower access hatch 616 sealably covering an opening in the lower shell 604, to which the upper shell 614 is attached in a watertight manner. The upper compartment 603 may also include an intermediate deck 617 having a hatch 618 sealably covering an opening therein. In order to maintain a vertical attitude of the elevator 601 at all times, permanent ballast 618 and variable ballast tanks 619 are installed as required. The tanks 619 are preferably pumpable rather than open to the sea as in the case of "soft" tanks.

The shells 604 and 614 carry one or more guide assemblies such as the guide assembly 620 comprising an elongated spring plate 621 extending parallel to the longitudinal axis of the chamber 601 and attached to the shell 614 by exploding or other remotely-removable fastenings 633, a guide bracket 622 rigidly attached to the upper end of the spring plate 621, a swing jaw 623 mounted pivotally about a pin 632 extending laterally through the guide bracket 622, a sliding jaw 624 having a slot 631 sealable about the pin 632, concave guide cables 625 and 626 at the upper ends of the jaws 623 and 624, respectively, forming when clamped together a generally tubular guide through which the cable 314b may be passed, guide rollers 627 and 628 mounted near the ends of the swing and sliding jaws 623 and 624 opposite the guides 625, 626, the axes of rotation of the rollers being horizontal and one raised above the other in the spring space 629 or other biasing means connected to the spring and sliding jaws 623 and 624 and urging the guides 625, 626 inwardly against the cable 314b, and a connecting rod 629a pivotally connected to the axes of the rollers 627, 628. The guide assembly 620 is designed to cooperate successively with one of the guide cables 314b and the corresponding tapered portion 314a and rigid guide member 314 shown in FIG. 14. When it is engaged with the guide cable 314b, it is guided by means of the cables guide cables 625 and 626, which when clamped together form a replaceable sliding sheave presenting an inner wear surface to the cable 314b. The wear surface is made of bronze, plastic, or some other material appreciably softer than the cable over which it slides.

The swing and sliding jaws 623 and 624 both extend in opposite directions from their connection with the bracket 622, the wear surfaces or guides 625, 626 being at their upper and the rollers 627 and 628 at their lower ends.

The structure at the lower end of the spring plate 621 is similar to that at the upper end and need not be described in full detail.

As the chamber 601 descends and the lower part of the guide assembly 620 encounters the tapered portion 314a (FIG. 14), the guide rollers 627 and 628 are forced apart against the resistance of the spring space 629. The guide
rollers 627 and 628 are each shaped with a waist 630 to facilitate centering of the rollers about the tapered portion 314 of the rigid guide member 314. The separating of rollers 627 and 628 connected to the lower ends of the sliding jaw 624 and the swing jaw 623, respectively, by the tapered portion 314a forces the sliding jaw 624 upwardly, the slot 631 sliding over the pin 632. The pin 632 is, of course, secured through the slot 631 and through holes in the swing jaw 625 and the bracket 622.

The movement of the sliding jaw 624 is accomplished by an inward swinging movement of the lower end of the swing jaw 625. These movements cause the cable guides 625 and 626 to separate and assume a position to clear the rigid guide member 314. The guiding function is thereupon performed by the rollers 627 and 628.

The use of rigid guide members 314 at the lower ends of the guide cables 314g facilitates a more accurate centering of the sealing chambers on the chamber 601 than would be the case if cables alone were used. Exact centering of a large chamber at the bottom of the sea by remote control is not always possible. Therefore, the seals for the joining of the various chambers constructed in accordance with the invention are given a certain flexibility; thus, the guide assembly 620 is mounted on the spring plate 621 in order to permit a moderate movement of the chamber 601 in relation to the rigid guide member 314 while the hold-down and clamping mechanisms are effecting the mutual sealing of adjacent chambers.

As much as the fastenings joining the spring plate 621 to the shell 614 are explodable or otherwise remotely removable, the chamber may be released independently from within if the guide mechanisms become fouled, to be returned to the surface either by its own buoyancy or by means of the fall 611. A weather deck 634 at the upper end of the chamber 601 and raling 635 around the weather deck facilitate use of the chamber 601 on the surface of the sea.

The upper hatch 615 sealably enclosing an opening formed in the upper end of the shell 614 may be replaced with a sealing neck similar to the one to which the lower end of the chamber 601 is sealed, to enable an auxiliary chamber to be lowered to the chamber 601 for rescue or repair purposes in the event of an emergency.

The chamber 601 may carry its own air supply or receive air through lines extending to the surface of the sea. If the chamber is surface-supported in this respect, the use of air-operated tools and other equipment may be advantageous. Communication with the surface of the sea may be by a cable trailed by the elevator 601 or by means of sonar.

Hold-down apparatus 613 attached to the exterior of the chamber 601 is similar to that previously described. FIG. 22 shows the production buoy 321 (shown also in FIG. 14) in detail. The buoy 321 is elongated along an axis and designed to float with its axis in an upright position in the surface of the sea and to support the operations of the various devices located at the well-head as described previously. In particular, the buoy 321 is adapted to transmit signals to and receive signals from the equipment at the well head, to supply power required during the various phases of the well operation, and to support a portion of the weight of the flexible line or trunk 319. The line or trunk 319 comprises a gas exhaust line 318, an oil discharge line 492, a power cable 641, and signal cables 642. The various lines and cables are clamped together to form line or trunk 319 by clamps 653 spaced at various locations between the surface and the bottom of the sea. The gas exhaust line 318 and oil discharge line 492 are flexible and may be made of a material such as reinforced rubber. The walls of the lines 318 and 492 need not have sufficient strength to enable the lines when empty to withstand the sea pressure without collapse. The ends of the line or trunk 319 (i.e., 75 the portion near the production buoy 321 and that near the separator chamber or chambers 311) are rigid and capable of withstanding the local sea pressure without collapse.

The buoy 321 comprises an outer watertight shell 644, a weather deck 645 at the upper end of the shell 644, an engine flat 646 secured to the shell 644 beneath the weather deck 645 and adapted to support power apparatus and other equipment, a fuel tank top 647 secured to the shell 644 beneath the engine flat 646, a conical buoy bottom 659 comprising the lower end of the shell 644, permanent ballast 651 attached to the exterior of the shell 644 near its lower end, a raling 652 around the weather deck 645, one or more vertically-disposed awning stanchions 653 attached to the weather deck 645 near the edges thereof, a metal awning 654 supported by the upper ends of the awning stanchions 653, an outer engine-flat access trunk 655 projecting upwardly from the weather deck 645 and provided with an upper hatch 655a, a valve compartment hatch 656 sealing an opening formed in the engine flat 646, a battery access trunk 656 extending from a valve compartment 651 to a storage compartment 653, a storage trunk 659 extending vertically through a fuel tank 682 and the storage battery compartment 683, a conductor extension or rigid connection 320 projecting downwardly from the lower end of the conical buoy bottom 659, a pickup buoy and mooring eye 661 and a boarding ladder 662.

The interior of the buoy 321 is divided into a number of compartments. A machinery and control compartment 663 of which the engine flat 664 constitutes the deck and the weather deck 645 forms the overhead contains such equipment as a motor-generator set 664 of sufficient size to handle the current requirements of the controls, lights, blowers and the like; a panel 665 housing various controls; a power panel 666 for handling both the operating power from the motor-generator 664 and the pumping power transmitted from the pickup vessel or tanker 324 (FIG. 14) to the wellhead for recovery of stored oil; a pumping power cable 667; radio transmitting and receiving equipment 668 by means of which signals can be transmitted for remote control of the well; an air duct or vent 669; an air exhaust line 670; a gas vent line 671 provided with an automatic igniter 673 for igniting the gas 675 and 676 for controlling a gas discharge valve 677 and an oil discharge valve 678 in the valve compartment 663.

The valve compartment 681 is immediately beneath the machinery and control compartment 663. The valve compartment 681 supplies the motor-generator 664 with fuel for protracted periods of time. Under certain conditions, the engine for the motor-generator 664 may use gas from the well as fuel.

The lowest compartment in the buoy 321 is the storage battery compartment 663, which contains batteries 664 and associated equipment.

On or above the weather deck 645 are a radio antenna 685, an air intake trunk 666, an engine exhaust muffler 687, required navigational aids such as the light 692 and an audible signal, a battery exhaust compartment 669 and a watertight power connection 329 to which the power cable 328 is attached by the pickup vessel 324 (FIG. 14), and the pickup buoy pennant or mooring line 327 secured permanently at one end to the mooring eye 661 and detachably at the other end to the pickup vessel 324 (FIG. 14).

Buoy mooring gear is attached to the conical bottom 659. The buoy mooring gear comprises a sliding or roller bearing 693, a retainer ring 694 attached to the shell 664, and a mooring ring 695 on the exterior of the buoy 321 and rotatable within the bearing 693 of the buoy 321. Mooring eyes 696 adapted to receive mooring lines 697 are attached to the mooring ring 695. The bearing 693 is supported by bearing brackets 698 and a cover plate 699. This mooring arrangement enables the
buoy 321 and the attached pickup buoys and lines to swing independently of the permanent buoy mooring lines 309. Under some conditions and in some locations such an arrangement may be undesirable, in which case the rotating mooring ring 305 may be locked in one position and the pickup buoys and the oil discharge lines taken aboard the pickup vessel. The oil discharge line is then disconnected, brought to the surface alongside the buoy 321, and there made fast in such a manner as to facilitate connecting upon the next visit of the pickup vessel. In the light of the preceding description, other systems of mooring within the spirit and scope of the invention will suggest themselves to workers skilled in the art. During the pick-up operation, the power and oil discharge lines are connected, the former to supply power to the transfer pump located at the wellhead and the latter to take aboard oil pumped to the surface of the sea.

The burning of gas to form a flare in an offshore well is common. While the flares are seldom accidentally extinguished even under the severest weather conditions, the pickup vessel 324 need be separated from the buoy 321 by only a short distance in order to avoid the danger of an unhappy fire. Preferably, of course, the pickup vessel 324 is not downwind of the buoy 321.

It is apparent that the various embodiments of the present invention provide for a high degree of division of function in underwater well construction and operation. Only the equipment which is actually needed for the operation of the well need be left at the wellhead. The remainder of the equipment, namely the drilling equipment and the servicing equipment, can be employed elsewhere. Further, whenever it is necessary to make inspection or repairs it is possible to do so with a minimum of personnel and equipment. Moreover, the capsule is safely on the bottom of the ocean and away from the destructive action of wind and waves.

Modern submarines are capable of operating at depths of many hundreds of feet, and sturdier submersible vessels at depths of several miles, so that by the methods of the present invention it is possible to exploit vast deposits of natural resources hitherto inaccessible. There is provided in accordance with the invention a method and apparatus permitting separation of the drilling, producing, and servicing phases of underwater well construction and operation. The representative embodiments described above are obviously susceptible of modification in form and detail within the spirit and scope of the invention. For example, they are adapted to drilling not only for oil but also for such other resources as sulphur and natural gas. Further, the mechanism 97, which has been described as operable only between the wellheads 88 and 89 of the chamber 80 can be readily extended through the deck 89 so that it is operable from the compartment 87. If the mechanism 97 is so extended, it can be used to form a watertight seal between the chamber 80 and the cap 14 before the hatch 94 is opened. In the case where the workers do not have to rely on the temporary seal formed by the compression of the packing 86 while they descend from the compartment 87 to the compartment 88. Also, the methods of sealing the cap 14 to the casing 17 and the vessel 10 or the chamber 80 are subject to numerous modifications. Moreover, the transponder 79a may be employed to locate a particular well in a field by releasing upon demand a buoy which carries the downhaul cable 79 to the surface.

Again, while the cap 116 is shown as being divisible along the plane nearer the lower end thereof to upper and lower portions 117 and 118, respectively, it is obvious that the plane may be at any other elevation with respect to the cap. Also, if the apparatus of the third embodiment of the invention is to be used under conditions such that the separation of gas from oil at the bottom of the sea is not desired, the chamber 310 may be modified with a pumping station using the same types of remote connectors. Accordingly, the invention is to be construed as including all of the modifications which fall within the scope of the appended claims.

We claim:

1. Apparatus for enclosing an underwater wellhead, comprising a lower capsule portion having an upper rim, an upper capsule portion having a lower rim removably attachable in sealed relation to said upper rim, whereby said portions form a hollow watertight capsule, biasing means mounted on one of said rims and adapted to exert a force against one side of the other of said rims, bracket means mounted on said one of said rims and co-operating with the other side of the other of said rims, and means provided on said other of said rims and bracket means, said biasing means, said bracket means and said biasing means co-operating to guide said rims into said relation.

2. A service chamber comprising a hollow watertight upper compartment, a lower diving-bell compartment, annular sealing means formed about the interior of said lower compartment, whereby said lower compartment may be sealed to a sealing neck inserted therein, a pair of relatively movable jaws connected to said chamber, and biasing means for urging said jaws into co-operative relationship, said jaws being adapted to co-operate with each other and with an elongated member extending between an underwater well and the surface of the water for guiding said chamber during movement from the surface of the water to an underwater well.

3. Apparatus for enclosing an underwater wellhead, comprising a lower capsule portion having an upper flanged rim, an upper capsule portion having a lower thickened rim removably attachable in sealed relation to said flanged rim, whereby said portions form a hollow watertight capsule, spring-mounting means mounted on said flanged rim, a spring mounted on said spring-mounting means and adapted to exert an outward force against the inside of said thickened rim, bracket means mounted on said flanged rim, sloping upwardly and outwardly and co-operating with the outside of said thickened rim, and biasing means mounted on the outside of said thickened rim and interposed between said thickened rim and said bracket means, said biasing means and said spring co-operating to guide said rims into said relation.

4. Apparatus as defined in claim 3 and further comprising a strain gauge mounted on said spring.

5. Apparatus as defined in claim 3 in which a groove is formed in said thickened rim and further comprising annular sealing means retained in said groove.

6. Apparatus as defined in claim 3 in which said spring-mounting means is adjustable.

7. A service chamber comprising a hollow watertight upper compartment, a lower diving-bell compartment, annular sealing means formed about the interior of said lower compartment, whereby said lower compartment may be sealed to a sealing neck inserted therein, a bracket connected to said chamber, a sliding jaw pivotally connected to said bracket, a sliding jaw having a slot formed therein, means extending through said jaw of said bracket, means for urging said jaws into co-operative relationship, said jaws being adapted to co-operate with each other and with an elongated member extending between an underwater well and the surface of the water for guiding said chamber during movement from the surface of the water to an underwater well, and biasing means for urging said means to guide said rims into said relation.

8. Apparatus as defined in claim 7 in which said means are formed on said said swing and sliding jaws comprises a pair of rollers respectively mounted on said swing and sliding jaws for receiving said elongated member therebetween.

9. Apparatus as defined in claim 7 in which said means are formed on said swing and sliding jaws comprise a pair of sliding wear surfaces respectively mounted on said swing and sliding jaws.
31. Apparatus as defined in claim 7 in which each of said swing and sliding jaws extends in opposite directions from its connection with said bracket and in which said means formed on said swing and sliding jaws for receiving said elongated member therebetween and a pair of sliding wear surfaces respectively mounted on said swing and sliding jaws, said rollers being displaced in a first and said surfaces in a second direction from said connection.

11. Apparatus as defined in claim 10 in which each of said rollers is formed with a waist intermediate its ends and in which each of said sliding surfaces is concave, whereby co-operation of said rollers and surfaces with said elongated member is facilitated.

12. Apparatus as defined in claim 7 and further comprising a second swing jaw pivotally connected to said bracket at a point vertically displaced from said first swing jaw, and second sliding jaw having a slot formed therein, means extending through the slot in said second sliding jaw for slidably connecting said second sliding jaw to said bracket at a point vertically displaced from said first sliding jaw, means formed on said second swing and sliding jaws and adapted to co-operate with each other and with said elongated member for guiding said chamber during movement from the surface of the water to an underwater well, and biasing means for urging said means formed on said second swing and sliding jaws into co-operative relationship.

13. Apparatus as defined in claim 12 in which said means formed on said second swing and sliding jaws comprise a pair of rollers respectively mounted on said swing and sliding jaws for receiving said elongated member therebetween.

14. Apparatus as defined in claim 12 in which said means formed on said second swing and sliding jaws comprise a pair of sliding wear surfaces respectively mounted on said swing and sliding jaws.

15. Apparatus as defined in claim 10 in which each of said second swing and sliding jaws extends in opposite directions from its connection with said bracket and in which said means formed on said second swing and sliding jaws comprises a pair of rollers respectively mounted on said swing and sliding jaws for receiving said elongated member therebetween and a pair of sliding wear surfaces respectively formed on said second swing and sliding jaws, said rollers being displaced in a first and said surfaces in a second direction from said connection of said second swing and sliding jaws with said bracket.

16. Apparatus as defined in claim 13 in which each of said rollers on said second swing and sliding jaws is formed with a waist intermediate its ends and in which each of said sliding surfaces on said second swing and sliding jaws is concave, whereby operation of said rollers and surfaces on said second swing and sliding jaws is facilitated.

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