Sept. 30, 1969 C. O. BAKER 3,469,627

SUBSEA PRODUCTION SYSTEM

Filed June 29, 1967 3 Sheets-Sheet 1

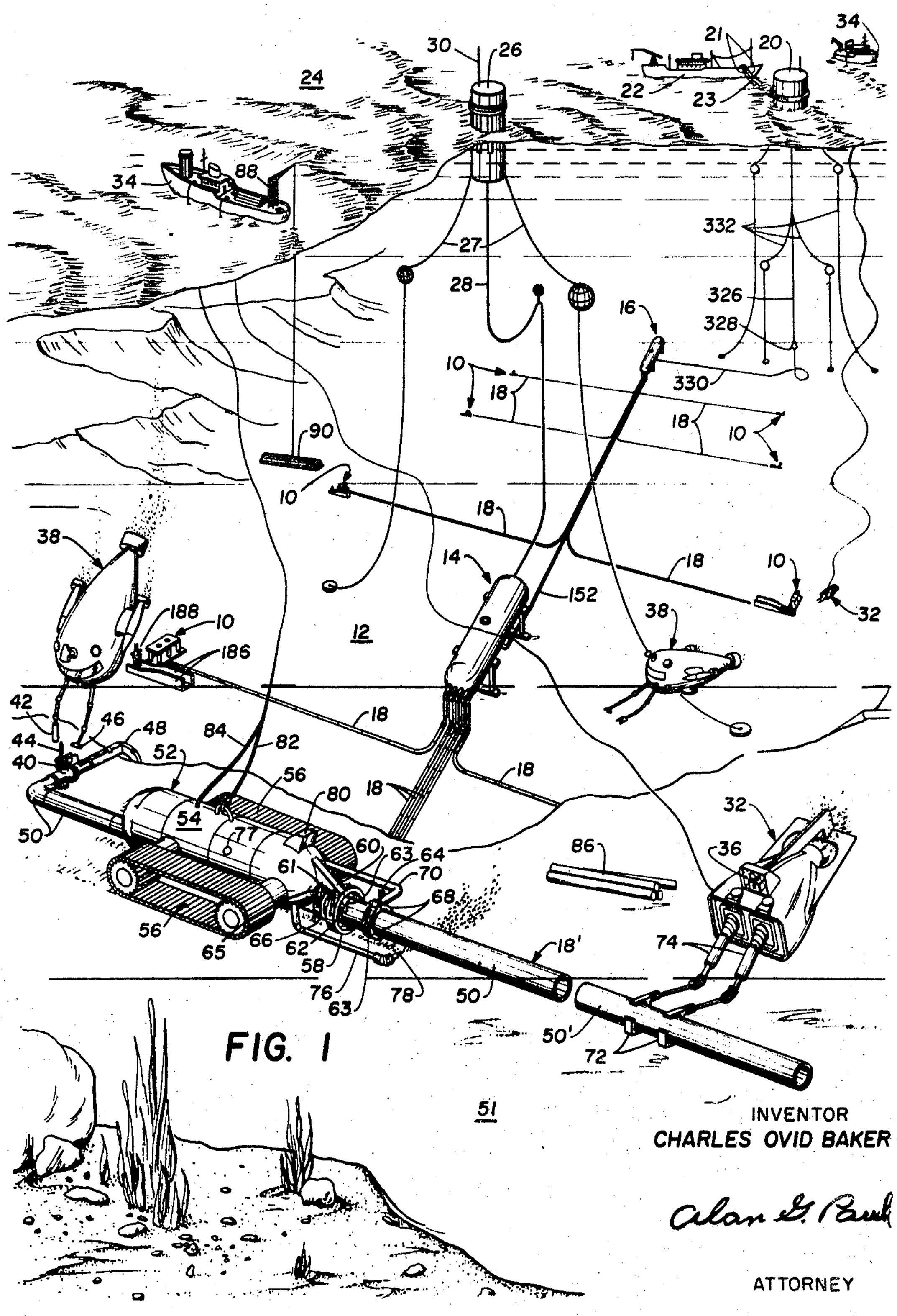

FIG. 1

INVENTOR
CHARLES OVID BAKER

Alan G. Rauh

ATTORNEY

SUBSEA PRODUCTION SYSTEM

Filed June 29, 1967 3 Sheets-Sheet 2

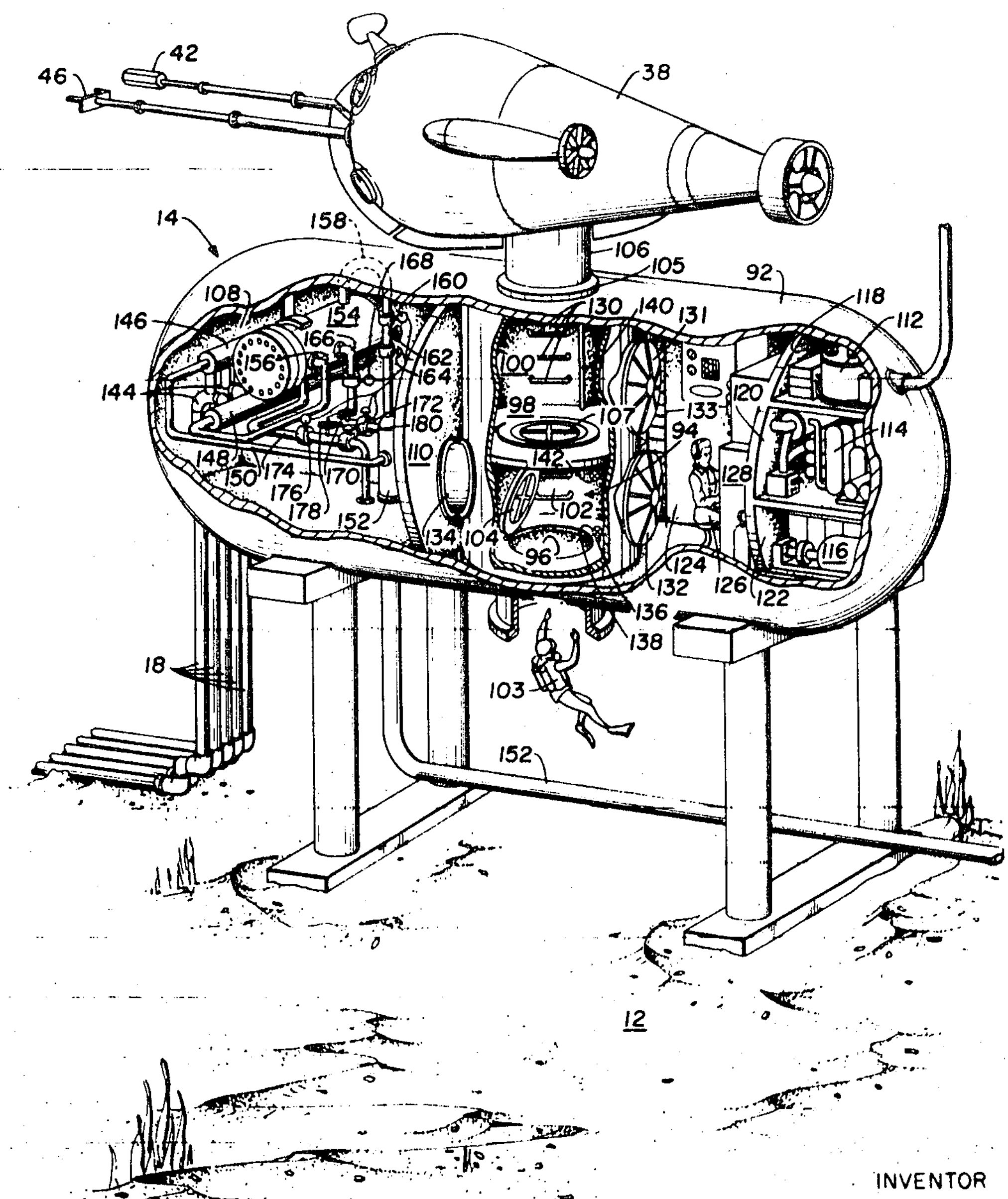

FIG. 2

INVENTOR
CHARLES OVID BAKER

Alan G. Paul

ATTORNEY

Sept. 30, 1969 C. O. BAKER 3,469,627

SUBSEA PRODUCTION SYSTEM

Filed June 29, 1967 3 Sheets-Sheet 3

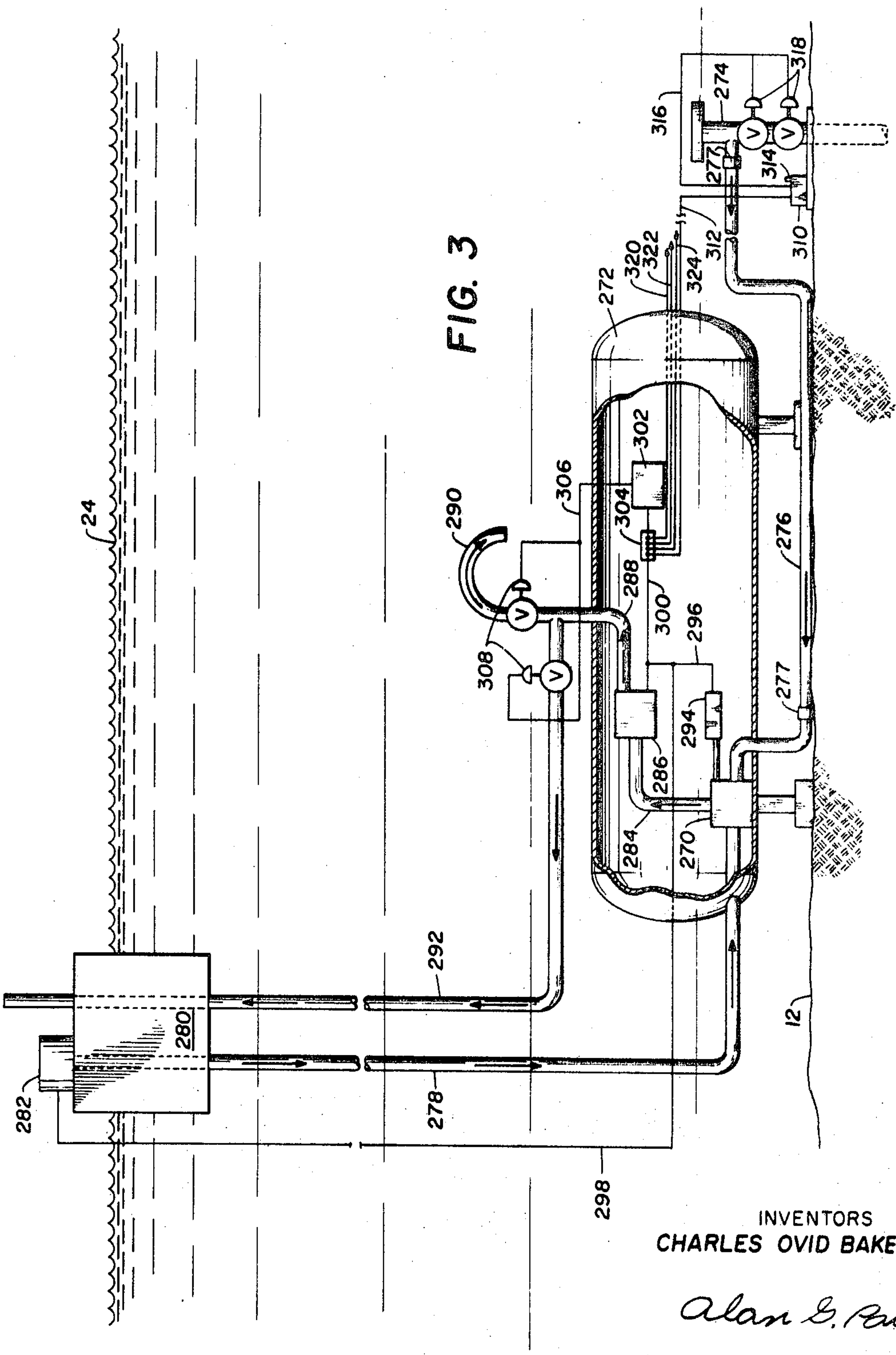

FIG. 3

INVENTORS
CHARLES OVID BAKER

BY Alan G. Pru[illegible]

ATTORNEY

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1

3,469,627
SUBSEA PRODUCTION SYSTEM

Charles Ovid Baker, Garland, Tex., assignor to Mobil Oil Corporation, a corporation of New York

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Int. Cl. E21b 33/035, 7/12, 43/01
U.S. Cl. 166—.5 7 Claims

ABSTRACT OF THE DISCLOSURE

This specification discloses a subsea system for the production of fluid minerals. The system includes a product gathering network provided with production satellites in which the gas-oil-water ratios of each well are periodically tested and the flow rates are automatically controlled. A power distribution network connects a central power station, either floating or bottom supported, at the site or on land nearby, with the various saellite stations and submerged wellhead units. Provision is made for entry into the satellites and diver maintenance at the submerged wellheads. General purpose submersible vehicles with articulated manipulators, as well as specialized robot submersibles such as pipe welders, permit diverless installation of equipment.

BACKGROUND OF THE INVENTION

Field of the invention

This invention relates to a subsea system for the recovery of subaqueous deposits of fluid minerals. By the term "fluid" is meant any slurry or other state of matter which will pass through a conduit or pipe. More particularly, the invention relates to the production of gas and/or oil from subaqueous formations utilizing a system of submerged wellheads and a product gathering network in combination with submersible automated and/or semi-automated equipment.

DESCRIPTION OF THE PRIOR ART

Present developments in the offshore oil and gas industry indicate that production efforts will be extended, in the near future, to undersea areas, such as the outer fringes of the continental shelves and the continental slopes, where a submarine production system is believed to be the most practical method of reaching the subaqueous deposits. Although hydrocarbons are the main concern at this time, it is contemplated that subaqueous deposits of sulfur and other minerals will be produced from beneath the seas in a very few years. While bottom-supported permanent surface installations have proved to be economically and technologically feasible in comparatively shallow waters, it is believed that in the deeper waters of the continental shelves (over three hundred feet), and the continental slopes (depths over six hundred feet), the utilization of such surface installations must be limited to very special situations. Installations extending above the water surface are also disadvantageous even in shallower water where there are adverse surface conditions, such as in the Arctic areas where the bottom-supported structure of above-surface production platforms are subject to ice loading. The tides, which may run up to thirty feet in the northern latitudes, such as in Cook Inlet, Alaska, tend to lift the ice formed on the legs of the platform and tear the anchoring means therefor completely out of the sea bottom as well as driving broken-up sheet ice laterally against the platforms at six to eight knots or more. In some areas commercial shipping and pleasure boats present a constant source of danger to above-surface installations, while recreation and area beautification may provide man-made obstacles to

2

their erection, particularly near seaside resort areas and seaport cities.

The sheltering of production equipment beneath the surface of the sea, while believed to be economically feasible at depths of over three hundred feet, even where adverse conditions are not present, still presents many technical problems, particularly with respect to the servicing and maintenance thereof. With a deep water subsea system, the majority of the maintenance and servicing problems encountered must be handled automatically, or at least by remote control, due to the cost and limitations on deep diving at the present time; however, here should be provisions for having divers at the scene of installed subsea equipment in the event that the necessary manipulations are too complicated for anything but direct human control. The use of submersible vehicles, with articulated manipulators, for performing a variety of subsea operations has been generally proven and such vehicles can fill much of the gap between completely automated equipment and operations that must be performed by divers.

Robots, such as those shown in the Johnson U.S. Patent No. 3,099,316, issued July 30, 1963, the Shatto U.S. Patent No. 3,165,899, issued Jan. 19, 1965, and the Shatto, Jr., U.S. Patent No. 3,163,221, issued Dec. 29, 1964, have been developed for the most part for working on subsea wellheads, in conjunction with guide rails or other engaging and guiding devices built on the wellheads, as shown. The Haeber U.S. Patent No. 3,261,398, issued July 19, 1966, does show, in a general way, the use of a track for guiding a robot through a bottom-mounted array of production equipment. The use of a drill string, extending from a surface vessel, also has been contemplated for actuating the controls of subsea equipment ("Drill Pipe Becomes Long-Handled Underwater Socket Wrench"—The Oil & Gas Journal, Jan. 24, 1966, pages 90–93). The Popich U.S. Patent No. 3,103,790, issued Sept. 17, 1963, shows a pipe trenching robot while the Shell British Patent No. 1,021,264, discloses a bottom traversing, general-purpose robot. The robots of both of these last two patents recited are designed to be controlled from a surface mother ship. However, no overall integrated design has been disclosed in the prior art for handling the installation, repair, and maintenance of a deep water subsea production system. For instance, there is no equipment known for performing wireline operations completely under water. The Ashe et al. U.S. Patent No. 3,041,090 is illustrative of the prior art, disclosing a foldable lubricator adapted to extend all the way from a submerged wellhead to the surface of the body of water where the wireline operations are conducted from a surface ship.

The use of a pressurized traveling chamber for transporting divers from the ocean bottom to a chamber aboard a surface ship is disclosed in the article entitled "Diving-Chamber Complex Speeds Subsea Salvage Job," The Oil & Gas Journal, June 20, 1966, pages 82 and 83. However, the utilization of a submersible, self-propelled vehicle as a pressurized, on-site, rest station is not shown in the prior art. The limiting of the use of surface vessels to the transportation of subsea equipment from shore, the lowering of subsea equipment to the marine bottom, and the transporting of collected and stored products, increases the independence of the production system from surface conditions.

SUMMARY OF THE INVENTION

In accordance with this invention, there is provided a subsea production system including satellite gathering stations for testing the produced effluent from submerged wellheads of spaced subaqueous wells whose products as directed therethrough, and in response, controlling the wellhead valves of the respective subaqueous wells. While the satellite stations are designed for automatic and/or remote operation, there are provided means for the safe entry of personnel for maintenance and repair. Furthermore, the satellite stations are each constructed so as to prevent pernicious vapors leaking from the production equipment from contaminating the life support sections of a satellite station.

An integral part of the subsea system of the present invention is a power distribution network connects a power generating station with the satellite stations and the wellheads. The power generating station if at the site can be a surface unit of the floating type or it alternatively can be mounted on a bottom-supported platform, depending, for the most part, on the water depth in which the subaqueous deposits are being produced. Another possibility is that of locating the power generating station ashore and connecting it with the offshore producing field through lines laid across the marine bottom. Preferably the power generating station is submerged along with the rest of the production equipment. By encapsulating the generating station within a shell, similar to those of the satellite stations, only fresh air and communication lines need be supported at the surface by small buoys.

The main subsea system discussed above also includes a back-up or fail-safe system adapted to manipulate the wellhead valves in case of a failure in satellite station-to-wellhead communication and to perform operations not adapted to be automatically controlled from the satellite station. The fail-safe system is provided with submersible vehicles, having articulated manipulators for the remote manual control of the submerged wellhead and flowline valves as well as for the installation of the subsea equipment. The remotely controlled submersible vehicles, controlled from a surface vessel, are complemented by manned submersible vehicles provided with pressurized life support rest chamber sections for divers working on the submerged equipment. A robot unit for welding pipe sections, in conjunction with the submersible vehicles having articulated manipulators, permits the units of the system to be interconnected by flowlines without divers. In very deep water, this becomes almost a necessity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a pictorial representation of a portion of a subsea producing system in accordance with this invention;

FIGURE 2 is an elevational view, partially broken away, of a subsea satellite station forming a portion of the subsea producing system of the present invention; and

FIGURE 3 is a schematic representation of a submerged, bottom-supported, power generating station.

DESCRIPTION OF SPECIFIC EMBODIMENTS

The subsea production system of the present invention has been designed specifically for offshore areas in which the water is too deep for the economical utilization of bottom-supported surface platforms, although it can be advantageously utilized in not so deep water where there are adverse surface conditions. The subsea system has the capability for automatic and/or remotely controlled installation, servicing, and maintenance, and comprises submerged wellheads spaced across a marine bottom and connected to an on-site storage facility through satellite gathering stations fixed on the marine bottom. Each of the satellite gathering stations is provided with multiple chambers capable of being maintained at independently controlled pressures: a central access chamber providing entry or exit of personnel directly into the water or into a submersible vehicle, a production chamber at one end including equipment, i.e., a test separator for providing the necessary information for controlling the gas and/or oil production of the individual wells, and a life support chamber at the other end having the air purification system, pumping equipment, and the electrical and electronic facilities for compiling and storing information and for acting on the production test results to control the subaqueous production equipment.

The submersible vehicles, both manned and remotely controlled, with their articulated manipulators, do more than just act to ferry personnel between a surface vessel and the satellite station, and control robot wireline units. Depending on the job to be performed, a number of different tools connectable to the outer ends of the individual manipulators can be utilized. With submersible vehicles carrying their own supplies of tools, almost any function that could be performed by a man with manual or power operated hand tools can be assigned to them. The submersible vehicles can perform such operations as adjusting valves on the wellheads and flowlines as well as aiding in the installation of the subsea equipment.

Now referring to FIGURE 1, there is shown a subsea production system in operation in the background and a continuation of the flowlines therefrom being installed on the ocean bottom in the foreground. Submerged production oil and/or gas wellhead units, generally designated **10**, on the marine bottom **12** are connected into the subsea system through satellite stations, generally designated **14** and **16**, by means of flowlines **18**. The satellite station **14** functions as a production gathering point, information center, and automatic control center for its associated wells, while the satellite station **16** provides all of the functions of the station **14** while also having added pumping facilities for forcing the produced hydrocarbons up to a floating storage tank **20**. The stored hydrocarbons are removed from the floating storage tank **20** by a tanker **22**, floating on the water surface **24**, which visits the storage tank **20** and is moored thereto at prescribed intervals. As shown, the tanker **22** is located with respect to the storage tank by mooring lines **21** while onloading through a floating hose **23** connected to an outlet of the storage tank **20**. A floating central control and power generating station **26** is moored above the subaqueous producing field by lines **27** and is connected to the satellite **14** by a bundle of electrical lines **28** for information input and retrieval, command signals, and the supplying of electrical power to the subsea system. It is contemplated that personnel would live on the station **26** to supervise continuously the operation of the subsea production system. Electric power is distributed, along the marine bottom **12**, to the various wellhead units **10** shown, the satellite station **16**, and other satellite stations **14** from the illustrated satellite station **14**.

Although the central control and power generating station **26** is illustrated as floating on the surface of the body of water just above the subsea production system, depending upon the distance from shore, the floating station **26** could be dispensed with entirely and the electrical power lines as well as the information input and retrieval and command signal lines could be laid across the ocean bottom to an onshore station. Another possibility is that the floating station **26**, while having the equipment for generating power built thereon, would be merely a link between the submerged satellite **14** and a station ashore for the transmission of information to and from shore and command signals to the satellite through the illustrated antenna **30**. A microwave relay system, of the type now utilized in conjunction with some platform-produced fields in the Gulf of Mexico, would be acceptable for this purpose.

Various valves and controls situated at the wellhead units **10** would normally be controlled by interconnecting hydraulic or electrical lines from within the satellites **14** and **16**. However, if there should be a breakdown in communication between a wellhead unit **10** and its respective controlling satellite **14** or **16**, articulated armed robot submersible vehicles, generally designated **32** (the nearer one shown handling pipe), remotely controlled from surface vessels **34**, would be utilized. Such vehicles, directed by the aid of remote viewers such as television cameras **36** in clear water, or sonic or laser viewers in murky water, mounted thereon, would be much less expensive than a manned vehicle with its attendant life support systems. However, in instances where direct observation is necessary, submersible vehicles having articulated manipulators, such as the illustrated submersible vehicles, generally deignated 38, are useful; the vehicle 38 at the right is observing a pipe-laying operation, while the vehicle 38 at the left is about to operate a flowline valve 40 by the use of a rotary actuator tool 42 adapted to fit an upwardly extending nut 44 forming the valve actuator. A tool, such as the rotary actuator tool 42, as well as a number of other tools to be used in conjunction with the articulated manipulators of submersible vehicles are pictured on pages 653–661 of the book Proceedings of OECON—Offshore Exploration Conference, 1966, published by M. J. Richardson Inc., 2516 Via Tejon, Palos Verdes Estates, Calif. The other articulated manipulator terminates in a platelike tool 46 used as a reaction member to prevent the vehicle 38 from turning rather than the valve actuator nut 44. The valve 40 would normally be controlled from a satellite station 14, 16 through the control line 48 strapped thereto. Along the outer shell of the submersible vehicles 38 are pockets or hooks (not shown) for carrying as many different tools as may be necessary. By using one of the many known quick release couplings, an articulated manipulator can easily be released from a first tool connected to the outer end thereof and to a second tool fixed thereon. As will be explained later, a similar manned submersible vehicle can also be utilized as a rest station for divers working at a nearby wellhead unit 10 or other equipment.

Individual wellhead units 10, as well as the satellite stations 14 and 16, can be installed at the proposed location without the need for divers. It is now well within the skill of the art to remotely locate equipment on the marine bottom 12, in the proper orientation, and secure it in place. One of the major problems remaining, however, is that of connecting the individual production units of the subsea system together. As shown in the foreground of FIGURE 1, sections of pipe 50 of a flowline 18′, to be connected between the illustrated satellite 14 and a wellhead unit 10 off to the right of the drawing in the foreground, are being installed on a shelf 51 of the marine bottom 12 by the use of one of the unmanned remotely controlled articulated submersible vehicles 32 and a robot welder, generally designated 52.

The robot welder 52 comprises a tanklike body 54 supported above the path of the flowline 18′, being installed, on a pair of opposed endless treads 56 driven by a motor and transmission means (not shown) within the tank 54. The robot welder 52 would normally be supported on the marine bottom 12 by the treads 56, but in areas where bottom sediments would not support the weight of the robot welder 52, buoyancy chambers would be built into the tanklike body 54.

Extending out ahead of the tank 54 is a welding ring 58 which encircles the flowline 18′ and is held in a vertical position by a strut 60 extending out from the front of the tanklike body 54. A welding head 62 is contained on a track (not shown) around the inside face of the welding ring 58 so that a welding bead is formed which completely encircles a joint 63 between abutting sections of pipe 50. The welding ring 58 is formed of a pair of semicircular members pivoted about the point of connection with the strut 60. A hydraulic piston cylinder 61, connected between a point on each semicircular member of the welding ring 58 and the pivot point to control the opening and closing of the welding ring 58. The ability of the welding ring to open permits the robot welder to mount a flowline 18 intermediate the ends thereof. A pair of aligned pipe clamps 64 and 66 hold the abutting ends of adjacent sections of pipe 50 together and in alignment prior to and during the welding operation. The pipe gripping portion of clamp 64 and a pair of semicircular jaws 68 are actuated by extensible struts having hydraulic piston-cylinder arrangements 63 connected between each of the jaws 68 and an outwardly extending anchoring arm 70 from which the jaws 68 pivot. The jaws of the clamp 66 are pivoted from the underside of the strut under the control of extensible struts 65. With the jaws of the clamps 64 and 66 reopening, the robt welder 52 can move up the flowline 18′ to the next point at which a weld is needed. The closing of the clamp 66 aligns the end of the last pipe section 50 of the flowline 18′ and the welding ring 58. The still opened jaws 68 of the clamp 64 permit the remotely controlled submersible vehicle 32 (in the right foreground) to slide a new pipe section 50′ into the jaws 68 of the clamp 64 by means of the hand or vice-type extension tools 72 at the ends of its articulated manipulators 74. A pile 86 of pipe sections is stacked on the shelf 51 just behind the flowline 18′ being fabricated. When the remotely controlled submersible vehicle 32 delivers a pipe section 50′, that it is carrying, to the robot welder 52, it is sent back to pick up another pipe section 50′ from the pile 86. The vessel 34 from which the remotely controlled submersible vehicle 32 and welder 52 are both controlled has a crane 88 capable of lowering further stacks 90 of pipe sections 50 down to the flowline 18′ being fabricated.

In connecting two of the subsea producing units with a flowline, it is advantageous to use a collet connector (not shown) at each fixed unit since the robot welder 52 is not suited to forming any but abutting welds between pipe sections of substantially equal diameters. To start the flowline, a first pipe section is transported by the submersible vehicle 32 to the fixed producing unit from which the flowline is to be started. The end of a pipe section is inserted into a collet connector forming the outer portion of a port in the unit. The collet connector is actuated to lock the pipe section in place from a central facility, or a surface vessel, or from the submersible vehicle. The robot welder 52 is then lowered onto the pipe section 50′, forming the beginning of a flowline with both sets of pipe clamps 64 and 66 as well as the welding ring 58 held open. When the welder 52 has settled down on the unfinished flowline, the welding ring 58 may be closed and is not again opened until the flowline is completed. Sections of pipe are added to the flowline and welded in place as discussed above. As the flowline reaches a point at which it is only one pipe section or less from the second producing unit, a measured pipe section is brought up which will lock in a collet connector terminating a port in the second unit while abutting the last pipe section of the unfinished flowline. The last joint is then welded between the measured pipe section and the unfinished flowline after which the clamps 64 and 66 as well as the welding ring 58 are all opened permitting the robot welder 52 to be lifted off of the pipeline 18′. At this time the collet connector on the second producing unit is actuated to complete the flowline.

Once the pipe section 50′ has been inserted into the enlarged opening through the clamp 64 and the new section of pipe 50′ abuts tightly against the last welded-on section 50, the jaws 68 of the clamp 64 are closed, aligning the pipe sections 50 and 50′ in abutting relationship. The traveling welding head 62 is then driven around the track within the ring 58 to form a circumferential bead around the joint after which both of the clamps 64, 66 are opened. The robot welder 52 then moves on up the flowline to the new outer end of the flowline 18′, one pipe section 50 away, and the sequence of operations is repeated. Since the pipe sections 50 tend to sink into the mud on the marine bottom 62, a means must be provided for forming a temporary path under the flowline 18′ so as not to hinder the movement of the clamps 64, 66 and the ring 58 as the welder 52 moves forward. A shallow trench is formed ahead of the robot welder 52 by a jet pipe 76 extending out parallel to the flowline 18′. The tip 78 of the jet pipe 76 is aimed to project fluid under pressure transversely toward, and down slightly below, the flowline

18'. The preferred method is to provide a pump (not shown) with the body **54** to pick up sea water through an intake port and drive the water out through the jet pipe **76**. A television camera **80** (or any other type of remote viewer as previously discussed) is mounted on top and at the front of the tanklike body **54** of the robot welder **52** so that the welding operations can be observed from the ship **34** (at the left-hand side of the drawing) at the surface. The ship **34** and the robot welder **52** are connected by a hoisting line **82**, and a control cable **84** through which the television signals are sent to the ship **34** and commands are transmitted to the welder **52** from the ship. Within the tanklike body **54** is the various equipment for directly controlling the movement of the robot welder **52**.

Now looking to FIGURE 2, the satellite station **14** has a hollow shell **92** comprising a cylindrical center section closed by hemispherical end sections and is divided interiorly into three airtight chambers. A central access chamber, generally designated **94**, provides an entrance into the satellite station **14** from one of the submersible vehicles **38** from above, or by a diver, through a lock **96** below. The access chamber **94** is cylindrical in shape and is divided vertically, by an intermediate lock **98**, into an upper compartment **100** through which personnel move between the interior of the satellite station **14** and the submersible vehicle **38** and a lower compartment **102** through which a diver **103** enters and leaves the satellite station **14**. Since the satellite station **14** would normally be maintained at atmospheric pressure, sealable hatches **104** and **107** are necessary at the lower and intermediate locks **96** and **98**, respectively. An upper lock **105** is also sealed (by a nonillustrated hatch) when no submersible vehicle **38** is engaged thereto by a depending intermediate access tube **106**. The submersible vehicle **38** also operates at atmospheric pressure normally, but an internal compartment therein, connected by the access tube **106** to the upper lock **105** of the satellite station **14**, as well as the entire central access chamber **94**, can be pressured up to accommodate divers who have worked in the open sea and require decompression. The divers in the pressurized compartment in the submersible vehicle **38** are transported to a surface ship where there are proper facilities for safe decompression.

All of the hydrocarbon products being produced through the satellite station **14** are confined to a processing chamber **108**, at one end of the satellite shell **92**, walled off by a bulkhead **110**, to prevent contamination of the atmosphere in the reminder satellite station **14** if there should be a leak in the processing equipment. The air purification equipment **112**, pumping equipment **114**, and electrical power facilities **116** are in separate sealed compartments **118** to **122**, respectively, of a control chamber **124** at the other end of the satellite station **14** from the hydrocarbon processing equipment. An operator **126**, shown sitting at a control console **128** in the control chamber **124**, can monitor and direct the equipment in the hydrocarbon chamber **108** as well as actuating valves at the wellhead units **10** and flowlines **18**.

Both the upper and lower compartments **100**, **102** of the access chamber **94** are normally closed to the sea and are held at atmospheric pressure. After the access tube **106**, depending from under the submersible vehicle **38**, makes contact with the lock **105** on the upper end of the satellite station **14**, the two are sealably connected and any water in the access tube **106** is pumped out by equipment on the submersible vehicle **38**. With an equalization of pressure, the hatch in the lock **105** is opened. Personnel can then enter the upper compartment **100** of the satellite station **14** directly from the submersible vehicle **38**, through the access tube **106** at atmospheric conditions. Personnel from the submersible vehicle **38** come down rungs **130**, fastened to the interior wall of the access chamber **94** to form a ladder, and enter the control chamber **124** through a safety airlock **131** and a ladder **133**.

If the services of a diver are necessary, scuba or "hard hat" diving equipment, stored in the chamber **124**, are utilized. Once the diving equipment is donned, the diver **103** enters the lower compartment **102**, through a safety airlock **132**, reseals the safety airlock **132** and makes sure the intermediate lock **142** is sealed, and then floods the lower compartment **102**. As the lower compartment **102** fills with water, the diver **103** opens the lower lock **96** and descends into the water. If the job to be performed takes an extended time at depths of more than several hundred feet, the diver **103** may be limited to as short a working time as one-half hour before he must come back to the satellite station **14** to rest. In such a case, more than one diver **103** could be used, the remaining members of the working team resting in the atmospheric portions of the satellite station **14** while one of the team works in the water and each one exiting in turn through the lower lock **96** when the last one returns to the satellite station. In such a manner, work can continue over long periods of time although any one diver **103** cannot stay very long in the hostile environment.

When performing maintenance or inspection work in the processing chamber **108**, the possibility of a gas leak in the equipment is checked by a workman donning life support gear such as scuba apparatus entering the chamber **108** with a hand-carried device for detecting toxic, pernicious gases that might be leaking from the processing equipment. Alternatively, a leak detector is mounted in the bulkhead **110** to sample the atmosphere within the compartment **108** while providing a visual indication to one either within the access chamber **94** or the control chamber **124**. If possible the leak is stopped by shutting off the processing equipment from within the control chamber **124**. The processing chamber **108** is then flooded while exhausting the contaminated atmosphere to the surrounding water. After re-establishing atmospheric conditions in the processing chamber **108**, the atmosphere within the processing chamber is again checked, and if it is safe a workman can enter to make repairs. If the leak cannot be stopped in this manner, it will be necessary for a workman, wearing life support gear, to enter the contaminated processing chamber **108** to manually stop the leak. In the event that gas is escaping into the processing chamber **108** at a high pressure, too high a pressure for a man to exhaust through his breathing equipment into the processing chamber **108**, an exhaust tube (not shown) would be connected from the life support gear back into the control chamber **124**.

It is important to contain the contaminated atmosphere in the processing and access chambers **108**, **94**. By sealing the safety airlock **132** and the intermediate lock **98** from within the access chamber **94** before opening a safety lock **134**, interconnecting the access chamber **94** within the processing chamber **108**, the noxious fumes can be contained in the lower compartment **102** of the access chamber **94** and the processing chamber **108**. After the maintenance or repair work is completed, the contaminated atmosphere within the processing chamber **108** and the access chamber **94** can be purged, by several alternate procedures. One way is to let in water under full pressure to displace the contaminated air through a line **136** by a hand-actuated control valve **138** in the lower compartment **102**. The contaminated air in the lower compartment **102** of the access chamber **94** and the processing chamber **108** would then be forced out through a line **140** controlled by hand-actuated valve **142** also in the lower compartment **102**. After the compartment **102** and the processing chamber **108** have been purged of the contaminated atmosphere therein by sea water, the valve **142** is closed and the sea water is pumped out through line **136** while air under atmospheric pressure is introduced. The water can also be expelled, through the line **136** without directly pumping it out by fresh air that is pumped in under pressure from the control chamber 124. Once all of the water has been expelled and the air pressure in the lower compartment 102 is brought back to atmospheric the safety airlock 132 is reopened to allow the workmen to re-enter the control chamber 124. There would normally be no decompression problems associated with forcing out the contaminated air with ambient pressure sea water as long as the high pressure was not held for more than a few minutes.

Whenever a man is exposed to high pressures, even for a short time, there is some risk. So, for maximum safety, it is preferred that the contaminated air be evacuated into the surrounding water through the line 140 with the help of a pump (not shown) in the line. The water would be again brought in through the line 136. A pressure regulator (not shown) should be included in the line 136 to prevent the water pressure inside the satellite shell 92 from rising much above atmospheric. After all of the contaminated atmosphere has been displaced, the water is pumped out as described above while air under atmospheric pressure is reintroduced. At this time the equipment is rechecked for leaks.

In the instance where there was a very high pressure leak into the chamber 108, it would be dangerous for a man even to enter the chamber 108 with any portion of his body uncovered since the contaminated atmosphere therein could dissolve human skin. In fact, a gas such as methane would pass right through flesh, into the body fluids, altering the body chemistry and killing the man exposed to these conditions. Workmen would either have to wear completely protective clothing or the chamber 108 would have to be flooded prior to being entered and the workman would then preferably work in the chamber 108 under water. Very few materials possess the ability to withstand the onslaught of the high pressure gas and yet have the flexibility necessary for a protective garment. If the leak can be remotely stopped the diver would work under water at atmospheric pressure. If it is not possible to stop the leak prior to the workman entering the processing chamber 108 the diver-workman must work at ambient water pressure.

If the diver-workman must work for a considerable time at ambient pressure, he must be transported to a decompression chamber on an attending surface vessel (not shown) after the repairs are completed. After the repairs are completed in the flooded processing chamber 108, the workman enters the compartment 102, seals the safety lock 134, and has the water therein pumped out. A breathable atmosphere is pumped into the compartment 102 at ambient pressure. This can be done easily by opening the valve 138, or the port 96, while pumping high pressure air into the lower compartment 102 to drive the water out. The upper compartment 100 is also pressurized. When all the water is evacuated from the lower compartment 102, the valve 138 or port 96, whichever was opened, is closed and the intermediate lock 98 is opened. The workman can now enter the pressurized compartment in the submersible vehicle 38 for transportation to the decompression chamber on the surface vessel without passing through an area of low pressure. Before a second repairman can enter the processing chamber 108 to check on the repair work, the pressure in the upper and lower compartment 100, 102 must be pumped down to atmospheric while the water in the chamber 108 is pumped out and replaced with air at atmospheric pressure so that leaks can be checked for at atmospheric conditions.

The flowlines 18, extending into the satellite station 14 at the end at which the processing chamber 108 is located, are each operatively connected by two-position three-way valves 144 to either a group manifold 146 or a test manifold 148. In turn, each one of the flowlines 18 is separately connected to the test manifold 148 while the remainder are cnnected to the group manifold 146. From the group manifold 146 the effluent, flowing through all but one of the lines 18, is conducted, through a main conduit 150, to a main outlet line 152 which in turn depends through the shell 92 of the satellite station 14 and extends across the marine bottom 12 to the pumping station in the satellite station 14 and therethrough to the floating storage tank 20. The effluent, from a single flowline 18 at a time, is directed into the test manifold 148 and therethrough into a test separator 154, through an inlet line 156. The separated-out gas leaves the separator 154 through an outlet line 158 and is injected back into the main effluent stream at the main outlet line 152. A meter 160 in the gas outlet line 158 provides a means for indicating the amount of gas flowing through the line 158. Also in the outlet line 158 is a manual shut-off valve 162 and an automatic valve 164 which is controlled by equipment from within the control chamber 124 of the satellite station 14 for increasing or decreasing the back pressure on the separator 154. An oil outlet line 166 also extends from the test separator 154 to the main outlet line 152. The oil outlet line 166 also has a meter 168, a manual shut-off valve 170, and an automatic valve 172. A dump line 174 is either connected directly between the sump of the separator 154 and the water outside the satellite station 14, for ridding the effluent of water separted out in the separator 154, or if the pressure in the separator is too low this waste liquid may have to be pumped out. Line 174 also includes a meter 176, a manual shut-off valve 178, and an automatic valve 180. An automatic satellite gathering and test system, of the type discussed above, has been explained in detail in the A. E. Barroll et al. Patent No. 3,095,889, issued July 2, 1963.

The power generating station 26, previously mentioned (shown in FIGURE 1), has large diesel engines, turbines, or any other convenient type of prime mover for driving electrical generators to provide the power necessary to operate the subsea equipment. The power is transmitted to the producing system through a cable forming a part of the bundle 28 extending between the surface generating station 26 and the satellite station 14. From the satellite station 14 the electrical power is distributed to the satellite station 16 and the other satellite stations 14 (not shown) which are necessarily spaced across the marine bottom 12. From each satellite station 14 and 16 the distribution lines then extend to each piece of subsea equipment at which electrical power is needed, including each of the wellhead units 10 being controlled, providing power for operating the valves of the wellheads 188 as well as for operating auxiliary equipment suchas the robot wireline unit 182.

For the protection of the generating station, this too is preferably located on the marine bottom 12. Such an arrangement is shown in FIGURE 4 where a prime power source, indicated at 270, is enclosed in a pressure resistant shell 272. The fuel for the prime power source 270 can be natural gas or a refined gasoline stored in a bottom-mounted tank, particularly if the power source 270 is an internal combustion engine or a gas turbine. When natural gas or low gravity petroleum is being produced in the subsea system, this is preferably taken directly from a subaqueous well and used as fuel. When a steam engine is the prime power source, any petroleum products produced, which will flow, can be burned to provide a power. As illustrated, the fuel is directed into the bottom-mounted shell 272 from one respective submerged wellhead 274 through an interconnecting flowline 276 laying on the marine bottom 12 and connected to the two fixed units by collet connectors 277. All of the production of the well may be used as fuel or, if the production capacity of the well is large, only a small portion of the production fluid is directed to the generating station, the remainder being fed directly into a flowline between the wellhead 274 and a satellite station 14, 16. The fresh air necessary for combustion is supplied through a flexible conduit 278 connected between the interior of the shell 272 and a small floating buoy 280. A compressor or blower 282 is mounted on the buoy 280 for insuring a large enough volume of air. The products of combustion from the power source **270** are directed through a line **284** into a compressor or pump **286** from which they are driven, via line **288** to discharge, either into the sea through conduit **290** or to the atmosphere through a flexible conduit **292** extending from the line **288** to the floating buoy **280**. The prime source, or engine, **270** drives an electrical generator **294** within the shell **272**. The resulting electrical power is transmitted directly to the pump **286** through the main electrical line **296** and to the blower **282** through the lines **296** and **298**. Electrical power is transmitted, by line **300**, from the main line **296** to a transformer station **302** in the shell **272** through a terminal board **304**. A line **306** transmits low voltage power from the transformer station **302** to the valves **308** controlling the flow of combustion products. Power is transmitted to a junction box **310** from the terminal board **304** through the interconnecting line **312**. Low voltage power is obtained at the junction box **310** by transformers therewithin. A watertight electrical connector **314** on the junction box **310** provides power for auxiliary equipment. A low voltage line **316** transmits power from the junction box **310** to the wellhead valves **318** for controlling the rate of delivery of fuel from the well. Other power lines **320–324**, for example, transmit electrical power from the main terminal box **304** to the various wellhead units **10**, satellite station **16**, and other satellite stations **14**. Although electrical power can be directly supplied to the individual wellhead units **10**, it is preferable to have the main power lines from the main terminal box **304** connect to terminal boxes (not shown) within each satellite station **14**, **16** and have the electrical power distributed therefrom to the respective wellhead units **10**.

Referring again to FIGURE 1, the floating storage tank **20** has a rigid transportation pipe **326** depending to a point just above the marine bottom **12** and terminating in a funnel **328**, a flexible line **330** extending from the funnel **328** to the pumping section in the satellite station **16**. A short section of the line **330**, at the end of the line connected to the rigid transportation pipe **326** within the funnel, is of a weaker material or of the material as the rest of the line **330**, but has a thinner wall. By this arrangement, if the floating storage tank **20** should break its moorings and float away, the interconnecting transportation path would tend to rupture, at its weakest point, in the flexible line **330** within the funnel **328**. This would permit most of the fluid products to be saved and only the small amount in the flexible line **328** to be lost. The fluid products in the rigid pipe **326** would be driven up into the storage tank **20** by the hydrostatic pressure. A pressure actuated switch (not shown) is included in the flexible line **330** to shut off the pump in the satellite station **16** if the flexible line **328** were to rupture. Such a switch would be actuated by abnormally high or low pressure, depending on the water depth and the pump outlet pressure. It is also advisable to mount a pressure controlled switch in the outer end of the flexible line **330**, just below the designed rupture portion to retain the fluid products in the flexible line **328**. Furthermore, the storage tank **20** is moored as far to the side of the subsea field as possible so that if it should break loose, its mooring lines **332**, extending to the marine bottom **12**, would not snag in the subsea equipment.

Although the present invention has been described in connection with details of the specific embodiments thereof, it is to be understood that such details are not intended to limit the scope of the invention. Each of the described units of the subsea system previously discussed could conceivably be utilized without each and every one of the other units. For example, the satellite station **14** could be used without the particular robot wireline unit **182** or the robot welder **52**. The terms and expressions employed are intended to be used in a descriptive sense only and there is no intention of excluding such equivalents in the invention described as fall within the scope of the claims. Now having described the subsea system herein disclosed, reference should be had to the claims which follow.

What is claimed is:

1. A subsea system for the production of minerals from subaqueous deposits through wells having wellheads located beneath the surface of a body of water wherein a plurality of underwater wellhead units are in operative connection with a central production facility by flowlines, at least one remotely actuatable wellhead valve on each of said underwater wellheads for controlling the flow of produced fluid from said well to said central production facility, said subsea system comprising:

an underwater power generating station having a pressure resistant shell;

a prime power source located within said power generating station and adapted to supply the necessary power for operating said subsea production system, said prime power source including a fuel burning engine;

a power distribution network for transmitting the power produced by said prime power source to each of said wellhead units to at least provide power for actuating said remotely actuatable wellhead valves;

a first conduit means extending to the surface of said body of water from said power generating station to provide air to said fuel burning engine;

a second conduit means for directing the exhaust of said fuel burning engine out of said shell of said power generating station, said second conduit means terminating in the surrounding body of water; and

means powered by said prime power source for raising the pressure of said exhaust in said second conduit means to facilitate driving said exhaust into said surrounding water.

2. A subsea system for the production of minerals from subequeous deposits through wells having wellheads located beneath the surface of a body of water wherein a plurality of underwater wellhead units are in operative connection with a central production facility by flowlines, at least one remotely actuatable wellhead valve on each of said underwater wellheads for controlling the flow of produced fluid from said well to said central production facility comprising:

an underwater power generating station having a pressure resistant shell;

a prime power source located within said power generating station and adapted to supply the necessary power for operating said subsea production system, said prime power source including a fuel burning engine;

a power distribution network for transmitting the power produced by said prime power source to each of said wellhead units to at least provide power for actuating said remotely actuatable wellhead valves;

a first conduit means extending to the surface of said body of water from said power generating station to provide air to said fuel burning engine;

a second conduit means for directing the exhaust of said fuel burning engine out of said shell of said power generating station;

an air compressor associated with said first conduit means for insuring a large enough volume of air at said fuel burning engine; and

means for powering said compressor from said fuel burning engine.

3. A subsea system for the production of minerals from subaqueous deposits through wells having wellheads located beneath the surface of a body of water wherein a plurality of underwater wellhead units are in operative connection with a central production facility by flowlines, at least one remotely actuatable wellhead valve on each of said underwater wellheads for controlling the flow of produced fluid from said well to said central production facility, said subsea system comprising:

an underwater power generating station having a pressure resistant shell;

a prime power source located within said power generating station and adapted to supply the necessary power for operating said subsea production system, said prime power source including a fuel burning engine;

a power distribution network for transmitting the power produced by said prime power source to each of said wellhead units to at least provide power for actuating said remotely actuatable wellhead valves;

a first conduit means extending to the surface of said body of water from said power generating station to provide air to said fuel burning engine;

a second conduit means for directing the exhaust of said fuel burning engine out of said shell of said power generating station, the fuel for said fuel burning engine being the fluid production of at least one of said wells of said subsea system; and

means for connecting at least a portion of the output of said fuel providing well to said fuel burning engine.

4. The subsea system of claim **3** wherein there is valve means, in said means for connecting at least a portion of the output of said fuel providing well to said fuel burning engine, for controlling the flow of fuel to said engine; and means for providing the power to operate said fuel controlling valve means from said prime power source.

5. The subsea system of claim **4** wherein said fluid provided by said well as fuel for said engine is natural gas.

6. The subsea system of claim **5** wherein said prime power source is an internal combustion engine.

7. A subsea system for the production of minerals from subaqueous deposits through wells having wellheads located beneath the surface of a body of water wherein a plurality of underwater wellhead units are in operative connection with a central production facility by flowlines, at least one remotely actuatable wellhead valve on each of said underwater wellheads for controlling the flow of produced fluid from said well to said central production facility, said subsea system comprising:

an underwater power generating station having a pressure resistant shell;

a prime power source located within said power generating station and adapted to supply the necessary power for operating said subsea production system, said prime power source including a fuel burning engine;

an electrical power distribution network for transmitting the power produced by said prime power source to each of said wellhead units to at least provide power for actuating said remotely actuatable wellhead valves, said distribution network comprising means within said underwater power generating station for converting mechanical power from said fuel burning engine to electrical power, and electrical transmission means extending between said underwater power source and said underwater wellhead units of said subsea production system to power said remotely actuatable valves;

a first conduit means extending to the surface of said body of water from said power generating station to provide air to said fuel burning engine;

a second conduit means for directing the exhaust of said fuel burning engine out of said shell of said power generating station;

said central production facility including a plurality of underwater satellite stations for combining the production of the respective wells whose produced fluid flows therethrough;

production equipment within each of said satellite stations, said production equipment comprising means for sequentially testing the produced fluid from each individual well and for controlling the production of each of said underwater wells in response to such testing to optimize the operation thereof;

means for powering said production equipment through said power distribution network; and

said power distribution network comprising main power transmission means between said power generating station and each of said satellite stations, and secondary power transmission means between each of said satellite stations and said wellhead units whose produced fluid is processed therethrough.

References Cited

UNITED STATES PATENTS

2,937,006	5/1960	Thayer	175—8 X
3,063,507	11/1962	O'Neill et al.	175—8
3,292,695	12/1966	Haeber	166—.5
3,366,173	1/1968	McIntosh	166—.5
3,369,368	2/1968	Wilson	61—69
3,380,520	4/1968	Pease	166—.5
3,391,734	7/1968	Townsend	61—69 X
3,400,730	9/1968	Anderson	166—45 X

CHARLES E. O'CONNELL, Primary Examiner

RICHARD E. FAVREAU, Assistant Examiner

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