

[54] SUBSEA PRODUCTION SYSTEM

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[58] Field of Search 166/0.5, 0.6

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[57] **ABSTRACT**

A submergible template structure is completely

equipped with manifolding for handling well production fluids, gas injection and well maintenance with through-the-flowline (TFL) pumpdown tools. The template is designed to contain a number of clustered wells and is provided with a pollution control system, electro-hydraulic power source and an unmanned manipulator unit capable of traveling on a track arranged on the template for specific maintenance work on valves, control pods, pipe sections, etc. The template is furnished power and control through an electrical cable laid to a remote surface power source. Pipelines connect the template manifolding to remote gathering terminals. The template structure and the manifolding are disconnectable and reconnectable in sections for removal, repair and replacement of damaged sections. The template structure is completely equipped at the surface and then lowered to the sea floor using lines and controlled buoyancy. Once on bottom, the template is leveled and piles driven to anchor it. Wells are drilled from floating rigs and the wellheads are grouped together on the template. Christmas trees are lowered and connected to the wellheads and to the manifolding. Basic well maintenance is performed with TFL equipment although the wells may be re-entered vertically from a floating rig when necessary. All valves are hydraulic fail-safe and manual valves in the manifold are operable by the manipulator unit. The manipulator is lowered to the track and positioned where desired when performing operation of the valves or basic maintenance on the valves and manifold.

11 Claims, 7 Drawing Figures

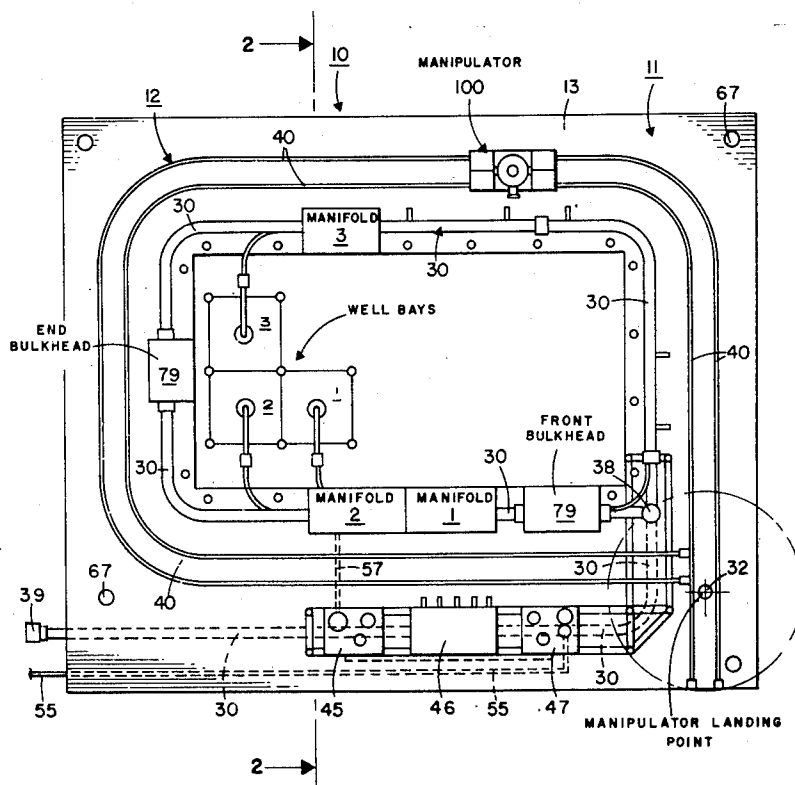
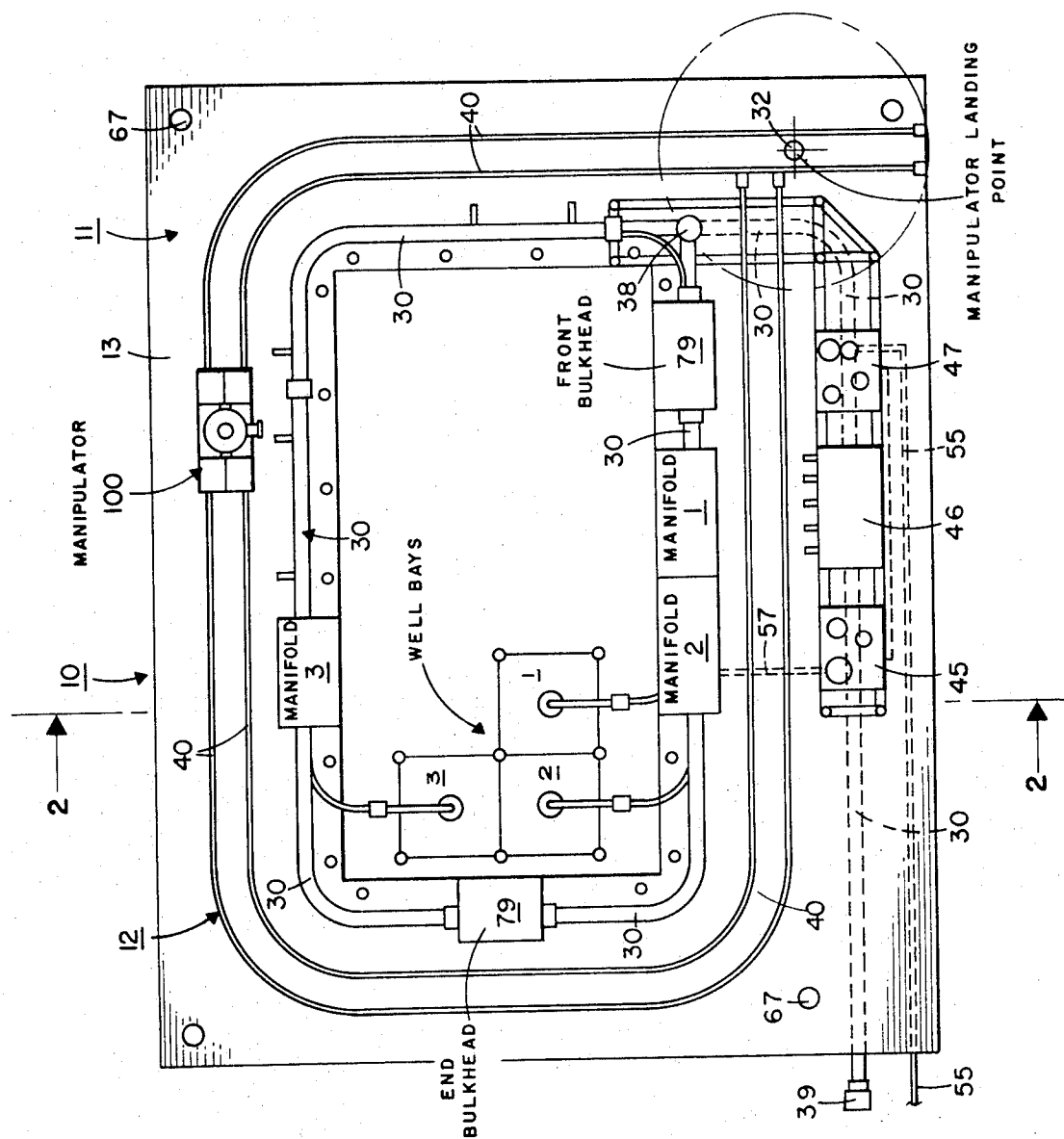


FIG. 1.



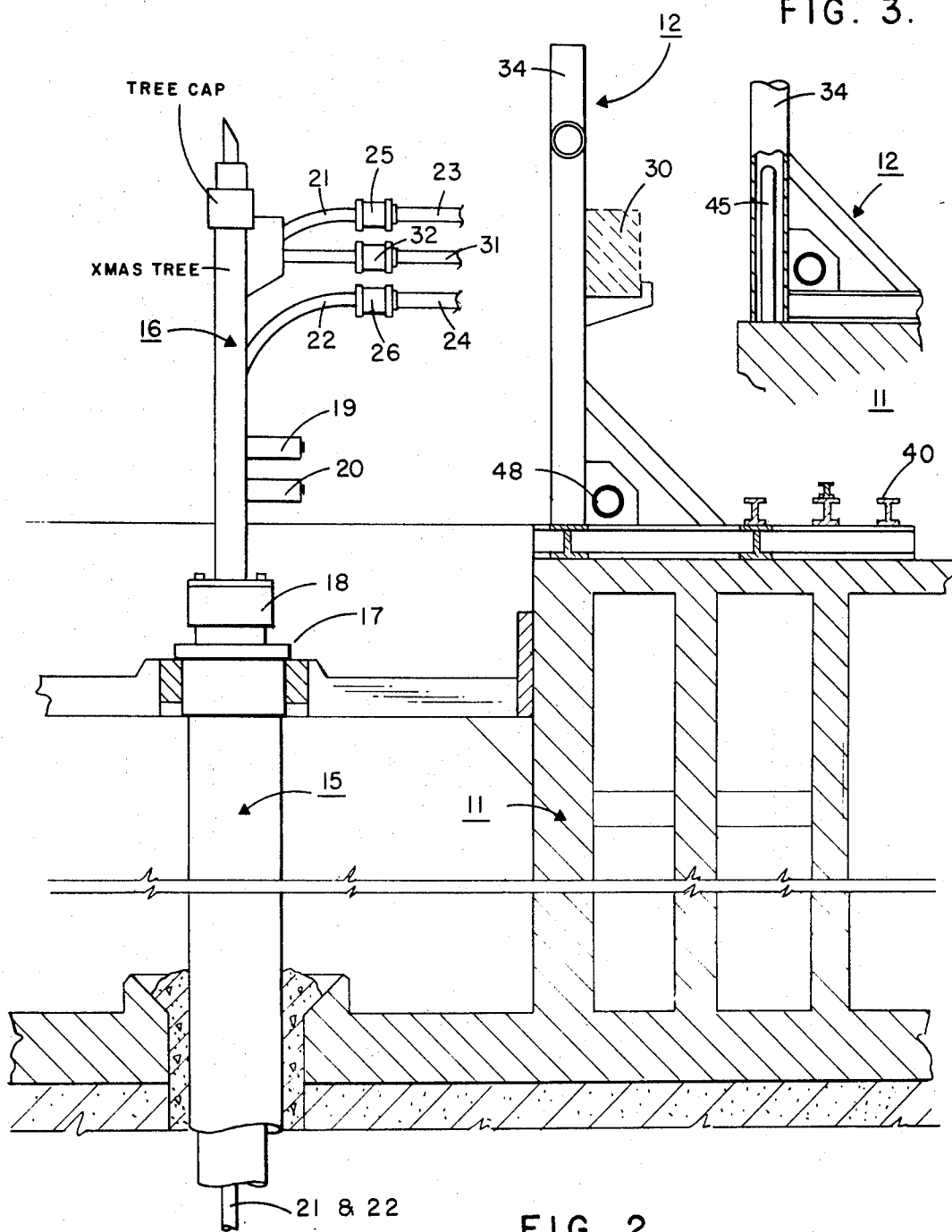


FIG. 4.

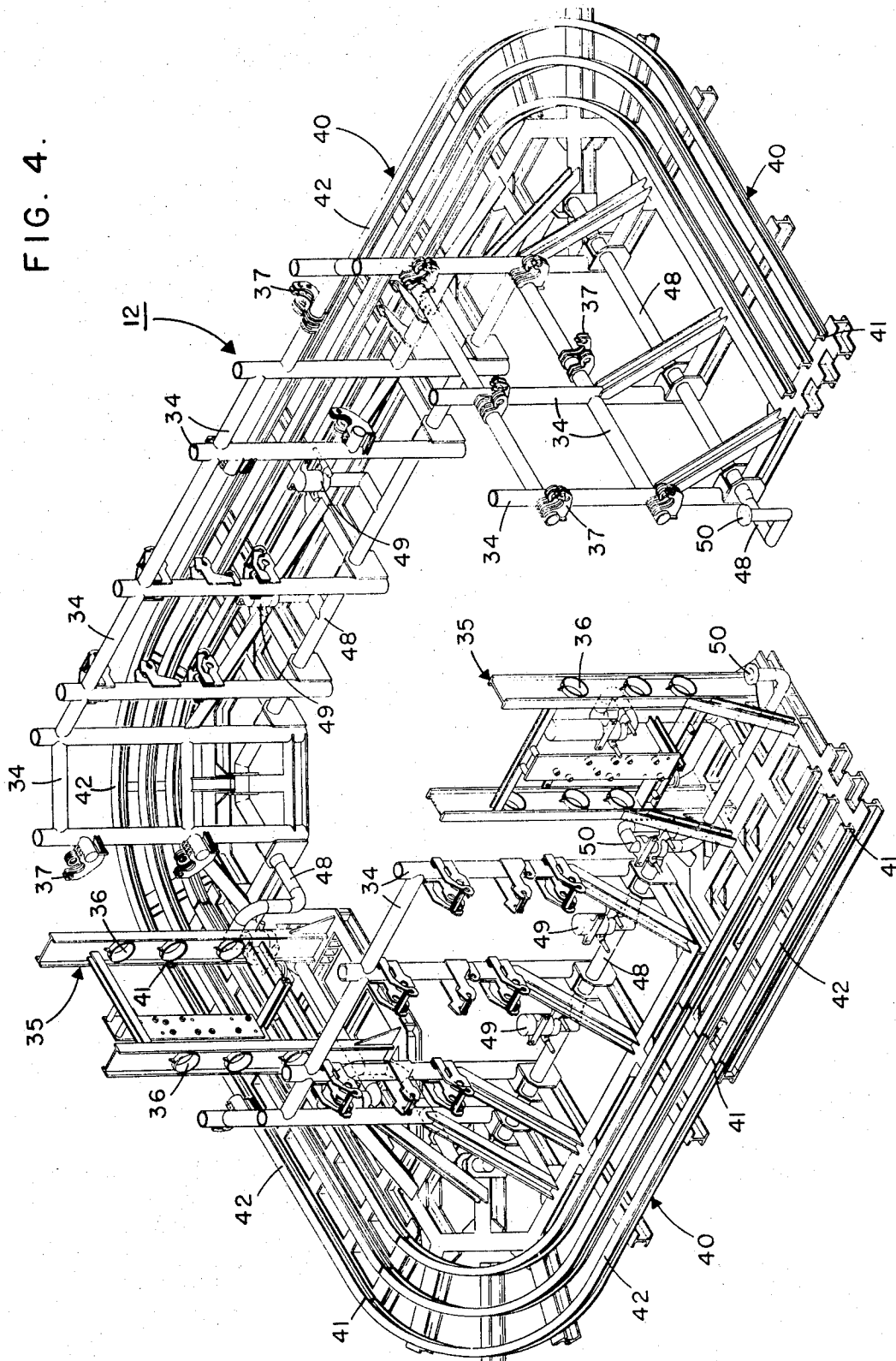


FIG. 5.

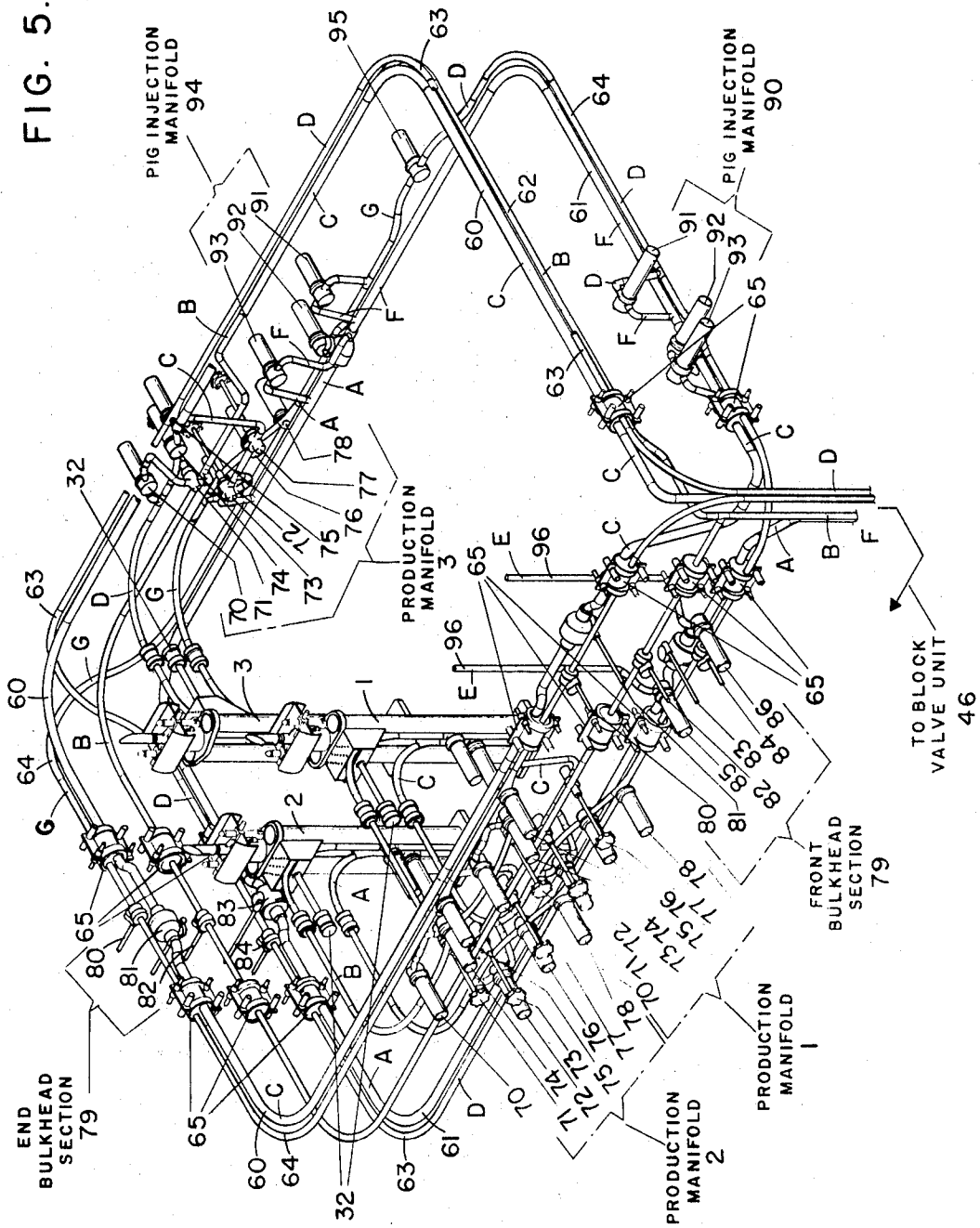


FIG. 6.

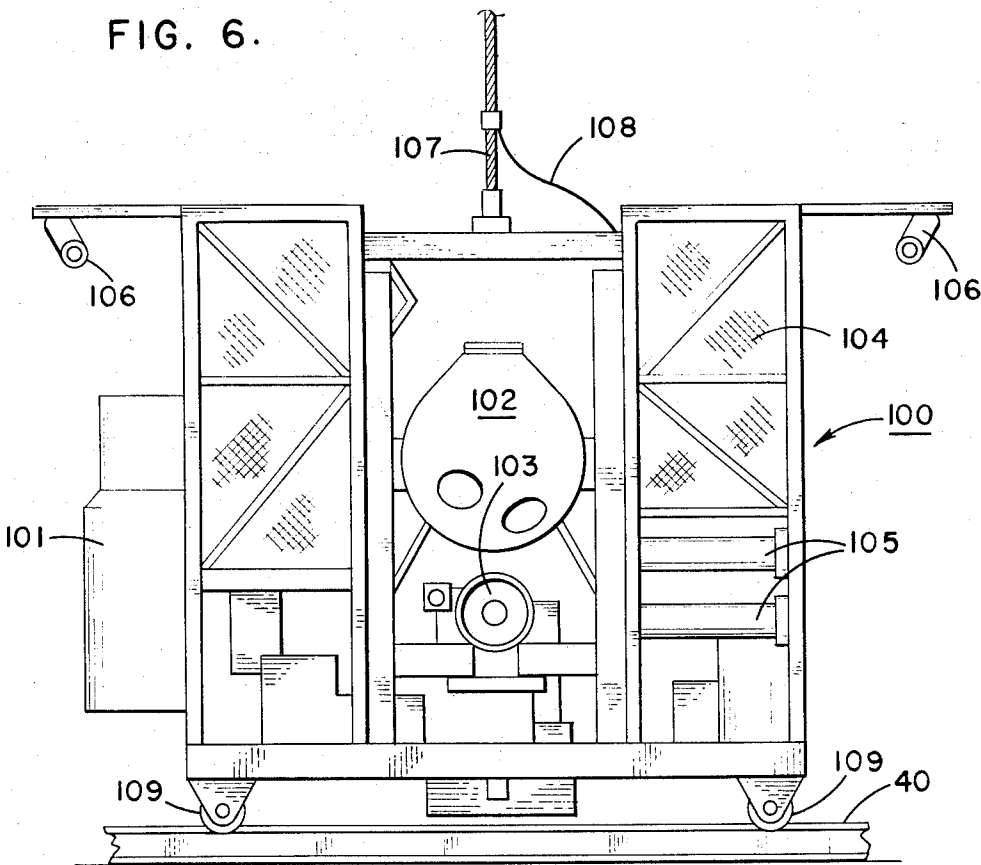
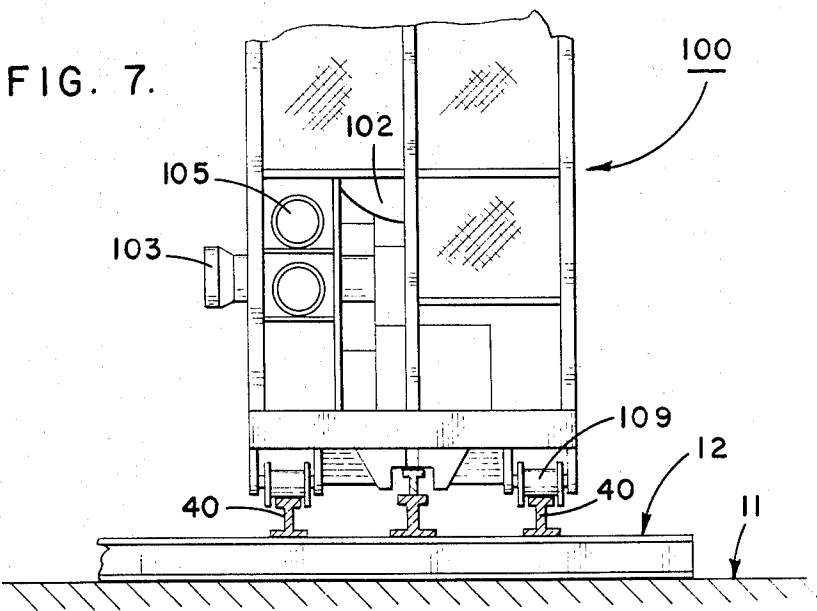


FIG. 7.



SUBSEA PRODUCTION SYSTEM

BACKGROUND OF THE INVENTION

The present invention concerns a subsea production system for remotely completing wells and handling production well fluids in offshore operations. The present invention also concerns the assembly, installation on the sea floor and operation of the subsea production system. The system is economically attractive, reliable, fail-safe, nonpolluting, remotely maintainable and particularly adaptable for use in deep water.

BRIEF DESCRIPTION OF THE INVENTION

The subsea production system of the invention comprises, briefly, a template containing a plurality of well bays and manifolding which includes production, maintenance and control piping looping the well bays. A track is arranged on the template about the well bays. The template structure, the manifold piping and the track have disconnect-reconnect points for separating selected sections of the template manifold piping and track for removal and replacement thereof. Also supported on the template are disconnectable and reconnectable hydraulic power, pipeline block valve, and electric power-transformer units. A remotely controlled manipulator is arranged on the track for movement to selected positions for operating valves and for maintenance operations.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of the subsea production system of the invention;

FIG. 2 is a view taken along lines 2—2 of FIG. 1;

FIG. 3 is a fragmentary view illustrating means for guiding a removable section of the upper support structure of the template into position on the base structure of the template;

FIG. 4 is an isometric view of a portion of the upper support structure of the template and the surrounding track;

FIG. 5 is an isometric view of the manifold piping assembly;

FIG. 6 is a front view of the submersible manipulator work unit mounted on the track; and

FIG. 7 is a fragmentary side view of the manipulator work unit.

The components of the subsea production system for a three well arrangement are shown in FIGS. 1 to 4. As shown in these figures, a template or platform 10 includes a truss framework base structure 11 and an upper framework support structure 12. Base structure 11 includes a base member 13 at mud line elevation and vertical and horizontal supports 14. A well, indicated at 15, has been drilled through each well bay, well pipe set and cemented in, and a Christmas tree 16 landed and connected to a wellhead 17 in accordance with the procedure shown and described in application Ser. No. 64,519 entitled *Multi-String Tubingless Completion Technique* filed Aug. 14, 1970, by Carl E. Reistle, III et al. Although a tubingless completion is described in that application, for purposes of the present invention the completion may be of the conventional type in which the dual production strings are not cemented in the well. Christmas tree 16 is connected to a wellhead assembly 17 by a connector 18. Master valves 19 and 20, positioned on the Christmas tree, control flowlines 21 and 22 connected to the dual pipe

strings in the well. Flowlines 21 and 22 connect to conduits 23 and 24, respectively, by connectors 25 and 26. Conduits 23 and 24 connect into the production headers of the manifold system which is shown and described in detail with reference to FIG. 5. A hydraulic conduit containing hydraulic control lines is also connected to Christmas tree 16 by a connector 32 to operate the various valves associated with the Christmas tree piping. These hydraulic lines connect to the hydraulic unit 33 through a closed hydraulic distribution system.

Manifold piping 30 extends into base support structure 11 under track 40 at 38, connects into block valve assembly 46, and then extends to outside template 10 and terminates in a piping connection 39. The lines from each header are provided with a master shut-in valve in block valve assembly 46.

Pressure sensors, not shown, are installed on production header lines upstream and downstream of the block valve skid. If the allowable operating pressure range is exceeded, the entire subsea production system will shut in. An electrically driven pump on the hydraulic power unit 45 charges an accumulator to provide hydraulic power to the hydraulic distribution system indicated by line 57. A suitable reserve of hydraulic pressure ample for valve operation is available from the accumulator. If standby hydraulic pressure is ever exhausted, all subsea production system valves will close automatically.

The electro-hydraulic system controls the subsea production system operation. A digital coded electronic signal sent to the subsea production system over cable 55 identifies (1) template location (2) the specific well or manifold to be actuated and (3) the function desired. The signal will actuate an appropriate solenoid on the subsea production system allowing hydraulic pressure to act on the valve operator. The electrical system also allows monitoring of pressure and temperature at selected points on the subsea production system and wellheads. Subsea electrical equipment is encased in an oil bed and functions at sea pressure to minimize the possibility of water leakage into the system.

The upper support structure 12 includes tubular support members 34 and bulk head supports 35 on which the manifold system is supported. The manifold pipes 30 extend through the openings 36 in bulk heads 35 and are also supported by clamps 37 attached to vertical support pipes 34. The upper support structure and the well bays are looped and surrounded by a track 40 which is formed by interlocking sections joined, as indicated at 41, for disconnection and reconnection along with separable sections of upper support structure 12 connected thereto and indicated at 42. Upper support structure 12 also supports, along the outside of track 40, a hydraulic power skid, indicated at 45, a block valve assembly skid indicated at 46 and an electric power skid indicated at 47. A multiple conductor cable 55 supplies power to unit 47 from a control station at the surface. Each of these skids are disconnectable and reconnectable for removal and replacement. A conduit 48 containing electrical power lines for supplying electrical power to the well control pods 49 is supported on the upper support structure, as shown. Conduit 48 is separable in removable sections as indicated at points 50. Sections of upper support structure 12 following removal for repair may be properly repositioned on

base support structure 11 by, for example, guiding vertical pipes 34 to fit over prong members 33 secured to base support structure 11 as shown in FIG. 3.

Openings 67 in the base structure may be employed to accommodate piles used to secure the template.

The manifold system 30 is shown in greater detail in FIG. 5. Two large production headers 60 and 61 completely loop production trees 1, 2 and 3 which are connected to production manifold sections 1, 2 and 3. A smaller gas lift supply header 62 and two smaller multipurpose headers 63 and 64 also loop the production trees. Disconnects 65 are positioned on the manifold pipes adjacent bulk heads 35 (see FIG. 4). Each production manifold section is provided with a gas-lift wing valve 70, a gas isolation valve 71, a production wing valve 72, a production isolation valve 73, a TFL wing valve 74, a TFL diverter 75, a TFL wing valve 76, a production isolation valve 77 and a TFL diverter 78. Front bulk head end bulk head sections 79 are each provided with a TFL block valve 80, a water flood and production block valve 81, a gas injection block valve 82, a production block valve 83 and a TFL block valve 84. Front bulk head section 79 is also provided with pan drain valves 85 and 86. Pig injection manifolding 90 includes pig launch valves 91, pig block valves 92 and bypass valves 93. A TFL cross-over valve is shown at 95. Pan drain lines are indicated at 96 and hydraulic control lines are indicated at 31.

As an illustration of the operation of the manifold system, tree No. 1 is on a water input well; tree No. 2 is on a gas-lifted oil well; and tree No. 3 is on an oil well being serviced by TFL tools. The various lines are identified as follows: production lines are designated A, gas injection lines are designated B, water flood and production lines are designated C, TFL lines are designated D and E, pan drain lines are designated F and the pig launch magazine is designated G. Arrows on the E TFL line indicate the path of fluid pumped to move TFL tools down the production casing after the tools pass TFL wind valve 76 in production manifold section No. 3. Return fluid simultaneously displaced up the parallel casing string (designated gas injection) by the TFL tools returns by way of the D TFL lines. The TFL cross-over valve 95 is opened, the TFL wing valve 76 is closed and the flow path is reversed when TFL service tools are initially pumped from the remote service station to the subsea production system.

The scraper pigging system built into the manifold assembly is for the purpose of cleaning the production pipelines. Scraper pigs can be stored in the system and released into the lines one at a time on command. A scraper pigging system suitable for use in the manifolding of the subsea production system described herein is described in U.S. Pat. No. 3,562,014 issued Feb. 9, 1971 entitled *Pipeline Scraper Launching System*. The disconnect flanges 65 located in every header at selected damage control points around the manifold loop allow removal and replacement of complete header sections.

The inverted drip pans are mounted over the entire subsea production system manifold as well as the pipeline block valve skid and electric power and hydraulic power skids. The pans are connected by piping to an oil sump. This pollution control system for the manifold system is described in U.S. Pat. application Ser. No. 174 entitled *Underwater Pollution Control* filed Jan. 2, 1970, by T. W. Childers. The equipment catches, col-

lects and disposes of any small amounts of oil that might escape during change out of a valve. Since the pans cover the entire manifold, they also entrap oil from any leak that might develop. Oil which accumulates under a drip pan will migrate up through the piping system and collect in the sump section. An inductive device mounted in the sump senses the hydrocarbon accumulation and shut-in sections of the subsea production system operation while simultaneously transmitting an alarm to the remote control station. Any additional accumulation of oil will eventually fill a part of the sump section and spill over into another section. The additional oil buildup will be sensed by the inductive device and shut in the entire subsea production system. Accumulation in the sump can be drained into the production header in the manifold upon command. An operator at the control station then can override the safety shut-in to determine cause of the oil accumulation. When located, the leaky section can be isolated and the remainder of the subsea production system returned to service. As an additional safety measure production lines operate at pressures less than hydrostatic head of the surrounding sea.

A manipulator work unit 100 illustrated in FIGS. 6 and 7 performs basic maintenance on the subsea production system valves and manifold. The unit runs on track 40 and has access to all well and subsea production system disconnect flanges, valves, etc.

An electrical umbilical cable to the surface provides power to move the unit along the track and to operate the manipulator arm. Television cameras monitor the operation. The components of the unit are illustrated in FIGS. 6 and 7 and include a replacement buoy 101 containing a haul down line, a bell 102 containing a complete control system, a drum for winding the haul down cable, a bumper to protect the end effector on the surface, a hydraulic supply with compensator and motors, an orientation bushing, an anchor, receivers for valves, end effector (working tool) 103, a motor starter pod, a transformer pod with volumetric compensator, an electric pod containing a command system, foam 104 for flotation, replacement valves 105, a lifting beam, TV cameras 106, a lifting cable 107, an electrical umbilical cable 108 and wheels 109.

In operation, the template support structure and manifolding are assembled at the surface and lowered through the water and set on the ocean bottom. The template is leveled and piles may be set through the template to anchor it or the template may be prelevleled by shaping the bottom of the template to conform to the shape of the sea floor. A well is drilled, well pipe set and cemented in and a Christmas tree landed and connected to the wellhead as described in the aforementioned application Ser. No. 64,519. The flowline and hydraulic connections between the tree and the manifold are made up and the electric and hydraulic equipment are tested. Then additional wells may be drilled and such equipment tested in a similar manner or the first drilled well may be completed and produced before any additional wells are drilled.

If maintenance work is to be done on a subsea production system manifold valve, for example, a buoy 101 is remotely released from the template to lift a line to the surface. The manipulator work unit 100 is moved to location by a ship and attached to the line. The work unit is positively buoyant and pulls itself down to the subsea production system following the line attached to

the buoy. The unit aligns itself and lands properly on the template track 40 as indicated at point 32. Upon landing, yolks engage an anchor to hold the unit on the track. An electrical umbilical cable 108 to the surface provides power to move the unit along the track and to operate the manipulator arm or effector 103. Television cameras monitor the operation. The effector 103 closes manual valves to isolate the valve to be replaced. The effector is then positioned over the valve body and removes it from the manifold, rotates and places the body in a rack on the work unit. A new valve section is picked up from another rack on the work unit and re-installed on the manifold. Seals on the replaceable valve element are tested by the work unit. The unit retraces its path to its landing point 32, releases the anchor and returns up the line to the surface. All mechanical, electrical and hydraulic subsea production system components are maintained in this manner. When it is necessary to handle large equipment items such as the hydraulic unit or manifold section, the manipulator will attach a line from the surface to the component, release it from the subsea production system and a boat or floating rig will then retrieve the unit.

If a maintenance job cannot be performed remotely, a man can be lowered in a bell attached to the work unit. The unit is provided with a self-contained power system which permits it to move along the track if the umbilical power cable to the surface should fail. Also the man can release the work unit from the anchor or release the bell from the work unit and allow it to float to the surface.

Changes and modifications may be made in the specific, illustrative embodiments of the invention shown and/or described herein without departing from the scope of the invention as defined in the appended claims.

Having fully described the method, apparatus, objects and advantages of our invention, we claim:

1. A subsea oil and/or gas production system comprising:
 a template including a base support structure and an upper support structure;
 a plurality of spaced apart well bays arranged on said upper support structure;
 a track arranged on said upper support structure about said well bays;
 a manifold system arranged on said upper support structure looping said well bays;
 first disconnect-reconnect means located at selected points on said manifold system to permit selective removal and replacement of sections of said manifold system;
 said upper support structure being formed in disconnectable-reconnectable sections to permit selective removal and replacement of sections of said upper support structure;
 said track being formed in disconnectable-reconnectable sections to permit selective removal and replacement of sections of said track;
 a wellhead in each of said well bays;
 a christmas tree mounted on each of said wellheads;
 a production manifold section connecting each christmas tree to said manifold system;
 each production manifold section including a plurality of removable and replaceable valves for use in controlling flow of fluids through said production manifold section; and

a manipulator unit capable of traversing said track and accessible to said reconnect-disconnect means for operation of said reconnect-disconnect means, said manipulator unit also being accessible to said valves for removal and replacement of said valves.

2. A subsea production system as recited in claim 1 in which said base support structure is located on the sea bottom and extends to an elevation at least sufficient to permit piping connected to said manifold system to extend under said track.

3. A subsea production system as recited in claim 2 in which said manifold system includes two large production headers and three smaller service headers, two of said service headers being capable of servicing wells by TFL techniques and the other service header being capable of servicing wells for gas-lift operations.

4. A subsea production system as recited in claim 3 in which said removable and replaceable valves include two TFL wing valves and a production wing valve.

5. A subsea production system as recited in claim 4 including removable and replaceable electric power, hydraulic power, and block valve units arranged on said upper support structure along the outer perimeter of said track.

6. A subsea production system as recited in claim 5 including electro-hydraulic pods associated with each christmas tree and mounted on said upper support structure for controlling operation of the well to which said christmas tree is connected.

7. A subsea production system as recited in claim 6 including a scraper pigging system arranged in said manifold system.

8. A method of assembly of a subsea well fluid production system comprising the steps of:

assembling at the surface of the sea a template including a base support structure containing a plurality of well bays and an upper support structure mounted thereon, said upper support structure supporting a track arranged about said well bays and a manifold system looping said well bays, said manifold system and said upper support structure and said track being formed so as to permit selective removal and replacement of sections thereof, said manifold system including removable and replaceable valves for controlling production of the well and servicing of the well and maintenance of the well, said upper support structure supporting outside said track electric, hydraulic, and block valve units removable from and replaceable on said upper support structure, said manifold system containing removable and replaceable pods for controlling operation of the valves;
 lowering said template and said equipment supported thereon to the sea bottom;
 drilling a hole and setting well pipes;
 running and setting a christmas tree on said well;
 connecting said christmas tree to said manifold system;
 connecting said manifold system to a pipeline;
 perforating said well;
 lowering to said track a manipulator capable of disconnecting and reconnecting components of said subsea production system including sections of said manifold system and said removable and replaceable units and of removing and replacing said valves;

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positioning said manipulator adjacent one of said valves to be removed;
removing said one valve by said manipulator; and
replacing said valve by said manipulator with another valve.

9. A method as recited in claim 8 including positioning said manipulator adjacent a component to be removed, and operating said manipulator to disconnect said component from said subsea production system.

10. A method as recited in claim 9 including lifting said disconnected component to the surface, repairing

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or replacing said component, returning said component to its initial position, and then operating said manipulator to reconnect said component into said subsea production system.

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11. A method as recited in claim 9 including removing said disconnected component by said manipulator and replacing said component by said manipulator and then operating said manipulator to reconnect said replaced component into said subsea production system.

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