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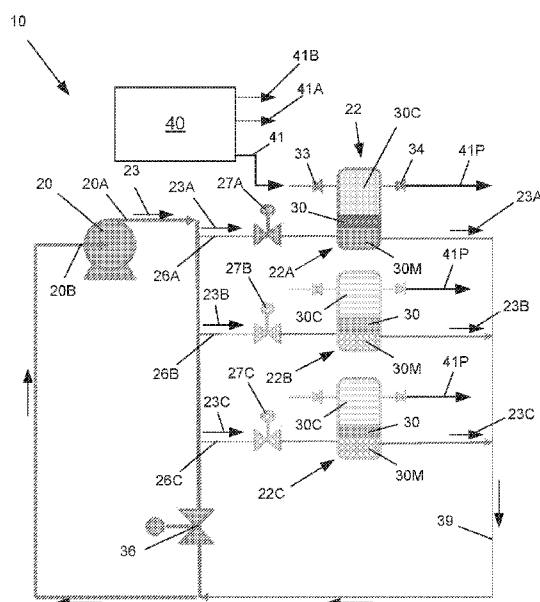


Figure 1A

(57) Abstract: A liquid injection system includes a motive fluid pump (20) that is adapted to supply a pressurized motive fluid (23, 25), at least one source (40) of a liquid (41), and at least one liquid injection pump (22) that is adapted to receive the liquid (41) from the at least one source (40) at a first pressure and to receive the pressurized motive fluid (23, 25) from the motive fluid pump (20), wherein receipt of the pressurized motive fluid (23, 25) into the at least one liquid injection pump (22) causes a discharge of the liquid (41P) from the at least one liquid injection pump (22) at a second pressure that is greater than the first pressure.

SUBSEA-POSITIONED LIQUID INJECTION PUMP AND BOOSTING SYSTEM FOR SUBSEA APPLICATIONS

TECHNICAL FIELD

The present disclosure generally relates to the treatment of subsea oil/gas wells, and, more particularly, to a subsea-positioned liquid injection pump and boosting system for subsea applications such as, for example, subsea oil/gas wells.

BACKGROUND

Production of hydrocarbons (oil and/or gas) from subsea oil/gas wells typically involves positioning several items of production equipment, *e.g.*, Christmas trees, manifolds, pipelines, flowline skids, and/or pipeline end terminations (PLETs) and the like, on the sea floor. Flowlines or jumpers are normally coupled to these various items of equipment so as to allow the produced hydrocarbons to flow between and among such production equipment with the ultimate objective of getting the produced hydrocarbon fluids to a desired end-point, such as a surface vessel or structure, an on-shore storage facility or pipeline, etc. Jumpers may be used to connect the individual wellheads to a central manifold. In other cases, relatively flexible lines may be employed to interconnect some of the subsea equipment items.

One problem that is sometimes encountered in the production of hydrocarbon fluids from subsea wells is that a blockage may form in a subsea flowline or in a piece of subsea equipment. These blockages can be caused, for example, by the formation of hydrates, paraffin, wax, and scale in the flowlines and production equipment. In some cases, the blockage can completely block the flowline/equipment while, in other cases, the blockage may only partially block the flowline/equipment.

In many cases, it is often desired to inject various liquids, *e.g.*, chemicals such as flow assurance chemicals, into the subsea production or injection equipment and/or flowlines to prevent or treat blockages and flow restrictions. The injection of chemicals into the subsea equipment can be performed continuously or periodically, or the injection may be related to a specific event, such as a shutdown of the equipment. Additionally, chemical injection can also be used to change chemical and mechanical properties of the process fluids that are injected into the formation, such as foaming characteristics, viscosity, and the like. This includes treating sea water that is injected in the formation in order to reduce its oxygen content and to provide biocide treatment.

Typically, chemicals that are to be injected into the subsea equipment/flowlines are stored on a surface vessel or platform along with a high pressure pumping system that is used to pump the chemicals to the subsea equipment/flowlines. The pumping system typically includes high pressure chemical injection pumps, metering valves, flow meters, etc. The chemicals are pumped in one or more dedicated or redundant lines that are part of an umbilical that extends from the surface vessel or platform to the subsea equipment/flowlines. Unfortunately, as subsea oil/gas wells are being drilled in ever deeper water, the umbilical gets longer and the cost of the umbilical increases commensurately.

In an effort to reduce the size of the umbilical, the industry is exploring ways to store chemicals subsea in applications that involve relatively long distance tiebacks. In order for the approach of storing chemicals subsea to work, multiple chemical injection pumps and/or metering mechanisms for multiple chemicals that are to be injected into multiple items of equipment and flowlines must be provided in the subsea environment. Electrically powering these subsea chemical injection pumps would be very costly and complex in terms of power distribution, speed

control, etc. Additionally, and depending on the type of pump involved, a flow measurement device or metering valve may also be required for each chemical injection line, which would also increase the cost and complexity of such a subsea system. As an example, in an illustrative example of a subsea chemical injection system where five different chemicals must be supplied to 10-12 different endpoints (*e.g.*, different items of equipment/flowline), the system might include 50-60 individual electrically powered chemical injection pumps, each of which must include the associated speed control circuitry and flow measuring devices.

The present disclosure is directed to a subsea-positioned liquid injection pump and boosting system that distributes, meters and pumps liquids, such as chemicals, for various subsea applications. The system disclosed herein is directed to avoiding, or at least reducing, the effects of one or more of the problems identified above.

SUMMARY

The following presents a simplified summary of the subject matter disclosed herein in order to provide a basic understanding of some aspects of the information set forth herein. This summary is not an exhaustive overview of the disclosed subject matter. It is not intended to identify key or critical elements of the disclosed subject matter or to delineate the scope of various embodiments disclosed herein. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is discussed later.

Generally, the present disclosure is directed to a subsea-positioned liquid injection pump and boosting system for subsea applications, such as, for example, subsea oil and gas wells. The system may be either an open system or a closed system.

One illustrative embodiment of a liquid injection system disclosed herein includes a motive fluid pump that is adapted to supply a pressurized motive fluid, at least one source of a liquid, and at least one liquid injection pump that is adapted to receive the liquid from the at least one source at a first pressure and to receive the pressurized motive fluid from the motive fluid pump, wherein receipt of the pressurized motive fluid into the at least one liquid injection pump causes a discharge of the liquid from the at least one liquid injection pump at a second pressure that is greater than the first pressure.

Also disclosed herein is a method that includes, among other things, supplying a liquid at a first pressure to at least one liquid injection pump from at least one source of said liquid, receiving a pressurized motive fluid from a motive fluid pump with said at least one liquid injection pump, wherein receiving said pressurized motive fluid increases a pressure of said liquid inside of said at least one liquid injection pump from said first pressure to a second pressure that is greater than said first pressure; and discharging said liquid having said second pressure from said at least one liquid injection pump.

BRIEF DESCRIPTION OF THE DRAWINGS

Certain aspects of the presently disclosed subject matter will be described with reference to the accompanying drawings, which are representative and schematic in nature and are not to be considered to be limiting in any respect as it relates to the scope of the subject matter disclosed herein:

Figures 1A and 1B schematically depict various illustrative embodiments disclosed herein of subsea-positioned liquid injection pump and boosting systems for subsea applications, such as subsea equipment;

Figures 2A-2C schematically depict aspects of an illustrative embodiment of a positive displacement pump that may be employed in the systems disclosed herein;

Figures 3A-3D schematically depict aspects of another exemplary embodiment of a positive displacement pump that may be employed in the systems of the present disclosure;

Figure 4 schematically depicts one illustrative embodiment of a subsea-positioned liquid injection pump and boosting system disclosed herein;

Figure 5 schematically depicts a further illustrative embodiment of a subsea-positioned liquid injection pump and boosting system disclosed herein;

Figure 5A is a graph depicts some aspects of a family of exemplary operational curves based on the illustrative system shown in Fig. 5;

Figures 6 and 7 schematically depict further exemplary embodiments of various techniques that may be used for packaging an embodiment of a subsea-positioned liquid injection pump and boosting system in accordance with the present disclosure;

Figure 8 illustrates one exemplary embodiments of an axial piston pump that may be employed in the systems disclosed herein; and

Figure 9 schematically depicts an illustrative embodiment disclosed herein for actuation of the axial piston pump included in one illustrative embodiment of a subsea-positioned liquid injection pump and boosting system disclosed herein.

While the subject matter disclosed herein is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the disclosed subject matter to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosed subject matter as defined by the appended claims.

DETAILED DESCRIPTION

Various illustrative embodiments of the disclosed subject matter are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

The present subject matter will now be described with reference to the attached figures. Various structures, systems and devices are schematically depicted in the drawings for purposes of explanation only and so as to not obscure the present disclosure with details that are well known to those skilled in the art. Nevertheless, the attached drawings are included to describe and explain illustrative examples of the present disclosure. The words and phrases used herein should be understood and interpreted to have a meaning consistent with the understanding of those words and phrases by those skilled in the relevant art. No special definition of a term or phrase, *i.e.*, a definition that is different from the ordinary and customary meaning as understood by those skilled in the art, is intended to be implied by consistent usage of the term or phrase herein. To the extent that a term or phrase is intended to have a special meaning, *i.e.*, a meaning other than that understood by skilled artisans, such a special

definition will be expressly set forth in the specification in a definitional manner that directly and unequivocally provides the special definition for the term or phrase.

As used in this description and in the appended claims, the terms “substantial” or “substantially” are intended to conform to the ordinary dictionary definition of that term, meaning “largely but not wholly that which is specified.” As such, no geometrical or mathematical precision is intended by the use of terms such as “substantially flat,” “substantially perpendicular,” “substantially parallel,” “substantially circular,” “substantially elliptical,” “substantially rectangular,” “substantially square,” “substantially aligned,” and/or “substantially flush,” and the like. Instead, the terms “substantial” or “substantially” are used in the sense that the described or claimed component or surface configuration, position, or orientation is intended to be manufactured, positioned, or oriented in such a configuration as a target. For example, the terms “substantial” or “substantially” should be interpreted to include components and surfaces that are manufactured, positioned, or oriented as close as is reasonably and customarily practicable within normally accepted tolerances for components of the type that are described and/or claimed. Furthermore, the use of phrases such as “substantially conform” or “substantially conforms” when describing the configuration or shape of a particular component or surface, such as by stating that “the configuration of the component substantially conforms to the configuration of a rectangle” or “a substantially rectangular configuration” should be interpreted in similar fashion.

The present disclosure generally relates to a subsea-positioned liquid injection pump and boosting system for use with subsea equipment. Figure 1A depicts one illustrative embodiment of a closed subsea-positioned liquid injection system 10 and Fig. 1B shows another exemplary embodiment of an open subsea-positioned liquid injection system 12. In certain embodiments, the closed and open systems 10, 12 may include many of the same components. Accordingly, a description of the several aspects and components of the closed system 10 may be equally applicable to the open system 12 as well. In some applications, the systems 10, 12 may be utilized to inject one or more chemicals into various items of equipment or flowlines that are positioned subsea, as well as to inject chemicals into an oil and gas well.

As shown in Fig. 1A, in one illustrative example the closed subsea-positioned liquid injection system 10 may be a motive fluid system that includes a subsea motive fluid pump 20 that is adapted to supply a pressurized motive fluid 23 to a plurality of hydraulically operated positive displacement pumps 22A-C, which may be collectively referred to below as “PD pumps 22” or “positive displacement pumps 22,” all of which are also positioned subsea. The motive fluid 23 is supplied to the PD pumps 22 from the motive fluid pump outlet 20A via a plurality of conduits or lines 26A-C, which may also be referred to collectively below as “lines 26.” In the illustrative examples depicted in Figs. 1A and 1B, both the closed and open systems 10, 12 are depicted as including three illustrative positive displacement pumps 22 (*i.e.*, PD pumps 22A-C). However, it should be appreciated by those of ordinary skill after a complete reading of the present disclosure that, in practice, any of the systems disclosed herein may include any desired number of positive displacement pumps 22 and associated lines 26, *e.g.*, either more or fewer than three, depending on the particular application.

As shown in Figs. 1A and 1B, each of the positive displacement pumps 22 may include a piston 30 (depicted schematically in Figs. 1A and 1B) that defines, in part, a motive fluid side 30M and a liquid side 30C of the positive displacement pumps 22. In general, the motive fluid pump 20 of either the closed system 10 or the open systems 12 may be adapted to provide a respective motive fluid 23, 25 to the motive fluid side 30M of the positive displacement pumps 22 so as to cause a higher-pressure pressurized liquid 41P (such as a chemical) on the

liquid side 30C of the positive displacement pump 22 to be injected into an item of subsea equipment (not shown) or into a subsea flowline (also not shown). In principal, any type of fluid may be used as the motive fluid 23 in the closed system 10, *e.g.*, oil-based fluid, sea water, etc. Furthermore, based on the layout of closed system 10, the motive fluid 23 may be circulated substantially continuously through the closed system 10 and substantially without the need for replenishment, hence the system 10 being referred to as a “closed” system. On the other hand, the motive fluid 25 utilized in the open system 12 may be the fluid of the environment in which the motive fluid pump 20 is positioned, *e.g.*, sea water, which may be circulated through the open system 12 on a once-through basis such that it is discharged from the system 12 after passing through the PD pumps 22, hence the system 12 being referred to as an “open” system.

In general, the systems 10, 12 disclosed herein are operated such that an adjustable amount or adjustable flow rate of the motive fluid 23, 25 (individually represented in Figs. 1A and 1B by the respective flow arrows or flow streams 23A-C, 25A-C) is supplied by the motive fluid pump 20 to each of the respective PD pumps 22A-C via the conduits or lines 26A-C. These supplied flow streams of motive fluid 23A-C, 25A-C cause a measurable and adjustable amount of the pressurized liquid 41P to be injected into a desired item of subsea equipment or subsea flowline without the need for utilizing traditional flow meters or metering valves.

With continuing reference to the closed system 10 and the open systems 12 shown in Figs. 1A and 1B, each of the positive displacement pumps 22A-C may include one or more valves that enable the systems 10, 12 to be operated in the manner described herein. For example the systems 10, 12 may include a plurality of motive fluid inlet throttle valves 27A-C (which may also be collectively referred to below as “valves 27” or “throttle valves 27”), each of which is associated with a respective one of the PD pumps 22A-C. In certain embodiments, the throttle valves 27A-C may be adapted to control and regulate the flow streams of motive fluid 23A-C, 25A-C to the motive fluid side 30M of each respective positive displacement pump 22A-C.

The open and closed systems 10, 12 may also include a plurality of fluid inlet check valves 33 for allowing one-directional flow of a liquid 41 from a subsea liquid source 40 to the liquid side 30C of each of the positive displacement pumps 22A-C. In some embodiments, the systems 10, 12 may also include a plurality of boosted fluid outlet check valves 34 that are adapted to allow one-directional flow of a higher pressure liquid, *e.g.*, the “pressurized” liquid 41P, from the liquid side 30C of each of the positive displacement pumps 22 to a desired injection point. As noted previously, the hydraulic operation of the positive displacement pumps 22 by the motive fluid 23, 25 acts to increase the pressure of the liquid 41 that is received by each PD pump 22 from the subsea liquid source 40, thereby enabling each of the PD pumps 22 to inject the higher pressure pressurized liquid 41P into a desired item of subsea equipment, or into a subsea flow line.

In certain exemplary embodiments, the throttle valves 27 of the closed system 10 are controlled so as to allow a desired flow rate of the pressurized motive fluid 23 into each of the PD pumps 22. More specifically, the throttle valves 27A-C associated with each of the respective positive displacement pumps 22A-C may be individually controlled such that the desired flow rates of the motive fluid streams 23A, 23B and 23C of the total motive fluid 23 can be supplied to each of the respective PD pumps 22A, 22B and 22C. Furthermore, the motive fluid streams 23A-C leaving the respective PD pumps 22A-C may then be effectively returned to the inlet 20B of the motive fluid pump 20 via the returns line 39, thus illustrating the “closed” aspect of the system 10. The closed system 10 may further include a throttle valve 36 positioned in a bypass line 37 that ties into the returns line 39. In this configuration, the throttle valve 36 may then be operated so as to control the outlet pressure and flow rate of the

motive fluid pump 20, and to maintain the pressure of the pressurized motive fluid 23 leaving the pump outlet 20A at a relatively higher pressure than that of the motive fluid 23 returning to the pump inlet 20B via the returns line 39. In at least some embodiments, any or all of the throttle valves 27, 36 may be equipped with an appropriately designed actuator, *e.g.*, a motor or a mechanical actuator, and/or an ROV interface. Depending upon the nature of the actuator, a robotic arm on an ROV may then be used to engage and operate the actuator on the throttle valves 27, 36, or in at least some embodiments the throttle valves 27, 36 may be operated by sending appropriate control signals to the actuator.

The configuration of the open system 12 may be similar in many aspects to the configuration of the closed system 10, differing primarily in the feed and discharge of the motive fluid 25 into and out of the system 12. For example, in the open system 12, the motive fluid 25 may include a liquid comprising the environment in which the motive fluid pump 20 is positioned, *e.g.*, sea water in a subsea environment, such that the motive fluid 25 is supplied to the inlet 20B of the motive fluid pump 20 and discharged back to the subsea environment via discharge lines 24A. As with the closed system 10, the throttle valves 27A-C associated with each of the positive displacement pumps 22A-C may be individually controlled such that a desired flow rate of the individual streams of motive fluid 25A, 25B and 25C of the total motive fluid 25 is supplied to each of the respective PD pumps 22A, 22B and 22C. In some exemplary embodiments, the open system 12 may also include the above-described throttle valve 36, which may be positioned in the bypass line 37. As with the closed system 10, the throttle valve 36 of the open system 12 may be operated so as to control the outlet pressure and flow rate of the motive fluid pump 20, and to maintain the pressure of the pressurized motive fluid 25 leaving the pump outlet 20A at a relatively higher pressure than the pressure at the pump inlet 20B. In certain embodiments, such as when the PD pumps 22A-C are single acting piston pumps, the open system 12 may also include an optional eductor 38 that is adapted to maintain a pressure on the motive fluid streams 25A-C at the outlets of each of the PD pumps 22A-C, as will be further described in conjunction with Figs. 3A-3D below.

In one illustrative embodiment, the motive fluid pump 20 may be a traditional subsea pump, *e.g.*, a subsea centrifugal pump or a piston pump and the like, that is driven by an electrical motor or a hydraulic motor. In certain embodiments, electrical power and/or hydraulic power for the motive fluid pump 20 may be supplied via a source of electrical or hydraulic power that is positioned subsea, whereas in at least some embodiments the electrical or hydraulic power source that may be located on a surface vessel or platform. In particular applications, the motive fluid pump 20 may generally be sized based upon factors such as, among other things, the total number of the PD pumps 22, whether operation of the PD pumps 22A-C is continuous, periodic or conditional, the required pressure and flow rate for injecting the pressurized liquid 41P into the subsea equipment or flow line (not shown), the water depth of the installation at the site wherein the well is located, etc.

In some exemplary embodiments, each of the pumps 22A-C may be a positive displacement piston pump, such as a single acting or double acting piston pump, whereas in other embodiments each of the PD pumps 22A-C may be a diaphragm pump. Figures 2A-2C schematically show one illustrative embodiment wherein the depicted positive displacement pump 22 may be a double acting piston pump, sometimes referred to below simply as a double acting pump or as a double acting PD pump. Additionally, Figs. 3A-3C schematically illustrate another exemplary embodiment wherein the PD pump 22 may be a single acting piston pump, sometimes referred to below simply as a single acting pump or as a single acting PD pump. Furthermore, it should be understood that the positive

displacement pump 22 describe below and depicted in the associated drawings may be representative of any one of the PD pumps 22A-C shown in Figs. 1A and 1B unless otherwise specifically noted.

Figure 2A schematically illustrates various aspects of an exemplary double acting positive displacement pump 22 while Figs. 2B and 2C depict the double acting PD pump 22 during certain operational sequences. With reference to Fig. 2A, the double acting positive displacement pump 22 may include a pump body 22X and a piston 30 positioned inside of the pump body 22X. Additionally, the PD pump 22 may also include a first motive fluid chamber 30M1, a second motive fluid chamber 30M2, a first liquid chamber 30C1, and a second liquid chamber 30C2. In some embodiments, the double acting PD pump 22 may also include a first motive fluid inlet/outlet 51 that is in fluid communication with the first motive fluid chamber 30M1 as well as a second motive fluid inlet/outlet 52 that is in fluid communication with the second motive fluid chamber 30M2. The above-described check valves 33, 34 for each of the first and second liquid chambers 30C1, 30C2 are also schematically depicted, however they may not be provided internally within the liquid chambers 30C1, 30C2, as is schematically depicted in Figs. 2A-2C. Rather, the check valves 33, 34 may be positioned in fluid conduit lines (not shown) that are operatively coupled to the double acting PD pump 22, as shown in Figs. 1A and 1B above. Also depicted in Figs. 2A-2C is the above-described subsea liquid source 40, the motive fluid pump 20, and the motive fluid inlet throttle valve 27 (representative of any one of the associated valves 27A-C) for controlling and regulating the motive fluid flow stream 23A, 25A to the double acting positive displacement pump 22. Additionally, Figs. 2A-2C further illustrate an exemplary 4-way three-position directional valve 50 that may be adapted to be operated in such a manner as to direct the flow of pressurized motive fluid 23A, 25A to each of the first motive fluid chamber 30M1 and the second motive fluid chamber 30M2, as will be described more fully below. The directional valve 50 may also be a two-position valve in at least some embodiments.

While the directional valve 50 shown in each of the drawings has been schematically depicted as a solenoid actuated valve, it should be understood that any type of appropriately designed directional valve and actuation principle may be used. For example, in some embodiments the directional valve 50 may be an electrically operated valve, such as a solenoid valve. In other embodiments, the directional valve 50 may be a valve that is mechanically actuated, such as by operation of a piston and the like, whereas in still other embodiments the directional valve 50 may be a hydraulically actuated valve. As such, the term “directional valve” as used in the description and in the appended claims should be understood to be a valve with actuator that is adapted to control fluid flow to and/or from a plurality of sources.

In terms of operating the systems 10, 12, it may be advantageous to operate the motive fluid pump 20 within a preferred operational range, or envelope, that includes both minimum and maximum motive fluid 23, 25 flow rates. These minimum and maximum flow rates of the motive fluid 23, 25 may in turn depend on the various design parameters of the systems 10, 12, such as the total number of positive displacement pumps 22, (e.g., PD pumps 22A-C) in operation, the amount of the motive fluid 23, 25 at the desired pressure, etc. It should also be understood that when the consumption range of the motive fluid 23, 25 is relatively wide, then under certain conditions the operational point of the motive fluid pump 20 may possibly move outside of its preferred operational envelope. However, the operational point of the motive fluid pump 20 may be returned to the desired operational envelope by changing the overall system operational curve (*i.e.*, the flow rate of the motive fluid 23, 25 versus differential pressure curve of the system). For example, in certain embodiments the flow rate and pressure of the motive fluid 23, 25 may be regulated by the throttle valve 36. Alternatively, in some embodiments a fixed

restriction device 35 (see Figs. 1B and 3), such as an orifice plate and the like, may be employed instead of the throttle valve 36 where there is little variation in the consumption of the motive fluid 25. In still other exemplary embodiments, the motive fluid pump 20 may be provided with a variable frequency drive so as to enlarge the preferred operating range of the motive fluid pump 20, thus allowing for a much wider system consumption range of the motive fluid 23, 25.

With further reference to Figs. 2B and 2C, certain operational sequences of the illustrative double acting positive displacement pump 22 are depicted that will be discussed below. As shown in Fig. 2B, it is assumed that the first motive fluid chamber 30M1 and the second motive fluid chamber 30M2 are filled with the motive fluid 23A, 25A, and the first liquid chamber 30C1 and the second liquid chamber 30C1 are filled with the liquid 41. In Fig. 2B, the directional valve 50 is in a first valve position such that the motive fluid 23A, 25A is directed to the first motive fluid chamber 30M1 via the first motive fluid inlet/outlet 51, while the motive fluid 23A, 25A in the second motive fluid chamber 30M2 is removed or vented via the second motive fluid inlet/outlet 52 and through the directional valve 50 to the returns line 39, after which it is either recirculated to the inlet 20B of the motive fluid pump 20 in the closed system 10 (see Fig. 1A) or discharged via the discharge lines 24A in the open system 12 (see Fig. 1B). Introduction of the motive fluid 23A, 25A into the first motive fluid chamber 30M1 in this manner causes the piston 30 to move or extend into the second liquid chamber 30C2 (*i.e.*, to the left in Fig. 2B), thereby increasing the pressure of the liquid 41 in the second liquid chamber 30C2. The check valve 33 in fluid communication with the second liquid chamber 30C2 prevents any reverse flow of the liquid 41 back into the liquid source 40. Higher pressure liquid 41P may then exit the second liquid chamber 30C2 of the double acting PD pump 22 and flow through the check valve 34 to the desired injection point, *e.g.*, subsea equipment, subsea flowline, etc. Also during this initial (leftward) movement of the piston 30, the liquid 41 is drawn into the first liquid chamber 30C1 through the check valve 33 associated with the first liquid chamber 30C1. Furthermore, the check valve 34 associated with the first liquid chamber 30C1 prevents a backflow of the higher pressure liquid 41P that is discharged from the second liquid chamber 30C2 into the first liquid chamber 30C1 and/or into the liquid source 40.

Moving now to the configuration depicted in Fig. 2C, the directional valve 50 has been actuated so as to move from the first valve position shown in Fig. 2B to a second valve position. With the directional valve 50 in the second valve position, the motive fluid 23A, 25A is directed to the second motive fluid chamber 30M2 via the second motive fluid inlet/outlet 52, while the motive fluid 23A, 25A in the first motive fluid chamber 30M1 is removed/vented via the first motive fluid inlet/outlet 51 and through the directional valve 50 to the returns line 39 (see Figs. 1A and 1B). As shown in Fig. 2C, this in turn causes the piston 30 to move to the right, which thereby increases the pressure of the liquid 41 in the first liquid chamber 30C1. Furthermore, the check valve 33 associated with the first liquid chamber 30C1 prevents any reverse flow of the liquid 41 from the chamber 30C1 back into the liquid source 40. Higher pressure liquid 41P then exits the first liquid chamber 30C1 of the double acting positive displacement pump 22 and flows through the check valve 34 to the desired injection point. During this movement of the piston 30 to the right and through the first liquid chamber 30C1, the liquid 41 is drawn into the second liquid chamber 30C2 through the check valve 33 associated with the second liquid chamber 30C2. Additionally, the check valve 34 associated with the second liquid chamber 30C2 prevents the backflow of the higher pressure liquid 41P (discharged from the first liquid chamber 30C1) into the second liquid chamber 30C2 and/or the liquid source 40.

Turning now to Figs. 3A-3D, Figure 3A schematically illustrates certain aspects of an exemplary single acting positive displacement pump 22, while Figs. 3B and 3C depict the single acting PD pump 22 during certain operational sequences. Additionally, Fig. 3D shows an optional embodiment of the operation step depicted in Fig. 3C wherein the previously described eductor 38 may be utilized. It should also be noted that various aspects of the single acting PD pump 22 shown in Figs. 3A-3D are substantially similar to related aspects of the double acting piston PD pump 22 of Figs. 2A-2C and therefore may not be fully described below.

With reference to Fig. 3A, the illustrated single acting positive displacement pump 22 may include a pump body 22X, a piston 30 positioned within the pump body 22X, a first fluid chamber 30M1, a second motive fluid chamber 30M2, and a liquid chamber 30C1. In some embodiments, the single acting PD pump 22 may also include a first fluid inlet/outlet 51 that may be in fluid communication with the first fluid chamber 30M1, as well as a second motive fluid inlet/outlet 52 that is in fluid communication with the second motive fluid chamber 30M2. The liquid chamber 30C1 may also be provided with corresponding check valves 33, 34 that, as with the double acting PD pump 22 of Figs. 2A-2C, may be provided internally within the liquid chamber 30C1, or may be positioned in fluid conduit lines (not shown) that are operatively coupled to the single acting PD pump 22, as shown in Figs. 1A and 1B. In certain embodiments, the piston may also be provided with a return spring 29 that is adapted to return the piston 30 to its original position after completion of the stroke that is caused by the pressure of motive fluid 23A, 25A, as will be further described with respect to Figs. 3C and 3D below.

Also depicted in Figs. 3A-3D is a subsea liquid source 40, a motive fluid pump 20, and a motive fluid inlet throttle valve 27 (representative of any one of the associated valves 27A-C) for controlling and regulating the motive fluid flow stream 23A, 25A to the single acting PD pump 22. Figures 3A-3D further illustrate an exemplary 3-way two-position directional valve 50 that may be adapted to be operated in such a manner as to direct the flow of pressurized motive fluid 23A, 25A to the second motive fluid chamber 30M2, as will be described more fully below. Of course, it should be understood that other directional valve configurations may also be used for the exemplary single acting PD pump 22.

With reference to Figs. 3B and 3C, certain operational sequences of the illustrative single acting positive displacement pump 22 are shown that will be discussed below. As shown in Fig. 3B, it is assumed that the second motive fluid chamber 30M2 is filled with the motive fluid 23A, 25A, the liquid chamber 30C1 is filled with the liquid 41, and the first fluid chamber 30M1 is biased to the fluid of the environment in which the motive fluid pump 20 is positioned, for example, sea water of a surrounding subsea environment. In Fig. 3B, the directional valve 50 is in a first valve position such that the motive fluid 23A, 25A may be directed to the second motive fluid chamber 30M2 via the second motive fluid inlet/outlet 52 while fluid in the first fluid chamber 30M1 is removed or vented via the first fluid inlet/outlet 51 to the surrounding environment, *e.g.*, sea water of a subsea environment, as indicated by the flow arrow 43. Introduction of the motive fluid 23A, 25A into the second motive fluid chamber 30M2 in this manner causes the piston 30 to move or extend into the liquid chamber 30C1 (*i.e.*, to the left in Fig. 3B), thereby increasing the pressure of the liquid 41 in the liquid chamber 30C1. The check valve 33 in fluid communication with the liquid chamber 30C1 prevents any reverse flow of the liquid 41 back into the liquid source 40, and higher pressure liquid 41P may then exit the liquid chamber 30C of the single acting PD pump 22 and flow through the check valve 34 to the desired injection point.

Moving now to the configuration depicted in Fig. 3C, the directional valve 50 may be actuated so as to move from the first valve position shown in Fig. 3B to a second valve position. In certain exemplary embodiments,

with the directional valve 50 in the second valve position the return spring 29 may then move the piston 30 to the right and back toward its original position as shown in Fig. 3B. Movement of the piston 30 in this manner thereby causes the motive fluid 23A, 25A in the second motive fluid chamber 30M2 to be removed or vented from the chamber 30M2 via the second motive fluid inlet/outlet 52 and through the directional valve 50 to the returns line 39, after which it is either recirculated to the inlet 20B of the motive fluid pump 20 in the closed system 10 (see Fig. 1A) or discharged via the discharge lines 24A in the open system 12 (see Fig. 1B). As shown in Fig. 3C, the piston movement also causes fluid of the surrounding environment, *e.g.*, sea water of a subsea environment, to be drawn back into the first liquid chamber 30M1, as indicated by the flow arrow 43. Additionally, during this rightward piston stroke the liquid 41 may be drawn into the liquid chamber 30C1 through the associated check valve 33. Furthermore, the check valve 34 associated with the liquid chamber 30C1 also prevents the higher pressure liquid 41P that was previously discharged from the liquid chamber 30C1 from flowing back into the liquid chamber 30C1. Depending on the overall design requirements of a given system, the force created by the return spring 29 may be adjusted as necessary so as to ensure that an appropriate stroke distance and response time is obtained for the particular application.

Figure 3D depicts an alternative embodiment of the configuration depicted in Figs. 3A-3C, wherein an eductor 38 may be used during the exemplary step of removing/venting the motive fluid 23A, 25A from the second motive fluid chamber 30M2. As shown in Fig. 3D, the motive fluid 23A, 25A exiting the second motive fluid chamber 30M2 may be directed to an eductor 38 (see Fig. 1B), which would then serve to maintain the pressure of the vented motive fluid 23A, 25A through the inlet/outlet 52 of the chamber 30M2 at a pressure level that is below the pressure of the surrounding fluid (*e.g.*, sea water) that is drawn back into the first fluid chamber 30M1 through the inlet/outlet 51, which can be at the pressure of the liquid source 40. Depending on the particular design and operating parameters of the eductor 38, the single acting positive displacement pump 22 shown in Fig. 3D may not require the return spring 29, that is, the return spring 29 may be removed from the system. In other embodiments, the single acting PD pump 22 of Fig. 3D may include both an eductor 38 and a return spring 29, such that the force that is required to be created by the return spring 29 may be substantially reduced over that required by a system that does not utilize the eductor 38.

In those embodiments where the positive displacement pump 22 is, for example, a double acting piston pump as is schematically shown in Figs. 2A-2C, the directional valve 50 may be operated in cycles to provide substantially continuous flow of pressurized liquid 41P to the desired injection point. In other embodiments where the PD pump 22 is a single acting piston pump as is schematically depicted in Figs. 3A-3D, the directional valve 50 may be operated so as to provide half-cycle flow of the pressurized liquid 41P to the desired injection point. Furthermore, if required, in at least some embodiments two or more single or double acting pumps 22 may be provided with shifted operational cycles so as to smooth the flow rate of the pressurized liquid 41P to the injection point.

In typical applications, the switching frequency of the directional valve 50 should be synchronized with the position of the piston 30. For example, when the piston 30 of a double acting PD pump 22 completes its full stroke, *e.g.*, when the piston 30 is fully extended into the second liquid chamber 30C2 as shown in Fig. 2B, the position of the directional valve 50 may be switched from the first valve position shown in Fig. 2B to the second valve position shown in Fig. 2C. In some embodiments, the automatic synchronized switching of the directional valve 50 may be provided by a switch that operates a relay when the piston 30 achieves its full stroke as shown in Fig. 2B. More

specifically, the relay may activate the directional valve 50 such that it is moved from the first valve position (Fig. 2B) to the second valve position (Fig. 2C) so as to move the piston 30 in the reverse or opposite direction, *i.e.*, to the right as shown in Fig. 2C. When the piston 30 reaches its fully extended position in the first liquid chamber 30C1, as shown in Fig. 2C, this process is reversed, and the directional valve 50 is switched from the second valve position (Fig. 2C) to the first valve position (Fig. 2B) so as to cause the piston 30 to move to the left. Thus, in this automated version of the systems 10, 12 with the directional valve 50 and the associated relays (not shown), the full travel of the piston 30 may be confirmed by detecting the activation or deactivation of the relay by a switch (not shown), or by detection of the switch status when the piston 30 has reached its full stroke. Furthermore, the flow rate of the pressurized liquid 41P supplied to the injection point may be readily calculated based upon the known full stroke volume of the piston 30 and the switching frequency of the directional valve 50.

Figure 4 schematically depicts one exemplary embodiment for controlling the switching frequency of the directional valve 50, wherein a plurality of piston position sensors 56 may be installed either in or adjacent to the positive displacement pump 22. Depending on the sensing requirements, the piston position sensors 56 may take any one of a variety of forms, *e.g.*, proximity sensors, magnetic pick-ups, and/or other forms of position detecting sensors. During pump operation, the piston position sensors 56 send a signal when the piston 30 has reached its full stroke position, and the position of the directional valve 50 may then be switched based upon the signal from the piston position sensor 56. The use of such piston position sensors 56 may be employed to eliminate, or to provide back up to, the switch (not shown) and to detect the position of the piston 30. The flow rate of the pressurized liquid 41P may also be calculated in the manner previously described above. Also shown in Fig. 4 is a generic subsea control module 52 that may be operatively coupled to the positive displacement pump 22 and the directional valve 50 via a plurality of relays and/or electronics 54. In certain embodiments, the relays and/or electronics 54 may be adapted to communicate with the piston position sensors 56 via sensor links 57 and to trigger switching of the directional valve 50 via switching link 59. Furthermore, the subsea control module 52 may be operatively coupled to the various relays and/or electronics 54 so as to provide power 55 to the relays/electronics 54, and also to allow communication 53 between the control module 52 and the relays/electronics 54 so that appropriate signals can be sent between the two.

Figure 5 schematically illustrates another embodiment of the systems 10, 12 wherein direct and positive confirmation of the position of the piston 30 may not be provided by a switch, or by the above-described piston position sensors 56. As shown in Fig. 5, the systems 10, 12 may be provided with a differential pressure sensor 58 that is adapted to measure or determine the pressure drop across the throttle valve 27, *i.e.*, the difference in pressure between the outlet 20A of the motive fluid pump 20 and the inlet of the motive fluid in the PD pump 22 (see Figs. 1A and 1B). In the illustrated embodiment shown in Fig. 5, the flow rate of the motive fluid 23A, 25A (and as a result, the flow rate of the higher pressure liquid 41P) may be determined from curves that are established and calibrated based on the operational characteristics of the systems 10, 12, such as the family of curves that are depicted in Fig. 5A. For example, a plot of the motive fluid flow rate (vertical axis 67 in Fig. 5A) versus the position (amount of restriction) of the throttle valve 27 (horizontal axis 68 in Fig. 5A) may be defined and calibrated for each of several differential pressure drop values across the throttle valve 27. The differential pressure that is obtained from the differential pressure sensor 58 may then be used to develop a specific curve for the motive fluid flow rate versus the restriction of the throttle valve 27, such as the differential pressure (DP) curves 69A-C shown in Fig. 5A, which are exemplary only and do not necessarily reflect any actual developed curves. Using

such defined and calibrated DP curves, the flow rate of the motive fluid 23, 25 (and the flow rate of the liquid 41P) may be determined based upon the known restriction, *i.e.*, the known position of the throttle valve 27. In operation, the throttle valve 27 may then be adjusted so as to achieve the desired flow rate of the motive fluid 23, 25, and as consequently the desired flow rate of the pressurized liquid 41P to the injection point. However, it should be understood that determining the flow rate of the pressurized liquid 41P using the system described in Fig. 5, *i.e.*, a system that does not provide positive confirmation of the position of the piston 30, may not be as accurate as other systems described above.

The closed and open systems 10, 12 may be packaged in a variety of different ways, such as is illustrated in Figs. 6-9 and described in further detail below. For example, Fig. 6 schematically depicts one such illustrative packaging embodiment wherein portions of the systems 10, 12 are positioned in a retrievable unit 60. In one illustrative example, the frequently operated moving parts of the systems 10, 12 that are subjected to normal wear and tear may be positioned within the retrievable unit 60, which is adapted to be retrieved from the subsea environment for maintenance, repair, and/or replacement as may be required. In some embodiments, the positive displacement pump(s) 22, the throttle valve(s) 27, the relay/electronics module 54, the piston position sensors 56, and the directional valve 50 may be positioned within the retrievable unit 60, as is shown in Fig. 6. Some of the components of the systems 10, 12 may also be positioned in an internal pressure tight housing or chamber 61 within the retrievable unit 60, wherein the housing or chamber 61 may be maintained at a pressure of about one atmosphere. As shown in the depicted example, the retrievable unit 60 may be provided with a plurality of quick connectors 62, which are schematically depicted only, so as to provide a means for supplying the motive fluid 23A, 25A from the motive fluid pump 20 and the liquid 41 from the liquid source 40. Furthermore, the quick connectors 62 may also provide a connection point for a conduit or line that is adapted to receive the pressurized liquid 41P from the retrievable unit 60 and to direct it to the desired injection point. Multiple such retrievable units 60 may be positioned subsea for a given application.

Figure 7 schematically depicts another exemplary packaging configuration that is similar in some aspects to the embodiment depicted in Fig. 6 above. In particular, Fig. 7 illustrates a packaging scheme wherein, on an overall system level, the motive fluid pump 20 and one or more retrievable units 60 may be positioned on the same structure that contains the processing equipment where the pressurized liquid 41P is to be supplied, such as a structure containing a manifold and/or a Christmas tree and the like. For example, the overall system may comprise three (or more) retrievable units 60, 60A, 60B, each of which may be operatively coupled to a control and distribution module 65 via a plurality of quick connectors 66, depicted schematically only in Fig. 7. In one embodiment, the control and distribution module 65 may include the subsea control module 52, the motive fluid pump 20 and the flow restriction device 35. The system depicted in Fig. 7 may also include a first liquid source 40A for storing a first liquid 41A, *e.g.*, in a subsea environment, and a second liquid source 40B for storing a second liquid 41B that is different than the first liquid 41A, *e.g.*, also in the subsea environment. As depicted, the retrievable unit 60 is adapted to receive motive fluid 23A, 25A and the first liquid 41A, and is further adapted to supply pressurized first liquid 41AP to a first desired injection point. The retrievable unit 60A may be adapted to receive motive fluid 23A, 25A and the second liquid 41B, and furthermore may also be adapted to supply a pressurized second liquid 41BP to a second desired injection point. In certain embodiments, the retrievable unit 60B may be adapted to receive motive fluid 23A, 25A and the first liquid 41A, and also to supply a pressurized first liquid 41AP to a third desired injection point.

Figures 8 and 9 depict an embodiment of the systems 10, 12 wherein the positive displacement pumps 22 may be used to inject the pressurized liquid 41P to a desired injection point may be an hydraulically actuated axial piston pump 70. In one exemplary embodiment, an axial piston pump 70 may be used for each desired injection site. Furthermore, the positive displacement pumps 22 shown in any of the prior examples above may be substituted for the axial piston pump 70. For ease of reference, the hydraulically actuated axial piston pump 70 is only depicted in the system shown in Fig. 9 which corresponds approximately to the system shown in Fig. 7.

As shown in Fig. 8, the axial piston pump 70 includes, among other things, a housing 71, a hydraulically actuated drive shaft 72, a drive shaft bearing 78, a swash plate 74, a shoe plate 80, a plurality of pistons 76 that are positioned in a cylinder barrel 82, a pump inlet 84 for receiving the relatively lower pressure liquid 41 (supplied from the liquid source 40) and a pump outlet 86 wherein the pressurized liquid 41P is supplied to the desired injection point. A schematically depicted hydraulically powered actuator 90 that may be provided to rotate the drive shaft 72 of the axial piston pump 70. In general, each of the pistons 76 is positioned within an individual hole or opening in the cylinder barrel 82. Additionally, the cylinder barrel 82 and the swash plate 74 are adapted to rotate with the drive shaft 72, and each of the pistons 76 is coupled to the swash plate 74 by a ball-and-socket connection 75. Furthermore, each of the pistons 76 is free to move axially (left-to-right in the drawing) within its own individual opening within the cylinder barrel 82 as the cylinder barrel rotates with the shaft 72.

In some illustrative embodiments, the amount of fluid that is displaced by the axial piston pump 70 with each rotation of the drive shaft 72 may be varied. With reference to Fig. 9, in one embodiment, the amount of pressurized liquid 41P produced by the axial piston pump 70 may be controlled by controlling the rotating speed of the hydraulically powered actuator 90, which may be adjusted by regulating the rate of motive fluid 23A, 25A supplied to the actuator 90 by adjusting the throttle valve 27. In another embodiment, the amount of pressurized liquid 41P produced by the axial piston pump 70 may be controlled by adjusting the tilt angle 81 (Fig. 8) of the swash plate 74. More specifically, the amount of pressurized liquid 41P produced by the axial piston pump 70 with each rotation of the shaft 72 depends upon the tilt angle 81 of the swash plate 74 relative to a line that is normal to the axis of rotation of the drive shaft 72.

In general, the greater the tilt angle 81 of the swash plate 74, the more fluid that is displaced with each rotation of the shaft 72. For example, if the tilt angle 81 of the swash plate 74 is zero, then there is no net flow of the fluid to or from the axial piston pump 70. However, when the swash plate 74 is tilted at a tilt angle 81 that is greater than zero, then the axial piston pump 70 receives some amount of the fluid (*e.g.*, the liquid 41) at the pump inlet 84 and discharges a higher pressure fluid (*e.g.*, the pressurized liquid 41P) via the pump outlet 86. With the swash plate 74 tilted as shown in Fig. 8, the uppermost piston 76 is in it fully retracted position and incoming fluid (*e.g.*, the liquid 41) is drawn into the opening associated with that uppermost piston 76 when that individual opening in the cylinder barrel 82 is aligned with the pump inlet 84. As the cylinder barrel 82 rotates, what was the uppermost piston is urged forward (*i.e.*, to the left in Fig. 8) due to the tilt of the swash plate 74. However, the fluid that was drawn into the individual opening when the piston was in the uppermost position is trapped or contained within the individual opening as the cylinder barrel 82 rotates and the piston moves forward within its individual opening of the cylinder barrel 82, thereby increasing the pressure of the trapped fluid as the barrel 82 rotates and as the piston 76 moves to the left in Fig. 8. The rotation of the barrel 82 is continued until such time as the piston 76 reaches its fully extended position (thereby increasing the pressure of the fluid to its maximum) and the opening in the cylinder barrel 82 associated with this particular piston is aligned with the pump outlet 86. At this point, the

pressurized liquid 41P is discharged from the pump 70 to the desired injection point. As shown in Fig. 9, in the systems employing an axial piston pump 70, a counter 83 may be provided to count the rotations of the shaft 72 during operations (*e.g.*, RPMs), and the output of that counter 83 may be provided to the subsea control module 52 via the RPM signal link 85. Note that in the embodiments wherein the axial piston pump 70 is used in lieu of the piston pumps discussed above, the directional valve 50 may be omitted.

As will be appreciated by those skilled in the art after a complete reading of the present application, the systems and methods disclosed herein may provide significant advantages to existing systems and methods as it relates to delivery of liquids, such as chemicals and the like, to equipment and flow lines that are positioned subsea. For example, the overall driver of the systems is a motive fluid 23A, 25A supplied by a single motive fluid pump 20 that may be positioned subsea (of course a back-up motive fluid pump 20 may be supplied and positioned subsea as part of the system). The amount or rate of the motive fluid 23A, 25A supplied to each of the PD pumps 22 (be they piston pumps, diaphragm pumps, or axial piston pumps) is regulated by controlling various throttle valves (*e.g.*, 27, 36), which, in turn, regulates the amount of the pressurized liquid 41P provided to each desired injection site. Thus, the systems disclosed herein provide an efficient and effective means to deliver chemicals to many different chemical injection sites without the need of having individual electrically driven chemical injection motors with variable frequency drives for each injection site and/or the associated metering valves/flow meters for each individual line. Moreover, by using the systems disclosed herein, the umbilical from a surface vessel or platform may be much smaller in size and less expensive. For example, using the systems disclosed herein, the electrical supply power lines used to power a number of individual electrically driven chemical injection pumps may be omitted. Even if there is not a source of electrical power positioned subsea to drive the single motive fluid pump 20, the umbilical would only need to carry sufficient power to drive the single motive fluid pump 20 and enough low voltage power to actuate the various throttle valves. In the case where the chemical storage is positioned subsea, the umbilical may be even further reduced in size in that chemical supply lines from the surface vessel or platform need not be part of the umbilical.

The particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. For example, the process steps set forth above may be performed in a different order. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the claimed subject matter. Note that the use of terms, such as “first,” “second,” “third” or “fourth” to describe various processes or structures in this specification and in the attached claims is only used as a shorthand reference to such steps/structures and does not necessarily imply that such steps/structures are performed/formed in that ordered sequence. Of course, depending upon the exact claim language, an ordered sequence of such processes may or may not be required. Accordingly, the protection sought herein is as set forth in the claims below.

CLAIMS**WHAT IS CLAIMED:**

1. A liquid injection system, comprising:

a motive fluid pump (20) that is adapted to supply a pressurized motive fluid (23, 25);

at least one source (40) of a liquid (41); and

at least one liquid injection pump (22) that is adapted to receive said liquid (41) from said at least one source (40) at a first pressure and to receive said pressurized motive fluid (23, 25) from said motive fluid pump (20), wherein receipt of said pressurized motive fluid (23, 25) into said at least one liquid injection pump (22) causes a discharge of said liquid (41P) from said at least one liquid injection pump (22) at a second pressure that is greater than said first pressure.

2. The liquid injection system of claim 1, wherein said liquid injection system is one of a closed system (10) and an open system (12).

3. The liquid injection system of claim 1, wherein said at least one liquid injection pump (22) comprises a plurality of liquid injection pumps (22A-C).

4. The liquid injection system of claim 1, wherein said at least one liquid injection pump (22) is a positive displacement pump.

5. The liquid injection system of claim 4, wherein said positive displacement pump is one of a double acting piston pump, a single acting piston pump, a diaphragm pump, and an axial piston pump.

6. The liquid injection system of claim 1, further comprising a throttle valve (27) that is adapted to regulate a flow of said pressurized motive fluid (23, 25) from said motive fluid pump (20) to said at least one liquid injection pump (22).

7. The liquid injection system of claim 1, further comprising at least one first check valve (33) that is adapted to control a flow of said liquid (41) from said at least one source (40) into said at least one liquid injection pump (22) and at least one second check valve (34) that is adapted to control said discharge of said liquid (41P) from said at least one liquid injection pump (22).

8. The liquid injection system of claim 1, wherein said at least one liquid injection pump (22) is a positive displacement piston pump, said positive displacement piston pump comprising:

a pump body (22X);

at least one motive fluid chamber (30M);

at least one liquid chamber (30C); and

a piston (30) positioned in said pump body (22X).

9. The liquid injection system of claim 7, wherein said at least one motive fluid chamber (30M) is adapted to receive said pressurized motive fluid (23, 25) from said motive fluid pump (20), and wherein said at least one liquid chamber (30C) is adapted to receive said liquid (41) from said at least one source (40).

10. The liquid injection system of claim 9, wherein a portion of said piston (30) is adapted to move into said at least one liquid chamber (30C) when said at least one motive fluid chamber (30M) receives said pressurized motive fluid (23, 25) from said motive fluid pump (20).

11. The liquid injection system of claim 10, wherein said movement of said portion of said piston (30) into said at least one liquid chamber (30M) is adapted to increase a pressure of said liquid (41) received in said at least one liquid chamber (30C) from said first pressure to said second pressure.

12. The liquid injection system of claim 7, wherein said positive displacement piston pump is a double acting piston pump, wherein said at least one motive fluid chamber (30M) comprises a first motive fluid chamber (30M1) and a second motive fluid chamber (30M2), and wherein said at least one liquid chamber (30C) comprises a first liquid chamber (30C1) and a second liquid chamber (30C2), said first and second motive fluid chambers (30M1, 30M2) being adapted to receive said pressurized motive fluid (23, 25) from said motive fluid pump (20), and said first and second fluid chambers (30C1, 30C2) being adapted to receive said liquid (41) from said at least one source (40).

13. The liquid injection system of claim 12, further comprising a directional valve (50), wherein said directional valve (50) is adapted to direct said pressurized motive fluid (23, 25) from said motive fluid pump (20) to said first motive fluid chamber (30M1) when said directional valve (50) is in a first valve position, and wherein said directional valve (50) is adapted to direct said pressurized motive fluid (23, 25) from said motive fluid pump (20) to said second motive fluid chamber (30M2) when said directional valve (50) is in a second valve position.

14. The liquid injection system of claim 13, wherein said piston (30) is adapted to increase a pressure of said liquid (41) received in said second liquid chamber (30C2) from said first pressure to said second when said pressurized motive fluid (23, 25) is received in said first motive fluid chamber (30M1) from said motive fluid pump (20), and wherein said piston (30) is adapted to increase a pressure of said liquid (41) received in said first liquid chamber (30C1) from said first pressure to said second pressure when said pressurized motive fluid (23, 25) is received in said second motive fluid chamber (30M2) from said motive fluid pump (20).

15. The liquid injection system of claim 13, wherein said directional valve (50) is adapted to vent said pressurized motive fluid (23, 25) from said first motive fluid chamber (30M1) when said directional valve (50) is in said second valve position, and wherein said directional valve (50) is adapted to vent said pressurized motive fluid (23, 25) from said second motive fluid chamber (30M2) when said directional valve (50) is in said first valve position.

16. The liquid injection system of claim 13, further comprising a control module (52) and at least one piston position sensor (56) positioned in or adjacent to said at least one liquid injection pump (22), wherein said at least one piston position sensor (56) is adapted to detect a position of said piston (30) within said pump body (22X) and to send a signal to said control module (52) based on said detected piston position, and wherein said control module (52) is adapted to control switching of said directional valve (50) from said first valve position to said second valve position based on said signal of said detected piston position received from said piston position sensor (56).

17. The liquid injection system of claim 1, wherein said liquid injection system is positioned in a subsea environment, the liquid injection system further comprising a control module (52) that is adapted to control said supply of pressurized motive fluid (23, 25) to and from said at least one liquid injection pump (22), wherein said at least one liquid injection pump (22) comprises a retrievable unit (60) that is adapted to be retrieved from said subsea environment, said retrievable unit (60) comprising a plurality of first connectors (62) that are adapted to removably couple said retrievable unit (60) to said motive fluid pump (20), to said at least one source (40) of said liquid (41), and to a conduit that is adapted to receive said discharge of said liquid (41P) at said second pressure from said at least one liquid injection pump (22).

18. The liquid injection system of claim 17, wherein said retrievable unit (60) is a first retrievable unit (60), wherein said control module (52) and said motive fluid pump (20) comprise a control and distribution module

(65), and wherein said plurality of first connectors (62) are adapted to couple said first retrievable unit (60) to said control and distribution module (65), said liquid injection system further comprising at least one second retrievable unit (60A, 60B) that is adapted to be retrieved from said subsea environment and a plurality of second connectors (66) that are adapted to removably couple said at least one second retrievable unit (60A, 60B) to said control and distribution module (65).

19. The liquid injection system of claim 18, wherein said at least one second retrievable unit (60A, 60B) is adapted to receive said liquid (41A, 41B) from said at least one source (40A, 40B) at said first pressure, to receive said motive fluid (23, 25) from said motive fluid pump (20), and to discharge said liquid (41AP, 41BP) at a second pressure that is greater than said first pressure

20. A method, comprising:
supplying a liquid (41) at a first pressure to at least one liquid injection pump (22) from at least one source (40) of said liquid (41);
receiving a pressurized motive fluid (23, 25) from a motive fluid pump (20) with said at least one liquid injection pump (22), wherein receiving said pressurized motive fluid (23, 25) increases a pressure of said liquid (41) inside of said at least one liquid injection pump (22) from said first pressure to a second pressure that is greater than said first pressure; and
discharging said liquid (41P) having said second pressure from said at least one liquid injection pump (22).

21. The method of claim 20, further comprising regulating a flow of said pressurized motive fluid (23, 25) from said motive fluid pump (20) to said at least one liquid injection pump (22) with a throttle valve (27).

22. The method of claim 20, further comprising controlling said supply of said liquid (41) from said at least one source (40) into said at least one liquid injection pump (22) with at least one first check valve (33) and controlling said discharge of said liquid (41P) from said at least one liquid injection pump (22) with at least one second check valve (34).

23. The method of claim 20, wherein receiving said pressurized motive fluid (23, 25) from said motive fluid pump (20) with said at least one liquid injection pump (22) comprises receiving said pressurized motive fluid (23, 25) in a motive fluid chamber (30M2) of said at least one liquid injection pump (22), wherein receiving said pressurized motive fluid (23, 25) in said motive fluid chamber (30M2) causes a piston (30) to move in a first direction within a body (22X) of said at least one liquid injection pump (22) and causes a first portion of said piston (30) to move into a liquid chamber (30C1) of said at least one liquid injection pump (22), said movement of said first portion of said piston (30) into said liquid chamber (30C1) increasing said pressure of said liquid (41) to said second pressure, wherein said liquid (41P) having said second pressure is discharged from said liquid chamber (30C1).

24. The method of claim 22, further comprising moving said piston (30) in a second direction within said body (22X) that is opposite to said first direction, said movement of said piston (30) in said second direction venting said pressurized motive fluid (23, 25) from said motive fluid chamber (30M2).

25. The method of claim 24, further comprising controlling supply of said pressurized motive fluid (23, 25) to said motive fluid chamber (30M2) by positioning a directional valve (50) in a first valve position, and controlling venting of said pressurized motive fluid (23, 25) from said motive fluid chamber (30M2) by positioning said directional valve (50) in a second valve position.

26. The method of claim 22, wherein said motive fluid chamber (30M2) is a second motive fluid chamber (30M2) and said liquid chamber (30C1) a first liquid chamber (30C1), the method further comprising:

supplying said liquid (41) at said first pressure from said at least one source (40) to a second liquid chamber (30C2) of said at least one liquid injection pump (22);

5 receiving said pressurized motive fluid (23, 25) from said motive fluid pump (20) in a first motive fluid chamber (30M1) of said at least one liquid injection pump (22), wherein receiving said pressurized motive fluid (23, 25) in said first motive fluid chamber (30M1) causes said piston (30) to move in a second direction within said body (22X) that is opposite to said first direction and causes a second portion of said piston (30) to move into a second liquid chamber (30C2) of
10 said at least one liquid injection pump (22), said movement of said second portion of said piston (30) into said second liquid chamber (30C2) increasing said pressure of said liquid (41) from said first pressure to said second pressure and said movement of said piston (30) through said body (22X) in said second direction venting said pressurized motive fluid (23, 25) out of said second motive fluid chamber (30M2); and

15 discharging said liquid (41P) having said second pressure from said second liquid chamber (30C2) of said at least one liquid injection pump (22).

27. The method of claim 26, further comprising controlling supply of said pressurized motive fluid (23, 25) to said second motive fluid chamber (30M2) by positioning a directional valve (50) in a first valve position, and controlling supply of said pressurized motive fluid (23, 25) to said first motive fluid chamber (30M1) and
20 venting of said pressurized motive fluid (23, 25) from said second motive fluid chamber (30M2) by positioning said directional valve (50) in a second valve position.

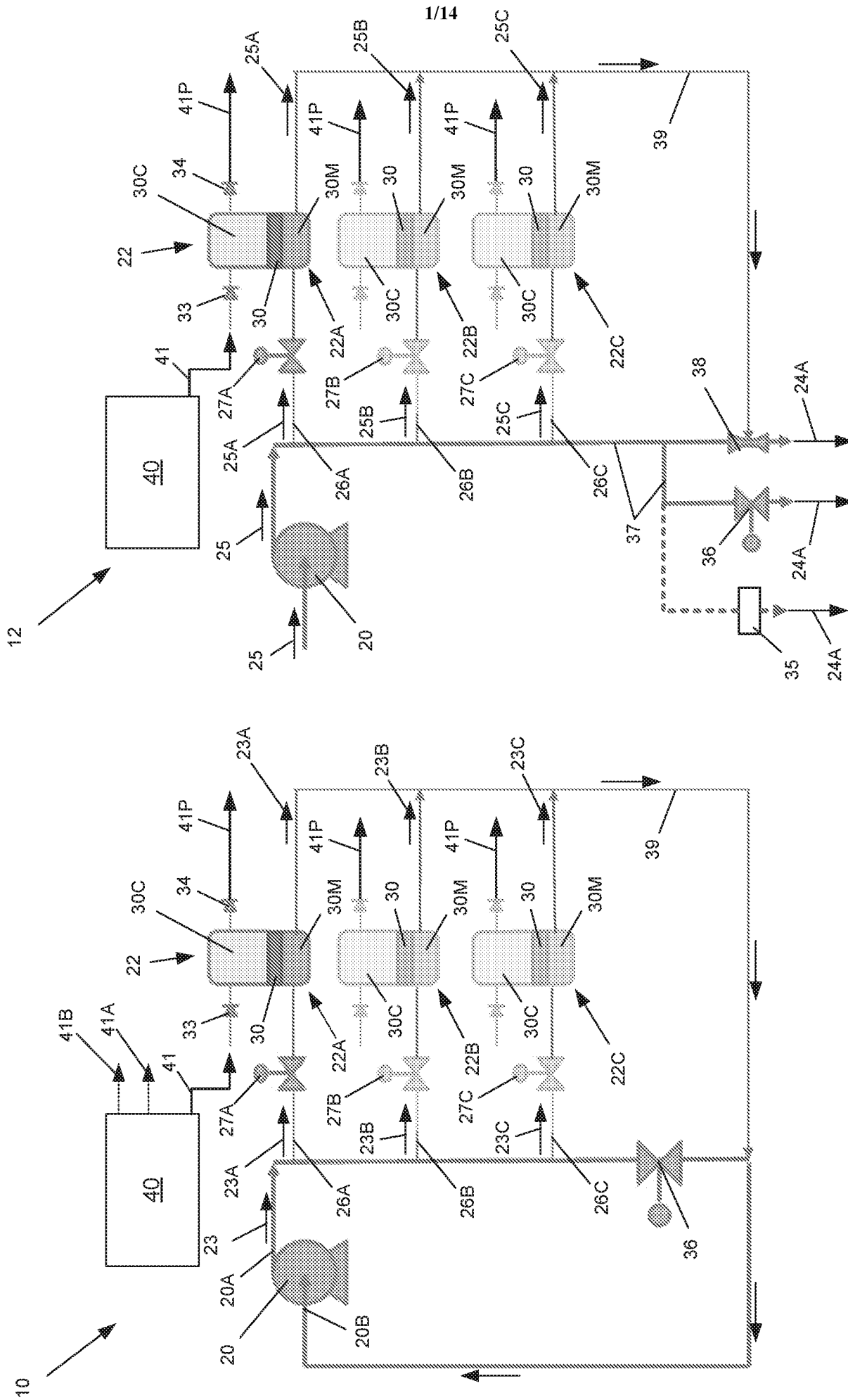


Figure 1B

Figure 1A

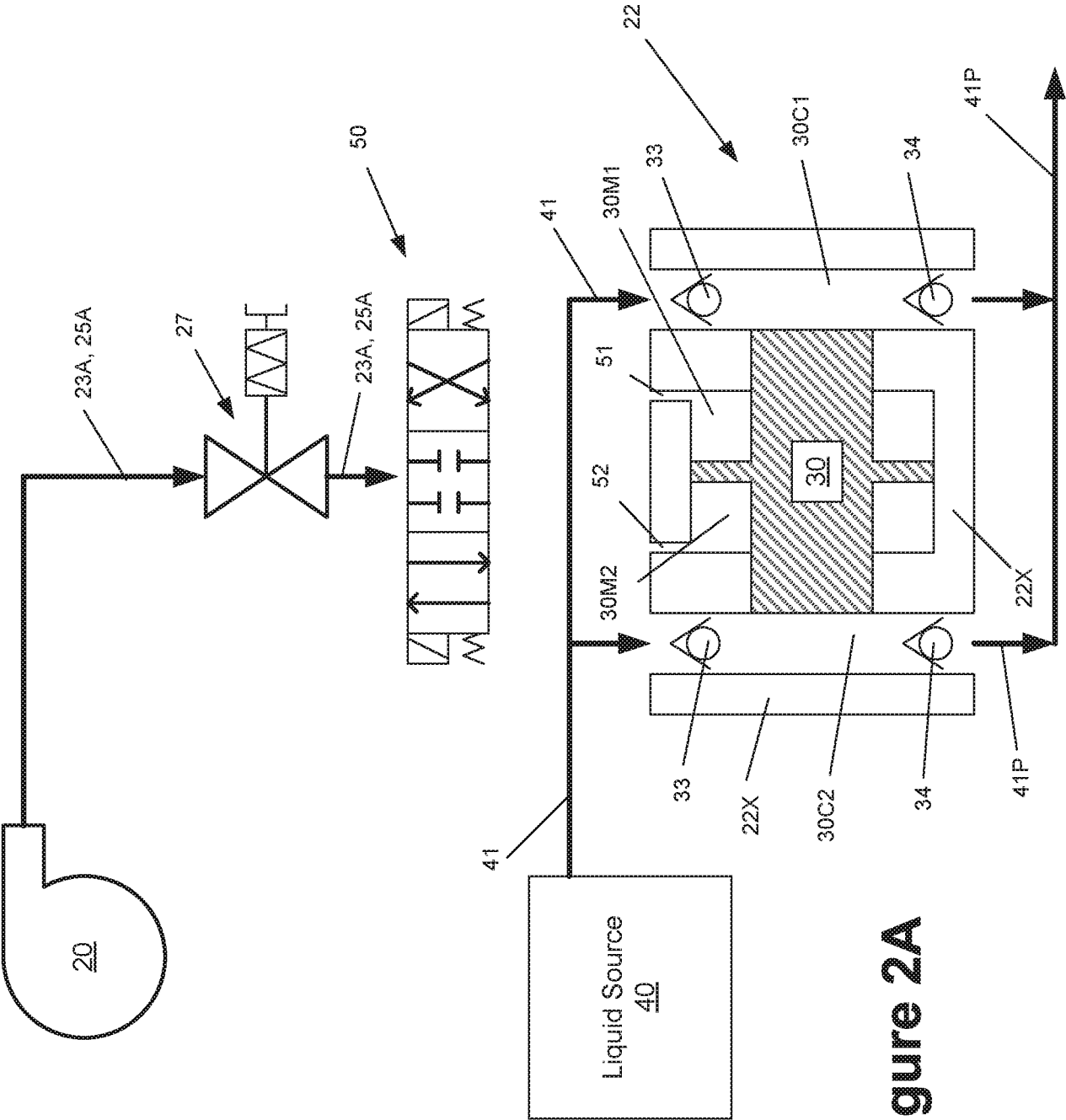


Figure 2A

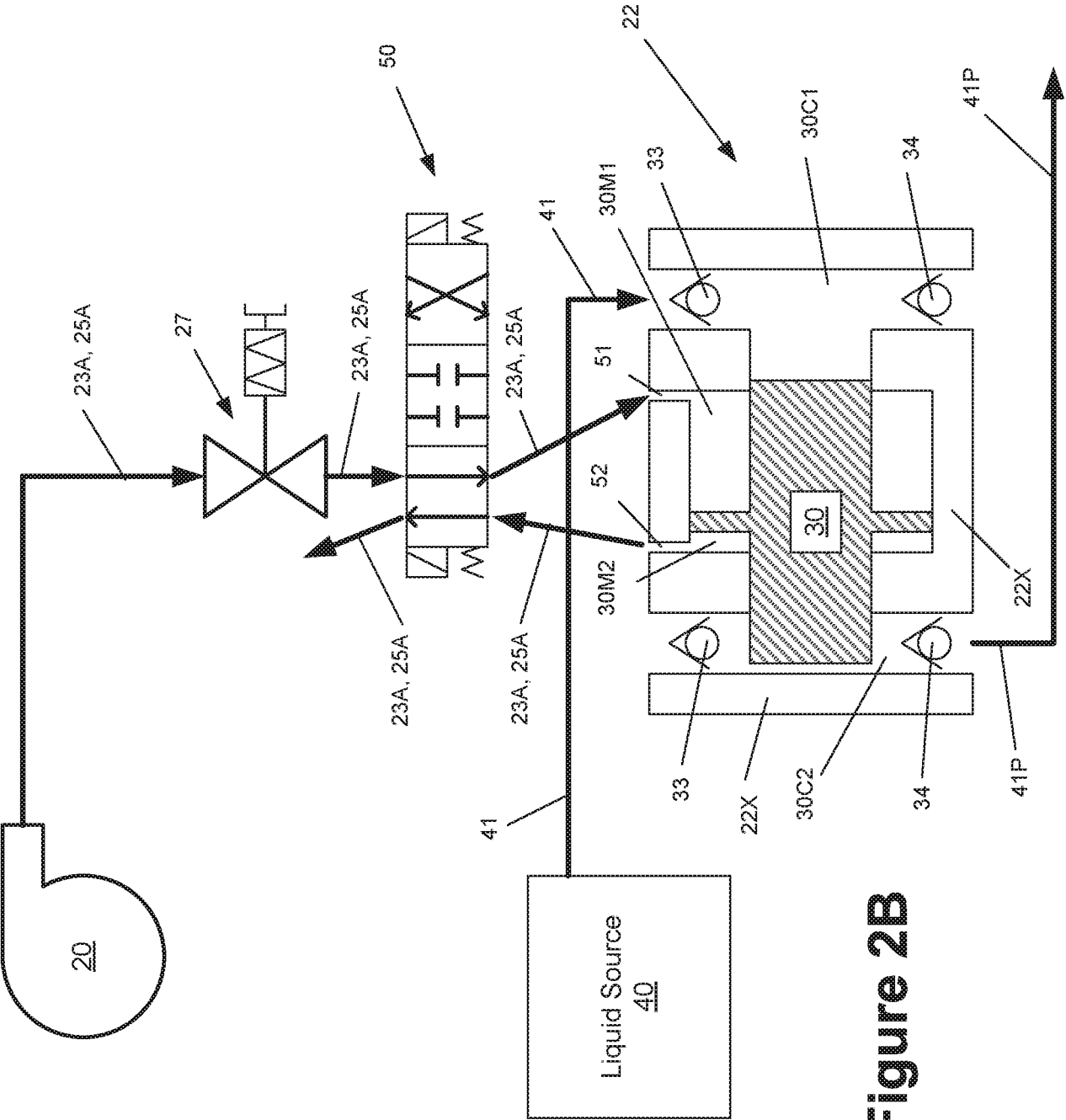


Figure 2B

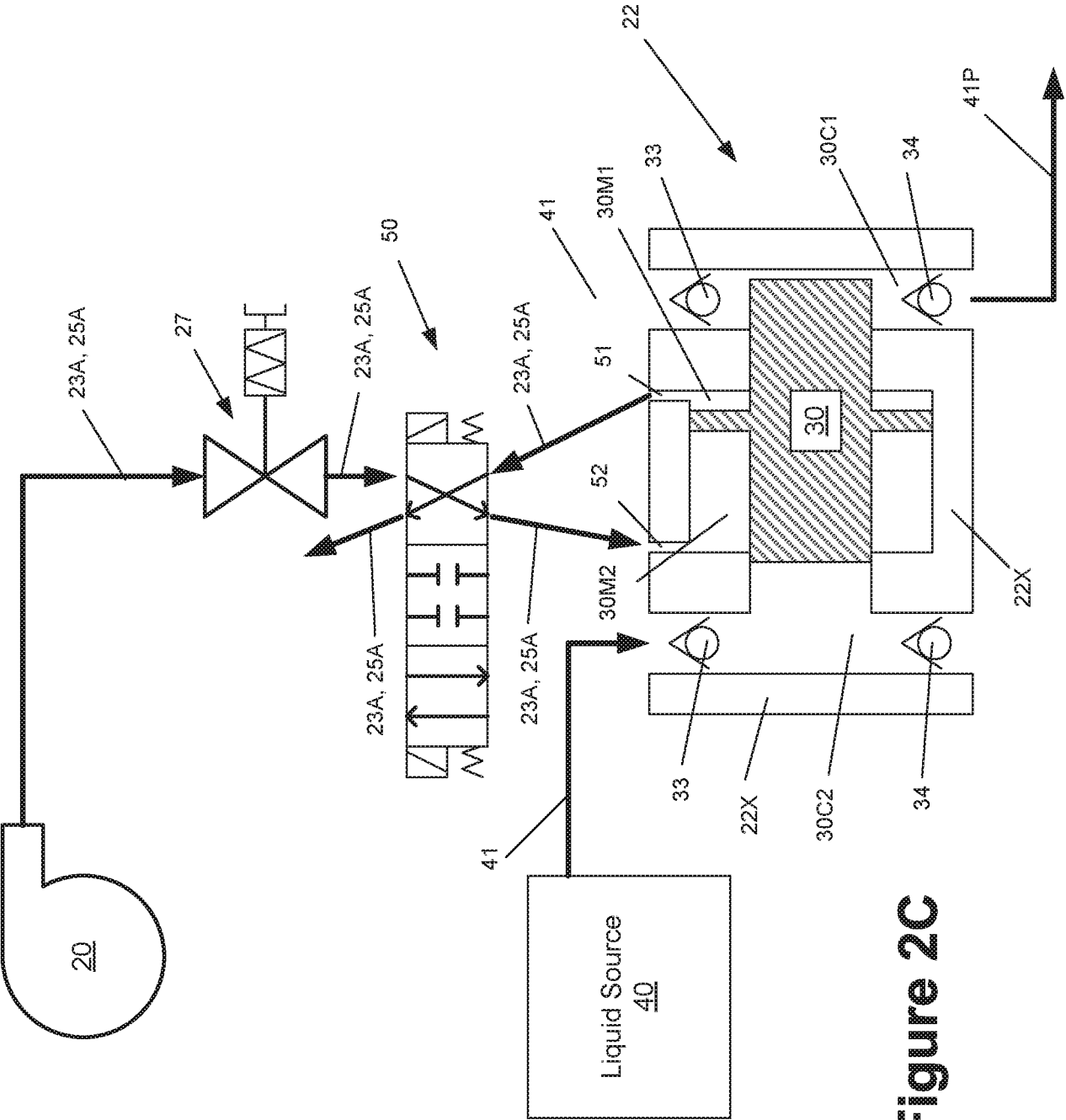


Figure 2C

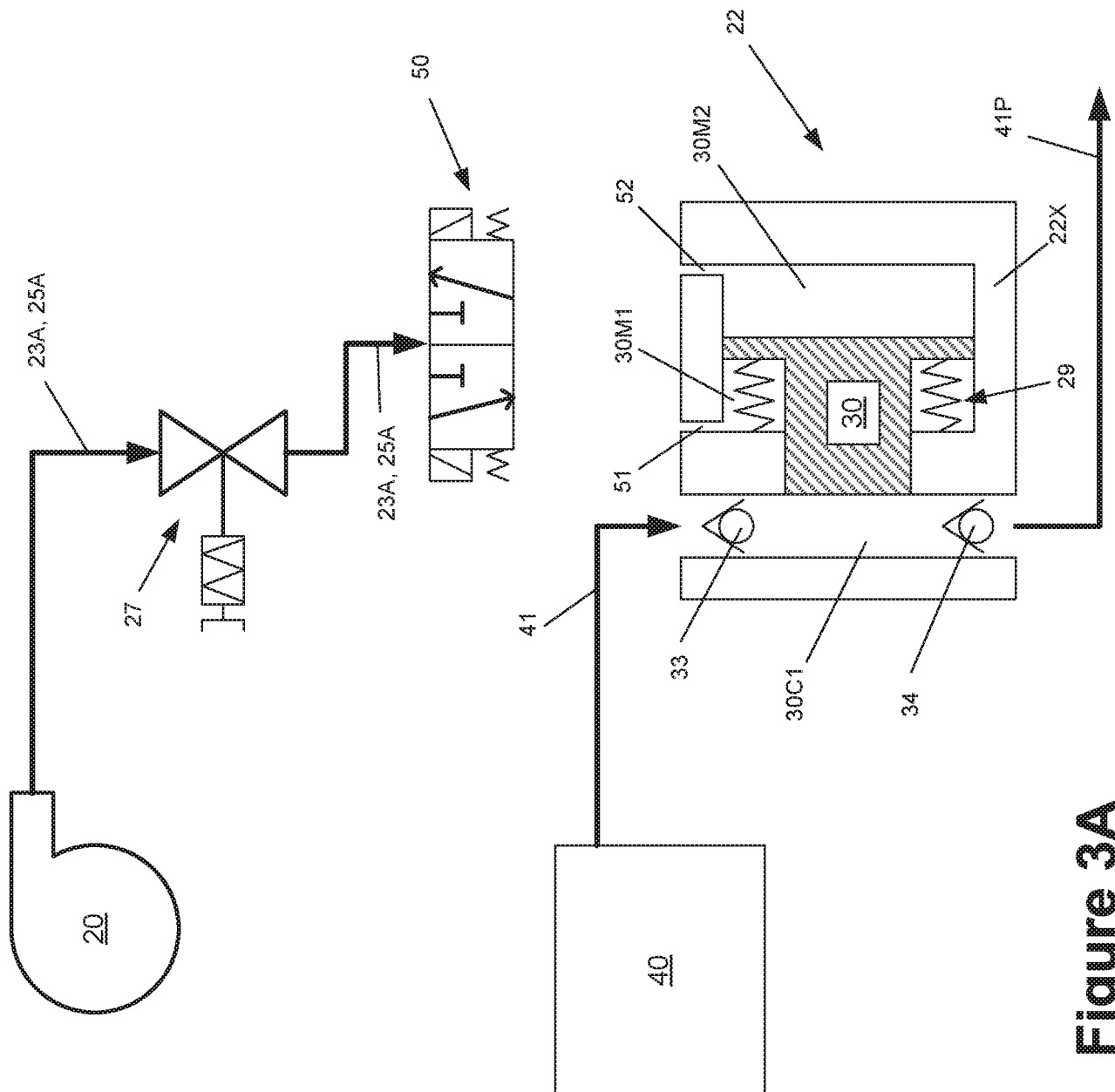


Figure 3A

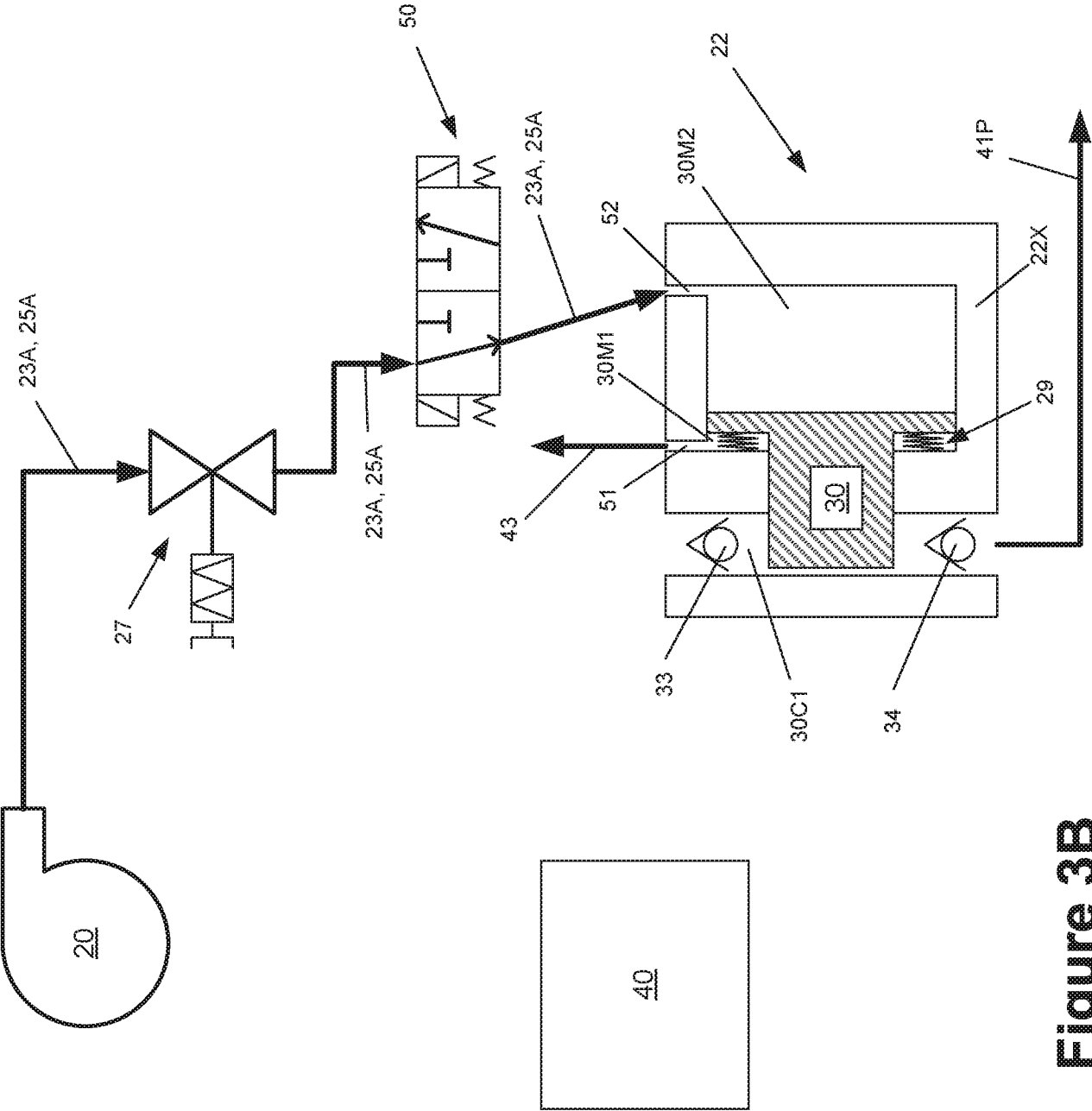


Figure 3B

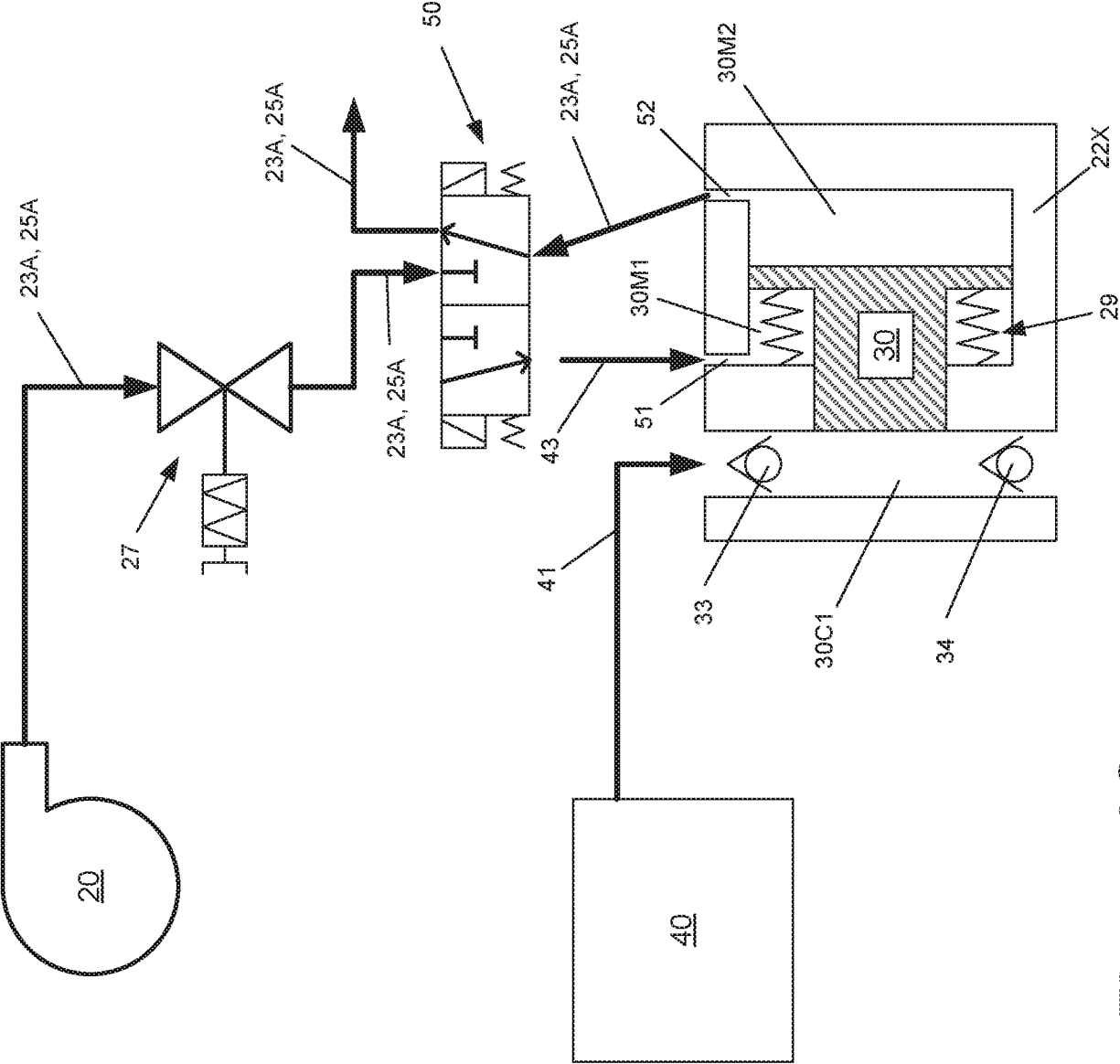


Figure 3C

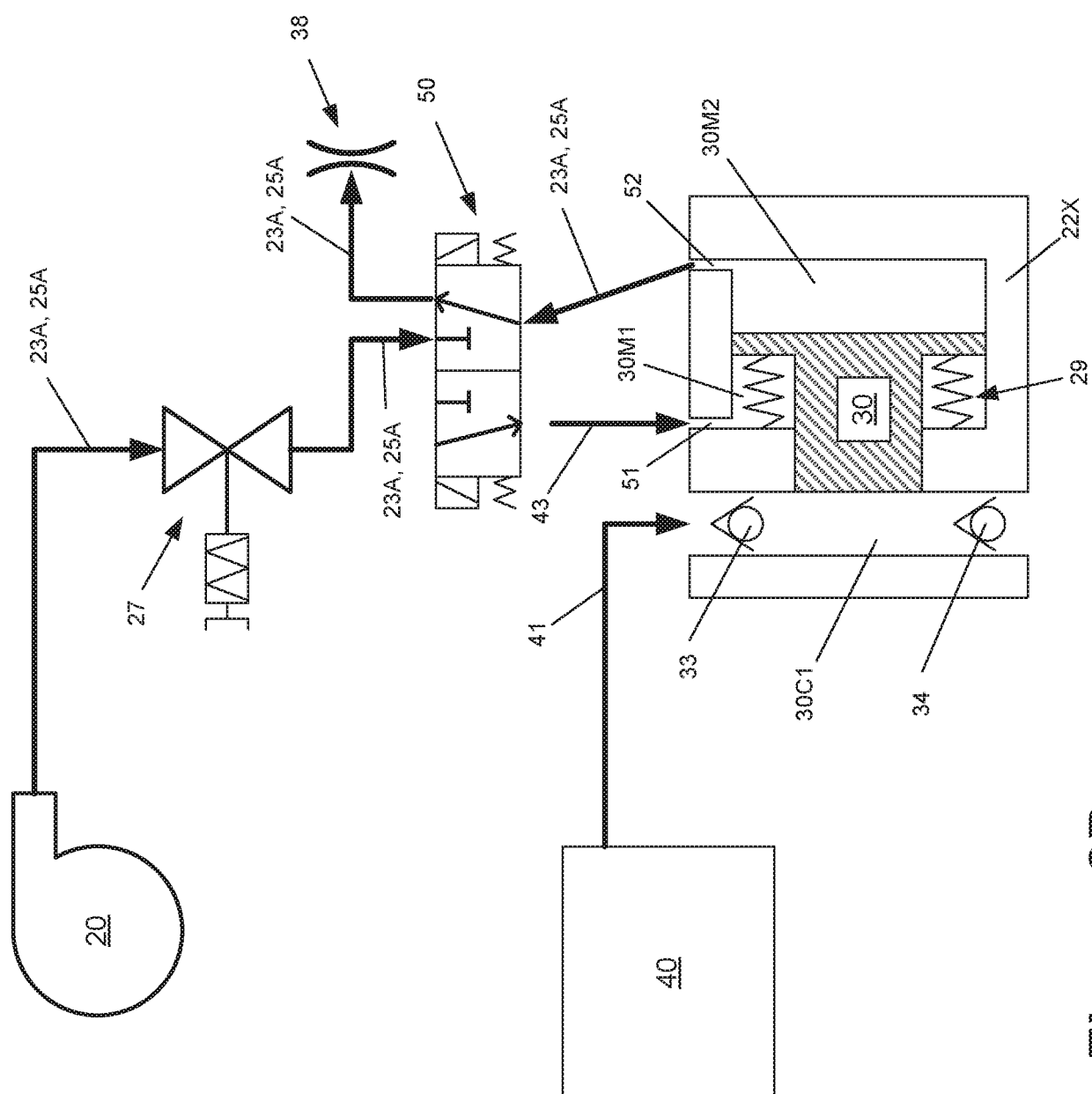


Figure 3D

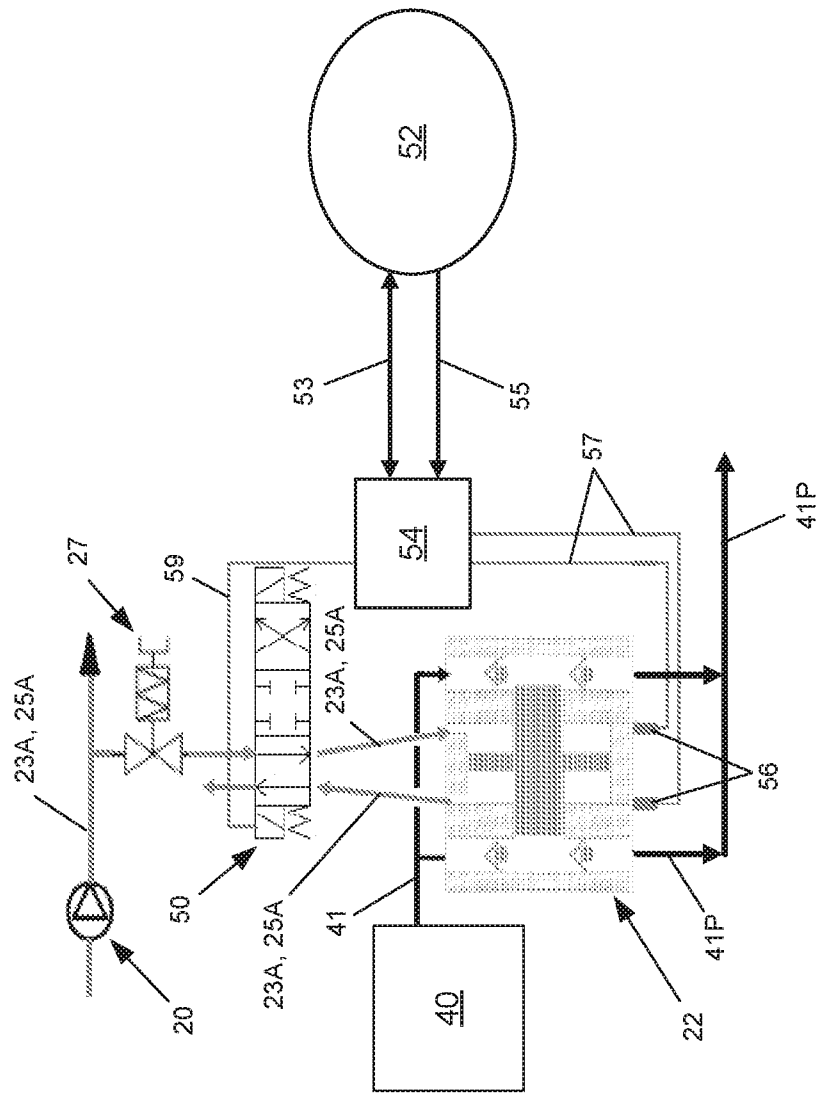


Figure 4

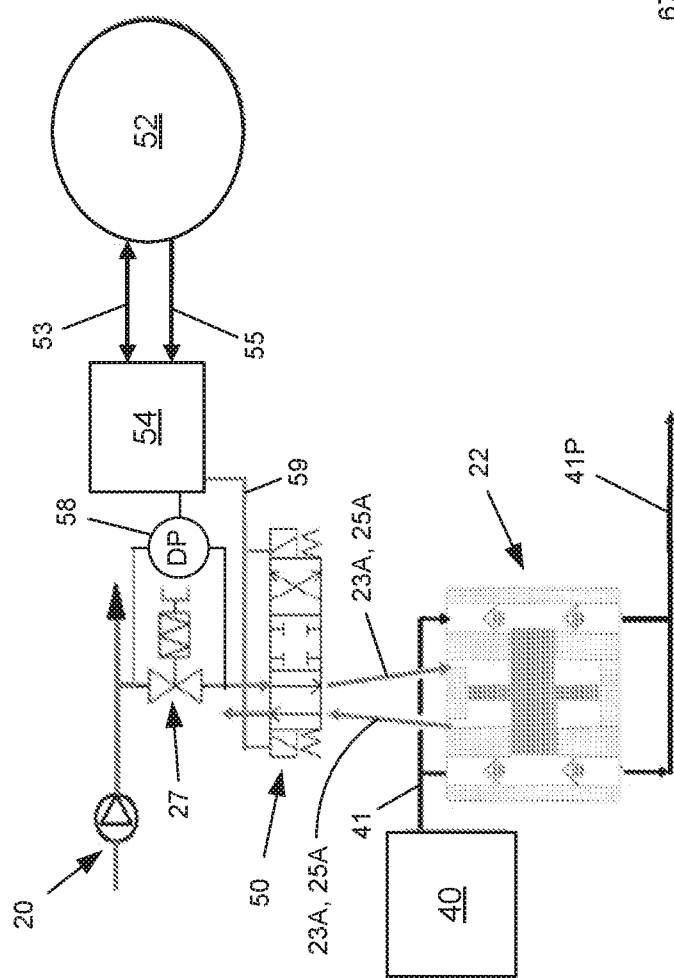


Figure 5

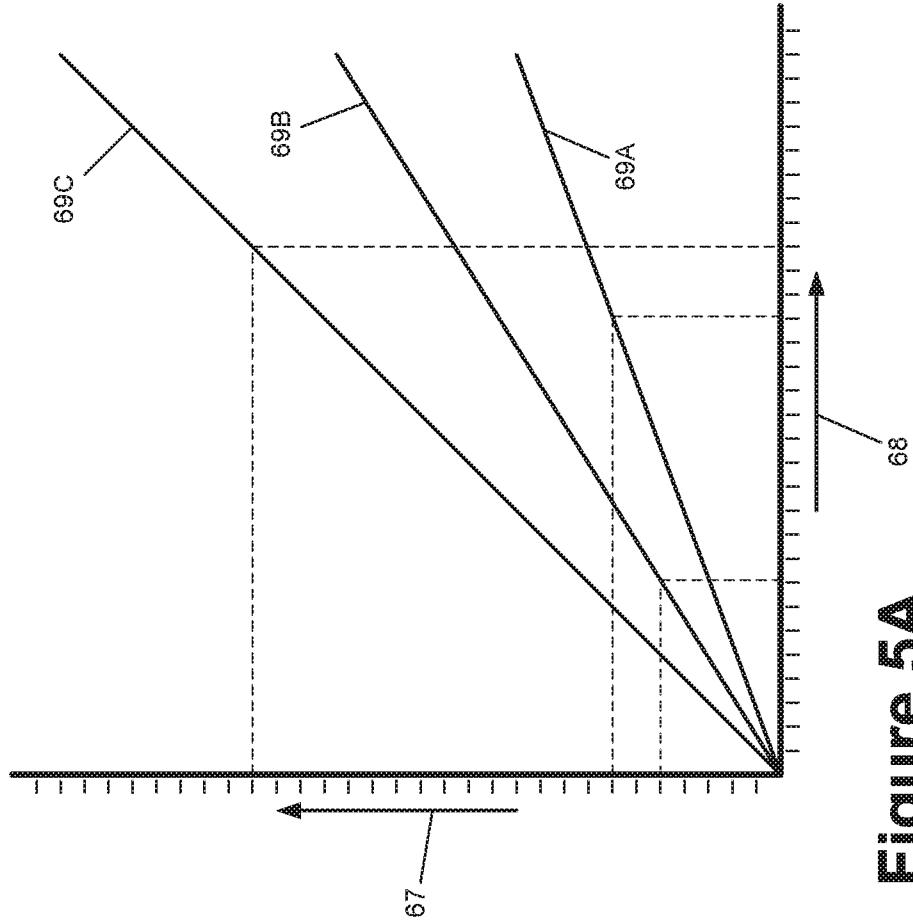


Figure 5A

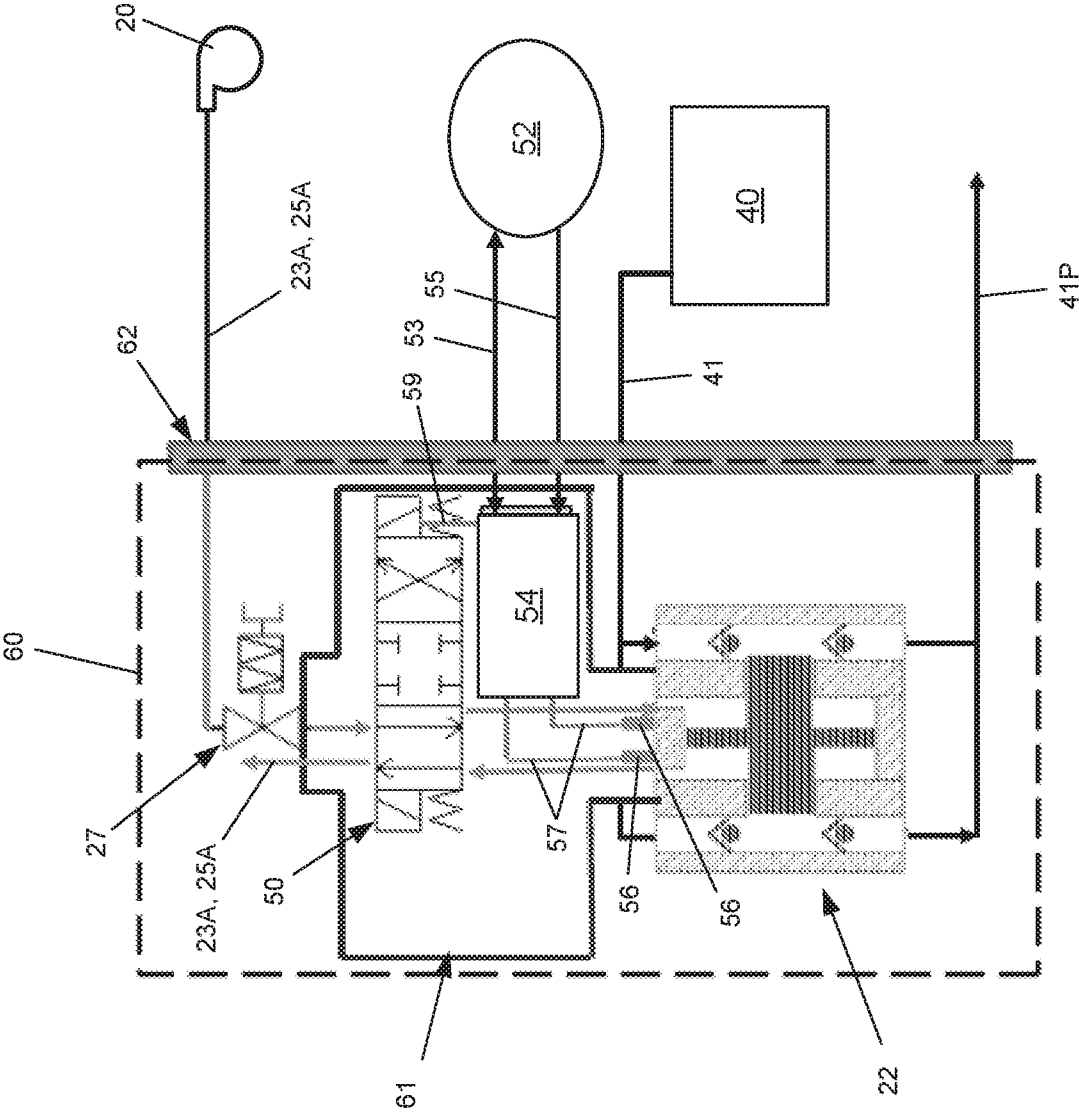


Figure 6

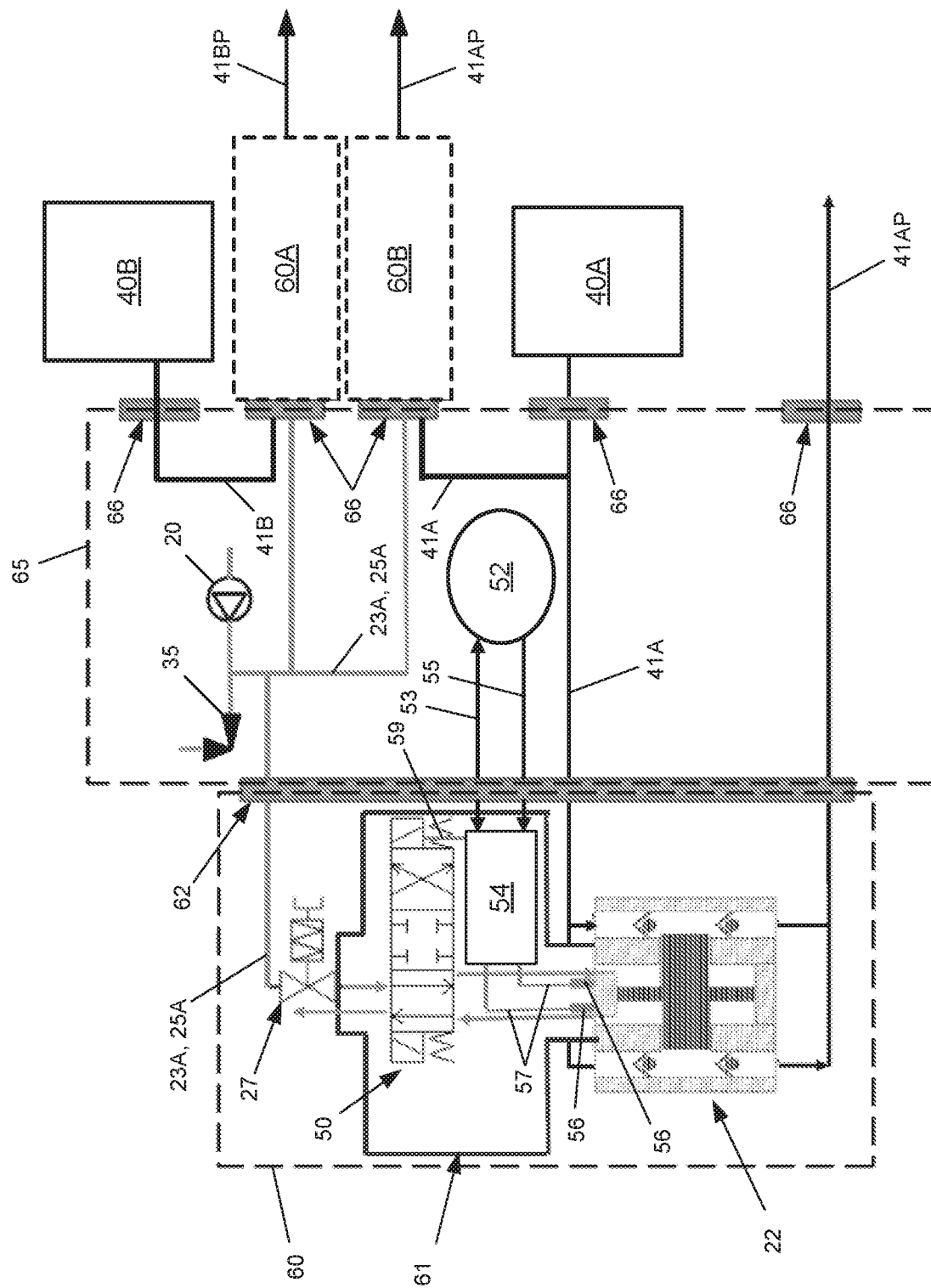


Figure 7

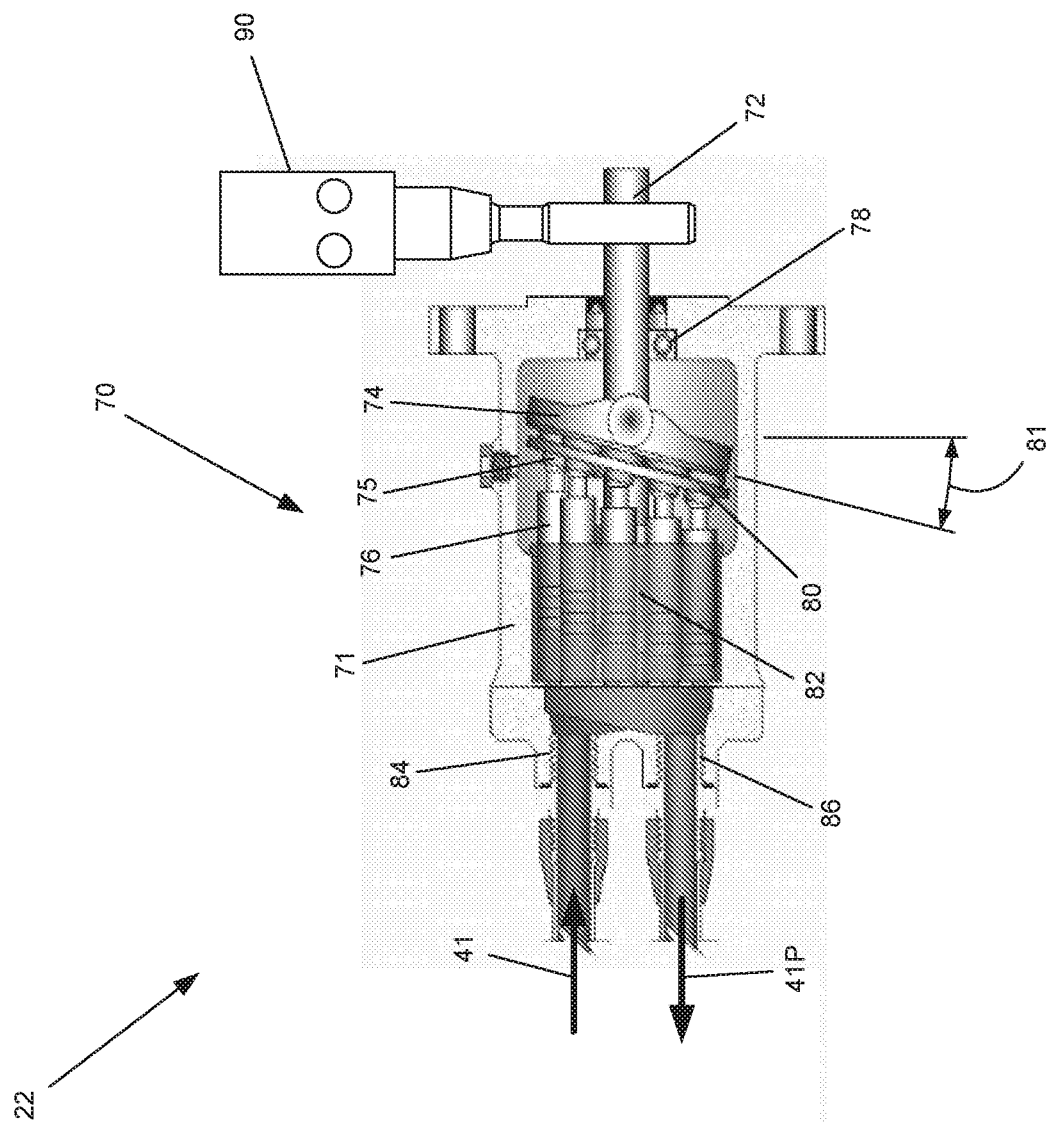


Figure 8

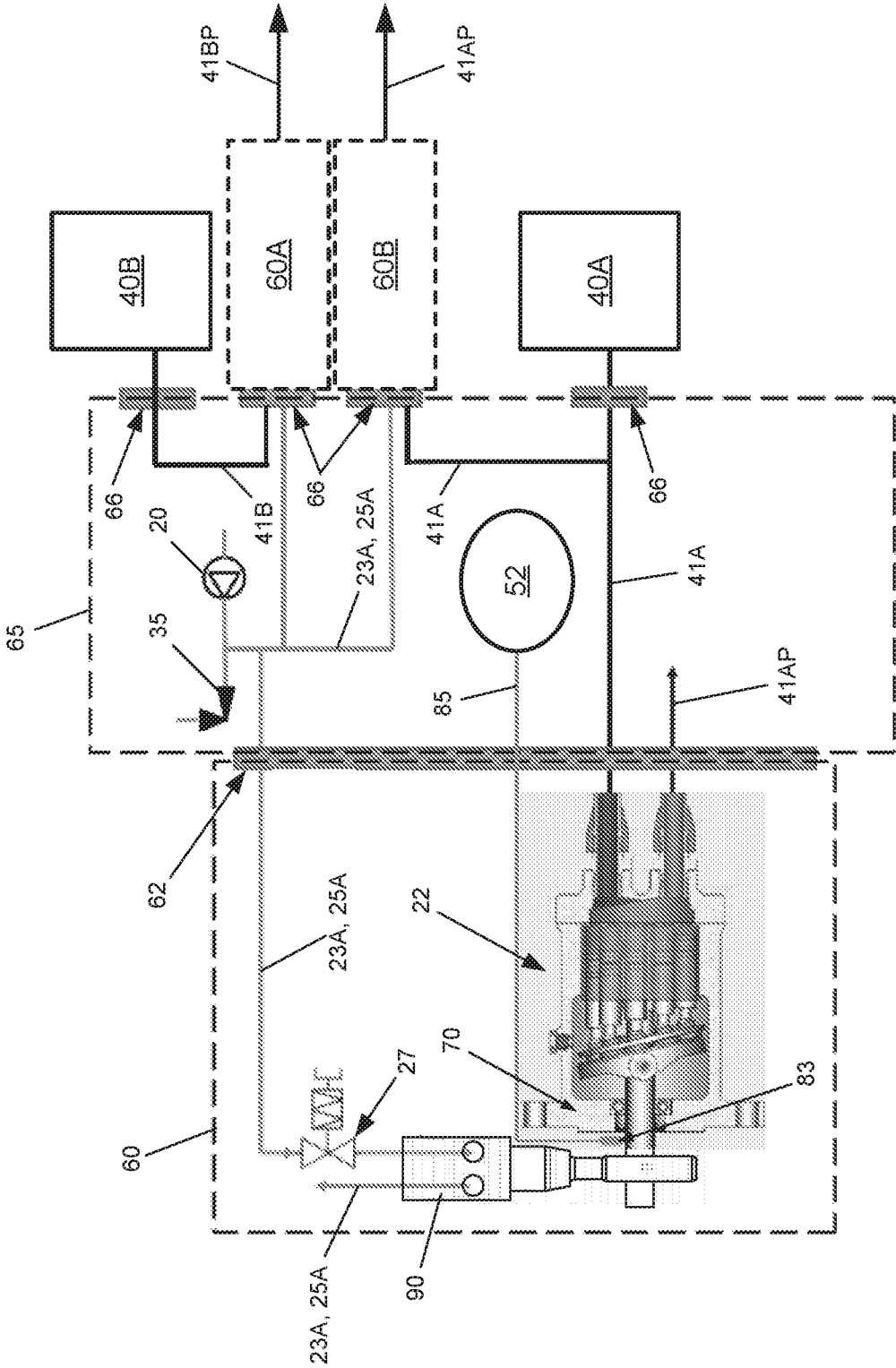


Figure 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/053621

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04B9/103 E21B37/06 E21B41/00 E21B41/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B F04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	NO 20 160 240 A1 (FMC KONGSBERG SUBSEA AS [NO]) 12 February 2016 (2016-02-12) the whole document -----	1-15, 17-27 16
X	US 2008/308270 A1 (WILSON DENNIS R [US]) 18 December 2008 (2008-12-18) paragraph [0067]; figures 1,6,7,10 -----	1
X	WO 2015/070114 A1 (KMT WATERJET SYSTEMS INC [US]) 14 May 2015 (2015-05-14) paragraph [0001] - paragraph [0002] paragraph [0016] - paragraph [0023] figure 4 -----	1
X	US 2006/204375 A1 (JUDGE ROBERT A [US] ET AL) 14 September 2006 (2006-09-14) the whole document ----- -/-	1



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search

18 December 2017

Date of mailing of the international search report

02/01/2018

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Authorized officer

Pieper, Fabian

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/053621

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 2012/101214 A1 (FOELKNER STEIN [NO]) 2 August 2012 (2012-08-02) the whole document -----	13
A	US 2008/264646 A1 (STEN-HALVORSEN VIDAR [NO] ET AL) 30 October 2008 (2008-10-30) paragraph [0033]; figure 3 -----	17-19

INTERNATIONAL SEARCH REPORT

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