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(54) **Apparatus and method for operating a subsea compression system in a well stream**

(57) Method for operating a subsea compression system and a subsea compression system in a well stream are disclosed. The subsea compression system comprising a compressor (1) and an electromotor driven pump (2), wherein the compressor is operable for compression of gas and the pump is operable for pumping liquid from the compression system. Compressed gas is

recycled from the compressor downstream side to the upstream side of the compressor via a turbo-expander unit (10) which is drivingly connected to a generator (17). The generator is configured to supply charging current to a battery (18) in response to recycling of compressed gas via the turbo-expander unit, wherein the pump is operable on electrical power that is supplied from the battery.

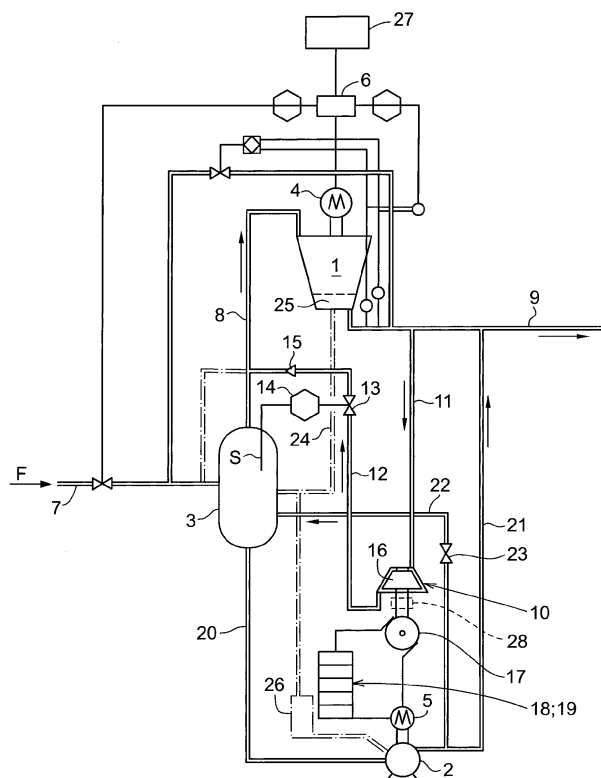


Fig. 3

Description

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to compression systems configured for raising pressure and flow of a well stream in subsea hydrocarbon production. More precisely, the present invention refers to improved apparatuses and methods for operating a subsea compression system configured for this purpose.

BACKGROUND AND PRIOR ART

[0002] Offshore gas production involves installations on the seabed which are controlled and powered from a land-based or sea-based terminal or host facility. Well fluid is transported via pipelines from a subsea production system to a receiving terminal to be further processed before the products are supplied to market. In the initial phases of production, the fluid reservoir pressure is usually sufficient for feeding the hydrocarbon fluids through the pipeline. Later in production, or in the case of very long distance between the well fluid reservoir and the receiving terminal, boosting of fluid pressure and flow may be required in one or more compression systems along the pipeline in order to maintain flow rate and production level.

[0003] In compression systems, gas in the well stream is fed to a compressor that is configured for discharging the gas downstream at a compressed state. Excess liquid may be extracted from the well stream and fed to a pump configured for pumping the liquid downstream, typically by injecting the liquid into the compressed gas that is discharged from the compressor. A re-mixed bi-phase well stream this way leaves the compression system at a raised pressure level and flow. Nevertheless, the subsea compression system may optionally be arranged for discharge of boosted gas and liquid flows via separate export lines.

[0004] The well stream may be collected in a separator vessel located upstream of the compressor and pump and configured for separation of gas from liquid, the separator providing predictable operating points for both the compressor and the pump with respect to liquid volume fraction or liquid level in the system.

[0005] Compressors used in subsea compression systems may be adapted to process wet gas containing a certain ratio of liquid. Thus in some applications, the separator may be replaced by a mixer that is configured for mixing of gas and liquid and feeding a homogenized wet gas to the compressor. However, a subsea centrifugal compressor, e.g., can normally not start liquid filled. Above a certain liquid level in the compression system, pumps will be required to drain the compressor system prior to start-up of the compressor.

[0006] Conventionally, each compressor and pump is typically driven by an electrical motor which is supplied operation and control power via an umbilical connecting

the compression system with its host facility. Thus, each pump motor in the conventional compression system requires for its operation an individual setup of power and control gear such as subsea switchgear, wet-mate electrical connectors, high voltage electrical jumpers and electrical control system components, cooling and lubrication circuits including valves and flow and pressure control, etc.

10 SUMMARY OF THE INVENTION

[0007] The present invention aims to simplify the power distribution from shore or surface to equipment located subsea.

15 **[0008]** The invention also aims at providing a distributed power generation scheme in a subsea compression system comprising a compressor and an electromotor pump, wherein the compressor is operable for compression of gas and the pump is operable for pumping liquid from the compression system.

20 **[0009]** Another object of the present invention is to provide for removal of collected liquid from a wet gas compressor before start-up of the compressor, in other words providing for drainage of the compressor without the compressor running.

25 **[0010]** At least one of the objects is met in a method for operation of the subsea compression system in a well stream, the compression system comprising a compressor and an electromotor pump, the compressor operable for compressing gas and the pump operable for pumping liquid from the compression system, the method comprising:

- 35 • providing a gas return line connecting a downstream side of the compressor with an upstream side of the compressor;
- arranging a turbo-expander unit in flow connection with the gas return line;
- connecting the turbo-expander unit drivingly to a generator configured for delivering charging current to a battery;
- 40 • operating the generator for charging the battery in response to recycling of compressed gas via the turbo-expander unit, and operating the pump on electrical power that is supplied from the battery.

[0011] The method may further comprise feeding gas via a gas feed line to the compressor from a vessel arranged in the well stream upstream of the compressor.

50 **[0012]** The method may further comprise the steps wherein gas and liquid in the well stream are mixed and fed as a homogenized wet gas to the compressor from a vessel configured as a mixer.

55 **[0013]** The method alternatively comprises the steps wherein gas and liquid in the well stream are fed separately to the compressor and the pump, respectively, from a vessel configured as a separator.

[0014] In connection with centrifugal compressors suit-

able for processing wet gas, e.g., the method may further comprise the steps wherein liquid is drained from the compressor into the vessel. In this connection, the pump may be operated in response to a detected liquid level in the compressor and/or vessel.

[0015] The method may alternatively comprise the steps wherein liquid is drained from the compressor into a separate drainage tank and the pump is operated for pumping liquid from the drainage tank in response to a measured liquid level in the drainage tank and/or compressor.

[0016] The method preferably comprises the step wherein the pump is operated on battery power for drainage of the compression system before start-up of the compressor.

[0017] A subsea compression system for a well stream according to the present invention comprises a compressor and an electromotor pump, wherein the compressor is operable for compressing gas and the pump is operable for pumping liquid from the compression system. A gas return line is arranged connecting a downstream side of the compressor with an upstream side of the compressor; a turbo-expander unit is arranged in flow connection with the gas return line; the turbo-expander unit is drivingly connected with a generator, the generator is configured to deliver charging current to a battery in response to recycling of compressed gas via the turbo-expander unit, and the pump is operable on electrical power that is supplied from the battery.

[0018] In a preferred embodiment a gas feed line is arranged to connect the compressor with a vessel arranged upstream of the compressor. The vessel may be a mixer mixing gas and liquid into a homogenized wet gas supplied to the compressor. The vessel may alternatively be a separator supplying gas and liquid separately to the compressor and the pump, respectively.

[0019] In a preferred embodiment the compressor is connected with the vessel for dumping drainage liquid from the compressor into the vessel via a drainage line. In this embodiment, liquid level detecting means in the vessel is arranged to control the operation of the pump.

[0020] In a preferred embodiment the compressor is arranged in flow connection with a drainage tank and liquid level detecting means in the drainage tank controls the operation of the pump.

[0021] In a preferred embodiment, the intake to the turbo-expander unit is connected to a compressed-gas discharge line between the compressor outlet and a liquid injection point on the compressed-gas discharge line, and the outlet from the turbo-expander unit is over a flow control valve connectable to a fluid line feeding wet gas to the compressor. The flow control valve is activated in response to a detected liquid volume level in the vessel.

[0022] The turbo-expander outlet may alternatively be connectable to the well stream flow upstream of the vessel.

[0023] In a preferred embodiment, an outlet from the pump is connectable to the vessel via a flow control valve

arranged in a liquid return loop.

[0024] Gas flow through the turbo-expander unit may be activated in response to a detected surge condition in the compressor.

5 **[0025]** The pump may be a positive displacement pump. A reduction gear or speed reduction device may be inserted between the turbo-expander unit and the generator.

10 **[0026]** In a preferred embodiment, the battery is a battery set in an uninterrupted power supply (UPS) system.

[0027] In other words, the differential pressure generated by the compressor is used to drive a turbo-expander driven generator to charge a battery or a set of batteries. The battery/batteries may be part of an uninterrupted power supply system (UPS).

15 **[0028]** Thus, the invention reduces the need for electric power from shore since the pump will be self-supplied with electric power generated *in situ*, and in addition the invention may charge batteries.

20 **[0029]** The turbo-expander unit is a centrifugal or axial flow turbine wherein compressed, high-pressure gas is expanded and the energy in the expanding gas is released for driving an expansion turbine or rotor in the turbo-expander unit.

25 **[0030]** In the present invention, the expansion turbine has an outgoing shaft which is drivingly connected to a generator configured to deliver charging current to battery/batteries. The generator and turbo-expander unit may be inter-connected directly, or indirectly via a reduction gear or a speed reduction device, e.g., inserted between the turbo-expander unit and the generator.

30 **[0031]** The turbo-expander unit is included in a gas feed loop including a gas feed line connecting the compressor downstream or discharge side with the upstream or intake side of the compressor. The pressure of the expanded gas exiting the turbo-expander unit may be kept above the gas pressure on the intake side of the compressor for recycling the gas to the gas flow upstream the compressor. Alternatively, the expanded gas may be returned to the upstream gas flow by means of an ejector driven by the gas flow on the compressor intake side.

35 **[0032]** The turbo-expander unit and generator may intermittently be driven to maintain the service capacity of the battery/batteries. The turbo-expander unit and generator may optionally be driven to generate operating power that is supplied directly to the pump.

40 **[0033]** The pump may be operated in response to a detected liquid volume level in the separator or mixing vessel, e.g., or in response to a detected liquid level in the compressor/compressor housing. The pump may be used as a drainage pump which is operated on battery power to drain the compressor system from liquid before start-up of the compressor.

45 **[0034]** The outlet on the discharge side of the pump may be connectable to the separator or mixing vessel for recycling of liquid via a flow control valve arranged in a liquid return loop, including a liquid return line, in order to avoid the risk of the pump running dry, e.g.

[0035] The pump may be stopped in the event of reaching a low liquid set point in the separator or mixing vessel. Further, the pump may have an external liquid service line for supply of methanol or glycol, e.g., which can be used for continuous and/or intermittent priming of the pump.

[0036] The flow circuit of the subsea compression system comprises a gas return line by which gas can be returned from the discharge side to the intake side of the compressor. An anti-surge recycling loop can be provided by the present invention by arranging for flow through the gas return line via the turbo-expander unit in response to a detected surge condition in the compressor. In a surge condition, liquid flow through the pump may be controlled for either of recycling of liquid to the vessel or for injection of liquid into the export line.

[0037] Several sets of compressors and pumps may be arranged in the subsea compression system, each set comprising a compressed gas return loop, a liquid return loop and turbo-expander unit, generator and battery package, respectively.

[0038] Two or more compressors or compressor stages may be arranged in series. A turbo-expander unit may be inserted in a compressed-gas return flow from a subsequent compressor or a subsequent compressor stage, respectively, to a previous compressor or previous compressor stage in the series.

[0039] An intercooler may further be installed between the compressors or compressor stages arranged in series.

[0040] Further advantages, advantageous features and embodiments of the invention will appear from the dependent claims and from the following detailed description of preferred embodiments.

SHORT DESCRIPTION OF THE DRAWINGS

[0041] The invention will be further explained below with reference made to the accompanying, schematic drawings. In the drawings,

Fig. 1 is a diagram illustrating schematically the setup of a prior art subsea compression system;

Fig. 2 is a diagram corresponding to Fig. 1, illustrating the setup of a subsea compression system according to the present invention, and

Fig. 3 is a simplified diagram illustrating an implementation of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0042] An overview of the main modules and flow circuits of a subsea compression system for well stream boosting is illustrated schematically in the diagram of Fig. 1. The subsea compression system receives bi-phase or

multi-phase well fluid from at least one subsea production system and feeds boosted well fluid F into one or more export pipe lines for further transport to a receiving terminal or host facility.

[0043] The subsea compression system comprises a compressor module including one or more compressors 1, a pump module including at least one electromotor driven pump 2. A vessel 3 that is located in the well stream upstream of the compressor may be configured as a separator separating gas from liquid in a bi-phase well fluid. The vessel 3 may alternatively be configured as a mixer that mixes liquid and gas into a homogeneous fluid or wet gas for delivery to the compressor. The vessel 3 may function as a drainage vessel for the system, receiving excess liquid that is returned from the compressor to the vessel 3. The vessel 3 may additionally be structured for dissolving liquid slugs in the well stream, for hydrate prevention and for sorting out solid particles entrained in the well stream, for gas scrubbing etc., so that in all cases compressible fluid (wet gas) is delivered to the compressor intake. The compressor 1 is designed for compressing the gas and discharging the gas at an elevated pressure into the export pipeline. The pump 2 is designed for injecting liquid, at an elevated pressure, to the gas flow discharged from the compressor.

[0044] High voltage power, low voltage power, hydraulic, control and utilities are supplied from the host facility via an umbilical connected to the subsea compression system. Utility and control power is distributed to consumers on the subsea compression system via transformers, power cables and wet-mate electrical connectors, switchgear, electrical jumpers, circuit breaker modules, etc. Since the compressor(s) and pump(s) are individually driven by dedicated variable speed drive (VSD) electrical motors 4 and 5, respectively, utility and control power equipment need to be individually installed for each motor. In the drawings, the dedicated utility and control power equipment is schematically represented through VSD-blocks 6.

[0045] Fig. 2 is an overview of a subsea compression system which is setup in utilization of the present invention. A noticeable difference in the architecture of Fig. 2 is the significantly reduced number of VSD-blocks 6, which can be reduced by 50 % as the result of driving the pump(s) 2 with electrical power generated in situ, i.e. subsea.

[0046] Naturally, the reduction in number of components that are required in the distribution of power to a subsea compression system applies to all components that would otherwise have been involved in the supply of electrical power from shore or surface.

[0047] A subsea compression system laid out in accordance with a preferred embodiment of the present invention is illustrated schematically in Fig. 3.

[0048] Without explicitly being explained in detail with reference to Fig. 3, a fully equipped and operative subsea compression system typically comprises import and export well stream manifolds and valves, flow and pressure

meters, recycling lines and valves, anti-surge control circuit and valves, lubrication and barrier fluid circuits and valves, umbilical head end, transformers, coolers, sand trap etc., and other equipment which is conventionally found on a subsea compression system. For reasons of clarity, the detailed structure and organization of modules and units which are of subordinated significance for the understanding of the invention have been excluded from Fig. 3.

[0049] In a subsea compression system implementing the invention, a well stream F is supplied via supply line 7. In a preferred implementation of the invention, the well stream is received in a vessel 3 configured as a mixer that effects mixing of gas and liquid contained in the well stream, producing a homogenized compressible wet gas which is delivered from the vessel 3 to the intake of compressor 1 via gas feed line 8.

[0050] Compressed gas is discharged from the compressor 1 via compressed gas discharge line 9 to outgoing piping and export pipe lines (not shown). At least a portion of the compressed gas is extractable from the compressor discharge line 9 for supply via gas feed line 11 to a turbo-expander unit 10. Expanded gas is discharged from the turbo-expander unit 10 and recycled to the upstream side of the compressor via expanded gas return line 12, over a flow regulation valve 13.

[0051] The flow regulation valve 13, which alternatively can be installed on the gas feed line 11 to the turbo-expander unit 10, may be controllable in response to a liquid volume level in the vessel 3 detected by sensor means S and applied in a subsea control unit 14 which controls the setting of the flow regulation valve 13. A one way valve 15 in the gas return line 12 prevents back flow into return gas line 12.

[0052] In alternative to returning the expanded gas from the turbo-expander unit 10 to the gas feed line 8 on the upstream side of the compressor 1 as illustrated by continuous lines in Fig. 3, the expanded gas may be returned further upstream on the upstream side of the compressor, such as to the vessel 3 or to the well stream upstream of the vessel 3, as illustrated in Fig. 3 by dash-dot lines extending the gas return line 12 to the upstream side of the vessel 3. The latter alternative may be advantageous, e.g., in a case where liquid is precipitated from the expanded gas on the discharge side of the turbo-expander unit 10.

[0053] The expansion turbine 16 in the turbo-expander unit 10 is drivingly connected to a rotor or stator in a generator 17. The generator 17 is connected to a set of batteries 18, the generator in operation supplying charging current to the batteries in result of feeding compressed gas to the turbo-expander unit 10 via the gas recycling loop 11, 12. The set of batteries may be incorporated in an uninterruptable power supply (UPS) system 19.

[0054] The pump motor 5 is powered from the battery/batteries 18, or in an alternative powered directly by the generator 17. In operation, the pump draws liquid from

the vessel 3 via liquid feed line 20 for injection into the compressed-gas discharge line 9, via liquid injection line 21 which connects to the discharge line 9 at a liquid injection point. If appropriate, recycling of liquid back to the vessel 3 can be accomplished via liquid return loop 22 and flow control valve 23, connecting the vessel 3 with the liquid injection line 21 on the discharge side of the pump.

[0055] In the above described embodiment which processes a homogenized bi-phase fluid, the pump 2 may be operating as a drainage pump that is only intermittently powered to drain the compression system from excess liquid. To this purpose, liquid that is collected in the compressor and in any auxiliary equipment may be returned to the vessel 3 via a drainage line 24. Operation of the pump 2, may be initiated in response to a measured liquid level in the vessel 3 and/or compressor.

[0056] Excess liquid may alternatively be collected in a separate drainage tank, such as a sump 25 arranged on the compressor or a drain pot 26 arranged in flow connection with the compressor. Operation of the pump may then be initiated in response to a measured liquid level in the compressor, in the sump or in the drain pot. The pump will then only run, on battery power, if the compressor is filled with liquid, and run until the liquid in the compressor casing and in any auxiliary equipment is at an acceptable level where it is safe to start the compressor.

[0057] In other embodiments, such as embodiments wherein the pump is operated more frequently e.g., the pump may be stopped in the event of reaching a low liquid set point/liquid level in the vessel 3 or compressor. The pump may also have an external liquid service line typically supplying methanol or glycol which can be used for continuous and/or intermittent priming of the pump.

[0058] Utility and control power may be supplied to the compressor motor 4 via VSD-block 6 and umbilical head end block 27 representing the necessary high and low voltage circuits, wet mate connectors, switchgear, circuit breakers, etc.

[0059] Compressors used in subsea compression systems may be designed for a substantial elevation of gas pressure, such as from about 40 bar at compressor intake to about 120 bar at compressor discharge, e.g. Heavy duty centrifugal wet gas compressors are generally used in this connection, typically operating at power ranging from about one to several tens of megawatt and at rotational speeds in the order of 8-12 000 rev per min.

[0060] The subject pumps when used in subsea compression systems are designed for boosting the liquid up to a pressure required for injection of the liquid into the compressed gas that is discharged from the compressor. Positive displacement pumps are useful in this connection, dimensioned for operating at power ranging from some tens of kilowatt to hundreds of kilowatt, and at rotational speeds of about 1500-4000 rev per min. In the implementation as a drainage pump, e.g., the pump may be designed for flow rates in the order of about 100 m³

per hour.

[0061] Compressors, positive displacement pumps or centrifugal pumps rotating at other operational speeds and operating power may however alternatively be used. Nevertheless, the present invention provides great freedom in the choice of rotating components in the compression station since the drive gas flow and resulting output torque and rotational speed can be controlled through the flow regulation valve 13.

[0062] A speed reduction or regulation device, indicated through a symbolic representation 28 in Fig. 3, such as a hydrodynamic torque converter or an electrical hysteresis clutch, e.g., can optionally be inserted between the turbo-expander unit and the generator and controlled between zero and 100 % lockup between driving and driven components, depending on the output torque required.

[0063] The distributed power supply and subsea power generation as disclosed above provides several advantages, among which are

- a simplified power distribution from topside/shore to pump,
- space and cost savings in result of less complex equipment and power control,
- drainage of the compressor made possible without the compressor running,
- simplified control by use of turbo-expander unit which can run at a wide range of rotational speeds,
- simplified pump control,
- a smooth anti-surge system, a better flow margin to compressor surge,
- charging of UPS batteries by utilizing excess power/pressure differential at periods when pump is not running.

[0064] The invention is not restricted to the embodiments described above. On the contrary, many possibilities to modifications thereof may appear to a skilled person from the teachings provided herein, without departing from the basic idea of the invention. Such modification may include, for example, a plurality of compressors and pumps arranged in the subsea compression system. Another modification foresees that two or more compressors or compressor stages are arranged in a series. In such embodiment, an intercooler may be installed between the compressors or compressor stages arranged in series. It is also conceivable to arrange an intermediate tapping and extraction of compressed gas between the compressors or compressor stages arranged in series, for supply to the turbo-expander unit.

[0065] These and other conceivable modifications, providing equal effects and advantages, are foreseen by the inventor, and shall be deemed included in the scope of the appended claims.

Claims

1. A method of operating a subsea compression system in a well stream, the compression system comprising a compressor (1) and an electromotor driven pump (2), the compressor is operable for compressing gas and the pump is operable for pumping liquid from the compression system, the method comprising:
 - providing a gas return line (11,12) connecting a downstream side of the compressor with an upstream side of the compressor;
 - arranging a turbo-expander unit (10) in flow connection with the gas return line (11,12);
 - connecting the turbo-expander unit drivingly to a generator (17) configured for delivering charging current to a battery;
 - operating the generator for charging the battery (18) in response to recycling of compressed gas via the turbo-expander unit, and operating the pump on electrical power that is supplied from the battery.
2. The method of claim 1, wherein gas is fed via a gas feed line (8) to the compressor (1) from a vessel (3) arranged in the well stream upstream of the compressor.
3. The method of claim 2, wherein gas and liquid in the well stream are mixed and fed as a homogenized wet gas to the compressor from a vessel (3) configured as a mixer.
4. The method of claim 2, wherein gas and liquid in the well stream are fed separately to the compressor and the pump, respectively, from a vessel (3) configured as a separator.
5. The method of claim 2, wherein liquid is drained (24) from the compressor (1) into the vessel (3).
6. The method of claim 2, 4 or 5, wherein the pump (2) is operated in response to a detected liquid level in the vessel (3) or compressor.
7. The method of any of claims 1-4, wherein liquid is drained from the compressor (1) into a separate drainage tank (25; 26) and the pump (2) is operated for pumping liquid from the drainage tank in response to a measured liquid level in the drainage tank or compressor.
8. The method of any previous claim, wherein the pump (2) is operated on battery power for drainage of the compression system before start-up of the compressor.

9. A subsea compression system for a well stream, the compression system comprising a compressor (1) and an electromotor driven pump (2), the compressor operable for compressing gas and the pump operable for pumping liquid from the compression system, **characterized in that**
- a gas return line (11, 12) is arranged connecting a downstream side of the compressor with an upstream side of the compressor,
 - a turbo-expander unit (10) is arranged in flow connection with the gas return line (11, 12),
 - the turbo-expander unit is drivingly connected to a generator (17), the generator configured to deliver charging current to a battery (18) in response to recycling of compressed gas via the turbo-expander unit, wherein the pump is operable on electrical power that is supplied from the battery (18).
10. The compression system of claim 9, wherein a gas feed line (8) is arranged to connect the compressor (1) with a vessel (3) arranged upstream of the compressor.
11. The compression system of claim 10, wherein the vessel (3) is a mixer mixing gas and liquid into a homogenized wet gas supplied to the compressor.
12. The compression system of claim 10, wherein the vessel (3) is a separator supplying gas and liquid separately to the compressor and the pump, respectively.
13. The compression system of any of claims 10-12, wherein the compressor (1) is connected with the vessel (3) for dumping drainage liquid from the compressor into the vessel via a drainage line (24).
14. The compression system of claim 12 or 13, wherein liquid level detecting means (S) in the vessel is arranged to control the operation of the pump (2).
15. The compression system of claims 9-12, wherein the compressor is arranged in flow connection with a drainage tank (26) and liquid level detecting means in the drainage tank controls the operation of the pump (2).
16. The subsea compression system of any of claims 9-15, wherein the intake to the turbo-expander unit (10) is connected to a compressed-gas discharge line (9) between the compressor outlet and a liquid injection point on the compressed-gas discharge line (9), and the outlet from the turbo-expander unit is over a flow control valve (13) connectable to a fluid line (8) feeding wet gas to the compressor (1).
17. The compression system of claim 16, wherein the flow control valve (13) is activated in response to a detected liquid volume level in the vessel (3).
18. The compression system of any of claims 10-17, wherein an outlet from the pump (2) is connectable to the vessel (3) via a flow control valve (23) arranged in a liquid return loop (22).
19. The compression system of any of claims 9-18, wherein gas flow through the turbo-expander unit (10) is activated in response to a detected surge condition in the compressor (1).
20. The compression system of any of claims 9-19, wherein the pump is a positive displacement pump.
21. The compression system of any of claims 9-20, wherein a reduction gear or speed reduction device (28) is inserted between the turbo-expander unit (10) and the generator (17).
22. The compression system of any of claims 9-21, wherein the battery (18) is a battery set in an uninterrupted power supply (UPS) system (19).

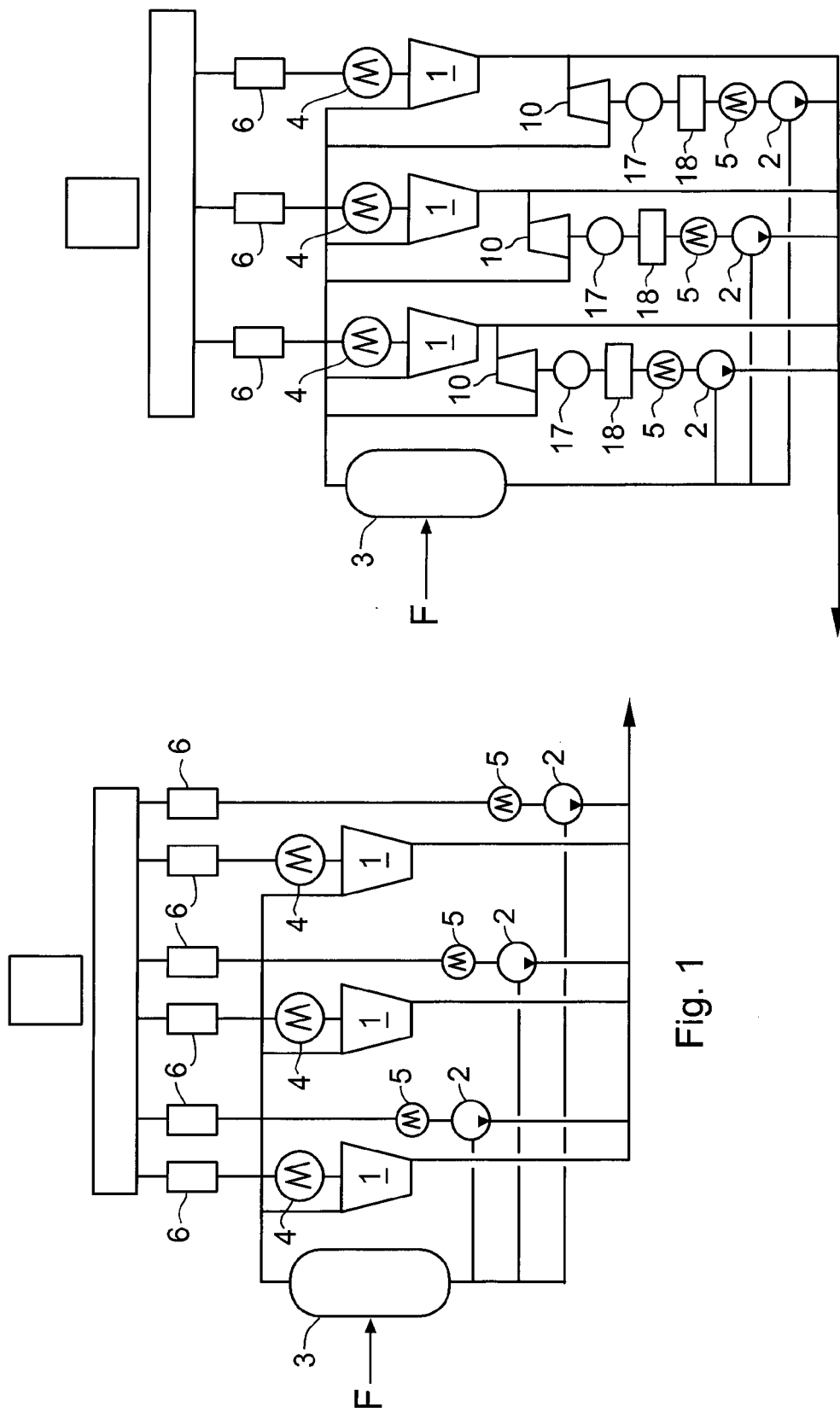


Fig. 2

Fig. 1

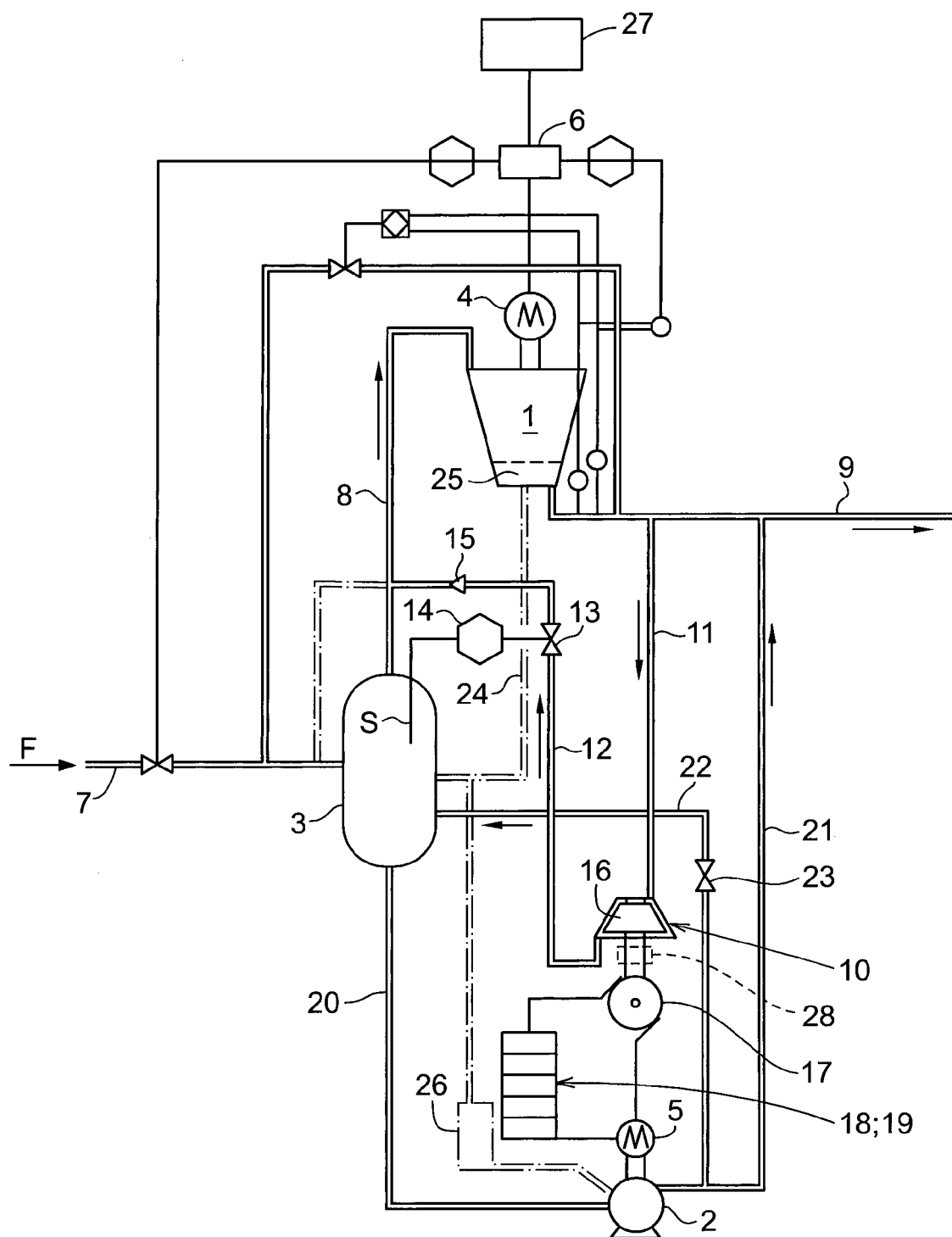


Fig. 3