

METHOD AND DEVICE FOR INTERFACING WITH SUBSEA PRODUCTION EQUIPMENT

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

5 Generally, the present invention relates to the operation and maintenance of subsea production equipment, and more specifically to devices and methods for interfacing with subsea production equipment during operation.

2. DESCRIPTION OF THE RELATED ART

10 In the oil and gas industry, the properties and characteristics of the various fluids that are produced from oil wells can be critical for a proper understanding and assessment of an oil and/or gas reservoir. For example, in many cases, reliable knowledge of the individual flow rates of the different fluid phases that might be produced from a given well, such as liquid hydrocarbons, gaseous hydrocarbons, and/or water and the like, is often required to facilitate proper reservoir management, optimize overall field development, enable accurate production allocations, and/or ensure that
15 operational control and flow assurance are maintained.

 One conventional approach employed in the oil and gas industry for collecting data on the fluids that are produced from an individual well involves obtaining a material sample from the producing well at the wellhead, and then analyzing the sample to determine its relative multiphase
20 constituents and characteristics. However, such an approach usually involves the use expensive equipment, *e.g.*, test separators, requires periodic intervention by field/test personnel, and does not readily lend itself to continuous monitoring or metering. Furthermore, it should be appreciated that for applications involving subsea completions, at least some of these issues may become even more
25 problematic. For example, the problems associated with obtaining samples from a subsea facility may be formidable, which may include thing such as the difficulty and cost associated with regularly accessing the subsea facility, the possibility of obtaining contaminated samples, and the

environmental concerns associated with sample spillage and/or well leakage at the point of sampling. Additionally, the complexity and/or physical geometry of the hardware associated with a given subsea facility may substantially affect access to the facility's various sampling points when conventional sampling equipment is used. As such, in at least some instances, a test sample may not be readily
5 obtained until the produced fluid has reached the surface through a dedicated test pipeline, where the sampling conditions may be more manageable. However, test samples obtained in this fashion may be degraded to some degree due to changes in temperature or pressure from the conditions at the wellhead, and/or the test samples may be contaminated by residual fluids that might still be present in the test pipeline from previous well tests or by corrosion byproducts from the test pipeline.

10 Furthermore, some subsea facilities involve multiple different wells, each of which may be producing fluids from different locations within a given reservoir or formation, or even from different formations. Moreover, in such cases each of the several different producing wells may be owned by different owners, and/or operated by different operators. However, as is the case in most subsea
15 installations, the fluids produced from any one of these several different wells are usually routed to a common production manifold or other similar structure, where they are then mixed with the fluids from other wells in the field before flowing through a single production pipeline to a central production platform. When, as noted above, a fluid sample is then obtained at the central production platform and tested, it may provide relative information on the mixture of fluids being produced from
20 the subsea installation as a whole, but that information may not be representative of any one particular well within the field. The issues associated with obtaining test samples from a mixture of several different production fluids are sometimes avoided by utilizing the production manifold valving to individually divert the various production fluids from the production manifold header to a test header. From there, a second line, *e.g.*, a dedicated test pipeline as noted above, can be used to send the
25 individual test samples to the surface. However, the sample degradation and environmental contamination issues described above still remain.

As may be appreciated, the characteristics and quantity of fluids that are produced from each of the wells in a given subsea installation may be different – and in some cases, significantly different. For example, a first well may produce fluids with a high percentage of liquid hydrocarbons and a relatively low percentage of produced water and/or noxious or corrosive gases, *e.g.*, hydrogen sulfide and the like. On the other hand, a second well in the same subsea installation may be drilled to a different depth within the same formation, or it may be drilled in an entirely different formation, and it may therefore produce fluids having substantially different characteristics, *e.g.*, a lower percentage of liquid hydrocarbons, or a higher percentage of gaseous hydrocarbons, or more produced water, or more hydrogen sulfide, etc. In such cases the second well may be considered to be less economically productive, and/or it may have a relatively higher operating and maintenance costs. Accordingly, it would be beneficial to have a clear understanding of the quantity and characteristics of the fluids that are produced from each individual well before they are combined with the fluids from other wells in the same subsea installation in the manifold or the pipeline leading to the production platform, so that each well might be properly evaluated on its own merits.

In recent years, the oil and gas industry has increasingly looked to the use of multiphase flow meters (MPFM's) in subsea applications as a valuable tool in assisting with the evaluation and assessment of the various individual producing wells in given subsea facility, and to offset the cost of a dedicated test pipeline. In practice, a different MPFM may be incorporated into the wellhead equipment for each individual producing well in a given subsea installation, where it is able to provide continuous information on the flow rates of the multiple fluid phases that are produced from the well, thereby facilitating at least some of the reservoir management goals described above. However, it should be appreciated that the fluid characteristics from any single producing well may vary over the effective life of the well, *e.g.*, the liquid hydrocarbon rate may decrease while the produced water rate increases, etc. Multiphase flow meters are generally calibrated and adjusted for greatest accuracy within a predetermined range of a given well's produced fluid properties, and when the actual characteristics of the produced fluids deviates from that predetermined range, measurement accuracy

may be compromised. Furthermore, measurement accuracy may also drift over time, should recalibration efforts based on actual fluid properties, *e.g.*, from test samples, become less frequent. Accordingly, it may still be necessary to periodically obtain specific fluid samples from each producing well so as to ensure that calibration and adjustment of a dedicated MPFM for a particular well is maintained within the appropriate accuracy range, although typically the sampling frequency is not generally as often as may have been previously required.

Figures 1A-1C schematically depict an illustrative prior art sampling system 110 that has been used in subsea oil and gas applications to obtain test fluid samples from a producing subsea well. As shown in Fig. 1A, the sampling system 110 includes a sampling tool 100 that, in a subsea environment, is typically mounted on and carried by a schematically-depicted underwater remotely operated vehicle (ROV) 130. Typically, the sampling tool has a height 109, a length 117, and a width 116. While different specific design configurations of the sampling tool 100 have been used in some prior art applications, both the height 109 and the length 117 of the sampling tool 100 typically range on the order of approximately 3-4 feet, whereas the width 116 is approximately 6-7 feet.

With reference to Fig. 1B, the ROV 130 is used to position the sampling system 110 adjacent to a side 159 of a piece of subsea equipment, such as a subsea structure 150, where a corresponding interface point, such as, for example, a sample coupling 151, is located. The sampling tool 100 includes docking probes 105 that are used to dock the sampling tool 100 to the subsea equipment, *e.g.*, the subsea structure 150, as the ROV 130 moves the sampling system 110 into place adjacent to the side 159. Also as shown in Fig. 1A, a belly skid 140 is mounted on the bottom side of the ROV 130, where additional equipment (not shown) necessary to operate the sampling system 110 may be located, such as pumps, valves, hydraulic and/or electrical equipment, containment bottles, purging equipment, and the like. In other applications, the sampling tool 100 may be mounted to the front side of belly skid 140 instead of to the front side of the ROV 130 as illustrated in Figs. 1B and 1C, in

which case the belly skid 140 may still be positioned below and mounted to the bottom side of the ROV 130 as shown in Fig. 1A.

The sampling tool 100 includes a sample coupling 101 having an axis 101x, one or more sample bottles 102, and a fluid communication system 103 (schematically depicted in Fig. 1A) that can provide fluid communication between the sample coupling 101 and the sample bottles 102. The fluid communication system 103 may include various pipes, conduits, tubing, fittings, valves and/or other typical piping system components and the like, which thereby allow a flow of a test fluid sample to move from the sample coupling 101 to the sample bottles 102.

Figure 1B schematically illustrates an elevation view of the sampling system 110 positioned adjacent to a piece of subsea equipment, *e.g.*, a wellhead 150, with the sampling tool 100 mounted on the front side 130a of the ROV 130. The subsea structure 150 is positioned above the sea floor 190, and includes a schematically depicted Christmas tree 154 for controlling the flow of production fluid out of a producing oil and gas well 170. The subsea structure 150 includes docking receptacles 155 that are sized and positioned to engage the corresponding docking probes 105 on the sampling tool 100. In one example, the subsea structure 150 also includes a sample coupling 151 that is sized and positioned to engage the sample coupling 101 on the sampling tool 100 when the docking probes 105 are docked with the docking receptacles 155, while an axis 151x of the sample coupling 151 is aligned with the axis 101x of the sample coupling 101. The subsea structure 150 also includes a fluid communication system 153 (schematically depicted in Fig. 1B) that can provide fluid communication between the production fluid that is being produced from the well 170, *e.g.*, from the Christmas tree 154, and the sample coupling 151, thereby allowing a test fluid sample to flow to the sample coupling 101 on the sampling tool 100, and thereafter to the sample bottles 102 via the fluid communication system 103.

Figure 1C schematically depicts a plan view of the sampling system 110 of Fig. 1B positioned adjacent to the side 159 of the subsea structure 150. As shown in Fig. 1C, the side 159 of the subsea structure 150 has a width 157 as presented to the approaching ROV 130 with the sampling tool 100 mounted thereon. The docking probes 105 and docking receptacles 155 are separated along the side 159 of the subsea structure 150 by a distance 156. Furthermore, the sampling tool 100 has an overall width 116, and the ROV 130 has an overall width 136.

Depending on the specific design and overall configuration of the subsea equipment where test fluid samples are obtained, *e.g.*, the subsea structure 150, the width 157 may be in the range of approximately 10-12 feet, and the distance 156 between the docking probes 105 and docking receptacles 155 may be on the order of 5-6 feet. Furthermore, as noted above, the width 116 of the sampling tool 100 may be about 6-7 feet, while the width 136 of the ROV 130 may be approximately 7-8 feet. Accordingly, it should be appreciated that in many applications, the sampling system 110, which includes both the sampling tool 100 and the ROV 130, can take up a significant amount of the available space, *e.g.*, the width 157, of the subsea structure 150 along the side 159 during the docking and sampling operations.

Also as shown in Fig. 1C, sampling system 110 has an overall length 138 that, in some applications, may be approximately 15-16 feet, or even greater. Furthermore, in order to ensure a proper approach during the docking activity, the sampling system 110 generally requires an appropriately sized docking space in front of the side 159 of the subsea structure 150 that has a docking space length 139 on the order of 25-30 feet, or even greater, depending on several factors such as the class (*e.g.*, size) of the ROV 130, and/or the type and proximity of any adjacent subsea equipment, and the like. Moreover, the axis 101x of the sample coupling 101 must be closely aligned with the axis 151x of the coupling 151, which means that the entire sampling system 110 – including the ROV 130 – must also be so aligned during at least the final portion of the ROV's approach to the subsea structure 150 during the docking operation. As such, it should be appreciated that the ROV-

mounted prior art sampling tool 100 shown in Figs. 1A-1C may not be readily adaptable to existing subsea equipment installations, due at least in part to the docking space and alignment requirements described above. Furthermore, even in new subsea installations that are specifically designed to accommodate an ROV-mounted sampling system, such as the sampling system 110, the sampling activities may be subject to some operational restrictions, also due at least in part to the vehicle docking limitations noted above.

During the sampling operation, it should be appreciated that any fluid samples that are taken from the producing subsea equipment should be extracted in such a state as to reflect the actual fluid components and/or conditions or the producing well 170 as closely as possible, so that any calibrations and/or adjustment to the MPFM's that are made based on the tested properties of the fluid samples result in metering accuracy. However, in some prior art applications, if the sample bottles used to store the extracted fluid samples (such as the sample bottles 102 of the sampling tool 100) are separated from the sampling point (such as the sample coupling 101) by too great a distance, some degree of fluid component separation and/or sample degradation may occur, which could thereby affect testing accuracy and subsequent MPFM adjustments. For example, in the prior art sampling system 110 illustrated in Figs. 1A-1C, the sample bottles 102 may be separated from the sample coupling 101 by a distance 112 such that the total flow distance that a test sample must flow through the fluid communication system 103 in order to reach a respective sample bottle 102 may be in the range of approximately 4-5 feet or even greater. Such a large flow distance may be significant enough to impact the quality of the test sample and the subsequent accuracy of any testing results.

Figures 2A-2C schematically depict another illustrative prior art sampling system 210 that includes a sampling tool 200, which is made up of a sample coupling 201 having an axis 201x, a sample bottle 202, and a fluid communication system 203 (schematically depicted in Fig. 2A) that can provide fluid communication between the sample coupling 201 and the sample bottle 202. In some cases, the sampling tool 200 is held by a robotic manipulator arm 231 that is mounted an underwater

ROV 230. The sampling tool 200 generally has a height 209 that is approximately 5-6 feet, a length 217 of about 2½-3 feet, and a width 216 that ranges from 2-4 feet, as more fully described below. Accordingly, unlike the prior art sampling tool 100 of Figs. 1A-1C described above, which typically has its greatest dimension along a substantially horizontal direction, *i.e.*, the tool's width 116, the sampling tool 200 shown in Fig. 2A-2C has its greatest dimension along a vertical direction, *i.e.*, the tool's height 209

Figure 2B schematically illustrates an elevation view of the sampling system 210 positioned adjacent to a piece of subsea equipment, *e.g.*, a wellhead 250, with the sampling tool 200 being held by the manipulator arm 231 mounted on the front side of the ROV 230. As with the prior art sampling system 110 of Figs. 1A-1C, the ROV 230 is used to position the sampling system 210 adjacent to a side 259 of, for example, a subsea structure 250, where a corresponding sampling point, such as a sample coupling 251, may be located. A belly skid 240 is mounted on the bottom side of the ROV 230, where additional equipment (not shown) necessary to operate the sampling system 210 may be located. The sampling tool 200 is connected to the belly skid 240 by umbilicals 206, which provide electrical, hydraulic, and/or fluid communication between the sampling tool 206 and the various pieces of support equipment 241 located on the belly skid 240.

With continuing reference to Fig. 2B, the subsea structure 250 includes a sample coupling 251 for engaging the sample coupling 201 on the sampling tool 200, during which time an axis 251x of the sample coupling 251 is aligned with the axis 201x. The subsea structure 250 also includes a fluid communication system 253 (schematically depicted in Fig. 2B) that can provide fluid communication between the production fluid that is being produced from the well 270, *e.g.*, from a Christmas tree 254, and the sample coupling 251 so that a test fluid sample can flow to the sample coupling 201 on the sampling tool 200, and thereafter to the sample bottle 202 via the fluid communication system 203.

As shown in Fig. 2B, the prior art sampling tool 200 has a substantially vertical packaging configuration, and the manipulator arm 231 is connected to the sampling tool 200 near an upper end 200 thereof. As noted above, the sampling tool has a height 209 that typically ranges from approximately 5-6 feet. Furthermore, the subsea structure 250 has a height 269, which may extend above the sea floor 290 approximately 8-10 feet, and the sample coupling 251 is positioned on the subsea structure 250 so as to provide adequate clearance 209c between the bottom 200b of the sampling tool 200 and the sea floor 290 while the sampling tool 200 is docked with the subsea structure 250. Accordingly, due to the height 209 of the sampling tool 200 relative to the height 269 of the subsea structure 250, viable locations for the sample coupling 251 may be limited, *i.e.*, to an upper portion of the subsea structure 250. Moreover, it should also be appreciated that, when docked, the sampling tool 200 may take up a significant portion of the vertical space that is available on the side 259 of the subsea structure 250, which may thereby limit the positioning of other equipment and/or access points on the subsea structure 250.

Figure 2C schematically depicts a plan view of the sampling system 210 of Fig. 2B positioned adjacent to the side 259 of the subsea structure 250. As shown in Fig. 2C, the side 259 of the subsea structure 250 has a width 257 as presented to the approaching sampling system 210 that may be on the order of 10-12 feet. The sampling tool 200 has an overall width 216 that ranges from approximately 1-2 feet at the upper end 200u, and approximately 4 feet at a lower end 200b (see, Fig. 2B), and as previously noted a length 217 on the order of approximately 2-2½ feet.

It should be appreciated that, even though the sampling tool 200 is supported by the manipulator arm 231 (instead of being directly mounted to an ROV as in the prior art sampling system 110), the sampling system 210 still requires an appropriately sized docking space in front of the side 259 of the subsea structure 250 so as to perform the requisite ROV approach and coupling/docking activities. Accordingly, the docking space length 239 adjacent to the side 259 may also be approximately 25 feet or even greater. As such, it should be appreciated that the manipulator arm-

supported sampling tool 200 shown in Figs. 2A-2C may not be readily adaptable to many existing subsea equipment installations, due at least in part to the docking space requirements described above.

5 Additionally, as shown in Fig. 2B, the sample bottle 202 is separated from the sample coupling 201 by a distance 212. In some cases, due to the overall size of the substantially vertically packaged sampling tool 200 as described above, the distance 212 can correspond to a total flow distance that a flow sample must flow through the fluid communication system 203 so as to reach the sample bottle 202 that is in the range of approximately 5-6 feet, or even greater. As noted previously, such a large flow distance can detrimentally affect the quality of the test sample the resulting accuracy
10 of any testing.

Moreover, as may be appreciated by those of ordinary skill in the art, the strength and load-carrying capacity of robotic manipulator arms that might typically be used on ROV's in subsea applications, such as the manipulator arm 231, is somewhat limited. For example, a typical ROV-
15 supported manipulator arms may have a maximum load capacity of approximately 250-600 pounds while undergoing an arm extension in the range of approximately 4-6 feet. On the other hand, in some cases the prior art sampling tool 200 may weigh as much as 500-1000 pounds. As such, the capabilities of the manipulator arm 231, including how far it may have to reach, can limit how and where the sampling tool 200 may be positioned relative to the ROV 230, due at least in part to the
20 load-carrying capacity of the manipulator arm 231. Furthermore, the size of the load and the distance it may have to be extended during the docking operation can also adversely affect the pitch (tilt) of the ROV 230, or change the center of buoyancy/gravity of the ROV 230. Accordingly, in the prior art sampling system 210 illustrated in Figs. 2A-2C, the manipulator arm 231 is generally only used to extend to sampling tool 200 relatively short distances away from the ROV 230, such as in the range of
25 about 2-3 feet. Furthermore, due to the relatively large overall size and weight of the sampling tool 200, the manipulator arm 231 generally does not have sufficient strength to rotate the sampling tool 200 into a non-vertical, *e.g.*, substantially horizontal, orientation, and as such the sampling tool 200 is

typically only supported and maintained in a substantially vertical orientation (as shown in Figs. 2A and 2B).

As may be appreciated, the overall size and maneuverability of the prior art systems described above present various restrictions and limitations on their use in at least some subsea production applications. Additionally, sample spillage and/or well leakage to the surrounding environment during the docking and sampling operations remains a matter of great concern. Accordingly, there is a need to develop equipment and methods that may overcome, or at least mitigate, one or more of the problems associated with the subsea production equipment interfacing operations outlined above.

SUMMARY OF THE DISCLOSURE

The following presents a simplified summary of the present disclosure in order to provide a basic understanding of some aspects disclosed herein. This summary is not an exhaustive overview of the disclosure, nor is it intended to identify key or critical elements of the subject matter disclosed here. 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 systems and methods for interfacing with subsea production equipment during operation. In one illustrative embodiment, a fluid sealing and transfer element is disclosed that includes, among other things, a flow body having a first end and a second end, a first flow groove proximate the first end, and a second flow groove proximate the second end. The illustrative fluid sealing and transfer element further includes first and second flow passages passing through the flow body, wherein the first flow passage intersects the first flow groove and the second flow passage intersects the second flow groove. Moreover, the fluid sealing and transfer element disclosed herein also includes and a third flow passage passing through the flow body, wherein the third flow passage intersects the first and second flow passages and facilitates fluid communication between the first and second flow grooves.

Also disclosed herein is an illustrative flow control system that is adapted to establish fluid communication between an interface tool and an equipment item, the flow control system comprising a movable transfer tube sealing cartridge having a first end, a second end, and a plurality of flow passages that are adapted to facilitate fluid flow between the first end and the second end. Additionally, the disclosed flow control system includes a movement apparatus that is adapted to move the movable transfer tube sealing cartridge to a flow position so as to facilitate fluid flow between a first flow channel of the equipment item and a second flow channel of the interface tool.

In another illustrative embodiment, an interface tool that is adapted to interface with an equipment coupling on subsea equipment is disclosed, the interface tool including an interface coupling that is adapted to be removably coupled to the equipment coupling on the subsea equipment during a coupling operation. Additionally, the interface tool also includes, among other things; and a flow control system that is adapted to establish fluid communication between the interface tool and the subsea equipment after the coupling operation. Moreover, the flow control system of the illustrative interface tool includes a fluid sealing and transfer element that is adapted to replace a replaceable fluid sealing and transfer element that, prior to the coupling operation, is positioned in the equipment coupling.

The present subject matter also discloses a system that is adapted to interface with subsea equipment, wherein the system includes an interface tool having an interface coupling, the interface coupling being adapted to be removably coupled to an equipment coupling on the subsea equipment during a coupling operation. Furthermore, the interface tool of the illustrative system disclosed herein also includes a fluid transfer element that is adapted to facilitate fluid communication between the interface tool and the subsea equipment after the coupling operation, the fluid transfer element being further adapted to replace a replaceable fluid transfer element that, prior to the coupling operation, is positioned in the equipment coupling. Additionally, the illustrative system disclosed herein also

includes, among other things, a manipulator arm that is adapted to support and position the interface tool during the coupling operation.

BRIEF DESCRIPTION OF THE DRAWINGS

5 The disclosure may be understood by reference to the following description taken in conjunction with the accompanying drawings, in which like reference numerals identify like elements, and in which:

10 Figures 1A-1C schematically illustrate a representative prior art system for obtaining production fluid test samples from a subsea structure;

 Figures 2A-2C schematically illustrate another representative prior art system for obtaining production fluid test samples from a subsea structure;

15 Figures 3A-3E schematically depict an embodiment of an illustrative system that is used to interface with subsea production equipment in accordance with the presently disclosed subject matter;

 Figure 4A is a component block diagram of an illustrative interface system of the present disclosure;

20 Figure 4B is a fluid schematic diagram of the interface system illustrated in Fig. 4A;

 Figures 5A-5G depict various aspects of an illustrative interface system disclosed herein;

25 Figures 6A-6H illustrate various aspects of an embodiment of a transfer tube sealing cartridge that may be used in conjunction with some illustrative embodiments of the present disclosure;

Figures 7A-7C shows some aspects of yet another illustrative interface configuration of the present disclosure;

Figure 8 schematically depicts various illustrative interface points for some illustrative types of subsea production equipment; and

Figure 9 schematically depicts various illustrative interface points for an illustrative subsea separator vessel.

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 invention 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 invention as defined by the appended claims.

DETAILED DESCRIPTION

Various illustrative embodiments of the present 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 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.

Generally, the subject matter disclosed herein is directed to various devices and methods for interfacing with subsea production equipment during operation. For example, in some illustrative embodiments, a subsea equipment interface system is disclosed that may be used to extract production fluid test samples from equipment in a subsea oil and gas installation during equipment operation without contaminating the sample to any appreciable degree, and without causing or permitting spillage of any appreciable amount of the production fluid to the subsea environment. Additionally, the disclosed system may also have fluid reservoirs of such a size so that any contaminants that may be present in various the lines that are used to extract the test fluid samples may be substantially flushed and/or isolated prior to sample extraction. Furthermore, the disclosed equipment system may also be arranged in a substantially compact configuration so as to minimize the length of the flow path along which the test samples must flow during sample extraction, thereby reducing sample separation, degradation, and/or contamination and the like.

In other embodiments, the disclosed subsea equipment interface system may also be used to perform equipment clean-out operations, *e.g.*, removing sand and/or other solids materials from separator equipment and the like. In still other illustrative embodiments, the subsea equipment interface system of the present disclosure may be used to perform other intervention activities on subsea equipment, such as, chemical injection and/or hydrate remediation at, for example, pipeline end termination (PLET) structures, subsea piping manifolds, and the like.

It should be noted that, where appropriate, like reference numbers shown in Figs. 3A-7C and used to describe the various embodiment set forth below generally refer to like elements. For example, the sampling tool “300” substantially corresponds to the sampling tools “400,” “500,” “600,” and “700,” the sample coupling “301” substantially corresponds to the sample couplings “401,” “501,” “601,” and “701,” the umbilicals “302” substantially correspond to the umbilicals “402,” “502,” “602,” and “702,” and so on. Accordingly, the reference number designations used to identify some elements of the presently disclosed subject matter may be illustrated in Figs. 3A-7C, but may not be specifically described in the following disclosure. In those instances, it should be understood that the numbered elements shown in Figs. 3A-7C which are not specifically described in detail below may substantially correspond with their like-numbered counterparts illustrated in other illustrative embodiments and described in the associated disclosure.

Figures 3A-3E depict various aspects of various embodiments of a subsea equipment interface system disclosed herein. Figures 3A and 3B schematically depicts an illustrative subsea equipment interface system 310 of the present disclosure that, in certain embodiments, may be adapted to obtain production fluid test samples from a piece of subsea production equipment, such as the subsea structure 350, which may be for example, a wellhead structure and the like. The interface system 310, may include an interface tool 300, which in the present embodiment may be, for example, a sampling tool (hereinafter, a sampling tool 300). The sampling tool 300 may include, among other things, an interface coupling 301, *e.g.*, a sample coupling 301, that has an axis 301x and is adapted to interface

with a corresponding sample coupling 351 (see, Fig. 3B) on the subsea structure 350. Furthermore, the sampling tool 300 may also include one or more sample bottles 302, and in some embodiments may also include a fluid communication system 303 (schematically depicted in Fig. 3A) that may be adapted to provide fluid communication between the sample coupling 301 and the one or more sample bottles 302. In certain illustrative embodiments, the sample bottles 302 may have a volume of approximately 0.5 liters so as to provide a sufficient sample size for all requisite testing, although sample bottles 302 having either a larger or a smaller volume may also be used. The fluid communication system 303 may include various piping system components (not shown) as may typically be used in a representative fluid communication system, such as pipes, tubing, conduits, flow channels, fittings, valves and the like, which may be adapted to control a flow of a fluid test sample from the sample coupling 301 to the one or more sample bottles 302. The fluid communication system 303 schematically depicted in Fig. 3A will be described in further detail with respect to Figs. 4A and 4B below.

In certain embodiments, the interface system 310 includes a robotic manipulator arm 331 that is adapted to support the sampling tool 300 by a handle 307, such as a T-bar handle and the like, that is adapted to releasably grasp the sampling tool 300. In some illustrative embodiments, the manipulator arm 331 may be operatively mounted on an underwater remotely operated vehicle (ROV) 330, both of which may be operated by personnel located on surface ship, a production platform, and the like, in a typical manner as is well known in the art. The interface system 310 may also include belly skid 340 that is removably coupled to the bottom side of the ROV 330, and which may contain additional equipment 341 (schematically shown in Figs. 3B-3E) that may be necessary to operate and/or control the sampling tool 300, such as pumps, valves, hydraulic and/or electrical equipment, containment bottles, purging equipment, and the like. Additionally, in at least some embodiments, the sampling tool 300 may be operatively connected to the belly skid 340 by a plurality of umbilicals 306, which may include hoses that can be used to flush or purge the fluid communication system 303, electrical cables to provide power to the sampling tool 300, and/or hydraulic or pneumatic lines to

provide operational control. Furthermore, in those embodiments wherein the umbilicals 306 include hoses for flushing or purging the fluid communication system 303, the umbilicals 306 may be heated, *e.g.*, with electrical heating coils (see, *e.g.*, Fig. 4A, described below), and/or wrapped in insulation, so as to substantially prevent or at least reduce the possibility that any hydrates that may be present in the production fluid may freeze as the production fluid travels from the sample coupling 301 to the equipment located in the belly skid 340 during the purging process.

Generally, the sampling tool 300 is significantly smaller than the comparable prior art sampling tools 100 and 200 described above. For example, in some illustrative embodiments, the sampling tool 300 may have length 317 and width 316 dimensions on the order of approximately 2 feet or less, and a height 309 of about 1-1½ feet or even smaller, although other sizes may also be used. Furthermore, in certain embodiments the sampling tool 300 may weigh approximately 50-100 pounds or even less, depending on the specific design of the sample coupling 301, the number of sample bottles 302, the size and extent of the fluid communication system 303, and the like. Accordingly, it should be appreciated that the smaller, lighter sampling tool 300 may impose significantly fewer limitations and/or restrictions on the manipulator arm 331, as compared to, for example, the prior art system 210 described above.

Figure 3B schematically depicts an elevation view of the interface system 310 of Fig. 3A as the sampling tool 300 is being positioned adjacent to a side 359 of the subsea structure 350. The subsea structure 350 is positioned above the sea floor 390 and has an overall a height 369 relative to the sea floor 390 that, depending on the wellhead design, may range from 8-10 feet. Additionally, the subsea structure 350 may include flow control equipment 354, *e.g.*, a subsea Christmas tree 354, for controlling the flow of production fluid out of an oil and gas well 370. As previously noted, the subsea structure 350 may include a respective sample coupling 351 having an axis 351x that is adapted to engage the sample coupling 301 on the sampling tool 300 so that a production fluid test sample may be obtained from the well 370. The subsea structure 350 may also include a fluid communication system 353 (schematically depicted in Fig. 3B) that may be adapted to provide fluid

communication between the production fluid that is being produced from the well 370, *e.g.*, from the Christmas tree 354, thereby allowing a fluid test sample to flow to the sample coupling 301 on the sampling tool 300, and thereafter to the one or more sample bottles 302 via the fluid communication system 303.

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As noted previously, the sampling tool 300 may be substantially smaller than, for example, the prior art sampling tool 200 described above. It should therefore be appreciated that the relatively smaller size of the sampling tool 300 may thereby facilitate easier handling and manipulation of the sampling tool 300 by the manipulator arm 331 during docking operations of the sample coupling 301 to the sample coupling 351 on the subsea structure 350. For example, in certain illustrative
10 embodiments, the reduced size of the sampling tool 300 may enable the manipulator arm 331 to more readily align the axis 301x of the sample coupling 301 with the axis 351x of the sample coupling 351 during the coupling operation.

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Figure 3C is a plan view of the illustrative embodiment depicted in Fig. 3B, and shows the sampling tool 300 positioned adjacent to the side 359 of the subsea structure 350. The side 359 of the subsea structure 350 has a width 357 that, in some embodiments, may be on the order of approximately 10-12 feet, although the various types of equipment that may be used in subsea application may have a variety of different widths 357. As shown in Fig. 3C, the sampling tool 300
20 has a width 316 as presented to the side 359 of the subsea structure 350, which, in some illustrative embodiments may be approximately 2 feet or even less, as previously described. Therefore, the width 316 of the sampling tool 300 may be significantly less than the comparable widths 116 and 216 of the prior art sampling tools 100 and 200, respectively, as shown in Figs. 1A-1C and 2A-2C. As a result, less space may have to be made available along the side 359 of the subsea structure 350 so as to dock
25 the sampling tool 300 and to perform the test fluid sampling activities described herein.

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Moreover, due to the substantially compact design of the sampling tool 300, the distance 312 between the sample coupling 301 and the sample bottle 303 may be substantially less than, for example, the comparable distances 112 and 212 of the prior art sampling systems 100 and 200, respectively. As such, the total flow distance that a test sample must flow through the fluid communication system 303 in order to reach a respective sample bottle 302 may be also be substantially reduced, and in certain illustrative embodiments may be on the order of only 2-3 feet, or even less. Furthermore, in at least some embodiments the flow distance may be less than approximately 1 foot. As such, the possibility that some amount of fluid component separation and/or sample degradation may occur when using the sampling tool 300 to extract test fluid samples from the well 370 may be substantially reduced when compared to the prior art sampling systems 100 and/or 200. Furthermore, as previously noted, in at least some illustrative embodiments, the sampling tool 300 may also include heating blankets and/or coils (see, *e.g.*, Fig. 4A, described below) and insulation so as to prevent the temperature of the sampling tool 300 or any fluids passing therethrough (*e.g.*, production test fluids, system purge fluids, etc.) from dropping below a predetermined temperature, such as approximately 70°F. In this way, it may be possible to substantially reduce the likelihood that hydrate freezing, sample separation, and/or sample degradation, may inadvertently occur.

As shown in the illustrative embodiment of Figs. 3B and 3C, the manipulator arm 331 may be adapted to extend away from the ROV 330 and manipulate the sampling tool 300 so that the tool 300 can be docked with the subsea structure 350. Accordingly, after the ROV 330 has approached and is positioned adjacent to the subsea structure 350, the manipulator arm 331 holding the sampling tool 300 may be operated so that sample coupling 301 engages with the sample coupling 351. The sample coupling 301 may then be secured in place on the side 359 of the subsea structure 350, as will be further described with respect to Fig. 6D below, and the manipulator arm 331 may thereafter release the handle 307 of the sampling tool 300, as shown in Fig. 3D. In this configuration, the only connection between the subsea structure 350 and the ROV 330 may therefore be by way of the

umbilicals 306 that connect the sampling tool 300 to the equipment 341 mounted in the belly skid 340.

As may be appreciated, in those embodiments of the present disclosure wherein the manipulator arm 331 is used to move the sampling tool 300 into position so that the sample coupling 301 engages the sample coupling 351, the production fluid test samples may be extracted from the well 370 without having to dock the entire ROV 330 on the side 359 of the subsea structure 350, as would be required with the prior art sampling system 110 illustrated in Figs. 1A-1C. Accordingly, substantially less space immediately adjacent to the subsea structure 350 may need to be dedicated for maintaining the position of the ROV 330 during test fluid sampling activities, as compared to the prior art systems 110 and 210. Furthermore, since, as noted above, the manipulator arm 331 does not need to support the sampling tool 300 throughout the test fluid sampling operation, the ROV 330 may be free to move away from a position that is substantially directly in front of the sample coupling 351 and the side 359 of the subsea structure 350 (as shown in Figs. 3B and 3C). In certain embodiments, this may provide adequate space so that other equipment, *e.g.*, another remotely operated subsea vehicle (not shown), may be moved into place adjacent to the subsea structure 350, thereby facilitating other maintenance and/or operating activities on the subsea structure 350.

Figure 3E schematically depicts another illustrative configuration of the sampling system 310 illustrated in Figs. 3A-3D. As shown in Fig. 3E, the manipulator arm 331 may be adapted so that at least part of the arm 331 can be adjusted at an angle relative to an axis 330x of the ROV 330, wherein it should be understood that the axis 330x is substantially aligned with a direction of forward travel of the ROV 330. Accordingly, the ROV 330 may therefore be allowed to approach the subsea structure 350 along a path 360x that is oriented along a plane that may not be substantially parallel to the axis 351x of the sample coupling 351, *i.e.*, is at a non-zero approach angle 360 relative to the axis 351x. By comparison, the prior art system 110 must generally approach a subsea structure, such as the subsea structure 150, along a path that is substantially parallel to the axis 151x, so that the docking

probes 105 of the sampling tool 100 can properly engage with the docking receptacles 155 on the subsea structure 150. See, *e.g.*, Fig. 1C.

For example, in some illustrative embodiments, the ROV 330 may approach the subsea structure 350 such that the axis 330x of the ROV 330 moves substantially along either a normal (*i.e.*, substantially perpendicular) or a non-normal path 360x relative to the side 359 of the subsea structure 350 where the sample coupling 351 is located. In certain embodiments of the present disclosure, the approach angle 360 of the ROV 330 relative to the axis 351x that may range, for example, from approximately 0° (*i.e.*, wherein the ROV 330 takes a substantially parallel approach relative to the axis 351x) to approximately 90° (*i.e.*, wherein the ROV 330 takes a substantially perpendicular approach relative to the axis 351x). Furthermore, in at least some embodiments, once the ROV 330 is positioned adjacent to the subsea structure 350, at least part of the manipulator arm 331 may be adjusted so that the sampling tool 300 is presented to the side 359 with the axis 301x substantially parallel to the axis 351x, so that the manipulator arm 331 can properly engage the sample coupling 301 with the sample coupling 351 on the subsea structure 350.

As thus configured, it may therefore be possible to have adequate access to, and obtain test fluid samples from, subsea production equipment, such as the subsea structure 350 and the like, without having a large space available in front of the side 359 of the subsea structure 350 so as to move and/or dock the ROV 330 with the subsea structure 350, such as the docking space length 139 that is required to maneuver the ROV 130 in the prior art system 110 illustrated in Fig. 1C. Furthermore, the enhanced ability of the sampling tool 300 to access the sample coupling 351 on the subsea structure 350 as depicted in illustrative embodiments of Figs. 3A-3E may be additionally advantageous in those situations wherein existing subsea equipment may have been modified to facilitate the extraction test fluid samples, but where full and/or unrestricted access to the sample coupling 351 from in front of the side 359 (see, *e.g.*, the docking space length 139 in the prior art system shown in Fig. 1C) may not be possible.

Figures 3B-3E schematically depict various illustrative embodiments of the present disclosure wherein the sample coupling 351 on the subsea production equipment, *e.g.*, the subsea structure 350, is configured such that the axis 351x of the sample coupling 351 is oriented substantially parallel to a horizontal reference plane 391. However, as may be appreciated by those having ordinary skill in the art, an axis 370x of the well 370 may not always be substantially aligned along a perfectly vertical orientation in an actual subsea installation. Accordingly, it should also be appreciated that the subsea structure 350 may not always project from the sea floor 390 such that the various working surfaces of the subsea structure 350 – *e.g.*, those surfaces where interface equipment and/or interface connections may be located, such as the side 359 – are substantially parallel to a perfectly vertical plane. Therefore, for purposes of the present disclosure, it should be understood that the horizontal reference plane 391 is defined as a plane that, in certain illustrative embodiments, may be substantially normal to a respective working surface of the subsea structure 350, *e.g.*, relative to the side 359, even though the axis of an actual oil and gas well, such as the axis 370x of the well 370, may not be substantially vertical.

As illustrated in Figs. 3B-3E, the manipulator arm 331 may be operated to bring the corresponding sample coupling 301 on the sampling tool 300 into position adjacent to the sample coupling 351 so that the sample coupling 301 can be moved in a substantially horizontal direction, *e.g.*, in a direction that is substantially parallel to the horizontal reference plane 391, so as to engage the sample coupling 351. It should be appreciated, however, that typical ROV-mounted robotic manipulator arms, such as the manipulator arm 331 may be adapted to have multiple degrees of freedom. Accordingly, the sample coupling 301 on the sampling tool 300 may be moved in substantially any direction so as to engage a corresponding sample coupling 351 that may be oriented along virtually any plane.

For example, in some applications, a respective sample coupling, such as the sample coupling 351 shown in Figs. 3B-3E, may be positioned on a respective piece of subsea production equipment,

e.g., a separator vessel, a pipeline end termination (PLET) structure, a flow module of a subsea Christmas tree, or a piping manifold such as a pipeline end manifold (PLEM) structure, and the like, such that the sample coupling 351 may be oriented in a substantially vertically upward direction. In such cases, an ROV, such as the ROV 330 of Figs. 3A-3E, may approach the subsea production equipment and/or the sample coupling 351 from above (rather than from the side, as shown in Figs. 3B-3E) and a manipulator arm, such as the manipulator arm 331 described above, may be operated so as to move the sample coupling 301 on the sampling tool 300 substantially vertically downward so as to properly engage the sample coupling 351. In other applications, the sample coupling 351 may be oriented in a substantially vertically downward direction, in which case the ROV 330 may approach the respective subsea production equipment and/or the sample coupling 351 from below, and the manipulator arm 331 may be operated so as to move the sampling tool 300 with the sample coupling 301 thereon in a substantially vertically upward direction. As may be appreciated, a sample coupling 351 located on a piece of subsea production equipment may therefore be oriented along almost any angle with respect to a horizontal or vertical plane, substantially without affecting the ability of the manipulator arm 331 to position and move a respective sample coupling 301 along a requisite axis so as to properly engage the sample coupling 301 with the sample coupling 351.

Figure 4A schematically depicts a component block diagram of one illustrative embodiment of an interface system 410 according to the present disclosure that may include an interface tool 400, a manipulator arm 431, and an ROV 430, on which may be mounted a belly skid 440 containing various support and/or operational equipment 441, as will be further described below. Additionally, in at least some embodiments, the interface tool 400 may be operatively connected to the equipment 441 on belly skid 440 by umbilicals 406, which may include a plurality of umbilicals 406a-e, as described in further detail below.

In the illustrative embodiment of Fig. 4A, the interface tool 400 may be, for example, a sampling tool (hereinafter, a sampling tool 400) as previously described with respect to Figs. 3A-3E above. In some illustrative embodiments, the sampling tool 400 may include an interface coupling 401 (*e.g.*, a sample coupling 401) that is adapted to interface with an interface coupling 451 (*e.g.*, a sample coupling 451) on a respective piece of subsea equipment (*e.g.*, a subsea structure; see, Figs. 3B-3E). Furthermore, in certain embodiments, the sampling tool 400 may include sample bottles 402a and 402b, and a fluid communication system 403. The fluid communication system 403 may be made up of, among other things, a plurality of 2-position/3-way valves that are adapted to direct fluid flows between the sample coupling 401, the sample bottles 402a/b, and various pieces of the equipment 441 on the ROV/belly skid 430/440, the operation of which will be further described below.

In some embodiments, the sample bottles 402a and 402b may each include a piston 402p that is adapted to minimize an amount of dead space within the sample bottles 402a/b prior to obtaining test fluid samples from a piece of subsea production equipment (not shown). Additionally, the samples bottles 402a and 402b are connected to and in fluid communication with metering valves 404a and 404b, respectively, which, in conjunction with the pistons 402p, may be adapted to facilitate a regulated flow of a respective test fluid sample into each of the test bottles 402a/b during a test fluid sampling operation, as will be further described below. The sampling tool 400 may also include heating coils 446c in appropriate locations as needed so as to maintain the sampling tool 400 and/or various components thereof above a predetermined temperature so as to thereby prevent hydrate freezing during the sampling operation.

It should be appreciated that, while two sample bottles 402a and 402b have been schematically depicted Fig. 4A, the total number of sample bottles used in any illustrative embodiment of the present disclosure may be varied as may be required by the specific system design parameters. For example, in certain embodiments, the sampling tool 400 may only include a single

sample bottle, *e.g.*, a sample bottle 402a, such as when overall equipment size restrictions may limit how many sample bottles can be packaged in the sampling tool 400. In other illustrative embodiments, three or more sample bottles, *e.g.*, sample bottles 402a-c, may be used when a larger equipment size can be effectively justified, or when specification requirements dictate additional samples. As such, for any embodiment disclosed herein that may use more or fewer than two sample bottles, the number of pieces of additional equipment, such as 2-position/3-way valves and metering valves, may also be commensurately adjusted. However, for illustrative purposes only, the following discussion shall be directed to those embodiments having two sample bottles 402a/b.

In one illustrative embodiment, the manipulator arm 431 is operatively mounted on the ROV 430, and furthermore holds and supports the sampling tool 400. In another illustrative embodiment, the ROV 430 also supports a belly skid 440, which may contain various support and/or operational equipment 441 as noted above. The equipment 441 may include, among other things, a methanol (MeOH) pump 442p and a supply of methanol in an MeOH supply reservoir 442. In some embodiments, the methanol may be used for cleaning and/or purging the fluid communication system 403, any flow lines that provide fluid communication between the sample coupling 451 and an isolation valve (not shown) on the subsea production equipment (not shown), and any umbilicals 406 that may provide fluid communication between the equipment 441 and the fluid communication system 403. In certain embodiments, the MeOH supply reservoir 442 may be in fluid communication with the 2-position/3-way valve 403c of the fluid communication system 403 of the sampling tool 400 by way of an umbilical 406a, which may be a suitable member such as a hose and the like. Additionally, the system may include a one-way valve 442a that is located downstream of the MeOH pump 442p, and that is adapted to prevent a backflow of methanol to the MeOH pump 442p.

The equipment 441 on the belly skid 440 may further include a purge reservoir 443 that is adapted to receive and store various fluids that are flushed or purged through sampling tool 400, such as, for example, seawater (which may be naturally present), MeOH (as indicated above), and/or old

production fluids that may be present in flow lines (not shown) between an isolation valve (not shown) on the subsea production equipment (not shown) and the sample coupling 451. In some embodiments, the purge reservoir may include an internal piston 443p, which, in conjunction with a metering valve 443a, may be adapted to facilitate a regulated flow of purge materials into the purge reservoir 443, as will be further described below. Furthermore, the purge reservoir 443 may be in fluid communication with the 2-position/3-way valve 403c of the fluid communication system 403 by way of an umbilical 406b, which may also be a suitable flow member, such as a hose and the like.

In certain embodiments, the support and/or operational equipment 441 may also include an ethylene glycol (MEG) supply reservoir 444, which may be used as in conjunction with the metering valves 404a/b for regulating a flow of test fluid samples into the sample bottles 402a/b during the sampling operation. Similarly, the MEG supply reservoir 444 may also be used in conjunction with the metering valve 443a so as to regulate a flow of purge material into the purge reservoir 443 during purging operations. Furthermore, in some embodiments, the MEG supply reservoir 444 may be in fluid communication with the metering valves 404a/b by way of an umbilical 406c (*e.g.*, a hose), and in fluid communication with the metering valve 443a by way of the flow line 443b.

Also as shown in Fig. 4A, the equipment 441 on the belly skid 440 may include a schematically-depicted valve control unit 445, which may be adapted to control the positions of the 2-position/3-way valves 403a-c of the fluid communication system 403 of sampling tool 400 during the various sampling and/or purging operations of the sampling system 410. The valve control unit 445 may be operatively coupled to the valves 403a-c of the fluid communication system 403 by way of an umbilical 406d, which may include, among other things, pneumatic, hydraulic, and/or electrical cables for providing signals and/or control influences to the 2-position/3-way valves 403a-c. Furthermore, in those embodiments of the present disclosure where heating coils 446c may be used to moderate or control the temperature of the sampling tool 400 and associated equipment, a schematically-depicted heating control unit 446 may also be included on the belly skid 440. In certain embodiments, the

heating control unit 446 may be operatively coupled to the heating coils 446c by way of an umbilical 406e, such as, for example, an electrical cable and the like.

In certain illustrative embodiments, the 2-position/3-way valve 403a of the fluid communication system 403 may be adapted to provide fluid communication between the sample coupling 401 and the 2-position/3-way valve 403b while in a first position, and to provide fluid communication between the sample coupling 401 and the sample bottle 402a while in a second position. In other embodiments, the 2-position/3-way valve 403b may be adapted to provide fluid communication between the 2-position/3-way valve 403a and the 2-position/3-way valve 403c while in a first position, and to also provide fluid communication between the 2-position/3-way valve 403a (as well as the sample coupling 401) and the sample bottle 402b while in a second position. In still other embodiments, the 2-position/3-way valve 403c may be adapted to provide fluid communication between the 2-position/3-way valve 403b (as well as the 2-position/3-way valve 403a and the sample coupling 401) and the MeOH pump 442p while in a first position, and to provide fluid communication between the 2-position/3-way valve 403b and the purge reservoir 443 while in a second position.

Figure 4B is a fluid flow schematic of the system 410 that is schematically illustrated in Fig. 4A, and which will hereafter be used to describe one illustrative operational embodiment of the system 410.

As a preliminary step to performing a purging and sampling operation on a piece of subsea production equipment (see, *e.g.*, the subsea structure 350 of Figs. 3B-3E, described above) with the sampling system 410, fluid communication is first established between the sample coupling 401 on the sampling system 410 and the sample coupling 451 on the respective piece of subsea equipment. See, for example, the subsea structure 350 shown in Figs. 3B-3E, described above. In certain illustrative embodiments of the present disclosure, this may be accomplished by a flow control system that is adapted to properly position an appropriately designed sealing and fluid transfer element, such

as the flow control system 680 and the transfer tube sealing cartridge 656 illustrated in Figs. 6B-6H, which will be described in further detail below.

After fluid communication has been established between the sample couplings 401 and 451, an isolation valve (not shown) positioned on or near the subsea production equipment may then be opened so that the sampling system 410 is in fluid communication with the production fluid in the subsea production equipment. Furthermore, the 2-position/3-way valves 403a-c of the fluid communication system 403 are each placed in the first positions described above, so that fluid communication is established between the subsea production equipment and the one-way valve 442a. In this configuration, flow is permitted from the MeOH pump 442p, through the one-way valve 442a and each of the 2-position/3-way valves 403a-c, and to the sample coupling 401, while flow is blocked to the sample bottle 402a by the 2-position/3-way valve 403a, to the sample bottle 402b by the 2-position/3-way valve 403b, and to the purge reservoir 443 by the 2-position/3-way valve 403c.

Thereafter, in some illustrative embodiments, the MeOH pump 442p is activated at a discharge pressure that is higher than the pressure of the subsea equipment so as to push a flow of MeOH from the MeOH supply reservoir 442, through the one-way valve 442a, through the 2-position/3-way valves 403a-c, through the sample couplings 401 and 405, and into the subsea production equipment (not shown). During this initial purge step, any seawater, solids particles (*e.g.*, sand, etc.), and/or residual production fluids that may be present in the respective flow lines of the sampling system 410 and/or the subsea production equipment (such as, for example, the fluid communication system 353 of Figs. 3B-3E) is substantially cleared from the flow lines. In certain embodiments, the MeOH pump 442p is operated until an amount of MeOH equal to at least one times (1x) the total volume of the respective valves, fittings, and flow lines on both the sampling system 410 and the subsea production equipment has been pumped through the system. In other embodiments, an amount of MeOH equal to approximately 2-3x the total volume may be pumped to provide a greater likelihood that all flow lines are substantially cleared of particulates and/or residual production fluids.

The MeOH pump 442p is then shut in so that the pressure in the sampling system 410 is balanced with the pressure in the subsea production equipment.

As a next step, the 2-position/3-way valve 403c is moved from the first position to the second position (as described above) so that fluid communication is established between the subsea production equipment and the purge reservoir 443, and so that flow is blocked to and/or from the MeOH pump 442p. In this configuration, a flow of fluid from the subsea production equipment (not shown) is permitted to flow back through the sample couplings 451 and 401, through each of the 2-position/3-way valves 403a-c, and into the purge reservoir 443. In some embodiments, fluid flow into the purge reservoir 443 is permitted until an amount of fluid that is at least equal to 1x the total volume of all flow lines has passed through the sampling system 410, so as to increase the likelihood that a substantially “pure” sample of production test fluid can be obtained in the sample bottles 402a/b. In other embodiments, as much as 2-3x the system volume is allowed to flow into the purge reservoir 443.

In certain embodiments, fluid flow into the purge reservoir 443 is regulated by the piston 443p, the metering valve 443a, and the MEG supply reservoir 444 (see, Fig. 4A). In operation, an amount of MEG 444a may be present in the purge reservoir 443 behind the piston 443p, *i.e.*, on the side of the piston 443p opposite of an inlet 443i where the purge material enters the purge reservoir 443 from the 2-position/3-way valve 403c. As the purge material enters the purge reservoir 443 at the inlet 443i, the piston 443p is displaced, and the MEG 444a is forced out of the purge reservoir 443 through an outlet 443o. The metering valve 443a may be adapted to control the flow rate and pressure of the MEG 444a as it flows out of the purge reservoir 443 and into the MEG supply reservoir 444, thereby facilitating a controlled influx of purge material into the purge reservoir 443, and/or a controlled discharge of MEG 444a out of the purge reservoir 443.

As noted above, an initial purge step may be performed so as to substantially remove fluids and other materials that may be present in the respective flow lines of the sampling system 410 and a fluid communication system on the subsea production equipment –collectively referred to hereinafter as a sampling/purging system circuit (not shown) – from the flow lines. In at least some embodiments of the present disclosure, the various several components that make up the sampling system 410 may be designed and operated such that any “dead,” or “trapped,” volumes that are not fully purged/flushed from the sampling/purging system circuit during the above-described purging operations may be substantially minimized. For example, the sampling system 410 may be adapted such that at least approximately 70% of the total pre-purged volume of fluids and other materials contained within the sampling/purging system circuit may be purged/flushed, whereas less than approximately 30% of the total pre-purged volume may remain trapped within the system after completion of the purging operations. Accordingly the likelihood that contaminated test samples may be acquired during a subsequently performed sampling operation may be substantially reduced.

After the sampling system 400 has been purged, and a substantially “pure” sample production fluid may now be present in the sampling system 400 downstream of the sample couplings 451 and 401, the 2-position/3-way valve 403a is then moved from the first position to the second position (as described above) so that fluid communication may be established between the subsea production equipment and the sample bottle 402a and flow is blocked to the 2-position/3-way valve 403b. In this configuration, a first test sample of substantially “pure” production fluid may then be allowed to flow into the sample bottle 402a. In some embodiments, the flow of the first production fluid test sample into the sample bottle 402a is substantially regulated by the piston 402p, the metering valve 404a, and the MEG supply reservoir 444, similar to the regulated flow of purge material into the purge reservoir 443. Prior to obtaining the first test sample, the piston 402p may be positioned close to an inlet 402i to the sample bottle 402a so as to minimize an amount of “dead,” or “trapped,” volume within the sample bottle 402a that may not be flushed or purged during the above-described purging operations. For example, in certain embodiments, the relative configurations of the sample bottle 402a and its

associated components – such as the 2-position/3-way valve 403a, the metering valve 404a, the piston 402p, and any inlet/outlet piping system components and the like – may be adapted such that any unpurged/unflushed trapped volume that may remain within the sample bottle 402a after completion of the purging operation may be less than approximately 2% of a total sample-receiving volume contained within the sample bottle 402a. See, *e.g.*, the sample-receiving volume 502v shown in Figs. 5D-5G and the detailed discussion thereof below.

As schematically shown in Figs. 4A and 4B, an amount of MEG 444b may also be present in the sample bottle 402a on the side of the piston 402p opposite of the inlet 402i. As the first test sample enters the test bottle 402a through the inlet 402i, the piston 402p is displaced, and the MEG 444b is forced out of the sample bottle 402a through an outlet 402o. As with the metering valve 443a on the purge reservoir 443, the metering valve 404a may be adapted to control the flow rate and pressure of the MEG 444b as it flows out of the sample bottle 402a and into the MEG supply reservoir 444 (see, Fig. 4A), until the sample bottle 402a is substantially completely filled. Furthermore, due to the minimized amount of unpurged/unflushed trapped volume that may remain within the sample bottle 402a as previously described, it should be appreciated that at least approximately 98% of the sample-receiving volume within the bottle 402a, such as the sample-receiving volume 502v shown in Figs. 5D-5G, may be filled with the first test sample, thus substantially reducing the likelihood of sample contamination.

In certain illustrative embodiments disclosed herein, after the test bottle 402a has been substantially filled with the first production fluid test sample, a second production fluid test sample may then be obtained in the sample bottle 402b. As a first step of obtaining a sample in the sample bottle 402b, flow to the sample bottle 402a may be blocked by moving the 2-position/3-way valve 403a from the second position back to the first position, so that fluid communication is re-established to the 2-position/3-way valve 403b. Next, the 2-position/3-way valve 403b is moved from the first position to the second position (as described above) so that fluid communication is established

between the subsea production equipment and the sample bottle 402b and flow is blocked to the 2-position/3-way valve 403c. In this configuration, a second test sample of substantially “pure” production fluid may then be allowed to flow into the sample bottle 402b. Flow is regulated into the sample bottle 402b via the metering valve 404b, piston 402p, and MEG supply reservoir 444 in substantially the same fashion as described above with respect to the first test sample, until the sample bottle 402b is substantially completely filled.

It should be appreciated that sampling sequence described above, *i.e.*, filling the sample bottle 402a first and filling the sample bottle 402b second, may be reversed. For example, after the fluid communication system 403 has been flushed with MeOH, and a reverse flow of production fluid been allowed to flow from the subsea production equipment into the purge reservoir 443 until a substantially “pure” production fluid sample is present in the fluid communication system 403, the 2-position/3-way valve 403b may be operated so as to establish fluid communication between the subsea production equipment and the sample bottle 402b. The sample bottle 402b may then be filled with a first production fluid test sample in the manner described above. Thereafter, the 2-position/3-way valves 403b and 403a may be re-positioned so that the second production fluid test sample is obtained in the sample bottle 402a.

In at least some illustrative embodiments, and after both substantially “pure” production fluid test samples have been obtained in the sample bottles 402a/b, each of the 2-position/3-way valves 403a-c may be re-positioned to the first position so as to re-establish fluid communication between the subsea production equipment and the one-way valve 442a that is downstream of the MeOH pump 442p. Furthermore, in this configuration, flow is once again blocked to the sample bottle 402a by the 2-position/3-way valve 403a, to the sample bottle 402b by the 2-position/3-way valve 403b, and to purge reservoir 443 by the 2-position/3-way valve 403c. Then, the MeOH pump 442p is once again activated so as to push a flow of methanol from the MeOH supply reservoir 442, through the one-way valve 442a, through the 2-position/3-way valves 403a-c, through the sample couplings 401 and 405,

and back into the subsea production equipment. In this way, the substantially “pure” production fluid that may still be present in sampling system 410 and in the flow lines between the sample coupling 451 and the isolation valve (not shown) on the subsea production equipment can be removed from the system so that it does not contaminate the subsea environment when the sample coupling 401 of the sampling tool 400 is disconnected from the sample coupling 451 on the subsea production equipment.

After a sufficient volume of MeOH is pumped through sampling tool 400 and the flow lines on the subsea production equipment so as to reduce the likelihood that any production fluid remains in either system (*e.g.*, at least 1x the total volume of both systems), the isolation valve on the subsea production equipment may be closed and the MeOH pump 442p shut in. Thereafter, fluid communication between the sample couplings 451 and 401 is discontinued and the sample coupling 401 is disconnected from the sample coupling 451. In certain illustrative embodiments disclosed herein, fluid communication between the sample couplings 451 and 401 may be discontinued by properly positioning an appropriately designed sealing and fluid transfer element, such as the transfer tube sealing cartridge 656 illustrated in Figs. 6A-6H, which will be described in further detail below.

Figures 5A-5G depict additional aspects of some illustrative embodiments of an interface system 510 that is adapted to interface with subsea production equipment. Figure 5A is a perspective view of a portion of an illustrative interface system 510 that may include an interface tool 500 that is adapted to be held and supported by a manipulator arm 531, which in turn may be operatively mounted on an ROV 530 (see, Fig. 5B). In at least some embodiments, the interface system 510 may be, for example, a sampling system (hereinafter, sampling system 510) and the interface tool 500 may be a sampling tool (hereinafter, sampling tool 500), as previously described with respect to Figs. 3A-3E and Figs. 4A-4B. The sampling tool 500 may have a housing 500h and a handle 507 mounted to the housing 500h, the handle 507 being adapted to be gripped by an appropriately designed gripper 532 coupled to the end of the manipulator arm 531. As previously described with respect to Figs. 3A-3E above, the manipulator arm 531 may also adapted to move the sampling tool 500 while in a subsea

environment and position the interface tool 500 adjacent to a piece of subsea production equipment, such as a subsea structure and the like (see, *e.g.*, the subsea structure 350 in Figs. 3B-3E).

In certain embodiments, the sampling tool 500 may include an appropriately designed interface coupling 501 having an axis 501x that is adapted to be removably coupled to a corresponding interface coupling (not shown) on a respective piece of subsea production equipment. For example, in some embodiments, such as the illustrative embodiment shown in Fig. 5A, the interface coupling 501 may be adapted so that it can be removably coupled to a standard interface connection, such as an API 17H type B interface flange and the like. The interface coupling 501 of Fig. 5A may include, among other things, a pair of symmetrical flange ring sections 501f that, when viewed together, form a substantially annular shape that is adapted to substantially encompass a corresponding API 17H type B interface flange. In some embodiments, the two flange ring sections 501f may be separated at the top by top space 501t, and in certain other embodiments, separated at the bottom by a bottom space 501z, wherein a latching mechanism, such as a latch 501L, may be positioned in the bottom space 501z. Furthermore, each flange ring section 501f may also include catch tab 501q at a top end thereof, the two catch tabs 501q straddling the top space 501t between the two flange ring sections 501f. Additional details and an operational discuss of the interface coupling 501 illustrated in Fig. 5A will be further described with respect to Figs. 6A-6H below.

It should be appreciated that other standard interface coupling configurations may also be used, such as, for example, an API 17H high-torque rotary interface and the like, as will also be described with respect to Figs. 7A-7C below. It should be further appreciated that, depending on the specific docking and interfacing requirements of the interface tool 500, other configurations, such as specially designed interface couplings, may also be used.

In some embodiments of the present disclosure, such as when the interface system 510 is adapted to be a sampling system 510 and the interface tool 500 is adapted to be a sampling tool 500 as

described with respect to Figs. 3A-3E and Figs. 4A-4B above, the sampling tool 500 may also include sample bottles 502a and 502b (see, Fig. 5D). Additionally, the interface tool may also include 2-position/3-way valves 503a and 503b, that may be used to facilitate a sampling operation for obtaining production fluid test samples, as previously described. Furthermore, the sampling system 510 may also include umbilicals 506, such as fluid transfer hoses, electrical cables, pneumatic and/or hydraulic lines and the like, which may be used to operatively couple the sampling tool 500 to support and/or operational equipment 541 positioned on a belly skid 540 that is mounted on the ROV 530 (see, Figs. 5B and 5C).

Figure 5B is a perspective view of another portion of the sampling system 510 of Fig. 5A, which may also include the ROV 530 with a belly skid 540 mounted to the bottom side thereof. As noted above, in some embodiments, the belly skid 540 may include support and/or operational equipment 541, which may be operatively connected to the sampling tool 500 via the umbilicals 506. Typically, the ROV 530 is linked to a support vessel or production platform (not shown) by a tether or umbilical 533, which may include a group of cables that carry electrical power, video and data signals back and forth between an operator on the vessel or platform and the ROV 530.

Figure 5C is a perspective view of the belly skid 540, which may be removably mounted to the ROV 530 shown in Fig. 5B by a plurality of connection posts 549. The belly skid 540 may be made up of a structure 547 having a plurality of equipment bays, such as the equipment bays 547a and 547b shown in Fig. 5C. As noted above, the belly skid 540 may be adapted to contain various pieces of support and/or operational equipment 541 (see, Fig. 5B), such as purge reservoirs 543, an MeOH pump (not shown), an electrohydraulic control package (not shown), a heating control unit (not shown) and the like. Additionally, the belly skid 540 may also be adapted to contain MeOH supply bags 542, which may be used to facilitate system purging operations, and/or MEG supply bags 544, which may be used to facilitate the regulation of fluid flows into the purge reservoirs 543, and/or the sample bottles 502a/b, as described with respect to Figs. 4A-4B above. In certain illustrative

embodiments, the MeOH/MEG supply bags 542/544 may be contained with perforated containment baskets 548 so as to expose the supply bags 542 and 544 to the surrounding subsea hydrostatic pressure, which, depending on the system design, may thereby balance the pressure of the system piping (not shown) and assist with MeOH pumping and/or MEG flow regulation.

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Figure 5D is partial exposed view of the interface (*e.g.*, sampling) tool 500 shown in Fig. 5A from a front perspective and Fig. 5E is a partial exposed view of the sampling tool 500 from a rear perspective, wherein the manipulator arm 531 has been removed from both views for clarity. As shown in Figs. 5D and 5E, the sampling tool 500 may include a suitably designed interface coupling 501, which may be adapted to interface with, for example, a standard interface connection such as an API 17H type B flange interface. Furthermore, the sampling tool 500 may include sample bottles 502a/b and 2-position/3-way valve assemblies 503a/b, and the valve assemblies 503a and 503b may include valve actuators 508a and 508b, respectively.

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In some embodiments, the sample bottles 502a/b may be removably attached to the housing 500h by, for example, a plurality of fasteners (not shown) at the fastener holes 562a. Similarly, the 2-position/3-way valve assemblies 503a/b, including the valve actuators 508a/b, may also be removably attached to the housing 500h by a plurality of fasteners (not shown) at the fastener holes 562b.

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The sample bottles 502a/b may each include an internal piston 502p, which is shown in Figs. 5D and 5E in an un-stroked position, *i.e.*, before a production fluid test sample has been obtained from a sampling point on a respective piece of subsea production equipment (not shown). The piston 502p is configured so as to substantially minimize the amount of trapped volume, or dead space, within the sample bottles 502a/b prior to obtaining samples, as is further illustrated in Fig. 5F and described below. Accordingly, at this stage of system operation, the sample-receiving volume 502v in the sample bottles 502a/b behind the piston 502p is substantially filled with MEG, which, as is described with respect to Figs. 4A and 4B above, may be used in conjunction with metering valves

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(see, *e.g.*, metering valves 404a/b of Figs. 4A and 4B) to help regulate a flow of the production fluid test samples into the sample bottles 502a/b.

It should be further appreciated that the sampling tool 500 may also include, among other things, a third 2-position/3-way valve and associated valve actuator (not shown), such as the 2-position/3-way valve 403c schematically depicted in Figs. 4A and 4B, that may be adapted to facilitate the cleaning and/or purging operations, as previously described.

Figures 5F and 5G are sectional perspective views of the sample bottle 502a, the 2-position/3-way valve assembly 503a, and valve actuator 508a of the sampling tool 500 shown in Figs. 5A, 5D and 5E. In certain embodiments of the present disclosure, the 2-position/3-way valve assembly 503a may include, for example, a ball 565 having a right-angled flow channel 565a passing therethrough, a valve stem 564 that is attached to and adapted to rotate the ball 565, and a stem gear 563c that is attached to and adapted to rotate the valve stem 564 and ball 565. The 2-position/3-way valve assembly 503a also includes a flow channel 567 that may provide fluid communication with a sample point on a piece of subsea production equipment (not shown), and a flow channel 566 that may provide fluid communication with an MeOH/purge system (see, *e.g.*, MeOH pump 442p and purge reservoir 443 in Figs. 4A and 4B). In at least some embodiments, the 2-position/3-way valve assembly 503a may further include a flow channel 502i that provides fluid communication with the sample bottle 502a.

As noted above, the sample bottle 502a may include an internal piston 502p that is adapted to separate and isolate a production test fluid sample from the supply of MEG that may be used to help regulate flow of the test sample into the sample bottle 502a, as previously described with respect to Figs. 4A and 4B. Accordingly, the piston 502p may also have a groove 502g for a seal ring (not shown), such as an o-ring seal and the like, that may be used so as to substantially prevent MEG from leaking into the test sample, or vice versa. In order to minimize the trapped volume within the sample

bottle 502a prior to obtaining a test sample, the piston 502p may also include a stem 502s having a shape and size that is adapted to substantially fill the inlet flow channel 502i (see, Fig. 5G), thereby substantially eliminating to a large degree any “dead” volumes within the sampling system that cannot be flushed or purged during a purging operation. In certain embodiments, the sample bottle 502a may also include a flow channel 502o that is adapted to provide fluid communication between the sample-receiving volume 502v of the sample bottle 502a on the back side of the piston 502p (*i.e.*, opposite the flow channel 502i) to an MEG supply via a metering valve (see, *e.g.*, the MEG supply reservoir 444 and metering valve 404a of Figs. 4A and 4B), thus regulating flow to the sample bottle 502a.

In at least some embodiments, the valve actuator 508a may be made up of, among other things, a cylindrically shaped gear-toothed rack 563a that is adapted to engage a pinion gear 563b. The pinion gear 563b is in turn adapted to engage the stem gear 563c of the 2-position/3-way valve assembly 503a. In certain embodiments, the rack 563a is further adapted to be axially actuated so as to turn the pinion gear 563b, which correspondingly turns the stem gear 563c, the valve stem 564, and the ball 565, thus moving the right-angled flow channel 565a that passes through the ball 565 from a first ball position to a second ball position. Furthermore, and as required, the rack 563a may be axially actuated in an opposite direction so as to move the right-angled flow channel 565a from the second ball position to the first ball position.

The 2-position/3-way valve assembly 503a is adapted so that when the ball 565 is set in the first ball position, the right-angled flow channel 565a may facilitate fluid communication between the above-noted sample point on a respective piece of subsea production equipment and the above-noted MeOH/purge stem, via the flow channels 567 and 566, respectively. Furthermore, in the first ball position, flow to the sample bottle 502a (via the flow channel 502i) is blocked by the ball 565. The 2-position/3-way valve assembly 503a is further adapted so that when the ball 565 is rotated to the second ball position, the right-angled flow channel 565a may facilitate fluid communication between the subsea production equipment and the sample bottle 502a (via the flow channels 567 and 502i,

respectively), and flow to or from the MeOH/purge system (via the flow channel 566) is blocked by the ball 565.

As shown in Fig. 5F, the ball 565 of the 2-position/3-way valve assembly 503a is in the first ball position, so that flow is blocked to the flow channel 502i (see, Fig. 5G) and the sample bottle 502a. In this configuration, the various flow lines through the sampling tool 500 can be cleaned and purged as described with respect to Figs. 4A and 4B above. Figure 5F also shows the piston 502p in the un-stroked position, so that the stem 502s of the piston 502p substantially fills the flow channel 502i, and the sample-receiving volume 502v of the sample bottle 502a on the back side of the piston 502p is substantially filled with MEG.

As shown in Fig. 5G, the valve actuator 508a has been actuated so as axially move the rack 563a and turn the pinion gear 563b and the stem gear 563c so as to move the ball 565 of the 2-position/3-way valve assembly 503a to the second ball position. In this configuration, fluid communication may be established between the subsea production equipment and the sample bottle 502a via the flow channels 567, 565a and 502i. Thereafter, a metering valve (not shown) downstream of the flow channel 502o may be opened, and a production fluid test sample may be pushed into the sample bottle 502a in a regulated manner via the concerted action of the piston 502p, the MEG on the back side of the piston 502p, and the metering valve. Figure 5G also shows the piston 502p in a fully-stroked position, *i.e.*, indicating that the piston 502p has been displaced by a flow of production fluid into the sample-receiving volume 502v of the sample bottle 502.

It should be appreciated that the various components and operational configurations of the sample bottle 502b, the 2-position/3-way valve assembly 503b, and the valve actuator 508b may be substantially the same as is described above for the sample bottle 502a, the 2-position/3-way valve assembly 503a, and the valve actuator 508a, respectively

Figures 6A-6H depicts various aspects of some illustrative equipment interface systems disclosed herein. Figure 6A is a perspective view of an illustrative interface tool 600 that is being positioned by an ROV-mounted manipulator arm (not shown; see, *e.g.*, the manipulator arm 531 shown in Figs. 5A-5B) adjacent to an interface coupling 651 that is located on a representative piece of subsea production equipment 650, such as, for example, a subsea structure and the like. In some illustrative embodiments, the interface coupling 651 may be a standard interface connection, such as an API 17H type B interface flange, and may therefore include an interface flange 651f that is adapted to be removably coupled to a corresponding interface coupling 601 on the interface tool 600. Additionally a removable transfer tube sealing cartridge 656 positioned in a bore 651b of the interface coupling 651, the configuration and operation of which will be described in further detail below.

In those embodiments of the present disclosure wherein the interface coupling 651 may be a standard API 17H type B interface flange, the interface coupling 601 on the interface tool 600 may include, among other things, a pair of symmetrical flange ring sections 601f that, when viewed together, form a substantially annular shape that is adapted to substantially encompass the API 17H type B interface flange. See, *e.g.*, Fig. 5A. In some embodiments, the two flange ring sections 601f may be separated at the top by top space 601t, and in certain other embodiments, separated at the bottom by a bottom space 601z, wherein a latching mechanism 601L may be positioned in the bottom space 601z. Each flange ring section 601f may also include catch tab 601q at a top end thereof, the two catch tabs 601q straddling the top space 601t between the two flange ring sections 601f. Furthermore, the interface coupling 601 may have an axis 601x that may be aligned with an axis 651x of the interface coupling 651 on the subsea production equipment 651 during a coupling operation, which will be further described with respect to Figs. 6D-6E below.

In some illustrative embodiments, the interface tool 600 may also include a housing 600h and a handle 607 mounted thereto that is adapted to be gripped by an appropriately designed gripper coupled to an ROV-mounted manipulator arm (see, *e.g.*, the gripper 532 and manipulator arm 531

shown in Figs. 5A-5B), which may then be used to move and position the interface tool 600 as noted above. In those embodiments wherein the interface tool 600 may be, for example, a sampling tool that is adapted to obtain production fluid samples from a piece of subsea production equipment during operation, the interface tool 600 may also include sample bottles 602a/b, as well as 2-position/3-way valve assemblies 603a/b and valve actuators 608a/b, that may be adapted for directing a flow of a production fluid test samples into the sample bottles 602a/b. Furthermore, it should be appreciated that the interface tool 600 may also include a third 2-position/3-way valve and associated valve actuator (not shown), such as the 2-position/3-way valve 403c schematically depicted in Figs. 4A and 4B, that may be adapted to facilitate the previously described cleaning and/or purging operations.

Figure 6B shows an illustrative transfer tube sealing cartridge 656 (hereinafter, transfer tube 656) that may be used in conjunction with any of the embodiments disclosed herein so as to seal a bore 651b of the interface couplings 651 located on the subsea production equipment 650, as shown in Figs. 6D-6E and described below. It should be further appreciated that Fig. 6B is also representative of a replacement transfer tube sealing cartridge 656r (hereinafter, replacement transfer tube 656r), that may be used to establish fluid communication between the interface couplings 651 on the subsea production equipment 650 and the interface coupling 601 on the interface tool 600 as shown in Figs. 6F-6G, and to replace the sealing cartridge 656 positioned in the bore 651b, as shown in Fig. 6H and described below. Furthermore, Fig. 6C is a cross-sectional view of the transfer tube 656 and replacement transfer tube 656r shown in Fig. 6B. Accordingly, it should be understood that, while the description of Figs. 6B-6C set forth below may only specifically refer to the transfer tube 656, the discussion is equally applicable to the replacement transfer tube 656r.

As shown in Figs. 6B and 6C the transfer tube 656 has a first end 656m and a second end 656n, as well as a plurality of seal rings 656s that are spaced over the length 656L of the transfer tube 656, each of which seals 656s is positioned in a respective seal ring groove 656t that runs continuously around the perimeter of the transfer tube 656. In at least some embodiments, the transfer

tube 656 may have a substantially cylindrical shape, as illustrated in Figs. 6B and 6C, such that the seal rings 656s run continuously around the circumference of the transfer tube 656. It should be appreciated, however, that shapes other than the cylindrical shape depicted in Figs. 6B and 6C may also be used for the transfer tube 656, depending on the design and shape of the bores 651b and/or 601b (see, Figs. 6D-6H) in which the transfer tube 656 may eventually be positioned, as described below.

In certain embodiments, each end 656m, 656n of the transfer tube 656 may have a chamfer or radius 656x, and in other embodiments, the transfer tube 656 may also have a flow groove 656g disposed proximate each end 656m and 656n. In some embodiments, the transfer tube 656 may also include flow blocking portions 656z that are positioned between the flow grooves 656g. Furthermore, at least some of the seal rings 656s (and associated seal ring grooves 656t) may be positioned adjacent to and on either side of each flow groove 656g, such that a pair of seal rings 656s straddles each flow groove 656g, whereas other seal rings 656s may be positioned so as separate the flow block portions 656z. In some embodiments, a first pair of intersecting flow passages 656a and 656b may be positioned in the flow groove 656g proximate the first end 656m and a second pair of intersecting flow passages 656c and 656d may be positioned in the flow groove 656g proximate the second end 656n. Each of the respective flow passages 656a-d extends in a substantially radial direction across the circumference of the respective flow grooves 656g, thereby providing fluid communication between the respective flow grooves 656g and the respective intersection points of each respective first and second pairs of intersecting flow channels 656a/b and 656c/d.

Additionally, the transfer tube 656 may also include an axial flow passage 656e that extends in a substantially axial direction between the respective intersection point of the first pair of intersecting flow passages 656a/b and the respective intersection point of the second pair of intersection flow passages 656c/d. Accordingly, fluid communication is thereby established between the flow groove 656g proximate the first end 656m and the flow groove 656g proximate the second

end 656n by way of the first pair of intersecting flow passages 656a/b, the axial flow passage 656e, and the second pair of intersecting flow passages 656c/d.

It should be appreciated that in at least some illustrative embodiments, the transfer tube 656 may be radially symmetrical with respect to a centerline axis running from the first end 656m to the second end 656n and along the axial flow passage 656e. Furthermore, the transfer tube 656 may also mirror symmetry with respect to a plane that is perpendicular to the centerline axis, such that the first end 656m, including the flow groove 656g and intersecting flow passages 656a/b adjacent thereto, is symmetrical the second end 656n, including the flow groove 656g and intersecting flow passages 656c/d adjacent thereto. Accordingly, in certain embodiments, the transfer tube 656 is substantially a reversible transfer tube, so that it can be inserted into a respective bore of a respective interface coupling, such as the bore 651b of the interface coupling 651 (see, Figs. 6D-6G) with the first end 656m inserted into the bore first, or with the second end 656n inserted into the bore first.

Figures 6D-6H illustrate an illustrative flow control system 680 that may be used in conjunction with one or more of the equipment interface systems of the present disclosure so as to establish fluid communication between an illustrative interface tool, such as the interface tool 600, and an illustrative piece of subsea production equipment, such as the subsea production equipment 650. Furthermore, in some embodiments, the flow control system 680 may be adapted to establish fluid communication in such a manner so as to substantially avoid leakage of production fluid from the interface tool and/or the subsea production equipment, thereby reducing the likelihood that contamination of the surrounding subsea environment may occur.

Figure 6D is a cross-sectional perspective view of the interface tool 600 of Fig. 6A during an initial step of removably coupling the interface coupling 601 to the interface coupling 651 on the subsea production equipment 650. In the illustrative embodiment shown in Fig. 6D, a flow channel 651a intersects the bore 651b of the interface coupling 651 at an opening 651o. In at least some

embodiments, the flow channel 651a is adapted to provide fluid communication between the bore 651b and an isolation valve (not shown) on the subsea production equipment 650 that, when opened, may allow a flow of production fluid to flow from the subsea production equipment 650, *e.g.*, subsea structure of an oil and gas well, to the opening 651o, and in certain configurations (see, *e.g.*, Figs. 6F and 6G), into to the bore 651b.

As shown in Fig. 6D, a transfer tube 656 may initially be positioned in the bore 651b such that the second end 656n of the transfer tube 656 is positioned proximate the face of the interface flange 651f, and so that neither of the flow grooves 656g on the transfer tube 656 are aligned with and/or positioned above the opening 651o of the flow channel 651a, and so that a flow blocking portion 656z blocks flow from the opening 651o. In at least some embodiments, the transfer tube 656 may also be positioned so that a pair seal rings 656s straddles the opening 651o to the flow channel 651a, thereby substantially sealing the bore 651b against any flow of material passing through the flow channel 651a.

In some embodiments of the present disclosure, the interface coupling 601 may include an interface flow body 601g attached to the front of the housing 600h, and each flange ring section 601f may be attached to the front of the interface flow body 601g. The latching mechanism 601L that is positioned in the bottom space 601z between the flange rings sections 601f (see, Fig. 6A) may be pivotably mounted to the interface flow body 601g by a suitably designed pivot mechanism (not shown), such as a pin and the like, in which the latching mechanism 601L may include a pin hole 601h as shown in Fig. 6D. Furthermore, the interface coupling 601 may also include a latch locking mechanism 601k positioned in an opening 601i in the interface flow body 601g. In some embodiments, the latch locking mechanism may be a spring- and/or pressure-assisted mechanism that may be adapted to pivot the latching mechanism 601L about the pivot mechanism so as to securely lock the latching mechanism 601L into place at the bottom of the interface flange 651f, as will be further discussed with respect to Fig. 6E below.

The flow control system 680 may include a front bore 601b in the interface flow body 601g that is substantially aligned with and separated from a rear bore 601c by a plunger stop 601y. Additionally, the flow control system may also include a housing bore 600b positioned in the front of the housing 600h of the interface tool 600, which may be substantially aligned with the rear bore 601c. In certain embodiments, the flow control system may include a plunger 601p that is adapted to move in a substantially axial fashion within the bores 601b, 601c, and 600b, as will be described with respect to Figs. 6E-6H below. The plunger 601p may have a first end 601m that is positioned on the front side of the plunger stop 601y, *i.e.*, on the side where the front bore 601b is located. The plunger 601p may also have a second end 601n that is positioned on the back side of the plunger stop 601y, *i.e.*, on the side where the rear bore 601c and housing bore 600b are located. Furthermore, the first end 601m of the plunger 601p is separated from the second end 601 by a plunger shaft 601w that is adapted to pass through an opening in the plunger stop 601y.

In certain illustrative embodiments, the first end 601m of the plunger 601p may include a seal ring 601s, such as an o-ring seal and the like, that is adapted to affect a substantially leak-proof seal between the first end 601m and the front bore 601b. Similarly, the second end 601n may also include a seal ring 601s that is adapted to affect a substantially leak-proof seal between the second end 601n and the rear bore 601c, as well as the housing bore 600b. In certain embodiments, the plunger stop 601y may be adapted to prevent the first end 601m of the plunger 601p from moving into the rear bore 601c of the interface flow body 601g, and to prevent the second end 601n from moving into the front bore 601b. Additionally, the plunger stop 601y may also include a seal ring 601s, *e.g.*, an o-ring seal, that is adapted to affect a substantially leak-proof seal between the plunger stop 601y and the plunger shaft 601w. Accordingly, the seal ring 601s of the plunger stop 601y may substantially prevent any fluid that may be present within the rear bore 601c and/or the housing bore 600b, such as, for example, hydraulic fluid and the like, from passing into the front bore 601b. Likewise, the seal ring 601s of the plunger stop 601y may also substantially prevent any fluid that may be present in the front bore 601b, such as production fluid from the subsea production equipment 650 and/or

MeOH/purge fluid from the interface tool 611, from passing into the rear bore 601c and/or the housing bore 600b.

The flow control system 680 may also include flow channels 601d and 601e that may be in fluid communication with the rear bore 601c of the interface flow body 601g, as well as a fluid flow channel 600d that may be in fluid communication with the housing bore 600b of the housing 600h. In some embodiments, the flow channels 601d/e and 600b may also be in fluid communication with a hydraulic and/or pneumatic control system (not shown) that may be used to control the operation of the various elements that make up the interface tool 600, *e.g.*, 2-position/3-way valves and/or metering valves and the like as are described above with respect to Figs. 4A-4B and Figs. 5D-5G. In certain embodiments, fluid flow through the flow channels 601d/e and 600d may be used to control the position of the plunger 601p inside of the bores 601b, 601c and 600b, as will be described below in additional detail. Furthermore, a spring 600s may be positioned inside of the housing bore 600b, between the second side 601n of the plunger 601p and a back end 600x of the bore 600b as shown in Fig. 6D. In at least some embodiments, the spring 600s may be attached at one end to the second end 601n of the plunger 601p and at another end to the back end 600x of the bore 600b, and may be adapted to extend the plunger 601p under certain operational conditions, as will also be described below.

In the illustrative configuration shown in Fig. 6D, the plunger 601p is in a fully retracted position, such that the first end 601m of the plunger 601p is substantially in contact with the front side of the plunger stop 601y. The flow control system 680 may also include a replacement transfer tube 656r, which may be positioned in the front bore 601b of the interface flow body 601g, such that a first end 656m of the replacement transfer tube 656r is proximate a face of the interface flow body 601g, and a second end of the replacement transfer tube 656r is substantially in contact with the first end 601m of the plunger 601p. In some embodiments, the flow control system may include a flow channel 601a that intersects the front bore 601b of the interface flow body 601g at an opening 601o.

In at least some embodiments, the flow channel 601a is adapted to provide fluid communication between the front bore 601b and any illustrative fluid communication system of the present disclosure (see, *e.g.*, the fluid communication systems 303 and 403 of Figs. 3A-3E and 4A, respectively).

5 As noted previously with respect to Figs. 6B and 6C above, the replacement transfer tube 656r is substantially the same size and configuration as the transfer tube 656. During an interface operation between the interface coupling 601 and the interface coupling 651, the flow control system 680 is actuated so that the replacement transfer tube 656r may be positioned to establish fluid communication between the bore 651b of the interface coupling 651 and the front bore 601b of the interface flow body 601g. See, Figs. 6E-6G, described below. In this way, fluid communication may also be established between the subsea production equipment 650 and any illustrative interface system disclosed herein (see, *e.g.*, the sampling systems 310, 410 and 510 described above), thereby facilitating the various interfacing operations previously described, such as, for example, cleaning and/or purging, production fluid sample extraction, chemical injection, hydrate remediation, and the like. Furthermore, after the flow control system 680 has performed the interfacing operations described above, the replacement transfer tube 656r may be positioned so as to replace the transfer tube 656 in the bore 651b of the interface coupling 651 (see, Fig. 6H), thereby re-sealing the interface coupling 651 with a new and reliable sealing cartridge.

10 In certain illustrative embodiments, an ROV-mounted manipulator arm, such as any manipulator arm disclosed herein (see, *e.g.*, manipulator arms 331 and 531 of Figs. 3A-3E and Figs. 5A-5B, respectively) may be used to move the interface tool 600 adjacent to and slightly above the interface coupling 651, so that the interface coupling 601 approaches the interface coupling 651 with the axis 601x tilted at an angle 660 relative to the axis 651x. In some embodiments, the angle 660 may range from 10° to 45°, depending on the specific design of the interface flange 651f, the flange ring sections 601f, the catch tabs 601q, and/or the latch mechanism 601L. Thereafter, the manipulator arm (not shown) may be used to hook the catch tab 601q at the top of each flange ring section 601f on the back side of the interface flange 651f near the top of the interface coupling 651.

In at least some embodiments, the manipulator arm may then substantially relax the weight of the interface tool 600, thereby allowing the face of the interface flow body 601g to contact and come to rest against the face of the interface flange 651f, as shown in Fig. 6E.

5 In certain embodiments, the spring-assisted latch locking mechanism 601k may pivot the pivotably mounted latch mechanism 601L so the latch mechanism 601L is locked into place at the bottom of the interface flange 651f, thereby securely coupling the interface coupling 601 to the interface coupling 651. Furthermore, as noted above, spring-assisted or hydraulic pressure may be applied in the opening 601i so as to augment the operation of the latch locking mechanism 601k, and
10 which may be continued throughout subsequent interfacing operations. In at least some illustrative embodiments, once the interface couplings 601 and 651 have been securely coupled and locked in place, the manipulator arm (not shown) may thereafter release the handle 607, and the manipulator arm and/or the ROV (not shown) may be moved away from the interface point, as described with respect to Fig. 3D above.

15 As shown in the illustrative embodiment of Fig. 6E, the interface couplings 651 and 601 may be adapted so that the bore 651b, *i.e.*, the axis 651x, of the interface coupling 651 is substantially aligned with the bores 601b/c, *i.e.*, the axis 601x, of the interface coupling 601. In this configuration, the replacement transfer tube 656r may be readily pushed from the bore 601b into the bore 651b so as
20 to establish fluid communication between the two interface couplings 651 and 601, as described below. Furthermore, as noted with respect to Figs. 6B and 6C above, both ends 656m and 656n of the replacement transfer tube 656r may have a chamfer 656x, which may facilitate easier movement of the replacement transfer tube 656r across an interface between the interface couplings 651 and 601 in the event the bores 651b and 601b may not be perfectly aligned. Additionally, in some illustrative
25 embodiments, one or both of the bores 651b and 601b may also be chamfered at the faces of the interface flange 651f and/or the interface flow body 601g, respectively, so as to further facilitate the movement of the replacement transfer tube 656r into the bore 651b.

Figure 6F illustrates the interface tool 600 and flow control system 680 shown in Figs. 6D and 6E, wherein the plunger 601p has been actuated so as to be moved to a first position along the co-axial bores 601b, 601c and 600b. As shown in Fig. 6F, the flow control system has been actuated to move the replacement transfer tube 656r past the face of the interface flange 651f and partially into a front portion of the bore 651b of the interface coupling 651, while the transfer tube 656 has been partially moved out of the bore 651b at an opposite end of the interface coupling 651. In some illustrative embodiments, the plunger 601p may be moved through the respective bores 601b/c and 600b by operation of a suitably designed hydraulic or pneumatic system (not shown), which may be in fluid communication with the bores 601c and 600b via the flow passages 601d/e and 600d. The hydraulic/pneumatic system may be adapted to control a flow of fluid through the flow passages 601d/e and 600d, and thereby control a flow of fluid into and/or out of the rear bore 601c and the housing bore 600b.

In the relative positions of the plunger 601p, the replacement transfer tube 656r, and the transfer tube 656 shown in Fig. 6F, the plunger 601p has been moved until the seal ring 601s on the second end 601n of the plunger 601p is substantially aligned with a point where the flow passage 601d intersects the rear bore 601c of the interface flow body 601g. While the plunger 601p is being moved, the first end 601m may contact and push against the second end 656n of the replacement transfer tube 656r so as to move the first end 656m of the replacement transfer tube 656r partially into the bore 651b of the interface coupling 651. At the same time, the first end 656m of the replacement transfer tube 656r may simultaneously contact and push against the second end 656n of the transfer tube 656 so as to move the first end 656m of the transfer tube 656 partially out of the bore 651b, and so that the flow blocking portion 656z of the transfer tube 656 no longer blocks the opening 651o of the flow channel 651a, as shown in Fig. 6F.

In some embodiments of the flow control system 680 described herein, the length of the plunger 601p may be adapted so that when the plunger 601p is in a first position as shown in Fig. 6F,

the flow groove 656g and intersecting flow passages 656c and 656d proximate the second end 656n of the replacement transfer tube 656r are substantially aligned with the opening 601o to the flow channel 601a of the interface flow body 601g. Similarly, the length of the replacement transfer tube 656r may also be adapted so that when the flow groove 656g and intersecting flow passages 656c/d proximate the second end 656n of the replacement transfer tube 656r are substantially aligned with the opening 601o to the flow channel 601a, the flow groove 656g and intersecting flow passages 656a and 656b proximate the first end 656m of the replacement transfer tube 656r are substantially aligned with the opening 651o to the flow channel 651a of the interface coupling 651.

As shown in Fig. 6G, fluid communication may thereby be established between the subsea production equipment 650 and the interface tool 600 by way of a substantially continuous flow path through: 1) the flow channel 651a; 2) the intersecting flow passages 656a/b; 3) the axial flow passage 656e; 4) the intersecting flow passages 656c/d; 5) and the flow channel 601a. In this configuration, interfacing operations, such as, cleaning and/or purging, production fluid sampling, or chemical injection and the like may be performed. It should be appreciated that, due to the configuration of each flow groove 656g relative to the respective intersecting flow passages 656a/b and 656c/d, flow between the flow channels 651a/601a and the axial flow passage 656e may be substantially unrestricted. Accordingly, the replacement transfer tube 656r may be rotated within the bores 651b and 601b to virtually any orientation substantially without affecting fluid communication between the subsea production equipment 650 and the interface tool 600.

It should be appreciated that, due to presence of the plurality of seal rings 656s spaced down the length 656L (see, Figs. 6B-6C) of the replacement transfer tube 656r, each of which runs continuously around the perimeter (*e.g.*, circumference) of the transfer tube 656r, the replacement transfer tube 656r may be moved along the bores 601b and 651b by the flow control system 680 in such a way as to substantially avoid any leakage into the surrounding subsea environment.

Figure 6H illustrates the interface tool 600 of Figs. 6D-6E after interfacing operations have been substantially completed, and wherein the flow control system 680 has been actuated to move the plunger 601p to a second position along the co-axial bores 601b, 601c and 600b. As shown in Fig. 6H, the entire length of the replacement transfer tube 656r has been moved past the face of the interface flange 651f. In this configuration, it should be understood that the replacement transfer tube 656r is adapted to take the place of transfer tube 656 within the bore 651b of the interface coupling 651.

As noted above, the plunger 601p may be moved through the bores 601b and 601c by operation of a suitably designed hydraulic or pneumatic system (not shown). Furthermore, regarding the relative positions of the plunger 601p, the replacement transfer tube 656r, and the transfer tube 656 shown in Fig. 6H, the plunger 601p has been moved until the second end 601n of the plunger 601p contacts the back side of the plunger stop 601y. In this position, the seal ring 601s on the second end 601n of the plunger 601p is properly located relative to a point where the flow passage 601e intersects the rear bore 601c of the interface flow body 601g so as to allow for hydraulic retraction of the plunger 601p. While the plunger 601p is being moved, the first end 601m may contact and push against the second end 656n of the replacement transfer tube 656r so as to move the replacement transfer tube 656r completely into the bore 651b of the interface coupling 651. Furthermore, in certain embodiments, the distance between the back side of the plunger stop 601y and the face of the interface flow body 601g may be adapted and so that the second end 656n of the replacement transfer tube 656r is properly positioned proximate the face of the interface flange 651f, as was previously the case with the transfer tube 656 shown in Fig. 6D. At the same time, the first end 656m of the replacement transfer tube 656r may simultaneously contact and push against the second end 656n of the transfer tube 656 so that transfer tube 656 is displaced along the bore 651b and ejected out of the back side of the interface coupling 651, as shown in Fig. 6H.

In some illustrative embodiments of the present disclosure, the flow control system 680 may position the replacement transfer tube 656r within the bore 651b in substantially the same position that was previously occupied by the transfer tube 656 as shown in Fig. 6D, *i.e.*, prior to the flow control system 680 having been actuated so as to establish fluid communication between the subsea production equipment 650 and the interface tool 600 as illustrated in Figs. 6F-6G and performing the interfacing operations described above. For example, the replacement transfer tube 656r may be positioned in the bore 651b so that neither of the flow grooves 656g on the replacement transfer tube 656r are aligned with and/or positioned above the opening 651o of the flow channel 651a, and so that a flow blocking portion 656z once again blocks flow from the opening 651o. Furthermore, in at least some embodiments, the replacement transfer tube 656r may also be positioned so that a pair seal rings 656s straddles the opening 651o to the flow channel 651a, thereby substantially re-sealing the bore 651b against any flow of material passing through the flow channel 651a. Moreover, and as previously noted above, it should also be appreciated that, due the presence of the plurality of seal rings 656r disposed along the length 656L (see, Figs. 6B and 6C) of the replacement transfer tube 656r, this operation may be performed in such a manner as to substantially reduce the potential that leakage to the surrounding environment may occur.

In certain illustrative embodiments, the spring 600s may be adapted so that, in the event power is lost to the hydraulic/pneumatic system, such that fluid pressure to the flow channels 601d/e and 600d is no longer available to actuate the plunger 601p, the spring 600s may be allowed to fully extend, thereby moving the plunger 601p to the position illustrated in Fig. 6H. In this way, the plunger 601p can properly position the replacement transfer tube 656r in the bore 651b of the interface coupling 651, thereby sealing both the subsea production equipment 650 and the interface tool 651, protecting the extracted fluid sample from contamination, and preventing spillage/leakage to the surrounding subsea environment. Similarly, the latch locking mechanism 601K may also be adapted so that if fluid pressure from the hydraulic/pneumatic system to the opening 601i may be lost,

the spring-assisted mechanism (not shown) may enable the latch mechanism 601L to be opened, and the interface tool 600 to be safely uncoupled.

In the illustrative embodiment shown in Figs. 6E-6H, the interface coupling 651 and the interface tool 601 are depicted as being oriented along a substantially horizontal axis. However, as may be appreciated by one of ordinary skill having the benefit of the presently disclosed subject matter, the interface couplings 651 and 601, including the latch mechanism 601L and latch locking mechanism 601k, may be readily adapted so as to facilitate a coupling operation wherein the interface coupling on the subsea production equipment 650 is oriented along a substantially non-horizontal axis, including, for example, a substantially vertical axis. Therefore, it should be appreciated that the interface systems disclosed herein are not limited to configurations wherein the interface coupling on a respective piece of subsea production equipment, such as the interface couplings 351, 451, 651 and/or 751 (see, Figs. 7A-7C) may be in a substantially horizontal orientation, due at least in part to the substantially compact configuration of the interface tools disclosed herein (*e.g.*, interface tools 300, 400, 500, 600 and/or 700), and the ability of an ROV-mounted manipulator arm to position the interface tools at substantially any position and orientation, as previously described.

Figures 7A-7C are perspective views of a portion of an illustrative interface system 710 that depicts some aspects of yet another illustrative interface tool 700 according to the present disclosure. As shown in Fig. 7A, the interface system 710 includes an interface tool 700 that is adapted to be held and supported by a manipulator arm 731, which in turn may be operatively mounted on an ROV (not shown), as previously described above. In certain illustrative embodiments, at least some elements of the interface tool 700 may be substantially similar to those illustrated and described with respect to Figs. 5A-5G above, and will not be addressed herein in any further detail.

The interface tool 700 may include an appropriately designed interface coupling 701 that is substantially based on a standard API 17H high-torque rotary interface configuration, and which is

adapted to be removably coupled to a corresponding interface coupling 751 on a respective piece of subsea production equipment 750 (see, Fig. 7B). The interface coupling 701 may have an axis 701x and include, among other things, an interface flow body 701g and a pair of latching mechanisms 701L disposed on opposite sides of the interface flow body 701g. As shown in Fig. 7A, a replacement transfer tube 756r, which may be substantially similar to the replacement transfer tube 656r illustrated in Figs. 6B-6G and described above, may be positioned in a bore 701b of the interface flow body 701g prior to removably coupling the interface coupling 701 on the interface tool 700 to the interface coupling 751.

Figure 7B is a close-up perspective view of the interface tool 700 shown in Fig. 7A as the interface coupling 701 is being positioned adjacent to and in front of the interface coupling 751 by the manipulator arm 731. In some embodiments, the interface coupling 751 may include a coupling housing 751h that may be attached to the subsea production equipment 750 by a plurality of fasteners 751z, such as bolts and the like. Furthermore, the coupling housing 751h may have a recess 751r with an axis 751x that is adapted to receive the interface flow body 701g of the interface coupling 701 during a docking and coupling operation, such that the interface coupling 751 may be considered to act as the “female” fitting of the interface connection, whereas the interface coupling 701 may be considered to act as the “male” fitting.

In certain embodiments, the coupling housing 751h may include a pair of slots 751s disposed on the inside of the recess 751r and on opposing sides thereof, and which may be adapted to receive, during a docking and coupling operation, the two latching mechanisms 701L that are positioned on opposite sides of the interface flow body 701g. Furthermore, each slot 751s may include an appropriate sized and positioned notch 751n that is adapted to receive a spring and/or pressure actuated locking clip 701c on each latching mechanism 701L so as to thereby securely couple the interface coupling 701 to the interface coupling 751 in a proper position.

Figure 7C is a perspective view of the interface tool 700 and the interface coupling 751 of Fig. 7B, showing an inside view of the recess 751r of the coupling housing 751h. As shown in Fig. 7C, a transfer tube 756, which may be substantially similar to the transfer tube 656 illustrated in Figs. 6B-6G and described above, may be positioned in a bore 751b of the interface coupling 751 prior to removably coupling the interface coupling 701 thereto. Accordingly, once the interface flow body 701g of the interface coupling 701 has been inserted into the recess 751r of the interface coupling 751 and secured in place with locking clips 701c of the latching mechanisms 701L, interfacing operations substantially as described with respect to Figs. 6F-6H may be performed – *e.g.*, establishing fluid communication between the subsea production equipment 750 and the interfacing tool 700, extracting production fluid samples, performing chemical injection operations, and the like.

Figure 8 schematically illustrates various illustrative interface points for some illustrative subsea production equipment where any one of the interface systems described herein, such as the interface systems 310, 410, 510, 610 and/or 710, may be utilized to perform specified interfacing operations. For example, Fig. 8 schematically illustrates an interface point 851a on a subsea structure 850a that may be positioned above an oil and gas well 870, such as any one of the subsea structures described above. Furthermore, the interface point 851a may be an interface coupling of the present disclosure that is substantially similar to one of the illustrative interface couplings 351, 451, 651 or 751, where an illustrative interface system may be coupled so that interfacing operations such as fluid sampling and/or cleaning and the like may be performed as described above.

In some embodiments, the subsea wellhead 850a may include a flow module 850b that may also, or alternatively, include an interface point 851b, such as an illustrative sample coupling and the like. In other embodiments, the flow module 850b may be connected by a flowline jumper 850c to a pipeline end termination (PLET) 850d, through which a flow of production fluid 870f may flow to other subsea production equipment, such as separator vessels and/or flow manifolds and the like. In certain embodiments, an interface point 851d, which may be any interface coupling of the present disclosure, may be located on the PLET 850d, where a respective interface system as described herein

may be coupled, and an interfacing operation performed, such as a chemical injection and/or hydrate remediation operation and the like.

Figure 9 schematically depicts various interface points for an illustrative subsea separator vessel 950. As shown in Fig. 9, the separator vessel 950 may receive a flow of production fluid 970f, which may then be separated inside the separator vessel 950 into various zones made up of different constituent components, such as, for example, a gas zone 970a and an oil zone 970b. Furthermore, the production fluid 970f may also include an amount of solids particulate matter, such as sand and the like, that also separates out in the bottom of the separator vessel 950 in a sand zone 970c. Separated flows of gas 971a and oil 971b from the gas zone 970a and the oil zone 970b, respectively, may then be sent to other subsea equipment, or to a production platform at the ocean surface.

Depending on the operational strategy of a subsea installation in general and of the separator vessel 950 in specific, various interface points may be included on the separator vessel 950 so as to obtain different type of fluid samples, and/or to perform other types of interfacing operations as previously described. For example, in some embodiments, an interface point 951a may be positioned at an inlet to the separator vessel 950, where the flow of production fluid 970f is received from another piece of subsea production equipment, *e.g.*, a subsea structure, flow module, PLET, and the like. Accordingly, fluid samples may be obtained from the interface point 951a so as to determine the quality and characteristics of the fluid flowing into the separator vessel 950. In other embodiments, an interface point 951b may be positioned at an outlet from the separator vessel 950, *e.g.*, where a flow 971b of separated oil from the oil zone 970b is discharged from the separator vessel, so that fluid samples may be obtained that can be used for various testing and evaluation purposes, such as evaluating the performance of the separator vessel 950. It should be appreciated that other interface points may also be positioned on the separator vessel 950, which may be used for any of the interfacing operations described herein.

As may be appreciated by those having ordinary skill in the art, maintenance, *i.e.*, clean-out, operations must generally be periodically performed on the separator vessel 950 so as to remove the sand in the sand zone 970c from the bottom of the separator vessel, as it may eventually affect the available volume within the separator vessel 950 as well as the separator's overall efficiency and performance. Typically, this clean-out operation requires that the separator vessel 950 be shut down and taken out of service so that the vessel can be opened and the sand removed from the sand zone 970c.

In certain illustrative embodiments, an interface point 951c may be positioned on the separator vessel 950 in the sand zone 970c so that an interface system of the present disclosure may be used to perform clean-out operation to remove sand from the sand zone 970c while the separator vessel 950 is in operation, thereby avoiding the periodic maintenance shut-down periods described above. For example, in some embodiments, the interface point 951c may include any of the interface couplings disclosed herein, such as the interface coupling 651 illustrated in Figs. 6A and 6D-6H and described above. Furthermore, an interface tool of the present disclosure, such as the interface tool 600 shown in Figs. 6A and 6D-6H, may be coupled to the interface point 951c (*e.g.*, to the interface coupling 651), and fluid communication established between the interface tool (*e.g.*, the interface tool 600) and the separator vessel 950 by way of a suitably designed fluid transfer element, such as the transfer tube sealing cartridge 656 shown in Figs. 6B-6H above. Thereafter, a purging operation may be performed substantially as described above with respect to the schematic diagrams illustrated in Figs. 4A-4B.

For example, in at least some illustrative embodiments, 2-position/3-way valves on the interface tool, such as the 2-position/3-way valves 403a-c of the interface system 410 shown in Figs. 4A-4B, may be actuated as described above so that methanol from an MeOH supply reservoir, such as the MeOH reservoir 442 of Figs. 4A-4B, can be pumped into the sand zone 970c in the bottom of the separator vessel 950 via the interface point 951. During this operation, movement of

sand in the sand zone 970c may be stimulated by the flow of methanol into the separator vessel 950. Next, one of the 2-position/3-way valves, such as the 2-position/3-way valve 403c, may be actuated so that a flow of fluid from the separator vessel 950 – which may include some combination of MeOH, sand from the sand zone 970c, and/or oil from the oil zone 970b – may be directed to flow
5 into a purge reservoir, such as the purge reservoir 443 of the interface system 410. In this way, at least a portion of the sand may be removed from the sand zone 970c.

Depending on the overall capacity of given interface system such as the interface system 410, which may be a function of the size of the MeOH supply reservoir 442 and the size of the purge
10 reservoir 443, the MeOH/purging/cleaning steps described above may be performed until: 1) the supply of MeOH is exhausted or the capacity of the purge reservoir is reached; or 2) the sand zone 970c in the separator vessel 950 has been substantially cleared of sand. In the event the sand zone 970c is not substantially cleared of sand, the performance of the separator vessel 950 may be re-evaluated to determine whether or not further immediate purging/cleaning of the separator vessel 950
15 may be required, in which case another interface system 410 may be brought into service so as to complete the operation. However, it should be appreciated that, due to the on-line purging/cleaning capabilities of the various interface systems disclosed herein, *i.e.*, while the subsea production equipment is still in operation, the overall efficiency and cost-effectiveness of a subsea installation utilizing the disclosed interface systems may be substantially enhanced.

20 As a result of the above-described subject matter, various systems and methods for interfacing with subsea production equipment while the equipment is in operation are disclosed, which may improve the cost and efficiency, as well as the environmental safety, of a subsea production installation.

25 The particular embodiments disclosed above are illustrative only, as the invention 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 invention. Accordingly, the protection sought herein is as set forth in the claims below.

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CLAIMS**WHAT IS CLAIMED:**

1. A fluid sealing and transfer element, comprising:

a flow body comprising a first end and a second end;

a first flow groove proximate said first end and a second flow groove proximate said second end;

first and second flow passages passing through said flow body, wherein said first flow passage intersects said first flow groove and said second flow passage intersects said second flow groove; and

a third flow passage passing through said flow body, wherein said third flow passage intersects said first and second flow passages and facilitates fluid communication between said first and second flow grooves.

2. The fluid sealing and transfer element of claim 1, wherein each of said first and second flow grooves are disposed around a perimeter of said flow body.

3. The fluid sealing and transfer element of claim 1, wherein said flow body comprises a cylindrical shape, wherein said perimeter is a circumference of said cylindrical shape, and wherein at least one of said first and second flow grooves is substantially continuously disposed around said circumference.

4. The fluid sealing and transfer element of claim 3, further comprising a plurality of seals, wherein each of said plurality of seals is substantially continuously disposed around said circumference.

5. The fluid sealing and transfer element of claim 1, wherein at least one of said first and second flow passages comprises a pair of intersecting flow passages.

6. The fluid sealing and transfer element of claim 1, wherein said fluid sealing and transfer element is adapted to be positioned at a flow position in a first coupling so as to establish a continuous flow path between a first flow channel of said first coupling and a second flow channel of a second coupling positioned proximate said first coupling.

7. The fluid sealing and transfer element of claim 6, wherein said fluid sealing and transfer element is adapted to establish said continuous flow path when said first flow groove is positioned in fluid communication with said first flow channel of said first coupling and when said second flow groove is positioned in fluid communication with said second flow channel of said second coupling.

8. The fluid sealing and transfer element of claim 1, wherein said fluid sealing and transfer element is adapted to be positioned at a sealing position in a first coupling so as to block flow between a first flow channel of said first coupling and a second flow channel of a second coupling positioned proximate said first coupling.

9. The fluid sealing and transfer element of claim 8, wherein said flow body further comprises a flow blocking portion between said first and second flow grooves, and wherein said fluid sealing and transfer element is further adapted to block said flow when said flow blocking portion of said flow body is positioned so as to block flow from said first flow channel of said first coupling.

10. A flow control system that is adapted to establish fluid communication between an interface tool and an equipment item, the flow control system comprising:

a movable transfer tube sealing cartridge comprising a first end, a second end, and a plurality of flow passages that are adapted to facilitate fluid flow between said first end and said second end; and

a movement apparatus that is adapted to move said movable transfer tube sealing cartridge to a flow position so as to facilitate fluid flow between a first flow channel of said equipment item and a second flow channel of said interface tool.

11. The flow control system of claim 10, wherein said movable transfer tube sealing cartridge is adapted to at least partially displace a replaceable transfer tube sealing cartridge from a sealing position in said equipment item when said movement apparatus moves said movable transfer tube sealing cartridge to said flow position.

12. The flow control system of claim 10, wherein said plurality of flow passages comprises a first flow groove that is positioned proximate said first end of said movable transfer tube sealing cartridge and a second flow groove that is positioned proximate said second end of said movable transfer tube sealing cartridge, and wherein said movement apparatus is adapted to position said movable transfer tube sealing cartridge so that said first flow groove is in fluid communication with said first flow channel of said equipment item and said second flow groove is in fluid communication with said second flow channel of said interface tool.

13. The flow control system of claim 10, wherein said movement apparatus is further adapted to move said movable transfer tube sealing cartridge to a sealing position so as to block fluid flow between said first and second flow channels.

14. The flow control system of claim 13, wherein said movable transfer tube sealing cartridge is adapted to replace a replaceable transfer tube sealing cartridge positioned in said

equipment item when said movement apparatus moves said movable transfer tube sealing cartridge to said sealing position.

15. The flow control system of claim 10, wherein said movable transfer tube sealing cartridge further comprises a flow blocking portion positioned between said first end and said second end, and wherein said movement apparatus is adapted to position said movable transfer tube sealing cartridge so that said flow blocking portion substantially blocks flow to or from said first flow channel of said equipment item.

16. The flow control system of claim 10, wherein said movement apparatus comprises one of a pneumatic and a hydraulic control system that is adapted to control movement of said movable transfer tube sealing cartridge.

17. An interface tool that is adapted to interface with an equipment coupling on subsea equipment, the interface tool comprising:

an interface coupling that is adapted to be removably coupled to said equipment coupling on said subsea equipment during a coupling operation; and

a flow control system that is adapted to establish fluid communication between said interface tool and said subsea equipment after said coupling operation, said flow control system comprising a fluid sealing and transfer element, said fluid sealing and transfer element being adapted to replace a replaceable fluid sealing and transfer element that, prior to said coupling operation, is positioned in said equipment coupling.

18. The interface tool of claim 17, wherein said interface tool is adapted to perform at least one interfacing operation with said subsea equipment after said fluid communication has been established.

19. The interface tool of claim 18, wherein said at least one interfacing operation comprises at least one of a purging operation, a fluid sampling operation, a clean-out operation, and a chemical injection operation.

5 20. The interface tool of claim 17, wherein said interface tool is adapted to be releasably supported by a manipulator arm, and wherein said interface tool is further adapted to be removably coupled to said equipment coupling by said manipulator arm.

10 21. The interface tool of claim 17, wherein an axis of said interface coupling is adapted to be substantially aligned with an axis of said equipment coupling during said coupling operation.

22. The interface tool of claim 21, wherein said interface tool is adapted to be oriented at a non-zero angle relative to a substantially horizontal reference plane after said coupling operation.

15 23. The interface tool of claim 17, wherein said flow control system comprises a movement apparatus that is adapted to move said fluid sealing and transfer element from said interface coupling to said equipment coupling.

20 24. The interface tool of claim 17, wherein said fluid sealing and transfer element is adapted to be positioned in a first position so as to facilitate said fluid communication.

25 25. The interface tool of claim 24, wherein said fluid sealing and transfer element is further adapted to be positioned in a second position so as to prevent said fluid communication.

26. The interface tool of claim 17, further comprising at least one sample bottle proximate said interface coupling, wherein said at least one sample bottle comprises a sample-

receiving volume that is adapted to receive a flow of a fluid sample from said subsea equipment during a sampling operation.

27. The interface tool of claim 26, wherein said sample bottle is adapted so that, after said sampling operation, said fluid sample fills at least approximately 98% of said sample-receiving volume.

28. The interface tool of claim 26, wherein a fluid flow distance between said interface coupling and said sample bottle is approximately 3 feet or less.

29. The interface tool of claim 28, wherein said fluid flow distance is approximately 1 foot or less.

30. The interface tool of claim 26, further comprising a fluid communication system that is adapted control said flow of said fluid sample into said at least one sample bottle.

31. The interface tool of claim 30, wherein said fluid communication system comprises a plurality of valves, wherein each of said plurality of valves is adapted to control fluid communication between at least three fluid sources.

32. The interface tool of claim 31, wherein at least one of said plurality of valves comprises a 2-position/3-way valve.

33. The interface tool of claim 31, wherein at least one of said plurality valves is adapted to facilitate fluid communication between said interface tool and a fluid flushing and purging system that is adapted to perform a purging operation so as to purge a residual fluid from a sampling/purging system circuit prior to said sampling operation, said sampling/purging system circuit comprising said

fluid communication system, said flow control system, and an equipment fluid communication system on said subsea equipment.

34. The interface tool of claim 33, wherein said fluid communication system is further adapted to control a flow of a purging fluid from said flushing and purging system to said subsea equipment during said purging operation.

35. The interface tool of claim 34, wherein said fluid communication system is further adapted to control said purging operation so that less than approximately 30% of a pre-purged volume of said residual fluid remains in said sampling/purging system circuit after said purging operation.

36. A system that is adapted to interface with subsea equipment, the system comprising:
an interface tool comprising an interface coupling, said interface coupling being adapted to be removably coupled to an equipment coupling on said subsea equipment during a coupling operation, said interface tool further comprising a fluid transfer element that is adapted to facilitate fluid communication between said interface tool and said subsea equipment after said coupling operation, said fluid transfer element being further adapted to replace a replaceable fluid transfer element that, prior to said coupling operation, is positioned in said equipment coupling; and
a manipulator arm that is adapted to support and position said interface tool during said coupling operation.

37. The system of claim 36, wherein said manipulator arm is further adapted to align an axis of said interface coupling with an axis of said equipment coupling during said coupling operation.

38. The system of claim 36, wherein said manipulator arm is adapted to release said interface tool after said coupling operation.

39. The system of claim 36, wherein said interface tool is adapted to be oriented at a non-zero angle relative to a substantially horizontal reference plane after said coupling operation.

40. The system of claim 36, wherein said system is adapted to perform at least one
5 interfacing operation on said subsea equipment.

41. The system of claim 40, wherein said at least one interfacing operation comprises at least one of a fluid sampling operation, a clean-out operation, and a chemical injection operation.

10 42. The system of claim 36, further comprising an ROV that is adapted to position said system adjacent to said subsea equipment, wherein said manipulator arm is mounted on said ROV.

15 43. The system of claim 42, wherein said ROV comprises an axis that is substantially aligned with a direction of forward travel of said ROV, and wherein said ROV is adapted to be positioned adjacent to said subsea equipment during said coupling operation so that said axis of said ROV is oriented along a plane that intersects an axis of said equipment coupling at a non-zero angle.

44. The system of claim 43, wherein said non-zero angle is approximately 90° or less.

20 45. The system of claim 42, further comprising an equipment skid supported by said ROV, said equipment skid comprising interfacing equipment that is adapted to facilitate said at least one interfacing operation.

25 46. The system of claim 45, wherein said interface tool is operatively coupled to said interfacing equipment.

47. The system of claim 45, wherein said interfacing equipment comprises at least one of a methanol supply, a methanol pump, a purge fluid reservoir, a glycol supply, a valve control unit, and a heating control unit.

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48. The system of claim 36, wherein said subsea equipment comprises one of a wellhead, a flow module, a pipeline end termination and a separator vessel.

49. The system of claim 36, wherein a configuration of said fluid transfer element is substantially the same as a configuration of said replaceable fluid transfer element.

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