A DRY SUBSEA TECHNIQUE TO DEVELOP OFFSHORE OIL AND GAS FIELDS

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In a nation that had unlimited natural resources until a few short years ago, it is paradoxical that the regions with the greatest energy demands per unit of area are the furthest away from sources of supply.

The Atlantic seaboard states, for example, have depended for many years on natural gas from Gulf Coast and Mid-Continent reservoirs, and on fuel oil refined locally from crude produced in these same areas plus that imported from other countries.

The West Coast has a similar problem but only with respect to gas. California oil fields, and some in the Rocky Mountain area, satisfy a major portion of the local demand for gasoline and fuel oil but natural gas consumed there is delivered by long pipelines - - most originating in West Texas.

It is also paradoxical that these two areas most in need of energy supplies are mounting the greatest resistance to development of existing sources.

A small crack formed in this resistance recently when the City of Santa Barbara granted Exxon Co. USA permission to construct a plant to process oil and gas produced via a platform in Federal waters offshore. This approval was later denied by another West Coast agency, so Exxon must resort to alternate production-handling techniques.

Residents of Atlantic Coast states are justifiably concerned over the development of additional industrial facilities in their midst. They have lived with foul-smelling, smoky air long enough and are just beginning to enjoy the benefits of recent legislation to abate these nuisances. There is a built-in fear that new industrial moves will bring on a return to previous conditions or introduce new ones. In the case of offshore oil development, they fear the visual pollution that platforms will create and the possibility that these platforms might be the cause of oil spills to spoil their beaches.

These fears are largely unfounded; an oil platform three miles offshore is a mere speck on the horizon, and modern drilling and production technology makes oil spillage a thing of the past. Safeguards imposed by USGS and other agencies place safety systems on top of safety systems to forewarn operators of abnormal conditions, and shut-in a portion or all of a platform if remedial action is not taken immediately.

One way to bypass the concerns over visual and environmental pollution and to assist development of oil and gas fields underlying deep water, is to go to the ocean floor. A proven technique is available which permits placement of wellheads and flow lines under hundreds of feet of water, out of sight, but still allows for remote operation and monitoring. A system of this type was installed for Shell Oil Co. in the late summer of 1972 in 375 ft of water and the well is producing today at a good rate.[1,2] Its cumulative production is now close to 1,000,000 bbl of oil and there was no human intervention during one 2-year producing interval.

THE LOCKHEED SYSTEM

Lockheed Petroleum Services Ltd. offers an oil and gas production system that allows operators to locate much of the producing equipment on the ocean floor, out of sight and far removed from shipping and weather hazards. Oil and gas wells are drilled from a drillship or semisubmersible drilling rig, and submarine flow lines carry produced fluids to a nearby platform.

With this system, a large oil or gas field can be developed without using multiple platforms, as one will serve an entire field when subsea well completions are used.

In a typical case, some wells will be drilled from the platform in a manner now considered conventional for the Gulf of Mexico, and the remainder will be completed subsea. Some operators choose to locate all wells on the ocean floor and use the platform to support tanks, pumps, compressors, and other fluid-handling equipment.

The Lockheed system also offers the advantage of early production - - a means of getting oil and gas to market faster than with conventional platform methods. One company, operating in the southern hemisphere, plans to use subsea completions connected by flow lines to a buoy or other floating storage facility. This circumvents the delay normally caused by platform construction lead time. An important fringe benefit of this procedure is the immediate cash flow to cover the cost of field development.

BASIC EQUIPMENT

The Lockheed subsea production system consists of three basic hardware elements. These are shown with key letters A, B, and C in Fig. 1; the wellhead cellar, service capsule and surface support vessel.

When well drilling is complete, and all casing and tubing installed, the wellhead cellar is lowered to the ocean floor from the drilling vessel using a special handling tool and the rig's drill pipe. The wellhead cellar locks onto the casing head forming a seal that confines well pressure and keeps out seawater.

The wellhead cellar is a cylindrical chamber designed to house the wellhead and associated control equipment, and maintain this equipment in a dry, one-atmosphere environment. The partially disassembled equipment is stowed in the cellar during the lowering to the ocean floor and later connected to the well and flow lines. The final hookup is made by men lowered to the wellhead cellar in the Lockheed service capsule (key letter B in Fig. 1). All work is done in a normal shirt-sleeve environment. No special training is required and no decompression time is needed. The system is completely diverless.

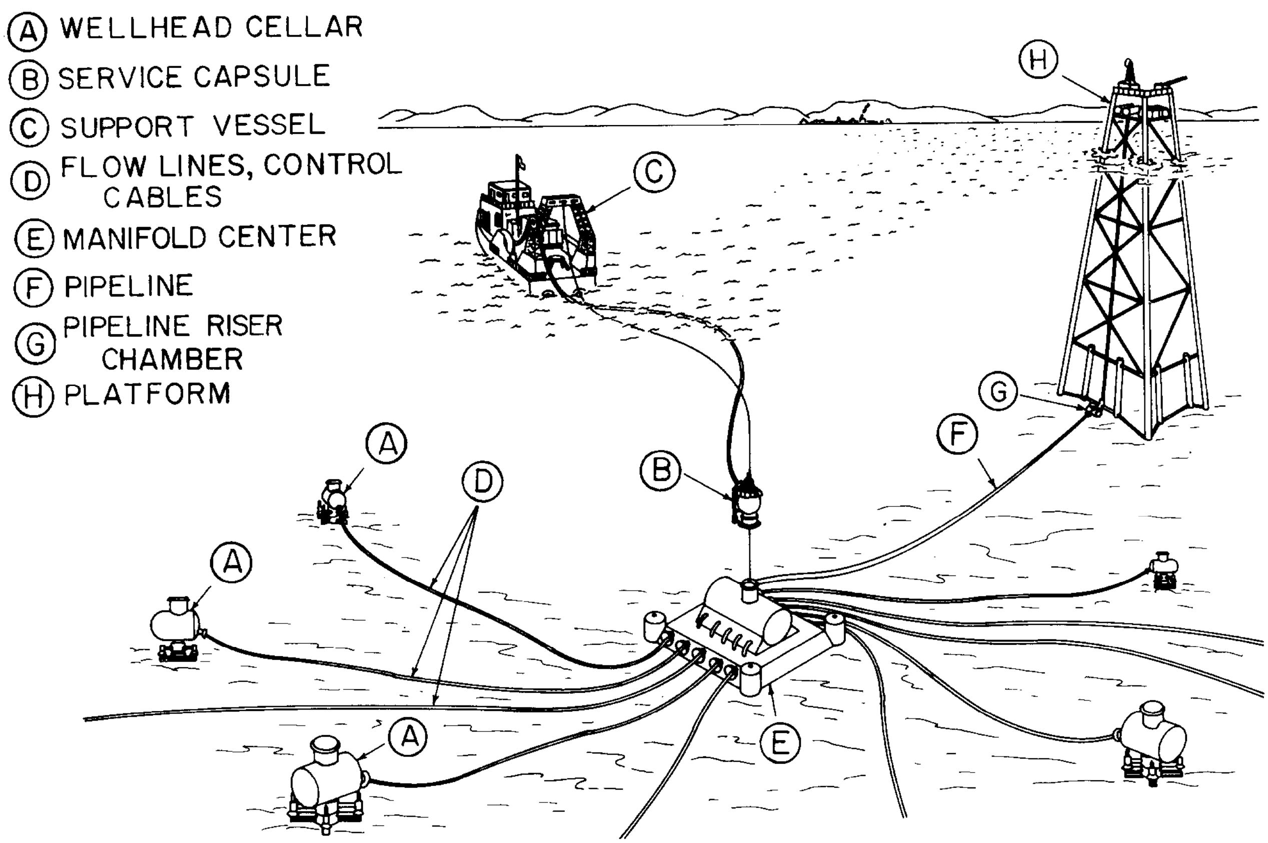

FIG. 1 LOCKHEED PETROLEUM SERVICES LTD. SUBSEA PRODUCTION SYSTEM

The Wellhead Cellar

The cutaway view of the wellhead cellar in the lower portion of Fig. 2 shows the well-control system schematically.

With the cellar on the ocean floor, locked on to the casinghead, the first operation is to pull in the flow line. Details of this pull-in and operation of the service capsule will be covered in later sections.

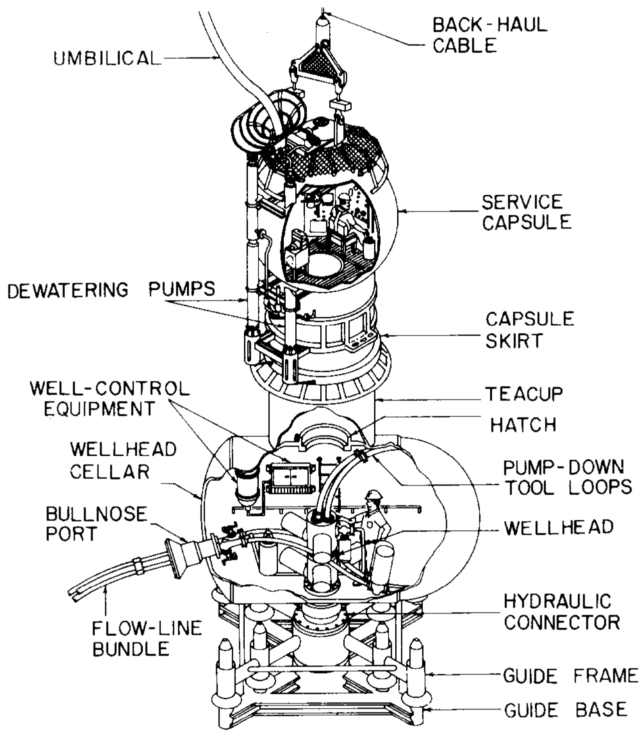

FIG. 2—LOCKHEED WELLHEAD CELLAR, BOTTOM; SERVICE CAPSULE, TOP

With the flow line pulled in, the installation crew begins to assemble the equipment stowed in the cellar. The wellhead is mounted on the casinghead flange, flow loops are connected from the wellhead to the pulled-in flow lines, and all hydraulic and electrical connections are completed.

The flow loops are designed to permit passage of tools that can be pumped through the flow lines to the wellhead and down into the well. These tools are capable of performing various functions down the well but require a minimum five-foot radius in flow-line bends.

When all connections are made and the installation complete, plugs in the well's tubing are removed and the well is put on production.

An auxiliary line connected into the annular space between the well's tubing and casing provides flexibility of operation and allows the introduction of fluids for corrosion and paraffin inhibition or gas for lifting the well fluids once reservoir pressure has declined.

The Service Capsule

The service capsule is shown in the upper portion of Fig. 2 and provides the vehicle in which men and materials are transported to the wellhead cellar. This buoyant capsule is launched from the stern of the surface support vessel shown in Fig. 1, key letter C.

When a descent is to be made to the wellhead cellar, a buoy is released from the cellar to carry a cable to the surface. Two release mechanisms are employed - - a hydraulic release system and a sonic backup. The buoy is retrieved at the surface and the cable is attached to the haul-down winch of the service capsule. Operation of the winch lowers the capsule to mate with the wellhead cellar.

When the capsule reaches the cellar, the newly formed volume created by the skirt of the capsule and the upper portion (teacup) of the wellhead cellar is dewatered, using pumps in the capsule. With dewatering complete, the capsule's lower hatch is opened, allowing personnel transfer to the teacup portion of the wellhead cellar. The atmosphere in the cellar is tested, and if found breathable, the cellar hatch is opened, permitting transfer of men and materials.

An umbilical attached to the capsule provides normal breathing air and electrical power to the capsule. The umbilical also provides communications conductors and cable for closed-circuit television. Through these communications links, the activity of the crew as well as the capsule environment is monitored on the surface. Two television receivers are constantly under surveillance, and control-room instruments show rate of air flow, oxygen and carbon dioxide levels, and capsule pressure.

The service capsule is rated for a water depth of 1200 ft with a payload rating, including four-man crew, of 4000 lb. It is positively buoyant by 2000 lb. Standby batteries are on board in case of umbilical failure, and emergency air scrubbers are good for 96 man-hr.

In the capsule's skirt, near the haul-down winch, is a pyrotechnic cable cutter. In case of emergency, the haul-down cable is severed, the skirt is flooded, and the capsule rises to the surface under its own buoyancy.

The normal rate of ascent and descent is 30 ft/min.

Flow-Line Pull-In

Making flow-line connections with the Lockheed system is a relatively simple operation. Remote stabbing of joints under water is not needed as the operation is under manned control at all times.

The wellhead cellar is equipped with an opening, called a bullnose port, Fig. 2, through which the flow line is pulled. When the cellar is locked onto the casinghead on the ocean floor, there is a plug in this port to prevent the entrance of seawater. On the inside of the port is a closed ball valve.

When the work crew first enters the wellhead cellar, after it is in position on the ocean floor, a test is made for pressure behind the ball valve to insure the absence of seawater inside the bullnose plug. With this test complete, the ball valve is opened and an inflatable buoy is inserted through the ball valve. Then the remainder of the pull-in equipment is installed as shown in Fig. 3. This consists of a buoy package, a wireline stripper and line wiper to prevent entrance of seawater, and the hydraulic pulling tool. The pull-in cable, attached to the inflatable buoy, is threaded through this equipment during installation, and buoy's inflation line is connected to a valve in the buoy package (not shown in Fig. 3).

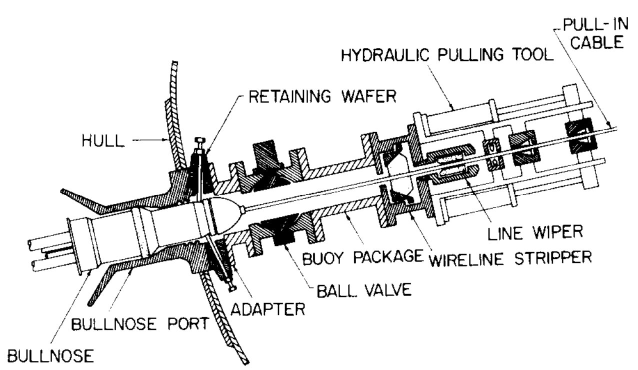

FIG. 3 – FLOW LINES ARE PULLED INTO THE WELLHEAD CELLAR WITHOUT WATER ENTRY USING THIS EQUIPMENT.

With this assembly complete, air pressure is supplied to the inside of the bullnose port to discharge the plug, allowing the inflatable buoy to move into the seawater as cable is pushed through the pull-in mechanism. Then the buoy is inflated, the inflating line released from its special fitting in the buoy package, and the buoy rises to the surface, carrying the pull-in cable with it.

On the surface, the buoy is retrieved and the cable is attached to a special fitting on the flow line, or group of flow lines. This fitting is called a bullnose. Its smooth rounded end is designed for easy entry into the bullnose port.

The number of lines to be laid depends on the type of well completion in the wellhead cellar, and on the type of control system selected for that well. If the well is a dual completion (two strings of tubing), for example, with access to the annular space between the tubing and casing, and the wellhead is under electrohydraulic control, a number of lines will be used. There will be one for each string of tubing, one for the annulus, a hydraulic fluid line, and an electrical cable. The bullnose is tailor-made for this combination of lines and is designed to hold all of them during the pull-in operation.

As the flow lines are lowered into the water from the pipe lay barge, the cable is pulled into the wellhead cellar by the hydraulic pulling tool. This is a linear winch with the gripping portion moving through 10-in. strokes, pulling the cable in on each stroke.

When the bullnose is pulled into the port, it is locked into position by the retaining wafer shown in Fig. 3. Seals on the bullnose prevent entry of seawater, allowing the disassembly of the pull-in mechanism. With this removed, a permanent seal is installed, the bullnose cap is removed, and the flow-line ends are exposed for connection.

Starting at this point, the remainder of the assembly operation is carried out in the same manner as on dry land, except that conditions are better. The air supplied to the wellhead cellar is dry and cool, and the total environment is constantly monitored to maintain ideal conditions.

THE MANIFOLD CENTER

From the foregoing description, it is obvious that a number of wells completed on the ocean floor, with flow lines leading to a platform from each, would result in a large number of seabed lines, and require the services of expensive lay barges for long periods of time.

The problem of the large number of long flow lines is diminished by the installation of a manifold center, Fig. 4, at a convenient location. This manifold center accepts flow lines from individual wells and commingles the produced fluids, sending the mixed stream to a platform through a single flow line or a pair of lines.

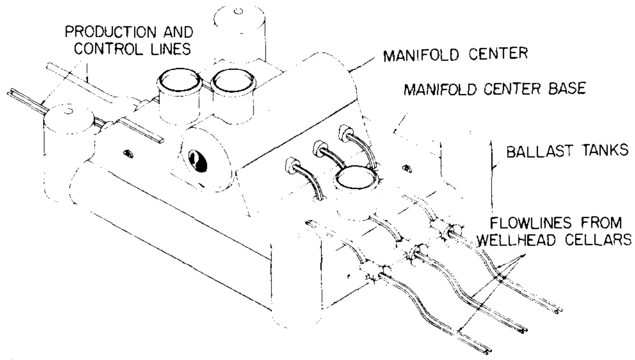

FIG. 4—THE LOCKHEED MANIFOLD CENTER COMMINGLES OIL AND GAS PRODUCTION FROM SEVERAL WELLS, REDUCING THE NUMBER OF FLOW LINES ON THE OCEAN FLOOR.

The manifold center contains all the valves and piping needed to permit segregation of fluids from a single well for test purposes, allow some connected wells to produce oil and gas while injecting water or other fluids in others, and still maintain pumpdown tool capability.

The base of the manifold center, Fig. 4, is made up of a number of compartments that are selectively flooded for installation. Each end compartment on the base is equipped with a teacup - - same as that on the wellhead cellar - - to permit mating with the service capsule. Flow lines are pulled into the bullnose ports on the manifold base in the same manner as in the wellhead cellar.

Hydraulic, electrohydraulic, or multiplex control systems may be used for remote valve operation and readout of valve position and other operating data. The control system can be as complex or as simple as the operator wants it to be.

Like the wellhead cellar, the manifold center is maintained in a dry, one-atmosphere condition at all times. Equipment installation, maintenance, and repair are all carried out in a shirt-sleeve environment. Most of the equipment inside the manifold center is off-the-shelf, dry-land type.

MULTIWELL TEMPLATES

Two key elements of the Lockheed subsea production system - - the wellhead cellar and the manifold center - - have been combined to reduce the number of flow lines needed on the ocean floor and permit drilling of several wells from a single location of the drilling vessel.

The multiwell template consists of a tubular (usually) steel framework that supports a number of wellhead cellars and a manifold center. Whether or not pumpdown tool capability is desired, there is no need for ocean-floor flow lines between each cellar and the manifold center because these are part of the basic template assembly. Figure 5 shows the arrangement for a multiwell template capable of handling pumpdown tools.

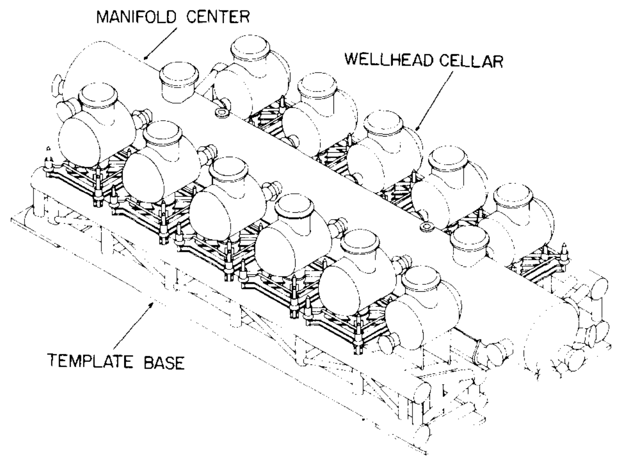

FIG. 5 THIS MULTIWELL TEMPLATE PERMITS DRILLING OF SEVERAL WELLS FROM A SINGLE LOCATION OF THE DRILLING VESSEL AND REDUCES THE NUMBER OF FLOW LINES THAT MUST BE LAID.

When an oil or gas reservoir is to be developed using the template approach, the template is first lowered to the ocean floor and leveled. Then the drilling vessel is anchored (or dynamically positioned) above the template and drilling proceeds through the template's well slots. As each well is completed, or after all wells have been drilled, a wellhead cellar is lowered onto the guide frame of each well and the hydraulic connector seated.

Then, the Lockheed service capsule is used to lower men and materials into each cellar in turn to make the necessary flow-line connection and assemble the Christmas tree and related valves.

When the wells are ready for production, only a single flow-line group to a nearby platform or shore facility is needed.

Applications of the Lockheed multiwell template include those offshore areas where vessels frequently anchor or where bottom conditions are not conducive to satellite well locations or successful laying of flow lines.

PIPELINE RISER CONNECTOR

The Lockheed one-atmosphere subsea production system has been applied to the problem of connecting pipelines to production platforms, resulting in a fully welded joint.

Previous techniques involved flanged or other mechanical connections completed by hard-hat divers working in a hostile environment. The work pace was slow, the decompression time was long, and the cost was high.

In the Lockheed technique, a work chamber is fixed to the base of the platform during the construction phase. The riser, or pipe carrying oil and gas to the platform deck, is welded into this work chamber at the platform base, at which point the riser is bent into the typical J-tube configuration, Fig. 6A.

The work chamber is equipped with a bullnose port of the same design as that used on the wellhead cellar, except it is large enough to accept a bullnose sized for the line being installed. A line 30 in. in diameter would be typical for an installation of this type.

Once the platform is set on location and the pipe lay barge standing by, a cable, threaded through the riser and out the bullnose port, is carried to the lay barge and attached to the bullnose on the end of the pipeline. As the lay barge assembles pipe joints, the cable is pulled through the bullnose port and up the riser to a winch on the platform deck. This operation continues until the bullnose is pulled into the port, at which time the lay barge continues laying pipe without delay.

Manned entrance is made into the work chamber using the Lockheed service capsule and the procedure described earlier. A permanent seal is applied to the pulled-ir pipeline and the bullnose cap is removed, Fig. 6B. This leaves the open end on the J-tube and the open end of the pipeline in near-

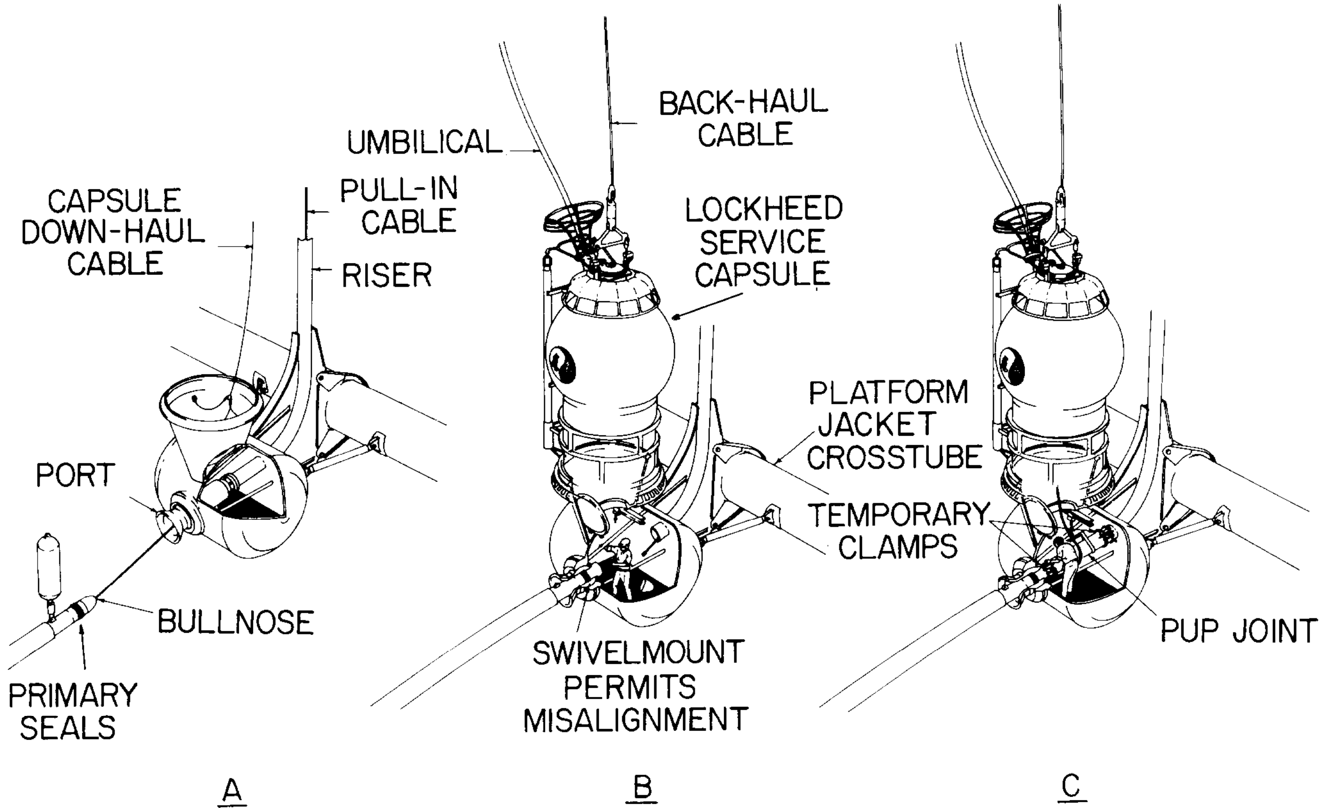

FIG. 6 THE LOCKHEED SERVICE SYSTEM ALLOWS INSTALLATION OF A FULLY WELDED CONNECTION BETWEEN OCEAN-FLOOR PIPELINES AND PRODUCTION PLATFORMS.

perfect alignment. At this point, a pup joint is lowered into the work chamber and welded in place, Fig. 6C, resulting in a fully welded pipeline system from the point of origin (manifold center, another platform, etc.) to the production platform deck.

EXPERIENCE RECORD

The installation made for Shell Oil Co. some three years ago was mentioned earlier. This was the prototype Lockheed installation and has served well as the proving ground for the entire system. The well is dually completed to produce two oil reservoirs at the same time.

The Lockheed wellhead cellar on the ocean floor is more than one mile away from the production platform to which the flow lines are connected. The electrohydraulic control system, used at first to operate valves and report on the well's status, has given way to a full hydraulic system. Pumpdown tools are used periodically to remove paraffin from the well's tubing.

The wellhead cellar was reentered in Oct. 1973, just about one year after the original installation, to make a minor repair in the hydraulic system.[3] Two entries were made in late summer, 1975, to install the new control system.

No trouble was encountered on the reentries, and other than the control-system problem there have been no operating difficulties.

Additional installations have been made recently. One wellhead cellar was installed for Union Oil Co., and two wellhead cellars and a manifold center have been installed for Shell Oil Co. Another is scheduled for Tenneco Oil Co. in early 1976. All are in the Gulf of Mexico in various water depths and all will be connected to existing production platforms.

Pipeline riser chambers are now being attached to the platform scheduled for installation in the North Sea's Thistle Field. Nine wellhead cellars and a nine-well manifold center are under construction for delivery to Petrobras, the Brazilian oil company, in 1977.

APPLICATIONS

While the basic premise for this paper was the need or desire to avoid visual pollution, the Lockheed subsea production system has characteristics making it adaptable to other applications.

Oil and gas fields located under deep water can be developed with subsea completions, with flow lines directed toward a platform located in shallow water. This avoids the high cost of deep-water platforms.

Shallow hydrocarbon reservoirs of large areal extent cannot be fully developed from a single platform because of limits imposed on horizontal deviation of wells. Under these conditions, the platform is used for as many wells as possible, and the remainder of the oil or gas field is penetrated by wells completed on the ocean floor.

In arctic areas where ice covers offshore waters during part of the year, and moving ice presents a hazard to fixed structures, oil and gas deposits can be exploited by use of subsea completions.

When an oil or gas reservoir is developed by conventional platform drilling, each well drilled increases the engineer's knowledge of the reservoir. Frequently, this new knowledge will lead to the decision that more wells will be needed than are provided for on the platform. In this case, the additional wells can be completed on the ocean floor and connected by flow lines to the platform facilities.

Oil wells usually flow naturally during the early life of a reservoir but may stop flowing if reservoir pressure declines. Lacking a natural pressure-maintenance mechanism, water or other fluids may have to be injected into the reservoir to continue economical oil recovery. The additional wells needed for this injection operation can be conveniently completed on the ocean floor with flow lines leading to pumps mounted on the platform. This eliminates the cost of a second platform.

The need to eliminate fixed structures in hazardous areas is obvious. One of the hazards avoided by placing oil and gas wells on the ocean floor is severe weather. The North Sea, for example, is famous for dangerous storms, and hurricanes frequently roam the Gulf of Mexico during late summer and early fall. Some of these bypass the Gulf and move up the east coast, along the Atlantic seaboard, extracting a huge toll in property damage.

Another hazard to be avoided is heavy shipping traffic. The navigational fairways leading to busy East Coast ports and the Mississippi river are sometimes jammed with freighters, tankers, and other large vessels. Any fixed structure not absolutely needed to improve the U.S. energy supply should be avoided.

CONCLUSION

A method is available to assist in the development of badly needed oil and gas reserves in U.S. offshore areas while protecting the residents from installations they might consider unsightly.

This same method provides oil companies with added degrees of flexibility in development techniques.

The subsea locations for oil and gas wells present no new hazards to a given area.

The Lockheed system for placing oil and gas wells on the ocean floor is proven by three years of successful operation.

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