MULTIPHASE PUMP FLOW RECIRCULATION SYSTEM

In accordance with certain aspects of the invention, a pump system is provided. The pump system includes a pump casing having a process fluid inlet chamber connected to a process fluid outlet chamber connected to a process fluid outlet through the pump casing. The pump system also includes rotors disposed inside the process fluid inlet chamber and the process fluid outlet chamber. The rotors are configured to pump a process fluid from the process fluid inlet chamber to the process fluid outlet chamber. In addition, the pump casing comprises one or more fluid injection inlets axially located between the process fluid inlet and the process fluid outlet.
FIG. 1
MULTIPHASE PUMP FLOW RECYCLING SYSTEM

BACKGROUND OF THE INVENTION

[0001] The embodiments described herein relate generally to pumps, and more particularly, to injecting fluids at various axial locations of a multiphase twin screw pump.

[0002] Screw pumps are rotary, positive displacement pumps that use two or more screws to transfer high or low viscosity fluids or fluid mixtures along an axis. For example, in one design, a twin screw pump may have two intermeshing counter-rotating rotor screws. The volumes or cavities between the intermeshing screws and a liner or casing transport a specific volume of fluid in an axial direction around threads of the screw. As the screws rotate, the fluid volumes are transported from an inlet to an outlet of the pump. In some applications, twin screw pumps are used to aid in the extraction of oil and gas from onshore and sub-sea wells. Twin screw pumps lower the back pressure on the reservoir and thereby enable greater total recovery from the reservoir. In many cases, a twin screw pump may be used to pump a multiphase fluid from a subsea well which may be processed to produce the petroleum products. One problem that can occur with twin screw pumps is excessive gas slippage at high gas volume fractions. Gas slippage may lead to losses in flow rates and pressure differentials delivered by the twin screw pump. In addition, gas slippage can cause excessive heat due to gas compression.

BRIEF DESCRIPTION OF THE INVENTION

[0003] In accordance with certain aspects of the invention, a pump system is provided. The pump system includes a pump casing having a process fluid inlet chamber connected to a process fluid inlet through the pump casing, and a process fluid outlet chamber connected to a process fluid outlet through the pump casing. The pump system also includes rotors disposed inside the process fluid inlet chamber and process fluid outlet chamber. The rotors are configured to pump a process fluid from the process fluid inlet chamber to the process fluid outlet chamber. In addition, the pump casing comprises one or more fluid injection inlets axially located between the process fluid inlet and the process fluid outlet.

[0004] A method is also provided for operating a pump. The method includes pumping a first fluid along an axis of a pump from an inlet to an outlet. The method also includes injecting a second fluid into the flow of the first fluid through a fluid injection inlet at an axial location between the inlet and the outlet.

[0005] The invention also provides a system having a twin screw pump. The twin screw pump is configured to pump a process fluid from a first axial location to a second axial location. The twin screw pump is also configured to inject an injected fluid into the flow of the process fluid at a third axial location between the first and second axial locations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0007] FIG. 1 is a diagrammatical representation of a screw pump system and a production platform;

[0008] FIG. 2 is a perspective view of a screw pump system, as shown in FIG. 1;

[0009] FIG. 3 is a detailed view of components within a screw pump system, including rotor screws and gears;

[0010] FIG. 4 is a cross-sectional view of a screw pump, illustrating the affect of gas slippage;

[0011] FIG. 5 is a cross-sectional view of a screw pump having a plurality of fluid injection locations;

[0012] FIG. 6 is a graph depicting normalized pressure rise from fluid inlets to a fluid outlet of the twin screw pump at varying levels of gas volume fractions; and

[0013] FIG. 7 is a cross-sectional view of a screw pump having a plurality of fluid injection locations through which the flow of injected fluids may be selectively adjusted.

DETAILED DESCRIPTION OF THE INVENTION

[0014] FIG. 1 is a schematic diagram of a screw pump system 10 that may be provided with a production platform 12 to pump a fluid for processing, storage and/or transport. As illustrated, the screw pump system 10 may be connected to the production platform 12 via a conduit or riser 14 that may be used to route a process fluid to the platform. The process fluid may be a multiphase fluid, such as raw petroleum based fluid from a subsea reservoir. In addition, the screw pump system 10 may be located on a sea or ocean floor 16, wherein the screw pump system 10 pumps the process fluid to a production platform floating on an ocean surface 18, or anchored to the sea floor. As illustrated, the screw pump system 10 may be located a distance 20 from the production platform 12, wherein the pump is used to create the pressure and force needed to pump the process fluid to the surface 18. In another embodiment, the screw pump system 10 may be located near an onshore oilfield and may be configured to direct a multiphase process fluid to holding tanks or other structures for processing or storage. In the illustrated example, the screw pump system 10 may be useful during the extraction of oil and/or gas from subsea wells, to reduce back pressure and assist in the extraction of the oil and/or gas. In the depicted embodiment, the screw pump system 10 uses two intermeshing screws to pump the process fluid. In the example, the screw pump may be referred to as a twin screw pump. As described in greater detail below, in addition to receiving a process fluid into an inlet and discharging the process fluid through an outlet, the screw pump system 10 may be configured to inject an injected fluid at various axial locations within the screw pump system 10. For example, in certain embodiments, the screw pump system 10 may be configured to re-circulate the liquid portion of the process fluid that has been pumped through the screw pump system 10, and re-inject the liquid portion of the process fluid at axial locations other than the inlet of the screw pump system 10.

[0015] FIG. 2 is a detailed perspective view of an embodiment of the screw pump system 10. The screw pump system 10 includes a twin screw pump 22, which includes two screws or rotors used to direct a process fluid at a high pressure to a downstream location. In other embodiments, the screw pump 22 may include more than two screws that intermesh to pump a process fluid. One of the screws may be coupled to a driving shaft 24, which may be coupled to a motor. The motor and the driving shaft 24 produce a rotational output used to drive a driving rotor that is coupled, via a gear, to drive a driven rotor. The moving volumes direct the process fluid downstream, thereby producing the necessary fluid flow and accompany-
ing pressure boost. Often, the pump and rotors will be configured such that thrust loads due to boosting cancel out for the most part, minimizing requirements of thrust bearings used to axially support and locate the rotors. In the forward flow configuration, thrust balancing is accomplished by having the process fluid, such as a petroleum-based multiphase fluid, enter the twin screw pump 22 via fluid inlets 28. By rotating the meshing threads of the rotor screws, the process fluid is driven from the twin screw pump 22 via a fluid outlet 30 to be located at the ends of each of the rotor shafts. The drive rotor 46 and the driven rotor 48 are intermeshing, where threads disposed on rotor shafts interlock to drive a process fluid from the inlet chambers near the peripheral portions of the rotors to an outlet chamber, located near the center of the rotors. Pump bearings are configured to support and enable rotation of the rotors 46 and 48, thereby enabling the process fluid to flow smoothly through the screw pump system 10. The gears 50 may be configured to intermesh, thereby driving the driven rotor 48 by a rotational and mechanical output of the drive rotor 46.

Similarly, the direction of flow may be reversed, flowing from a central inlet to the outlets at opposite ends of the screws, known as a reverse flow configuration. For consistency sake, the embodiments described herein have a forward flow configuration. However, the techniques described herein may similarly be applied to the reverse flow configuration. More specifically, in certain embodiments, the twin screw pump 22 may include either a plurality of fluid inlets 28 with a single fluid outlet 30 (e.g., the forward flow configuration), or a plurality of fluid outlets 30 with a single fluid inlet 28 (e.g., the reverse flow configuration). In either embodiment, as described in greater detail below, the twin screw pump 22 will include one or more fluid injection inlet between each combination of fluid inlet 28 and fluid outlet 30.

More specifically, as illustrated, the twin screw pump 22 includes fluid inlets 28, which direct a process fluid flow 32 to inlet chambers. The inlet chambers are configured to receive the process fluid and, in certain embodiments, may be encompassed by rigid structures or walls, such as bulkhead separators. Further, an outlet chamber is located between the inlet chambers. The outlet chamber may be separated from the inlet chambers by the bulkheads, which enable the management of pressure within and between the respective chambers. The outlet chamber may be configured to direct the multiphase process fluid out through the fluid outlet 30 as the process fluid outflow 34.

The twin screw pump 22 includes an upper end chamber 36 and a lower end chamber 38. The driving rotor shaft 24 is configured to enter the upper end chamber 36 to drive the screw rotors. In addition, the upper end chamber 36 is coupled to an upper radial bearing flange 40. Similarly, the lower end chamber 38 is coupled to a lower radial bearing flange 42. The bearing flanges 40 and 42 are each coupled to a central pump casing cover 44 which may contain the inlet chambers, as well as the outlet chamber. The inlet chambers may be coupled to fluid inlets 28, which route the multiphase process fluid from the sub-sea well or other fluid supply unit. The fluid inlets 28 may be tangentially located with respect to the central pump casing cover 44. Accordingly, the fluid inlets 28 may swirl the process fluid, thereby agitating and mixing particulates within the process fluid to prevent settling and buildup of particulates in the inlet chambers. The fluid outlet 30 is coupled to the outlet chamber and is configured to direct the process fluid out of the twin screw pump 22. In addition, as described in greater detail below, although not illustrated in FIG. 2, the twin screw pump 22 may include a plurality of fluid injection inlets for injecting fluid at various axial locations along the twin screw pump 22.

FIG. 3 is a detailed side view of an embodiment of components included in the twin screw pump 22. As illustrated, the rotors 46 and 48 may be coupled to gears 50 which may be located at the ends of each of the rotor shafts. The drive rotor 46 and the driven rotor 48 are intermeshing, where threads disposed on rotor shafts interlock to drive a process fluid from the inlet chambers near the peripheral portions of the rotors to an outlet chamber, located near the center of the rotors. Pump bearings are configured to support and enable rotation of the rotors 46 and 48, thereby enabling the process fluid to flow smoothly through the screw pump system 10. The gears 50 may be configured to intermesh, thereby driving the driven rotor 48 by a rotational and mechanical output of the drive rotor 46.

In certain embodiments, additional fluids may be introduced into the twin screw pump 22 at axial locations other than the fluid inlets 28. For example, the liquid portion of the multiphase process fluid that has been pumped through the twin screw pump 22 and has exited through the fluid outlet 30 may be re-circulated back into the twin screw pump 22. In certain embodiments, the re-circulated liquid portion of the process fluid may be re-injected at or near the fluid inlets 28 of the twin screw pump 22. However, because the re-circulated process fluid may be at a substantially higher pressure than the process fluid entering through the fluid inlets 28, the pressure of the re-circulated process fluid may need to be reduced before being re-injected, leading to boosting losses and reduction in the overall efficiency of the twin screw pump 22.

The embodiments described herein may use the re-circulated liquid portion of the process fluid in a more efficient manner by re-injecting the re-circulated process fluid at various locations within the pump, for example, at various axial locations along the screw rotors 46, 48. Doing so maximizes the performance of the twin screw pump 22 at the highest gas volume fractions for the longest durations possible. More specifically, the disclosed embodiments maintain pump boosting capabilities of the twin screw pump 22 while boosting up to and including 100% gas for hours at a time, if not longer. It should be noted that, although re-circulated process fluid through the twin screw pump 22 is one type of fluid that may be injected at various axial locations along the twin screw pump, other fluids may be re-injected in the manner described herein. For example, exemplary injected fluids may include various fluids from umbilicals associated with the production platform 12 of FIG. 1, seawater near the screw pump system 10 of FIG. 1, and so forth.

The disclosed embodiments also address two detrimental effects that can occur due to high gas volume fractions in the twin screw pump 22. In particular, at high gas volume fractions, clearances within the twin screw pump 22 may become dry, allowing slippage of the gas through the clearances much more rapidly than the liquid. FIG. 4 is a cross-sectional side view of a twin screw pump 22, illustrating the effect of gas slippage. As illustrated, when clearances 52 between the rotors 46, 48 and an inner casing (or liner) 54 of the twin screw pump 22 and/or between the rotors 46, 48 and the inner casing 54 of the twin screw pump 22 become dry, the gas may slip in a direction opposite the flow direction 56 of the multiphase process fluid, as illustrated by arrows 58. As the gas slips, the performance of the twin screw pump 22 may decline, for instance, through a reduction in the volume flow rate or a reduction in the pressure increase across the twin screw pump 22. It should be noted that the slip tends to occur more between the perimeter of the rotors 46, 48 and the inner casing 54 of the twin screw pump 22 than between the rotors 46, 48.

Another situation that develops at high gas volume fractions is that the gas becomes heated due to compression. With a minimal amount of liquid within the twin screw pump
22, the heat of compression is absorbed by the liquid and the temperature increase within the twin screw pump 22 is limited. However, if the gas volume fraction increases too much, the rotors 46, 48 tend to heat faster than the inner casing 54, causing greater thermal expansion of the rotors 46, 48 than the inner casing 54. If the rotors 46, 48 expand too much with respect to the inner casing 54, rubbing will begin to occur between the rotors 46, 48 and the inner casing 54 and it may be necessary to shut the twin screw pump 22 down to avoid damage. In general, the twin screw pump 22 cannot be designed with larger clearances to accommodate such thermal expansion mismatch, as doing so may adversely affect the performance of the twin screw pump 22 under all operating conditions.

[0024] Re-circulation and/or injection of fluids into the twin screw pump 22 is a solution that may be employed to address the gas slippage and thermal expansion problems described above, and keep the twin screw pump 22 within operable ranges. However, it is also desirable to minimize the amount of re-circulation and/or injection as it may have a negative impact on the volume flow rate delivered by the screw pump system 10. For re-circulation, it is also desirable to minimize the pressure loss from discharge to fluid re-injection, as this represents a source of power loss and inefficiency of the twin screw pump 22. Therefore, it is important to find an appropriate balance with respect to re-circulation and/or injection. An optimal solution is not to displace fluid entering the twin screw pump 22 with re-circulated or injected fluid as this reduces volumetric efficiency, but to ensure that a sufficient amount of liquid exists in the right places within the twin screw pump 22. More specifically, in light of the gas slippage and thermal expansion issues described above, it is important to ensure there is a sufficient amount of liquid where slippage and gas compression occur.

[0025] Therefore, unlike conventional re-circulation techniques, which limit gas volume fractions by delivering liquid to the inlets, the disclosed embodiments deliver liquid in such a way that minimizes the quantity of liquid that is recycled and also minimizes the pressure drop of the recycled liquid. In particular, the pressure differential between re-injected liquid is smaller near the fluid outlet 30 of the twin screw pump 22 than near the fluid inlets 28 of the twin screw pump 22. The disclosed embodiments take advantage of this by re-injecting the liquid at various points between the fluid inlets 28 and the fluid outlet 30 of the twin screw pump 22. The amount of liquid delivered to each point may be passively or actively adjusted to provide sufficient liquid while also minimizing the liquid used and the amount of pressure dropped.

[0026] FIG. 5 is a cross-sectional side view of the twin screw pump 22 having a plurality of fluid injection locations. As described above, the process fluid flow 32 enters through the fluids inlets 28 and is directed into the inlet chambers 60, 62. The rotors 46, 48 then boost the pressure of the process fluid flow 32 and direct the process fluid flow into the outlet chamber 64. The process fluid outflow 34 then exits through the fluid outlet 30. In addition, as illustrated in FIG. 5, additional fluids (e.g., the liquid portion of the process fluid re-circulated back through the twin screw pump 22) may be injected at various axial locations along the twin screw pump 22. For example, in the embodiment illustrated in FIG. 5, additional fluid flows may be injected at various injection locations 66, 68, 70, 72, 74, 76 along the inner casing 54 of the twin screw pump 22. The injection locations 66, 68, 70, 72, 74, 76 are axially located with respect to a central axis 78 between the fluid inlets 28 and the fluid outlet 30. More specifically, the injected fluids are not injected at or near the fluid inlets 28. Locating the injection locations 66, 68, 70, 72, 74, 76 between the fluid inlets 28 and the fluid outlet 30 of the twin screw pump 22 minimizes the losses in pressure drop in cases where the injected fluid is the re-circulated liquid portion of the process fluid.

[0027] In certain embodiments, only one additional fluid flow may be injected through one injection location. 66, 68, 70, 72, 74, 76 on either side of the fluid outlet 30. However, in general, each injection location 66, 68, 70, 72, 74, 76 will have a complimentary injection location 66, 68, 70, 72, 74, 76 on opposite axial sides of the fluid outlet 30. For example, in one embodiment, injection location 66 may be used in addition to injection location 72. Having complimentary injection locations 66, 68, 70, 72, 74, 76 on opposite sides of the fluid outlet 30 cancels out axial forces exerted by and against the components of the twin screw pump 22.

[0028] In other embodiments (e.g., such as the embodiment illustrated in FIG. 5), multiple injection locations on both sides of the fluid outlet 30 may be used. Although illustrated as having three injection locations 66, 68, 70 on one axial side of the fluid outlet 30 and three complimentary injection locations 72, 74, 76 on the opposite axial side of the fluid outlet 30, more or fewer injection locations may be used on either side of the fluid outlet 30. For example, in certain embodiments, the twin screw pump 22 may have 1, 2, 3, 4, 5, 6, or even more injection locations on either side of the fluid outlet 30. In addition, although illustrated as being located on the outlet side 80 of the twin screw pump 22, in other embodiments, the injection locations 66, 68, 70, 72, 74, 76 may be located on the inlet side 82 of the twin screw pump 22.

[0029] As illustrated, each of the injection locations 66, 68, 70, 72, 74, 76 are generally aligned with a respective lock 84 (e.g., a groove between threading of the rotors 46, 48). As such, the injected fluid mixes with the process fluid between the rotors 48 and the inner casing 54 in the respective lock 84. The exact axial locations of the injection locations 66, 68, 70, 72, 74, 76 may be determined based on operating parameters of the twin screw pump 22. More specifically, the injection locations 66, 68, 70, 72, 74, 76 may be selected such that the flow rates of the process fluid through the twin screw pump 22 are maximized, and the pressure drops experienced are minimized. In addition, although illustrated as generally aligned with respective locks 84, in other embodiments, the injection locations 66, 68, 70, 72, 74, 76 may not be aligned with respective locks 84. Rather, the injection locations 66, 68, 70, 72, 74, 76 may be in proximity of a cavity for half a screw rotation, and in proximity of the outer diameter of the rotors 46, 48 for the other half. This is due in part to the helical shape of the rotors 46, 48.

[0030] FIG. 6 is a graph 86 depicting normalized pressure rise from the fluid inlets 28 to the fluid outlet 30 of the twin screw pump 22 at varying levels of gas volume fractions. More specifically, the graph 86 depicts a first normalized pressure rise curve 88 at zero gas volume fractions, a second normalized pressure rise curve 90 at a gas volume fraction greater than zero, a third normalized pressure rise curve 92 at a higher gas volume fraction than the second normalized pressure rise curve 90, and a fourth normalized pressure rise curve 94 at a higher gas volume fraction than the third normalized pressure rise curve 92. Each normalized pressure rise curve 88, 90, 92, 94 depicts the normalized pressure (e.g., “normalized boost”) as (P(x)-P_inlet)/(P_outlet-P_inlet), where x
is the normalized distance along the central axis 78 of the twin screw pump 22 from the fluid inlets 28 to the fluid outlet 30. $P(x)$ is the pressure of the process fluid at axial location $x$, $P_{inlet}$ is the pressure of the process fluid at the fluid inlets 28, and $P_{outlet}$ is the pressure of the process fluid at the fluid outlet 30.

[0031] As illustrated, as the gas volume fraction increases, the normalized pressure rise curve becomes more concave until the gas volume fraction becomes too high. At this point, the clearances 52 described above with respect to FIG. 4 gradually begin allowing gas slippage instead of liquid. At some point, the amount of gas slippage becomes so high that the normalized pressure rise curve reverts back to the first normalized pressure rise curve 88 associated with zero gas volume fractions. However, when the gas slippage increases to these levels, if the twin screw pump 22 is being operated at a fixed $\Delta P$ (e.g., pressure differential), the flow rate delivered by the twin screw pump 22 may be reduced to approximately zero. Alternatively, if the twin screw pump 22 is being operated at a fixed flow rate, the $\Delta P$ (e.g., pressure differential) supplied by the twin screw pump 22 may similarly be dramatically reduced.

[0032] In addition, it should be noted that the amount of gas slippage that occurs is proportional to the slope of the normalized pressure rise curve. The volumetric efficiency of the twin screw pump 22 is determined by the amount of slippage that occurs from the first stage of the twin screw pump 22 (e.g., near the fluid inlets 28), depicted on the normalized pressure drop curves as the normalized distance 98. If there is no $\Delta P$ (e.g., pressure differential) in the first stage, the twin screw pump 22 passes along 100% of the volume of process fluid that it holds. This causes problems at low gas volume fractions, however, the problems may be exacerbated if the twin screw pump 22 runs dry. Conversely, when the twin screw pump 22 is operating efficiently, the liquid slippage (e.g., as opposed to gas slippage) occurs towards the last stage of the twin screw pump 22 (e.g., near the fluid outlet 30), depicted on the normalized pressure drop curves as the normalized distance 98.

[0033] In addition, it should be noted that the slippage occurs from right to left (i.e., from the fluid outlet 30 towards the fluid inlets 28) on the normalized pressure rise curves. As such, injecting fluids closer to the fluid outlet 30 than to the fluid inlets 28 of the twin screw pump 22 may lead to greater increases in process fluid flow rates, overall pressure boosting capabilities, and overall efficiency of the twin screw pump 22. More specifically, in the case of the process fluid being re-circulated and re-injected back into the twin screw pump 22, the amount of boosting work lost is minimized. In other words, because the process fluid is re-injected at injection locations having pressures higher than at or near the fluid inlets 28, the pressure of the re-circulated process fluid does not need to be reduced before being re-injected into the twin screw pump 22. In addition, keeping the pump wet may also help carry away excess heat that occurs due to gas compression.

[0034] Although illustrated in FIG. 5 as utilizing passive injection of fluids into the injection locations 66, 68, 70, 72, 74, 76, in certain embodiments, the flow of fluids through the injection locations 66, 68, 70, 72, 74, 76 of the twin screw pump 22 may be actively and selectively adjusted. For example, FIG. 7 is a cross-sectional side view of the twin screw pump 22 having a plurality of fluid injection locations 66, 68, 70, 72, 74, 76 through which the flow of injected fluids may be selectively adjusted. For example, each of the fluid injection locations 66, 68, 70, 72, 74, 76 may be associated with a respective flow control valve 100, 102, 104, 106, 108, 110, which may be used to control the flow of the injected fluid through the fluid injection location 66, 68, 70, 72, 74, 76. In particular, the flow of the injected fluid may be selectively adjusted whether only one fluid injection location 66, 68, 70, 72, 74, 76 is used on either axial side of the fluid outlet 30, or whether a plurality of fluid injection locations 66, 68, 70, 72, 74, 76 are used on either side of the fluid outlet 30.

[0035] In addition, the screw pump system 10 may include a controller 112 for selectively adjusting the injection flow rate through the fluid injection locations 66, 68, 70, 72, 74, 76. More specifically, the controller 112 may be configured to determine appropriate fluid injection flow rates and to actuate the respective flow control valves 100, 102, 104, 106, 108, 110 to ensure that the fluid injection flow rates are achieved. The controller 112 may, in certain embodiments, be a physical computing device uniquely programmed to actuate the flow control valves 100, 102, 104, 106, 108, 110. More specifically, the controller 112 may include input/output (I/O) devices for determining how to control the flow control valves 100, 102, 104, 106, 108, 110. In certain embodiments, the controller 112 may also include storage media for storing historical data, theoretical performance curves, and so forth.

[0036] In certain embodiments, the controller 112 may determine appropriate fluid injection flow rates based on operating conditions of the twin screw pump 22. For example, one or more sensors 114 may be used to collect data relating to operating parameters (e.g., pressures, temperatures, flow rates, and so forth) of the twin screw pump 22. The data relating to these operating parameters may be delivered to the controller 112, which may use this operating data to determine how to selectively adjust the fluid injection flow rates to optimize the performance of the twin screw pump 22.

[0037] Technical effects of the invention include re-circulating and/or injecting fluids at various axial locations along the twin screw pump 22. Injecting fluid at various axial locations of the twin screw pump 22 may be advantageous for several reasons. For example, the amount of liquid used will be minimized. The liquid that slips between the clearances 52 (e.g., described above with respect to FIG. 4) near the fluid outlet 30 of the twin screw pump 22 tends to continue through the same clearances 52 of the upstream stages (e.g., closer to the fluid inlets 28). Thus, an optimal location for the fluid injection locations 66, 68, 70, 72, 74, 76 is downstream (e.g., near the fluid outlet 30), preferably around the perimeter to wet the clearances 52 between the rotors 46, 48 and the inner casing 54. In addition, as described above, additional injection may occur at upstream locations (e.g., closer to the fluid inlets 28), where appropriate. Additionally, as described above, the gas compresses and heats by virtue of the slippage flow. If the slippage flow is generally liquid, there will always be enough liquid to receive the heat of compression, thereby minimizing the detrimental effects of the heat of compression.

[0038] In addition, the pressure drop of the re-circulated process fluid may be minimized using the disclosed embodiments. Because the re-injected process fluid will be boosted to the discharge pressure of the twin screw pump 22, it is generally more efficient to inject the re-circulated process fluid toward the higher-pressure outlet than at or near the lower-pressure inlet. Additionally, the re-circulation flow rate has an inherent self-adjusting feature. For example, as the gas
volume fraction increases, the compressibility of each stage increases. Accordingly, the pressure rise per unit of slippage or re-injection fluid increases. As such, at low gas volume fractions, the pump cavities accept smaller amounts of flow and the amount of re-circulation received will be reduced. As described above, re-circulation flow splits may be selectively adjusted to provide optimal distribution. The re-circulation to the last stage (e.g., near the fluid outlet 30) may be the most optimal, however, additional flow may also be directed to stages upstream as well. As also described above, the impedance of each re-circulation flow line may be optimized passively (e.g., using orifices or other restrictions) or actively (e.g., using flow control valves). It should also be noted that, for vertically-configured axially-balanced twin screw pumps 22, the requirements for the upper screws may be different from the lower screws.

[0039] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

1. A pump system, comprising: a pump casing having a process fluid inlet chamber connected to a process fluid inlet through the pump casing, and a process fluid outlet chamber connected to a process fluid outlet through the pump casing; and rotors disposed inside the process fluid inlet chamber and the process fluid outlet chamber, wherein the rotors are configured to pump a process fluid from the process fluid inlet chamber to the process fluid outlet chamber; wherein the pump casing comprises one or more fluid injection inlets axially located between the process fluid inlet and the process fluid outlet.

2. The pump system of claim 1, wherein the pump casing comprises a plurality of process fluid inlet chambers connected to a plurality of process fluid inlets or a plurality of process fluid outlet chambers connected to a plurality of process fluid outlets, and a fluid injection inlet axially located between each combination of process fluid inlet chamber and process fluid outlet chamber.

3. The pump system of claim 2, comprising a plurality of fluid injection inlets between each combination of process fluid inlet chamber and process fluid outlet chamber.

4. The pump system of claim 3, comprising a controller configured to selectively adjust the flow rate of fluid through each fluid injection inlet.

5. The pump system of claim 4, comprising sensors configured to communicate operating parameters of the pump system to the controller, wherein the controller selectively adjusts the flow rates of fluid through the fluid injection points based at least in part on the operating parameters.

6. The pump system of claim 5, wherein each fluid injection inlet is associated with a respective flow control valve, and wherein the controller selectively adjusts the flow rates of fluid through the fluid injection points by actuating each respective flow control valve.

7. The pump system of claim 1, wherein the process fluid or some component thereof is re-circulated through the one or more fluid injection inlets.

8. The pump system of claim 1, wherein a fluid other than the process fluid is injected into the one or more fluid injection inlets.

9. The pump system of claim 1, wherein the one or more fluid injection inlets are axially aligned between threading of one of the rotors.

10. A method for operating a pump, comprising: pumping a first fluid along an axis of a pump from an inlet to an outlet; and injecting a second fluid into the flow of the first fluid through a fluid injection inlet at an axial location between the inlet and the outlet.

11. The method of claim 10, wherein the first fluid or some component thereof is re-circulated through the pump as the second fluid.

12. The method of claim 10, wherein the axial location of the fluid injection inlet is selected based on operating conditions of the pump.

13. The method of claim 10, comprising injecting a plurality of fluids into the flow of the first fluid through a plurality of fluid injection inlets at axial locations between the inlet and the outlet.

14. The method of claim 13, comprising selectively adjusting the flow rates of the plurality of injected fluids.

15. The method of claim 14, comprising monitoring operating parameters of the pump, and selectively adjusting the flow rates of the plurality of injected fluids based at least in part on the monitored operating parameters.

16. A system, comprising: a twin screw pump configured to: pump a process fluid from a first axial location to a second axial location; and inject an injected fluid into the flow of the process fluid at a third axial location between the first and second axial locations.

17. The system of claim 16, wherein the process fluid or some component thereof is re-circulated through the twin screw pump as the injected fluid.

18. The system of claim 16, wherein the third axial location is selected based on operating parameters of the twin screw pump.

19. The system of claim 16, wherein the twin screw pump comprises two rotors configured to pump the process fluid from the first axial location to the second axial location, and wherein the third axial location corresponds to a groove between threads of one of the rotors.

20. The system of claim 16, comprising a sub-sea oil and gas extraction system comprising the twin screw pump.

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