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Hydraulic locking mechanism for downhole valve

Abstract

A bi-directional valve with valve elements having compliant features biasing them together to maintain a sealing interface that defines a fluid communication barrier within the valve. Parting the valve elements from one another removes the sealing interface allow fluid communication across the valve elements. The valve includes a side port and a choke member that selectively blocks fluid flow through the valve when moved adjacent the side port and selectively opens the valve to fluid communication when moved away from the side port. The choke member remains adjacent the side port until the valve elements are spaced a distance apart greater than that at which valve erosion or fluid cavitation occurs. Also included with the valve are systems for counterbalancing forces exerted onto the valve from differential pressures.

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References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
1884548	12/1931	Alexander	N/A	N/A
2952268	12/1959	Blum	137/155	E21B 43/123
3016844	12/1961	Vincent	N/A	N/A
3086593	12/1962	Chitwood	137/155	E21B 43/123
3722527	12/1972	Blackwell	137/155	E21B 43/123
3754597	12/1972	Garrett	N/A	N/A
4901798	12/1989	Amani	166/324	E21B 34/101
6705404	12/2003	Bosley	N/A	N/A
6715550	12/2003	Vinegar et al.	N/A	N/A
6758277	12/2003	Vinegar et al.	N/A	N/A
7896082	12/2010	Lake et al.	N/A	N/A
8985227	12/2014	Nikiforuk	N/A	N/A
9187994	12/2014	Themig	N/A	N/A
9284816	12/2015	Radford	N/A	N/A
9416621	12/2015	Mackenzie et al.	N/A	N/A
10294763	12/2018	Kleppa	N/A	N/A
11187059	12/2020	Churchill	N/A	N/A
2014/0182855	12/2013	Woodford	N/A	N/A
2017/0016290	12/2016	Manwill	N/A	E21B 34/10
2018/0179855	12/2017	Messa et al.	N/A	N/A
2020/0318741	12/2019	Zhang et al.	N/A	N/A
2021/0108736	12/2020	Park et al.	N/A	N/A
2022/0056784	12/2021	Culbertson et al.	N/A	N/A

FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
2623750	12/2016	RU	N/A

OTHER PUBLICATIONS

International Search Report and Written Opinion for PCT Application No. PCT/GB2023/051917 dated Dec. 21, 2023. (STL037). cited by applicant
International Search Report and Written Opinion for PCT Application No. PCT/GB2023/052137

dated Nov. 9, 2023. (STL040). cited by applicant
Partial International Search Report for PCT Application No. PCT/GB2023/051917 dated Oct. 31, 2023. (STL037). cited by applicant

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application claims priority to and the benefit of U.S. Provisional Application Ser. No. 63/398,035, filed Aug. 15, 2022, and is a continuation-in-part of U.S. application Ser. No. 18/355,051, filed Jul. 19, 2023, and which claimed priority to and the benefit of then U.S. Provisional Application Ser. No. 63/390,853, filed Jul. 20, 2022; the full disclosures of which are incorporated by reference herein in their entireties and for all purposes.

BACKGROUND OF THE INVENTION
1. Field of Invention
(1) The present disclosure relates to pressure compensating a downhole valve actuator.
2. Description of Prior Art
(2) Lift systems for unloading liquids from a well include pumps, such as electrical submersible pumps ("ESP"), which pressurize the liquid downhole and propel it up production tubing that carries the pressurized fluid to surface. Sucker rods and plunger lift pumps are also sometimes employed for lifting liquid from a well. In wells having an appreciable amount of gas mixed with the liquid a two-phase fluid may form and gas is sometimes separated from the fluid upstream of the ESP and routed to surface separately from the pressurized liquid. In some instances, compressor pumps are employed to pressurize the two-phase fluid to lift it to surface. A gas lift system is another type of artificial lift system, and that injects a lift gas, typically from surface, into production tubing installed in the well. The lift gas is usually directed into an annulus between the production tubing and sidewalls of the well, and from the annulus into the production tubing. Gas lift is commonly employed when pressure in a formation surrounding the well is insufficient to urge fluids to surface that are inside of the production tubing. By injecting sufficient lift gas into the production tubing, static head pressure of fluid inside the production tubing is reduced to below the pressure in the formation, so that the formation pressure is sufficient to push the fluids inside the production tubing to surface. Fluids that are usually in the production tubing are hydrocarbon liquids and gases produced from the surrounding formation. Sometimes these fluids are a result of forming the well or a workover and have been directed into the production tubing from the annulus.
(3) The lift gas is typically transported to the well through a piping circuit on surface that connects a source of the lift gas to a wellhead assembly mounted over the well. Usually, valves are mounted on the production tubing for regulating the flow of lift gas into the production tubing from the annulus. Some types of these valves automatically open and close in response to designated pressures in the annulus and/or tubing, while other valve types are motor operated and controlled by signals delivered from a remote location. Shortcomings of many current valve designs include valve leakage from thermal effects and damage due to erosion, chatter, miscalibration to well conditions, or cavitation when throttling high pressure fluids. High pressures in wells from static head also create issues for actuating downhole valves; such as large static loads applied to actuation

components or increased pressure differentials across an actuator housing.

SUMMARY OF THE INVENTION

(4) Disclosed is an example of a system for controlling a flow of fluid, and that includes a valve assembly, where the valve assembly is made up of a housing, a chamber in the housing having an inlet and an outlet, valve elements in the chamber each having a seal face, a fluid flow barrier in the chamber formed when seal faces on adjacent valve elements are brought into sealing contact with one another, forward and rearward compartments in the chamber that are on opposing sides of the fluid flow barrier, and a locking piston in the chamber having a side in pressure communication with the inlet and an opposing side in pressure communication with the outlet, the locking piston being selectively moved into a locking position and biased against an end of the first valve element that is in communication with the outlet. In one example the valve elements are a seat member and a plug assembly, and alternatively, a stem is included which has an end coupled to an end of the plug assembly. In this example, the system further optionally includes a motor attached to an end of the stem distal from the plug assembly, where energizing the motor moves the plug assembly towards and away from the seat member to selectively change the valve assembly between open and closed configurations; and where the locking piston is slidable with respect to the stem or is formed along a portion of the stem having an enlarged diameter. In an embodiment, an interface is defined where the plug seal face and seat member seal face are in sealing contact. In examples, pressure in the inlet exceeds pressure in the outlet. In an alternative, the valve assembly further includes a port formed radially through a sidewall of the housing adjacent the inlet, a port formed radially through the sidewall of the housing on a side of the locking piston distal from the fluid flow barrier, and a line connecting the ports. The valve assembly further optionally includes a port formed radially through the sidewall of the housing on a side of the locking piston distal from the fluid flow barrier, and where the inlet and the port are in communication to ambient. The seat member and plug assembly are optionally compliant with one another.

(5) Another example of a system for controlling a flow of fluid is disclosed and that includes a valve assembly, where the valve assembly is made up of a housing, a chamber in the housing; valve elements in the chamber each having a seal face, a barrier in the chamber formed when seal faces on adjacent valve elements are brought into sealing contact with one another, compartments in the chamber that are adjacent one another and on opposing sides of the barrier, the compartments being at different pressures, and a locking piston in a one of the compartments that is at a lower pressure, the locking piston being selectively biased against an end of a one of the valve elements that is between the locking piston and the barrier. The locking piston is optionally biased against the one of the valve elements by a pressure differential between fluid flowing into the valve assembly and fluid flowing out of the valve assembly. In an alternative, a locking force is applied to the one of the valve elements from the locking piston that offsets an opposing force from a pressure differential that is applied to the one of the valve elements. The system optionally further includes an actuator and a stem attached to the actuator, where the locking piston is coupled with the stem, and where an end of the stem distal from the actuator is in selective abutting contact with the a one of the valve elements, and is selectively moveable away from the a one of the valve elements.

(6) A method of controlling a flow of fluid is also disclosed, and that includes obtaining a valve assembly that comprises a housing, an inlet, an outlet, a valve seat, a plug member, and a stem connected between the plug member and an actuator, where the plug member is selectively in sealing contact with the valve seat to form a barrier to fluid flow through the valve assembly to define a closed configuration, and where the plug member is moveable away from the valve seat to form a passage between the valve seat and plug member to form a pathway for fluid flow through the housing and to define an open configuration. In this example the method also includes reducing a compressive load in the stem by biasing the plug member against the valve seat. The valve assembly of this example method optionally also includes a locking piston slideably disposed in the housing on a side of the plug member opposite the valve seat, where the compressive load in the

stem is generated by a difference between pressures of inlet and outlet flows to and from the valve assembly, and where the plug member is biased against the valve seat by communicating the pressure of the inlet flow to a side of the locking piston opposite the plug member. In an example, the inlet flow enters the valve assembly through an opening in the housing that is located a side of the valve seat opposite the plug member, and where the pressure of the inlet flow is communicated to the side of the locking piston opposite the plug member through a port formed in a sidewall of the housing. The pressure of the inlet flow is optionally communicated to the side of the locking piston opposite the plug member through a line that is external to the housing. In one embodiment, the actuator is coupled to a motor, the inlet and outlet are in communication with portions in a wellbore separated by a tubular disposed in the wellbore, in this embodiment the method further includes energizing the motor to move the plug assembly away from the valve seat to reconfigure the valve assembly into the open configuration so that lift gas flows between the portions in the wellbore and through the valve assembly.

Description

BRIEF DESCRIPTION OF DRAWINGS

(1) Some of the features and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings, in which:

(2) FIG. **1** is a side sectional view of an example of a valve in a closed configuration and with opposing sealing surfaces in contact.

(3) FIG. **2** is a side sectional view of the valve of FIG. **1** in the open configuration and with the opposing sealing surfaces spaced away from one another.

(4) FIG. **3** is a side sectional view of the valve of FIG. **2** in an open configuration and with the opposing sealing surfaces spaced farther away from one another.

(5) FIG. **3**A is a schematic example of a processor and actuator coupled with the valve assembly of FIG. **1**.

(6) FIG. **3**B is an alternate embodiment of the valve assembly of FIG. **2** that includes a check valve.

(7) FIG. **4** is a side section view of an example of lift gas flowing from an annulus, through the valve of FIG. **1**, and into production tubing.

(8) FIG. **5** is a side section view of an example of lift gas flowing from production tubing, through the valve of FIG. **1** and into an annulus.

(9) FIG. **6** is a side sectional view of an example of an alternate example of a valve assembly with a floating sleeve for reducing loads to a valve actuator.

(10) FIG. **7** is a side sectional view of an example of an alternate example of a valve assembly with a locking piston for reducing loads to a valve actuator.

(11) FIGS. **8**A and **8**B are side sectional views of an example of an alternate example of a valve assembly with a locking piston for reducing loads to a valve actuator.

(12) FIGS. **9**A-**9**C are side sectional views of an example of an alternate example of a valve assembly with a locking piston for reducing loads to a valve actuator.

(13) FIGS. **9**D-**9**F are side sectional views of an example of an alternate example of a valve assembly with an actuator having an enlarged stem for reducing loads to a valve actuator.

(14) FIGS. **10**A and **10**B are side sectional views of an example of an alternate example of a valve assembly that equalizes pressure in the actuator to ambient.

(15) While subject matter is described in connection with embodiments disclosed herein, it will be understood that the scope of the present disclosure is not limited to any particular embodiment. On the contrary, it is intended to cover all alternatives, modifications, and equivalents thereof.

DETAILED DESCRIPTION OF INVENTION

(16) The method and system of the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings in which embodiments are shown. The method and system of the present disclosure may be in many different forms and should not be construed as limited to the illustrated embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey its scope to those skilled in the art. Like numbers refer to like elements throughout. In an embodiment, usage of the term “about” includes +/−5% of a cited magnitude. In an embodiment, the term “substantially” includes +/−5% of a cited magnitude, comparison, or description. In an embodiment, usage of the term “generally” includes +/−10% of a cited magnitude.

(17) It is to be further understood that the scope of the present disclosure is not limited to the exact details of construction, operation, exact materials, or embodiments shown and described, as modifications and equivalents will be apparent to one skilled in the art. In the drawings and specification, there have been disclosed illustrative embodiments and, although specific terms are employed, they are used in a generic and descriptive sense only and not for the purpose of limitation.

(18) Shown in FIG. **1** is a side sectional view of an example of a valve assembly **10** having an annular valve housing **12**, within the housing **12** is a chamber **13** that extends along an axis A.sub.10 of the valve assembly **10**. A side port **14** is formed radially through a sidewall of housing **12**. Spaced axially from side port **14** is another side port **16** (FIG. **2**) formed radially through the sidewall of housing **12**. An edge of side port **16** proximate side port **14** is referred to as a forward portion **17**. An annular seat member **18** is shown coaxially within the chamber **13** with a lengthwise portion proximate port **14** having a radial thickness that remains substantially constant along its length. A distance axially away from port **14** the radial thickness of the seat member **18** increases to define a forward face **20** having a generally frusto-conical configuration. Axially past the forward face **20**, the radial thickness of seat member **18** reduces along its axial length to form a rearward face **22** shown having a frusto-conical configuration. A seal face **24** is defined along a lengthwise portion of the rearward face **22**, and also has a frusto-conical profile. In alternatives, seal face **24** has other profiles, such as a generally spherical profile or other standard configurations. A passage **26** extends axially through the seat member **18**, an outer diameter of passage **26** is defined by the inner diameter of seat member **18**.

(19) In the example shown, a spring **28** is disposed within the chamber **13** and has a rearward end abutting a forward terminal end of seat member **18** that faces towards the port **14**. Spring **18** applies a biasing force against member **18** in a rearward direction axially away from side port **14**. Also included with valve assembly **10** is a plug **30** having a conically shaped outer surface, the outer diameter of which increases with distance from the port **14**. A forward portion **31** of plug **30** is shown inserted within passage **26**. A seal face **32** is formed on an outer surface of forward portion **31** that is shaped complimentary to seal face **24**; in the example of FIG. **1**, seal faces **24**, **32** are in sealing contact with one another to form a sealing interface I that is a barrier to fluid communication between the member **18** and plug **30**. Example materials on seal faces **24**, **32** that form the sealing interface I include elastomers, thermoplastics, metals, like materials, and combinations. On a rearward end **33** of plug **30** is a cylindrically shaped spindle **34** shown projecting axially away from forward portion **31** and extending into a recess **36**, which is formed axially within a forward end of an elongated actuator stem **38** disposed within chamber **13**. A spring **40** is provided in recess **36** that exerts a biasing force urging the plug **30** in a forward direction and against seat member **18**. In the embodiment of FIG. **1**, and as described in more detail below, spring **40** is strategically formed or selected to have a designated spring constant.

(20) Valve assembly **10** illustrated in FIG. **1** is in a closed configuration, which in an example is defined by opposing seal faces **24**, **32** being in sealing contact and that forms interface I along the faces **24**, **32** that circumscribes the respective inner and outer surfaces of passage **26** and plug **30**. In a non-limiting example of operation, the valve assembly **10** is put into the closed configuration

by exerting an axial force onto one or both of seat member **18** and plug **30** to bring seal faces **24**, **32** into sealing contact and form interface I; the axial force is optionally provided by moving actuator stem **38** towards seat member **18**. In an alternative one or both springs **28**, **40** become at least partially compressed by putting valve assembly **10** in the closed configuration. Seat member **18** and plug **30** are maintained in sealing contact with one another by the combination of spring **28** which biases the seat member **18** in the direction of plug **30**, and spring **40** which biases plug **30** in the direction of seat member **18**. As illustrated by arrow A.sub.18 and arrow A.sub.30, seat member **18** and plug **30** are each selectively movable along axis A.sub.10. Adjacent portions of chamber **13** on opposing sides of interface I define compartments **42**, **44**. In addition to blocking fluid communication across interface I when faces **24**, **32** are in sealing contact, examples exist in which interface I forms a pressure barrier to pressure isolate compartments **42**, **44** from one another.
(21) For the purposes of discussion herein, the term compliant or compliancy, regarding seal elements in a valve, describes a seal element or elements that in response to displacement (such as from a thermal effect) of itself or a corresponding seal element, repositions or can be repositioned to maintain sealing contact with the corresponding seal element. In a non-limiting example, the seat member **18** and plug **30** are referred to as valve elements and that provide a dual compliant functionality, the springs **28**, **40** illustrate examples of dual biasing means. An advantage of the valve assembly **10** having the dual compliant valve elements with the dual biasing means is that sealing contact between plug **30** and seat member **18** is maintained continuously when the valve assembly **10** is put into the closed configuration and is not compromised by thermal effects of material expansion or contraction that might could cause leakage or sealing surface separation in a valve with non-compliant elements.
(22) Referring now to FIG. **2**, plug **30** is moved axially away from seat member **18** to space apart the seal faces **24**, **32**, which removes the interface I (FIG. **1**) and allows fluid communication between compartments **42**, **44**. Further shown in FIG. **2** is a choke member **46** integrally formed onto actuator stem **38** a distance L.sub.38 from plug **30**. For the purposes of reference, an end of choke member **46** proximate plug **30** is referred to as a forward end **47**. In the illustrated example an outer diameter of choke member **46** is substantially equal to an inner diameter of chamber **13**, which forms an interface along where an outer surface of choke member **46** and an inner surface of the side wall of housing **12** are in contact with one another. This contact interface between choke member **46** and inner sidewall of housing **12** defines a fluid flow barrier between chamber **13** and side port **16**. In this example, the fluid flow barrier between side port **16** by choke member **46** substantial blocks fluid flow through the valve assembly **10** and between ports **14**, **16**. In the example shown, by selectively spacing choke member **46** a distance L.sub.38 from plug **30**, fluid F in valve assembly **10** remains substantially static inside chamber **13** as plug **30** is being separated from and moved away from seat member **18**.
(23) Referring now to FIG. **3**, plug **30**, stem **38**, and choke member **46** are shown in a subsequent step of operation in which all have moved laterally farther away from seat member **18**. In the example shown, a portion of choke member **46** is positioned forward of side port **16**, so that no obstacles to fluid flow are between side port **16** and chamber **13**. In the example of FIG. **3**, environments E.sub.14, E.sub.16 are ambient to side ports **14**, **16**; in alternatives environments E.sub.14, E.sub.16 are separate and distinct from one another and/or are at different pressures. In an example sequence of operation occurring between FIG. **2** and FIG. **3**, forward end **47** of choke member **46** moves rearward of forward portion **17** of port **16** to partially expose port **16** to chamber **13** to provide fluid communication between ports **14**, **16** through chamber **13**. Providing fluid communication between ports **14**, **16** initiates the stream of flowing fluid FF through ports **14**, **16**, the volumetric flow of the fluid flow stream increases as the choke member **46** is moved farther rearward to expose a greater area of the port **16** to the chamber **13** to increase a cross sectional area of the fluid flow path through the valve assembly **10**. In examples when pressure in environment E.sub.14 exceeds that of environment E.sub.16, so that a fluid FF in environment E.sub.14 enters

chamber **13** through side port **14**, flows as a stream of flowing fluid FF through chamber **13**, and exits chamber **13** through side port **16**. In examples when pressure in environment E.sub.16 exceeds that of environment E.sub.14, so that a fluid FF in environment E.sub.16 enters chamber **13** through side port **16**, flows as a stream of flowing fluid FF through chamber **13**, and exits chamber **13** through side port **14**. In an example, the magnitude of distance L **38** is strategically set so that seal faces **24**, **32** are at least a threshold distance apart to create a flow area FA between seal faces **24**, **32** of adequate dimensions so that a velocity of flowing fluid FF passing through the flow area FA is below a magnitude at which erosion or cavitation of either seal face **24**, **32** occurs or could occur. An additional advantage of the present disclosure is that a barrier to fluid flow through the valve assembly **10** is set a distance away from the sealing interface I and seal faces **24**, **32** and that prevents cavitation or erosion to the seal faces **24**, **32** as high-velocity jets or cavitations can collapse before reaching the seal faces **24**, **32**. In a non-limiting example of operation, a determination of the flow area FA that is above a threshold magnitude to avoid erosion or cavitation in seal faces **24**, **32** is dependent on the flowing fluid FF, such as its characteristics, properties, and constituents, and conditions of the flowing fluid FF, such as its temperature, pressure, and expected pressure differential of the flowing fluid FF through the valve assembly **10**. It is believed it is within the capabilities of one skilled in the art to determine values of a threshold flow area FA and threshold distance between opposing sealing faces **24**, **32** at which cavitation or erosion of components in the valve assembly **10** does not occur. Example resources for determining these values include API Spec 19G2 and Crane Technical Paper No. 410, both of which are incorporated by reference herein in their entireties and for all purposes.

(24) In the example shown in FIG. **3**A, valve assembly **10** is coupled with an actuator **48**, which provides an actuating force for moving onto valve stem **38**. Included in FIG. **3**A is a processor **50** disposed within a portion of housing **12** spaced away from valve assembly **10**. Processor **50** is in communication with actuator **48** and selectively provides command signals for controlling operation of actuator **48** and opening and closing of valve assembly **10**. In embodiments, the processor **50** is part of an information handling system, and further includes memory accessible by the processor, nonvolatile storage area accessible by the processor, and logics for performing each of the steps described herein.

(25) An alternative example of a valve assembly **10**B is shown in a side sectional view in FIG. **3**B, and having a check valve **51**B with a spring **52**B inside housing **12**B on a side of seat member **18**B opposite plug **30**B. In this example, check valve **51**B is between side port **14**B and seat member **18**B. In a non-limiting example of use of valve assembly **10**B, check valve **51**B limits flow between ports **14**B, **16**B to a forward direction, and spring **52**B biases valve **51**B to a closed position when flow is in a rearward direction to prevent dual flow through the valve assembly **10**B.

(26) Shown in a side partial sectional view in FIG. **4** is an example of valve **10** included in a gas lift system **52** being used for lifting liquid L from a well **54**. Well **54** is shown intersecting a subterranean formation **56** and having perforations **58** that extend radially outward from the well **54** into the formation **56**. Perforations **58** also intersect casing **59** that lines the well **54**. Production tubing **60** is inserted within the casing **59**. Fluid F.sub.58 within formation **56** flows from the formation **56** through perforations **58** into the well **54**, shown within a bottom of well **54** are liquid L and gas G components of fluid F.sub.58. Pressure inside formation **56** forces fluid F.sub.58 from the bottom of the well **54** upward into the production tubing **60**. A packer **61** spans between the tubing **60** and casing **59** to force fluid F.sub.58 into production tubing **60**. An upper end of production tubing **60** connects to a wellhead assembly **62** shown on surface **63**. Included with gas lift system **52** is a lift gas source **64** shown containing an amount of lift gas **66**. Examples of a lift gas source **64** include adjacent wells, a gas line manifold, in-situ gas from another well (not shown), compressors, and other known or future developed sources of gas for use in a lift gas application. A line **68** attaches to a discharge of the lift gas source **64** and provides a conduit for transporting the lift gas **66** into an annulus **70** that is defined in a space between the production

tubing **60** and casing **59**. In a non-limiting example, valve **10** is configured so that environment E.sub.14 (FIG. **3**) is within, a part of, or in communication with annulus **70**, and environment E.sub.16 (FIG. **3**) is within or is in communication with tubing **60**; alternatively, valve **10** is configured so that environment E.sub.16 is within, a part of, or in communication with annulus **70**, and environment E.sub.14 (FIG. **3**) is within or is in communication with tubing **60**.
(27) Also included with the gas lift system **52** are a series of pressure operated valves **72** that are shown mounted to an exterior of the production tubing **60** at different depths within the well **54**. In an example, valves **72** include surface controlled valves, pressure production valves, injection pressure valves, and optionally are inside production tubing **60**. Valves **72** attach respectively to outlet ports **74** that extend through the sidewall of the production tubing **60** and in examples are automatically changeable between the open and closed configurations in response to pressure within the production tubing **60** or annulus **70**. Illustrated in FIG. **4** is an example of injecting lift gas **66** from lift gas source **64** into production tubing **60** via valves **72** or valve **10**. Lift gas bubbles **76** are shown inside liquid L in production tubing **60** that reduce a density of liquid L for promoting the upward flow of liquid L to the wellhead assembly **62**. As shown, valve **10** connects to a controller **82** via a communication circuit **84** that carries signals between the controller **82** and valve **10**, examples of the circuit **84** include electrically conductive members, fiber optics, hydraulic lines, and wireless telemetry. Included in this example are sensors **86**, **88** in communication with the production tubing **60** and sensor **90** in communication with a production line **92**. Sensors **86**, **88**, **90** optionally sense conditions inside the tubing **60**, annulus **70**, injection line **68**, or production line **92**, where example conditions include pressure, temperature, fluid properties, fluid composition and the like. In the example shown, fluid exiting wellhead assembly **62** and into production line **92** is referred to as production fluid PF, which includes liquid L, gas G, and optionally some amounts of lift gas **66**. Production line **92** carries production fluid PF to a terminal location **94**. In alternatives, terminal location **94** include one or more of a distribution center where production fluids from other wells are collected combined into a transmission line, a location where the production fluid PF is containerized for delivery elsewhere, or a processing facility where the production fluid PF is refined or conditioned.
(28) In an example, side port **14** (FIG. **3**) selectively provides communication between chamber **13** and ambient of the valve **10** and side port **16** provides selective communication between chamber **13** and tubing **60**. Optionally, side port **16** selectively provides communication between chamber **13** and ambient of the valve **10** and side port **14** provides selective communication between chamber **13** and tubing **60**. For the purposes of discussion herein, ambient defines the environment surrounding the housing **12**.
(29) Referring back to FIG. **3**B, in examples in which port **16**B is in communication with annulus **70** (FIG. **4**) and valve assembly **10**B is in an open configuration, fluid injection from annulus **70** to tubing **60** (FIG. **4**) is selectively permitted through valve assembly **10**B. As noted above, the biasing of spring **52**B to close check valve **51**B blocks reverse flow from tubing **60** to annulus **70**, which prevents high pressure that may be present in the tubing **60** from communicating into the annulus **70**.
(30) Illustrated in a side sectional view in FIG. **5** is an alternative example of a lift gas system **52**A in which fluid produced from well **54** F.sub.58 is forced upwards within annulus **70**. In this example lift gas **66** is directed into the production tubing **60** through line **68**A. Lift gas **66** exits production tubing **60** through valve **10**, through one or more of valves **72**, or through both. In this example lift gas bubbles **76** form in the liquid L shown in annulus **70** between tubing **60** and casing **59**; lift gas bubbles **76**, gas G, and liquid L form at least a part of produced fluid PF shown being carried in production line **92**A to terminal location **94**.
(31) Referring now to FIG. **6** shown in a side sectional view is an example of an embodiment of a valve assembly **110** having an annular valve housing **112** and within the housing **112** is a bore **113** that extends along an axis A.sub.110 of the valve assembly **110**. A side port **114** is formed radially

through a sidewall of housing **112**. Spaced axially rearward from side port **114** is another side port **116** formed radially through the sidewall of housing **112**. In embodiments, port **114** is selectively in communication with tubing **60** while side port **116** is in communication with annulus **70** (FIG. **4**), or vice versa. A sleeve-like floating chamber **117** is shown coaxially within the chamber **113**, an axial end of floating chamber **117** is closed and which defines a bulkhead **118**. A port **119** is formed through a radial sidewall of floating chamber **117** and is shown registered with port **114**. An end of floating chamber **117** distal from bulkhead **118** is open, proximate the open end sidewalls of the floating chamber **117** are profiled obliquely radially inward to form a forward face **120** that faces bulkhead **118** and has a generally frusto-conical configuration. A distance axially rearward of the forward face **120** the sidewalls of the floating chamber **117** are profiled obliquely radially outward to form a rearward face **122**, which has a frusto-conical configuration that faces away from bulkhead **118**. In the example shown, the sidewalls of floating chamber **117** between faces **120**, **122** have a substantially constant thickness and define an axial passage **123**. A seal face **124** is defined along a lengthwise portion of the rearward face **122**. In alternatives, seal face **124** has other profiles, such as a generally spherical profile or other standard configurations.

(32) A cylindrically shaped end cap **126** is illustrated having a rearward portion inserted into a forward end of housing **112** and that defines a compartment **127** between end cap **126** and bulkhead **118**. A flange circumscribes a mid-portion of end cap **126** and is shown abutting a forward end of housing **112**. A spring **128** is shown disposed within the compartment **127** that applies a biasing force against floating chamber **117** in a direction axially away from end cap **126**. In examples, floating chamber **117** is selectively reciprocatingly moveable within bore **113**, similar to operation of seat member **18** (FIG. **1**) described above. A passage **129** is shown formed axially through end cap **126**, in the example of FIG. **6** passage **129** is in communication with annulus **70** (FIG. **4**).

(33) Still referring to FIG. **6**, valve assembly **110** further includes a conically shaped plug **130** with a forward portion **131** shown inserted within passage **123**. A seal face **132** is formed on an outer surface of forward portion **131** that is shaped complimentary to seal face **124**. In the example of FIG. **6**, seal faces **124**, **132** are in sealing contact with one another to form a sealing interface I.sub.110, which circumscribes the respective inner and outer surfaces of passage **123** and plug **130**, and that is a barrier to fluid communication between the floating chamber **117** and plug **130**. When seal faces **124**, **132** are in sealing contact as shown in FIG. **6**, valve assembly **110** is in a closed configuration. On a rearward end of plug **130** is a spindle **133** that projects axially away from forward end **131**. A slot **134** is formed through spindle **133**, slot **134** has and elongate side shown extending lengthwise along a portion of spindle **133**. A pin **135** inserts into slot. Spindle **133** is a cylindrically shaped member and extends into a recess **136** formed axially within a forward section **137** of a choke member **138** shown disposed within bore **113**. Forward section **137** is an elongate annular member shown disposed lengthwise in the bore **113** and generally aligned with axis A.sub.110. In an example, pin **135** couples with section **137** and is in interfering contact with slot **134** to engage plug **130** with choke member **138**. A rearward section **139** of choke member **138** is shown having an outer diameter that increases with distance from forward section **137** to form a frusto-conical portion, and past the frusto-conical section the rearward section **139** is substantially cylindrical and with an outer diameter largely the same as the inner diameter of the bore **113**. A spring **140** is provided in a bottom of recess **136** and that as shown exerts a biasing force urging the plug **130** against floating chamber **117**. A compartment **142** is formed inside floating chamber **117** between bulkhead **118** and interface I.sub.110. Forward section **137** has an outer diameter less than an inner diameter of bore **113** so that a compartment **144** is formed in the annular space between bore **113** and forward section **137**. Forward section **137** extends lengthwise between interface I.sub.110 and where rearward section **139** transitions from a frusto-conical shape to a cylindrical shape. When seal faces **124**, **132** are in sealing contact a pressure barrier is formed along interface I.sub.110 that blocks pressure and fluid communication between compartments **142**, **144**.

(34) Valve assembly **110** of FIG. **6** further includes an actuator stem **146**, which is shown in bore

113 and that has an elongate length generally aligned with axis A.sub.110. A forward end of stem **146** inserts into a bore **148** formed partially through rearward section **139**. In the example shown, stem **146** is coupled to choke member **138**, such as with a threaded connection in bore **148**. An annular piston **154** is shown slidingly disposed in an annulus between stem **146** and inner surface of housing **112**. In the example shown, a motor **156** connects to an end of stem **146** opposite section **139**, and which selectively exerts an actuating force onto stem **146**. Motor **156** is disposed in a compartment **158** that is optionally filled with a fluid, that in examples include one or more of a hydraulic or dielectric fluid. Fluid is optionally pressure equalized to ambient by exposing piston **154** to ambient pressure via port **116**. Piston **154** is axially moveable within housing **112** and shown having seals for pressure isolating its forward and rearward ends from one another.

(35) In examples, valve assembly **110** of FIG. **6** operates similar to valve assembly **10** of FIG. **1** as described above and is changed from a closed configuration to an open configuration by energizing motor **156**, which in turn exerts an axial force onto actuator stem **146** and plug **130** to move actuator stem **146** and plug **130** rearwardly and separate seal faces **124**, **132**. Separating seal faces **124**, **132** extends passage **123** to between seal faces **124**, **132** and provides communication between compartments **142**, **144** via passage **123**. When in the open configuration choke member **138** is moved rearward so that all or a substantial portion of port **116** interfaces directly with compartment **144**. Fluid from tubing **60** enters valve assembly **110** through registered ports **114**, **119**, flows into compartment **142**, along passage **123**, and exits into annulus **70** through port **116**. Valve assembly **110** of FIG. **6** also has the advantage of reducing cavitation along seal faces **122**, **124** by strategically sizing choke member **138** so that rearward portion **139** is adjacent port **116**, to hinder fluid flow through port **116**, until faces **122**, **124** are spaced a distance apart from one another so that that faces **122**, **124** are not subject to the cavitation and/or erosion described above. The valve assembly **110** selectively functions in dual compliant fashion similar to valve assembly of FIG. **1** as described above and maintains a compliant engagement of seal faces **124**, **132** by springs **128**, **140**. Valve assembly **110** is further configured to avoid overstressing the actuation hardware when the valve assembly **110** is subjected to pressure differentials that exceed design and/or anticipated magnitudes.

(36) In a non-limiting example of operation of the valve assembly **100** of FIG. **6**, ports **114**, **119** are in communication with tubing **60** while ports **116** and **129** are in communication with annulus **70**. As shown, a surface area A **127** on a forward side of bulkhead **118** faces and is exposed to compartment **127**, and a rearward side of bulkhead **118** has a surface area A.sub.142 facing and exposed to compartment **142**. Surface areas A.sub.127, A.sub.142 are strategically sized so that the total force Ft exerted against plug **130** and floating chamber **117** from pressure differences between tubing **60** and annulus **70** is less than that to create damage to actuator stem **146**, actuator **156**, or other hardware used in actuating valve assembly **110** or otherwise associated with valve assembly **110**.

(37) Referring now to FIG. **7**, shown in a side sectional view is an example of a valve assembly **210** having an annular valve housing **212** with a chamber or bore **213** that extends along an axis A.sub.210 of the valve assembly **210**. A side port **214** is formed radially through a sidewall of housing **212** that provides communication between bore **213** and tubing **60**. In alternatives, side port **214** provides communication between bore **213** and annulus **70**. An equalizing port **215** is formed through sidewall of housing **212** shown spaced circumferentially away from side port **214** and in communication with side port **214** across bore **213**. An equalizing line **216** connects to port **215** and extends outside housing **212** an axial distance where it connects to another equalizing port **217** formed through the housing **212**. Portions of bore **213** adjacent ports **215**, **217** are in pressure communication with one another via ports **215**, **217** and line **216**. An annular seat member **218** is shown coaxially disposed within the bore **213** and spaced axially away from side port **214**. Seat member **218** is axially moveable within bore **213** and has an outer surface in sealing contact with an inner surface of housing **212**. A portion of seat member **218** proximate port **214** has a radial

thickness that remains substantially constant along its length, and at a distance axially away from side port **214** the inner surface of the seat member **218** is profiled obliquely radially inward to define a forward face **220** having a generally frusto-conical configuration. A distance rearward of the forward face **220**, the inner surface of seat member **218** is profiled obliquely radially outward to form a rearward face **222** shown having a frusto-conical configuration. A planar section **223** of seat member **218** between the forward and rearward faces **220**, **222** has a radial thickness greater than the portion of seat member **218** adjacent the side port **214**. A seal face **224** is defined along adjacent portions of the planar portion **223** and rearward face **222**. In alternatives, seal face **224** has other profiles, such as a generally spherical profile or other standard configurations. A passage **226** extends axially through the seat member **218**.
(38) A spring **228** is shown within bore **213** and in biasing contact with a forward end of seat member **218** opposite rearward face **222**. In the example shown, spring **228** and seat member **218** are within a recess formed radially along an inner surface of housing **212**. A cylindrical end cap **229** is shown having a portion inserted into an open end of housing **212** on a side of side port **214** opposite spring **228**. A flange circumscribes a mid-portion of end cap **229** and that abuts a forward end of housing **212**. Valve assembly **210** further includes a conically shaped plug **230** with a forward portion **231** shown inserted within passage **226**. A seal face **232** is formed on an outer surface of forward portion **231** that is shaped complimentary to seal face **224**, as shown seal faces **224**, **232** are in sealing contact with one another to form a sealing interface I.sub.210 that is a barrier to fluid communication between seat member **218** and plug **230**. On a forward end of plug **230** a spindle **233** is provided which projects axially away from forward end **231**. A slot **234** is shown formed through spindle **233**, slot **234** has an elongate side that extends lengthwise along a portion of spindle **233**. A pin **235** is inserted through slot **234** and oriented transverse to axis A.sub.210 of valve assembly **210**. Spindle **233** is a cylindrically shaped member and extends into a recess **236** shown formed axially within a forward portion **237** of a choke member **238**. Forward portion **237** is an elongate annular member shown extending lengthwise in the bore **213** and generally aligned with axis A.sub.210. In an example, pin **235** couples with forward portion **237** and is in interfering contact with slot **234** to retain plug **230** to choke member **238**. Forward portion **237** has an outer diameter less than an inner diameter of bore **213**. A rearward section **239** of choke member **238** joins an end of forward section **237** distal from plug **230**. Rearward section **239** outer diameter increases with distance from forward section **237** to form a frusto-conical portion; past the frusto-conical portion the rearward section **239** is substantially cylindrical and with an outer diameter largely the same as the inner diameter of the bore **213**. A spring **240** is in recess **236** and that as shown exerts a biasing force urging the plug **230** axially against seat member **218**. A port **241** is shown formed radially through a sidewall of housing **212** and adjacent rearward section **239**. A compartment **242** is formed inside bore **213** between plug **229** and interface I.sub.210. An annular space between the inner surface of housing **213** and outer surface of forward section **237** defines a compartment **244**, which extends lengthwise between interface I.sub.210 and where rearward section **239** transitions from a frusto-conical shape to a cylindrical shape. In the example shown, the interface between rearward section **239** and inner surface of housing **212** is not sealed so that port **241** is in pressure communication with compartment **244**. When seal faces **224**, **232** are in sealing contact substantially along their respective circumferences, a pressure barrier forms along interface I.sub.210, which blocks pressure and fluid communication between compartments **242**, **244**. The example of valve assembly **210** shown in FIG. **7** is in a closed configuration and occurs when opposing seal faces **224**, **232** are in sealing contact to form interface I.sub.210 along the faces **224**, **232**. As shown interface I.sub.210 circumscribes the respective inner and outer surfaces of passage **226** and plug **230**.
(39) Still referring to FIG. **7**, in bore **213** is an elongate actuator stem **246** having a length generally aligned with axis A.sub.210. An annulus **247** is formed in the radial space between actuator stem **246** and inner surface of housing **212**. A forward end of stem **246** inserts into a bore **248** formed

partially through rearward section **239**, which couples stem **246** to choke member **238**; such as by a threaded connection in bore **248**, a press fit, welding, bonding, or the like. An annular locking piston **252** and an annular equalizing piston **253** are shown disposed in the annulus **247**, equalizing piston **253** is spaced axially rearward of locking piston **252**. Seals (shown as O-rings in this example) for pressure isolating forward and rearward ends of pistons **252**, **253** are optionally provided on the inner and outer diameters of pistons **252**, **253** that form fluid barriers between inner surfaces of pistons **252**, **253** and stem **246**, and also between outer surfaces of pistons **252**, **253** and the inner surface of housing **212**. The pistons **252**, **253** are slideable along axis A.sub.210, such as in response to pressure differentials on their opposing end surfaces. Compartments **254**, **255** are formed in the annulus **247** respectively between pistons **252**, **253**, and between piston **252** and rearward section **239**. Port **217** is adjacent compartment **254**, so that compartment **254** is in pressure communication with compartment **242** via line **216**. A motor **256** is shown connected to an end of stem **246** opposite section **239**, and which selectively exerts an actuating force onto stem **246**. Motor **256** is disposed in a compartment **258** that is optionally filled with a fluid, such as a hydraulic or dielectric fluid.

(40) When in the example of a closed configuration shown in FIG. **7**, the valve assembly **210** functions in dual compliant fashion and maintains a compliant engagement of seal faces **224**, **232** by springs **228**, **240**. Valve assembly **210** of FIG. **7** is changed from the closed configuration to an open configuration similar to that shown in FIGS. **2** and **3** as described above. In the open configuration, plug **230** is moved axially rearward so that sealing faces **224**, **232** are spaced apart from one another. In an example of changing from a closed to open configuration, motor **256** is energized by electricity from a power source **260** via line **262**, which exerts an axial force onto stem **246** causing it to move rearward, and through connection of the stem **246** to the rearward section **239**, plug **230** is drawn away from seat member **218** to remove interface I.sub.210 and extend passage **226** to between sealing faces **224**, **232**. Extending passage **226** between sealing faces **224**, **232**, puts compartments **242**, **244** in communication via passage **226**. When in the open configuration, choke member **238** is moved rearward so that all or a substantial portion of port **241** interfaces directly with compartment **244**. Similar to operation of valve assembly **10** described above, fluid from tubing **60** enters valve assembly **210** through port **214**, flows into compartment **242**, along passage **226**, and exits into annulus **70** through port **241**. Valve assembly **210** of FIG. **7** similarly has the advantage of reducing cavitation along seal faces **222**, **224** by strategically sizing choke member **238** to hinder flow across port **241** until faces **222**, **224** are spaced apart from one another.

(41) In an example of operation when port **214** is in communication with production tubing **60**, port **241** is in communication with annulus **70**, and pressure in production tubing **60** exceeds pressure in annulus **70** ("tubing/annulus pressure differential"), a pressure differential is created between compartments **254**, **255**. Force F.sub.242 schematically represents oppositely directed forces resulting from the tubing/annulus pressure differential across the seat member **218** and plug **230**, and force F.sub.252 schematically represents oppositely directed forces resulting from the tubing/annulus pressure differential across piston **252**. Force F.sub.252 urges piston **252** into compartment **255**, and without a seal between rearward section **239** and inner surface of housing **212**, fluid F is forced from compartment **255**, across the interface between section **239** and inner surface of housing **212**, and either into compartment **244** or out of bore **213** through port **241**. After the fluid F is expelled from compartment **255** and with continued tubing/annulus pressure differential applied across piston **252**, piston **252** comes into biasing contact with rearward section **239**, which exerts force F.sub.252 onto choke member **238** in a direction opposite to force F.sub.242. Creating and applying piston force F.sub.252 in a direction opposite to force F.sub.242 locks choke member **238** against rearward movement and reduces forces transmitted to actuator stem **246** and other actuation hardware created by tubing/annulus pressure differential. In the example of FIG. **7**, an operational range of valve assembly **210** is expanded to include scenarios

when tubing pressure exceed annulus pressure by an amount to generate a force F.sub.242 which exceeds design limitations or that damages the valve assembly **210**. One example of a force F.sub.242 which exceeds design limitations or damages the valve assembly **210**, is a force F.sub.242 that generates a force in shaft **246** exceeding a yield strength of shaft **246**. Examples of damage to the valve assembly **210** include deformation of one or more components of the valve assembly **210**. In an alternative, and depending on a designated operational scenario, a radial thickness of piston **242** is adjusted to achieve a designated force F.sub.252 to counter force F.sub.242, so that creates forces and/or stresses exerted onto components in the valve assembly **210**, due at least in part from force F.sub.242, remain below the yield strength of these components.

(42) Another example of a valve assembly **310** is shown in side-sectional views in FIGS. **8**A and **8**B and made up of an annular valve housing **312** having a chamber or bore **313** that extends along an axis A.sub.310 of the valve assembly **310**. A forward end **314** of valve assembly **310** is shown open to the annulus **70**, which communicates bore **313** with annulus **70** through forward end **314**. Spaced axially rearward from forward end **314** is a flow port **316** formed radially through a sidewall of housing **312** and that is in communication with tubing **60**. An equalizing port **317** is formed radially through the sidewall of housing **312** and spaced rearward of flow port **316** and that is open to annulus **70**. An annular seat member **318** is shown coaxially disposed within the bore **313** and disposed axially between forward end **314** and flow port **316**. Seat member **318** is axially moveable within bore **313** and has an outer surface in sealing contact with the inner surface of housing **312**. A portion of seat member **318** proximate end **314** has a radial thickness that remains substantially constant along its length, and at a distance axially away from end **314**, the inner diameter of the seat member **318** decreases with distance from end **314**, which increases a radial thickness of seat member **318**, and that creates a frusto-conical profile on the seat member **318** along the length of increasing thickness. A forward face **320** is formed along the frusto-conical profile. A distance axially rearward of the forward face **320** the radial thickness of seat member **318** reduces along an axial length of seat member **318** to form a rearward face **322**, which also has a frusto-conical configuration. Between the forward and rearward faces **320**, **322** an inner diameter of seat member **318** is substantially constant to define an annular section **323** that has a radial thickness greater than the portion of seat member **318** distal from rearward face **322**. A seal face **324** is defined along adjacent portions of the annular section **323** and rearward face **322**. Seal face **324** alternatively has other profiles, such as a generally spherical profile or other standard configurations. A passage **326** extends axially through the seat member **318**.

(43) A spring **328** is shown within bore **313** and in biasing contact with an end of seat member **318** proximate end **314**. A ring **329** mounted in inner surface of housing **312** on a side of spring **328** opposite seat member **318** provides an axial backstop for spring **328**. In the example shown, spring **328** and seat member **318** are within a recess formed radially into an inner surface of housing **312**. Valve assembly **310** further includes a plug **330** with a conically shaped forward portion **331** shown inserted within passage **326** and that faces towards open end **314**. A seal face **332** is formed on an outer surface of forward portion **331** that is shaped complimentary to seal face **324**, as shown seal faces **324**, **332** are in sealing contact with one another to form a sealing interface I.sub.310 that is a barrier to fluid communication between seat member **318** and plug **330**. Interface I.sub.310 circumscribes the respective inner and outer surfaces of passage **326** and plug **330**. Valve assembly **310** of FIG. **8**A is in a closed configuration when opposing seal faces **324**, **332** are in sealing contact. On a rearward end of plug **330** is a spindle **333** shown projecting axially away from forward end **331**. A slot **334** is shown formed through spindle **333**, which has and elongate side extending lengthwise through spindle **333**. A pin **335** is shown inserted into slot **334**. Spindle **333** is a cylindrically shaped member having a free end extending into a cylindrically shaped recess **336** that is formed axially within a forward section **337** of a choke member **338**. Forward section **337** is an elongate annular member set lengthwise in the bore **313** and generally aligned with axis A.sub.310. In an example, pin **335** extends radially from within slot **334** and through an opening

(not shown) formed in a sidewall of forward section **337** to couple plug **330** with choke member **338**. Forward section **337** has an outer diameter spaced radially inward from inner surface of housing **312**. Choke member **338** includes a rearward section **339** shown joined to an end of forward section **337** distal from plug **330**. Rearward section **339** outer diameter increases with distance from forward section **337** to form a frusto-conical portion; past the frusto-conical portion the rearward section **339** is substantially cylindrical and with an outer diameter largely the same as the inner diameter of the bore **313**. A helical elongate spring **340** is shown lengthwise in recess **336** that exerts a biasing force urging the plug **330** against seat member **318**. A compartment **342** is defined inside bore **313** between forward end **314** and interface I.sub.310, and a compartment **344** is formed in the annular space between the inner surface of housing **313** and outer surface of forward section **337**, compartment **344** extends axially between interface I.sub.310 and where rearward section **339** transitions from a frusto-conical shape to a cylindrical shape. In the example shown, the interface between rearward section **339** and inner surface of housing **312** is not sealed so that port **316** is in pressure communication with compartment **344**. When seal faces **324**, **332** are in sealing contact a pressure barrier is formed along interface I.sub.310 that blocks pressure and fluid communication between compartments **342**, **344**.
(44) Still referring to FIGS. **8**A and **8**B, shown in bore **313** is an elongate actuator stem **346** that is lengthwise generally aligned with axis A.sub.310. An annulus **347** is formed in the radial space between actuator stem **346** and inner surface of housing **312**. A forward end of stem **346** inserts into a bore **348** formed lengthwise and partially through rearward section **339** and in a side opposite forward section **337**; and which couples stem **346** to choke member **338**, examples of coupling include a threaded connection in bore **348**, a press fit, a weld, or integrally formed. A locking piston **352** and a rearward piston **353** are shown as annular members that are disposed in the annulus **347** at axially spaced apart locations. Seals (shown as O-rings in this example) for pressure isolating opposing forward and rearward ends of pistons **352**, **353** are optionally provided on the inner and outer diameters of pistons **352**, **353** to form pressure and fluid seals between inner surfaces of pistons **352**, **353** and stem **346** and outer surfaces of pistons **352**, **353** and inner surface of housing **312**. The pistons **352**, **353** are slideable along axis A.sub.310, such as in response to pressure differentials on their opposing end surfaces. Compartment **354** is formed in the annulus **347** between pistons **352**, **353**, and compartment **355** is formed in the annulus **347** between piston **352** and rearward section **339**. Compartment **354** is in pressure communication with annulus **70** via port **317**. A motor **356** is shown connected to an end of stem **346** opposite section **339**, and which selectively exerts an actuating force onto stem **346**. An example of a power source **360** is schematically shown connected to motor **356** via a power line **362** for selectively delivering electricity to motor **356** to energize motor **356**. Motor **356** is disposed in a compartment **358** that is optionally filled with a fluid, such as a hydraulic or dielectric fluid DF. As piston **353** is axially moveable within housing **312** in response to pressure a differential between compartments **354**, **358** and compartment **354** is in pressure communication with ambient via port **317**; pressure in compartment **358** is maintained substantially equal to ambient. In this example piston **353** operates as a pressure equalizing piston for equalizing pressure in compartment **358** with pressure in annulus **70**.
(45) When in the closed configuration shown in FIGS. **8**A and **8**B, the valve assembly **310** functions in dual compliant fashion and maintains a compliant engagement of seal faces **324**, **332** by springs **328**, **340**. In an example of changing from a closed configuration shown in FIGS. **8**A and **8**B, to an open configuration, (such as in FIG. **3**), motor **356** is energized by electricity from power source **360** via cable **362**, which exerts an axial force onto stem **346** causing stem **346** to move rearward and draw plug **330** away from seat member **318** so that sealing faces **324**, **332** are spaced apart from one another, which extends passage **326** to between sealing faces **324**, **332** and removes interface I.sub.310. Without interface I.sub.310 forming a barrier to fluid flow between faces **324**, **332**, communication exists between compartments **342**, **344** via passage **326**. Further

rearward movement of choke member **338** spaces choke member **338** away from flow port **316** so that all or a substantial portion of flow port **316** interfaces directly with compartment **344** and choke member **338** is out of interfering contact with fluid F flowing between compartment **344** and tubing across port **316**; removing barriers to flow between ports **214**, **241** puts the valve assembly **310** into an open configuration.

(46) Referring specifically to FIG. **8**A, in the example shown pressure in tubing **60** exceeds pressure in annulus **70**, which pressurizes compartment **344** to above that of compartment **342**. The resulting pressure differential between compartments **342**, **344** generates a resultant force that drives plug **330** against seat member **318** as shown and engages seal faces **324**, **332**. With seal faces **324**, **332** engaged, sealing interface I.sub.310 is energized to define a barrier in valve assembly **310** to flow between annulus **70** and tubing **60**. The embodiment of FIG. **8**A depicts dynamic seals that do not require unloading. Further in this example, pressure in compartment **355** exceeds that of compartment **354** creating a pressure differential across opposing end surfaces of locking piston **352** to urge locking piston **352** rearward and away from choke member **338**. In this scenario damaging forces from the tubing/annulus pressure differential are avoidable by strategic sizing of the stem **346** diameter in relation to that of the plug **330**. When valve assembly **310** of FIG. **8**A is moved into the open configuration as described above, fluid F in tubing **60** flows across port **316**, into bore **313**, through passage **326**, into forward end **314**, and then to annulus **70**.

(47) In the example of FIG. **8**B, pressure in annulus **70** exceeds pressure in tubing **60** to define an annulus/tubing pressure differential that in turn creates a pressure differential across piston **352**. Forces F.sub.342, F.sub.352 schematically represent oppositely directed forces resulting from the annulus/tubing pressure differential across the seat member **318** and plug **330** and piston **352** respectively. This pressure differential urges piston **352** into compartment **355** (FIG. **8**A), and without a seal around rearward section **339** fluid F is forced from compartment **355**, past section **339**, and through port **316**—which eliminates compartment **355**. With continued annulus/tubing pressure differential applied across piston **352**, piston **352** comes into biasing contact with rearward section **339** and exerts force F.sub.352 onto choke member **338** that is in a direction opposite to force F.sub.342. Creating piston force F.sub.352 in a direction opposite to force F.sub.342 locks choke member **338** from further rearward movement and reduces forces transmitted to actuator stem **346** and other actuation hardware resulting from annulus/tubing pressure differential. In this example piston **352** creates an equalizing and locking force. By applying a reducing countering force to lock rearward movement against stem **346**, valve assembly **310** remains functional when pressure in annulus **70** exceeds that of tubing **60** by an amount that might otherwise generate a force F.sub.342 that exceeds design limitations in stem **346** or other actuation hardware that could be damaging to the valve assembly **310**. In an alternative, and depending on a designated operational scenario, a surface area of an end of piston **352** is adjusted to achieve a designated force F.sub.352.

(48) In an example of operation of the valve assembly **310** of FIG. **8**B when in the open configuration, fluid in annulus **70** enters valve assembly **310** through forward end **314**, flows into compartment **342**, along passage **226**, and exits into tubing **60** through port **316**. Valve assembly **310** of FIG. **8**B has the advantage of reducing cavitation along seal faces **322**, **324** by strategically sizing choke member **338** to hinder flow across port **316** until faces **322**, **324** are spaced apart from one another.

(49) Referring now to FIGS. **9**A-**9**C, which are side sectional views of a valve assembly **410** embodiment that is ambient to the annulus **70**, and depict an example of operation. Valve assembly **410** includes an annular valve housing **412** with a chamber or bore **413** that extends along an axis A.sub.410 of the valve assembly **410**. A forward end **414** of valve assembly **410** is shown open to the annulus **70**, which communicates a forward portion of bore **413** to annulus **70** through forward end **414**. Spaced axially rearward from forward end **414** is a flow port **416** formed radially through a sidewall of housing **412** and that is in communication with tubing **60**. An equalizing port **417** is

formed radially through the sidewall of housing **412** and spaced rearward of flow port **416** and that is in open communication with annulus **70**. An annular seat member **418** is shown coaxially disposed within the bore **413** and disposed axially between forward end **414** and flow port **416**. Seat member **418** is axially moveable within bore **413** and has an outer surface that is in sealing contact with the inner surface of housing **412**. A portion of seat member **418** proximate end **414** has a radial thickness that remains substantially constant along its length, and at a distance axially away from end **414** the inner diameter of the seat member **418** decreases with distance from end **414** thereby increasing radial thickness of seat member **418** to create a frusto-conical profile on the seat member **418** along the length of increasing thickness. A forward face **420** is formed along the frusto-conical profile. A distance axially rearward of the forward face **420** the radial thickness of seat member **418** reduces along an axial length of seat member **418** to form a rearward face **422**, which also has a frusto-conical configuration. Between the forward and rearward faces **420**, **422** on seat member **418** is a planar section **423** that has a radial thickness greater than the portion of seat member **318** distal from rearward face **422**. A seal face **424** is defined along a portion of rearward face **422** adjacent planar section **423**. Seal face **424** alternatively has other profiles, such as a generally spherical profile or other standard configurations. A passage **426** extends axially through the seat member **418**.

(50) A spring **428** is shown within bore **413** and in biasing contact with an end of seat member **418** proximate end **414**. A ring **429** mounted in inner surface of housing **412** on a side of spring **428** opposite seat member **418** provides an axial backstop for spring **428**. In the example shown, spring **428** and seat member **418** are within a recess formed radially along an inner surface of housing **412**. Valve assembly **410** further includes a plug **430** having a plug element **431** shown inserted within passage **426**. Plug element **431** is shown having a hemispherical shape, and a surface of plug element **431** facing open end **414** is curved; a seal face **432** is on a portion of this surface of plug element **431** and in contact with rearward face **422**. Seal faces **424**, **432** of FIG. **9**A are in sealing contact with one another to form a sealing interface I.sub.410 that is a barrier to fluid communication between seat member **418** and plug **430**. Interface I.sub.410 circumscribes the respective inner and outer surfaces of passage **426** and plug **430**. Valve assembly **410** is in a closed configuration when opposing seal faces **424**, **432** are in sealing contact. Mounted on a rearward facing surface of plug element **431** is a cylindrical pedestal **433** shown projecting axially away from plug element **431**. Pedestal **433** extends axially through an opening **434** formed through a planar plug mount **435** shown transversely mounted in bore **413**. Flowports **436** are shown formed axially through the plug mount **435**, which are spaced radially outward from opening **434**. A free end of pedestal **433** is shown inserted into a shallow cylindrically shaped recess **437** formed on a forward-facing surface of a choke member **438**. As shown, choke member **438** is substantially cylindrical with an optional bevel on its outer circumference proximate its forward end. Rearward of the bevel, choke member **438** has an outer circumference that is in close contact with an inner surface of housing **412**. Opposing axial ends of choke member **438** are in pressure and fluid communication with one another along an outer surface of choke member **438**. In the example of FIG. **9**A choke member **438** is adjacent port **416**.

(51) A helical elongate spring **440** is shown circumscribing a lengthwise portion of pedestal **433** adjacent plug element **431** and having a rearward end in abutting contact with plug mount **435**. Spring **440** of FIG. **9**A exerts a biasing force urging the plug **430** against seat member **418**. A compartment **442** is defined inside bore **413** between forward end **414** and interface I.sub.410, and a compartment **444** is formed in the annular space between the inner surface of housing **413** and outer surface of pedestal **433**. In the example shown, fluid and pressure communication exists along the interface between choke member **438** and inner surface of housing **412** so that port **416** is in pressure communication with compartment **444**. When seal faces **424**, **432** are in sealing contact a pressure barrier is formed along interface I.sub.410 that blocks pressure and fluid communication between compartments **442**, **444**.

(52) Further illustrated in FIGS. **9**A-**9**C is an elongate actuator stem **446** set lengthwise in bore **413** and generally aligned with axis A.sub.410. An annulus **447** is formed in the radial space between actuator stem **446** and inner surface of housing **412**. A forward end of stem **446** inserts into a bore **448** formed lengthwise and partially through choke member **438** and in a side opposite recess **437**. A forward end of stem **446** couples to choke member **438** inside bore **448**, examples of coupling include a threaded connection in bore **448**, a press fit, a weld, or integrally formed. Locking piston **452** and rearward piston **453** are shown as annular members disposed in the annulus **447** at axially spaced apart locations. Seals (shown as O-rings in this example) for pressure isolating opposing forward and rearward end surfaces of pistons **452**, **453** are optionally provided on the inner and outer diameters of pistons **452**, **453** to form pressure and fluid seals between inner surfaces of pistons **452**, **453** and stem **446** and outer surfaces of pistons **452**, **453** and inner surface of housing **412**. The pistons **452**, **453** are slideable along axis A.sub.410, such as in response to pressure differentials between their opposing forward and rearward end faces. Compartments **454** (FIG. **9**A), **455** (FIG. **9**C) are formed in the annulus **447** respectively between pistons **452**, **453** and between piston **452** and choke member **438**. Compartment **454** is in pressure communication with annulus **70** via port **417**. A motor **456** is shown connected to an end of stem **446** opposite section **439**, and which selectively exerts an actuating force onto stem **446**. An example of a power source **460** is schematically shown connected to motor **456** via a power line **462** for selectively delivering electricity to motor **456** to energize motor **456**. Motor **456** is disposed in a compartment **458** that is optionally filled with a fluid, such as a hydraulic or dielectric fluid DF. Similar to piston **353** of FIG. **8**A described above, piston **453** operates to equalize pressure in compartment **358** with ambient and acts as a pressure equalizing piston.
(53) As noted above, compartments **442** and **454** are in pressure communication with annulus **70** and compartment **444** is in pressure communication with tubing **60**. In the example illustrated in FIG. **9**A, pressure in annulus **70** exceeds pressure in tubing **60** to create pressure differences between compartment **444** and compartments **442**, **454** that in turn result in pressure differentials between opposing axial sides of plug **430** and piston **452**. The pressure differential across plug **430** creates a force that is directed rearward along axis A.sub.410, and the pressure differential across piston **452** creates a force that is directed forward along axis A.sub.410. As shown in FIG. **9**A, the stem **446** is positioned to urge choke member **448** against plug **430** with a force that exceeds the rearwardly directed pressure force exerted onto plug **430**. In this example, the forward force exerted by piston **452** counters the rearward force from plug **430**. The force from motor **456** onto stem **446** also arrests rearward movement of plug **430** to maintain seal faces **424**, **432** in sealing contact and keep the valve assembly **410** in the closed configuration. Further shown in FIG. **9**A is that the annulus/tubing pressure differential on opposing faces of piston **452** moves piston **452** forward into abutting contact with the choke member **438**. When in the closed configuration depicted in FIG. **9**A, the valve assembly **410** functions in dual compliant fashion and maintains a compliant engagement of seal faces **424**, **432** by springs **428**, **440** and the pressure in annulus **70** that pushes seat **418** into plug **430**.
(54) Valve assembly **410** of FIG. **9**A is changed from the closed configuration to an open configuration (FIG. **9**B) by energizing motor **456** with electricity from power source **460** via cable **462**, which moves stem **446** and attached choke member **438** away from pedestal **433**. A spring constant of spring **440** is strategically designated to be less than a force created by exposing opposing sides of plug **430** to the different pressures in the annulus **70** and tubing **60**; which causes spring **440** to compress when choke member **438** is moved away from pedestal **433** to permit rearward movement of plug **430** in response to the annulus/tubing pressure differential. Moving plug **430** away from seat member **418** removes interface I.sub.410 so that compartments **442**, **444** are in communication via passage **426**. When in the open configuration choke member **438** is drawn rearward with stem **446** substantially rearward of flow port **416** and out of interfering contact with fluid F flowing between compartment **444** and tubing **60** across port **416**. Port **417** in

combination with piston **452** generates a counter force F.sub.447 that opposes forces from annulus/tubing pressure differential to lock choke member **438** against rearward movement and offset damaging effects onto the stem **446** or other actuation hardware.
(55) In the example of FIG. **9**C the pressure in tubing **60** exceeds pressure in annulus **70** that forces plug **430** into sealing engagement with seat member **418**. In this example plug **430** operates as a check valve. The annulus/tubing pressure differential also urges piston **452** rearward against a collar coupling **464** shown installed between adjacent sections of housing **412**. Potentially damaging forces from the annulus/tubing pressure different are not exerted onto the stem **446**.
(56) An alternate example of a valve assembly **410**A is shown in a side sectional view in FIGS. **9**D-**9**F in which a piston **466**A is integrally formed on stem **446**A. Piston **466**A has an outer surface that extends radially outward from stem **446**A and into contact with an inner surface of collar coupling **464**. O-ring seals **468**A on an outer surface of piston **466**A are in sealing contact with inner surface of collar coupling **464** to define a barrier to pressure communication between compartments **444**A and **454**A. In the example of FIG. **9**D pressure in annulus **70** is greater than pressure in tubing **60**, and similar to valve assembly **410** of FIG. **9**A, valve assembly **410**A of FIG. **9**D is in the closed configuration due to positioning of the stem **446**A. In FIG. **9**D, piston **466**A and seals **468**A are strategically located forward of port **417**, which creates a forwardly directed force from the pressure mismatch across seals **468**A that counters forces resulting from pressure differential between compartment **442** (same as annulus **70** pressure) and compartment **444**A (same as tubing **60** pressure) and locks against rearward movement of choke member **438**A.
(57) Referring now to FIG. **9**E, here operation is similar to that described in FIG. **9**B, that is, the annulus **70** is at a greater pressure than the tubing **60** and the valve assembly **410**A is changed to the open configuration by energizing motor **456**. Pressure from annulus **70** forces plug **430** rearward and compresses spring **440**. This opens passage **426** to provide a pathway for fluid F to flow through valve assembly **410**A from annulus **70** into tubing **60**.
(58) In the example of FIG. **9**F, pressure in tubing **60** exceeds pressure in annulus **70** so that plug **430** is energized into a closed configuration similar to that described above in FIG. **9**C. Here, the respective radial dimensions of the piston **466**A and collar connector **464**A are strategically dimensioned to avoid damaging forces being exerted to the stem **446**A or other actuation hardware under anticipated pressure excursions in tubing **60**.
(59) Referring now to FIG. **10**A, shown in a side sectional view is an example of a rearward portion of valve assembly **410** illustrating components making up the actuator **48**. In this embodiment, actuator **48** includes motor **456**, a gearbox **470**, and screw drive assembly **472**. Gearbox **470** couples to an output of motor **456** and screw drive assembly **472** couples to an output of gearbox **470**. In a non-limiting example of operation, gearbox **470** converts to designated values torque and revolutions per minute ("rpm") delivered from an output shaft (not shown) on motor **456**. Screw drive assembly **472** includes an elongated lead screw **474**, shown disposed in the bore **413** and parallel with axis A.sub.410, an output of gearbox **470** rotates lead screw **474** at the designated values of rpm and torque. The rotational torque and motion in the lead screw **474** is transferred in the form of linear motion and force to a nut **476** shown circumscribing a portion of lead screw **474**. Nut **476** is shown coupled to lead screw **474** via complementary helical flights and grooves formed respectively on lead screw **474** and nut **476**. An elongated coupling **478** connects between nut **476** and a rearward end of stem **446** and transfers forces from nut **476** to stem **446** for changing valve assembly **410** between open and closed configurations as discussed above. An optional position sensor **480** is shown inside housing **412** and that circumscribes a portion of coupling **478**. On a side of motor **456** opposite gearbox **470** is a penetration **482** that provides a hermetically sealed inlet for an electrical bus **484** (FIG. **10**B) to connect between processor **50** and motor **456**. In alternatives, penetration **482** also provides a passage for power cable **462** (FIG. **9**A) to connect to motor **456**.
(60) Referring back to FIG. **10**A, piston **453** is shown in bore **413** disposed axially between

coupling **478** and port **417**. Piston **453** is moveable along axis A.sub.410 and has inner and outer seals that form barriers to fluid communication axially between forward and rearward ends of piston **453**. The inner seal blocks axial communication along an interface between piston **453** and stem **446**, and the outer seal blocks axial communication along an interface between piston **453** and inner surface of housing **412**. As shown, pressure in annulus **70** is communicated to chamber **454** via port **417**, as piston **453** is moveable along axis A.sub.410, piston **453** is forced by pressure differences between chambers **454**, **458** into the chamber **454**, **458** having the lower pressure. In a non-limiting example of operation, fluid in chamber **458** (which is shown as dielectric fluid DF) is at about atmospheric pressure when disposed into the well **54** (FIG. **4**). As the valve assembly **410** is lowered deeper into the well **54** hydrostatic forces increase pressure in the annulus **70** and chamber **454**, which automatically moves piston **453** rearward to exert a compressive force onto the dielectric fluid DF, which correspondingly increases pressure in chamber **458** to equalize with ambient pressure. Similarly, when annulus **70** pressure reduces, such as a lowering of hydrostatic pressure of fluid in annulus **70** or raising the valve assembly **410** to a lower depth in the well **54** (FIG. **4**), piston **453** is moved forward in response to the lowered ambient pressure so that pressure in chamber **458** equalizes with pressure in annulus **70**.
(61) Advantages of the disclosed valve assembly **410** include that pressure equalization between the actuator **48** and ambient is within the same housing **412** as the actuator **48** and components making up the rest of the valve assembly **410**. Moreover, strategic placement of port **417** allows for an equalizing piston **453** that is also substantially coaxial with the housing **412**. Integrating equalization capability into the housing **412** eliminates the need for fluid fittings on the housing **412** for connection to external equalizing components, which reduces the size of the valve assembly **410** and sources of fluid leakage. Further advantages of the pressure balancing include removing pressure drive for downhole gases/fluids to contaminate motor, allows for thinner walled actuator housing because it is not pressure bearing, and removes high pressure dynamic seals in the actuator.
(62) The present invention described herein, therefore, is well adapted to carry out the objects and attain the ends and advantages mentioned, as well as others inherent therein. While a presently preferred embodiment of the invention has been given for purposes of disclosure, numerous changes exist in the details of procedures for accomplishing the desired results. For example, the valve assemblies described herein are optionally used in circulation valves or for general flow such as water injection, production, oil injection, gas production, and the like. In alternatives, the plugs **30**, **130**, **230**, and **330** have outer surfaces that are curved similar to plugs **430** and vice versa; and embodiments of the plugs **30**, **130**, **230**, **330**, and **430** include configurations that are planar and/or disk-like, spherical, elliptical, combinations thereof, and other known and later developed shapes. These and other similar modifications will readily suggest themselves to those skilled in the art and are intended to be encompassed within the spirit of the present invention disclosed herein and the scope of the appended claims.

Claims

1. A system for controlling a flow of fluid comprising: a valve assembly comprising, a housing, a chamber in the housing having an inlet and an outlet, valve elements in the chamber each having a seal face, a fluid flow barrier in the chamber formed when seal faces on adjacent valve elements are brought into sealing contact with one another, forward and rearward compartments in the chamber that are on opposing sides of the fluid flow barrier, and a locking piston in the chamber having a side in pressure communication with the inlet and an opposing side in pressure communication with the outlet, the locking piston being selectively moved into a locking position into biasing contact against an end of a one of the valve elements that is in communication with the outlet.
2. The system of claim 1, wherein the valve elements comprise a seat member and a plug assembly

and wherein the locking piston is biased by a difference in pressure between the inlet and outlet.
3. The system of claim 2, wherein the valve assembly further comprises a stem having an end coupled to an end of the plug assembly.
4. The system of claim 3, further comprising a motor attached to an end of the stem distal from the plug assembly, wherein energizing the motor moves the plug assembly towards and away from the seat member to selectively change the valve assembly between open and closed configurations.
5. The system of claim 4, wherein the stem extends through the locking piston and the locking piston is slidable along the stem.
6. The system of claim 1, further comprising a stem having an end coupled to an end of one of the valve elements that in communication with the outlet, wherein the stem extends through a bore that extends axially through the locking piston, and wherein the locking piston slides along the stem in response to a pressure differential.
7. The system of claim 1, wherein an interface is defined where the plug seal face and seat member seal face are in sealing contact.
8. The system of claim 1, wherein pressure in the inlet exceeds pressure in the outlet.
9. The system of claim 8, wherein the valve assembly further comprises a port formed radially through a sidewall of the housing adjacent the inlet, a port formed radially through the sidewall of the housing on a side of the locking piston distal from the fluid flow barrier, and a line connecting the ports.
10. The system of claim 8, wherein the valve assembly further comprises a port formed radially through the sidewall of the housing on a side of the locking piston distal from the fluid flow barrier, and wherein the inlet and the port are in communication to ambient.
11. The system of claim 1, wherein resilient members are disposed on opposing sides of the seat member and the plug assembly for biasing the seat member and the plug assembly against one another so that the seat member is compliant with the plug assembly.
12. A system for controlling a flow of fluid comprising: a valve assembly comprising, a housing, a chamber in the housing; valve elements in the chamber each having a seal face, a barrier in the chamber formed when seal faces on adjacent valve elements are brought into sealing contact with one another, compartments in the chamber that are adjacent one another and on opposing sides of the barrier, the compartments being at different pressures, and a locking piston in a one of the compartments that is at a lower pressure, the locking piston being selectively moved into contact with and biased against an end of a one of the valve elements that is between the locking piston and the barrier, a side of the locking piston being in communication with a fluid flowing into the valve assembly and an opposing side of the locking piston being in communication with a fluid flowing out of the valve assembly.
13. The system of claim 12, wherein the locking piston is biased against the one of the valve elements by a pressure differential between the fluid flowing into the valve assembly and the fluid flowing out of the valve assembly.
14. The system of claim 12, wherein a locking force is applied to the one of the valve elements from the locking piston that offsets an opposing force from a pressure differential that is applied to the one of the valve elements.
15. The system of claim 12, further comprising an actuator and a stem attached to the actuator, wherein the locking piston is intersected by the stem and slideable thereon, and wherein an end of the stem distal from the actuator is in selective abutting contact with the a one of the valve elements, and is selectively moveable away from the a one of the valve elements.