

VALVE

The present invention relates to a valve suitable for use in injection of fluid into a wellbore, typically an offshore wellbore for petroleum production, particularly, but not exclusively, for use in a gas injection/gas lift system.

5 BACKGROUND

In hydrocarbon production, when a wellbore is drilled into a hydrocarbon bearing earth formation, the fluid pressure in the formation may be sufficient to cause hydrocarbons from the formation to flow up the wellbore to the surface. In some wells, however, the formation pressure is insufficient to do this, and hydrocarbon
10 production from the well requires the use of an artificial lift system to supplement the formation pressure to lift the hydrocarbons from the formation to the surface.

One such artificial lifting system is a "gas lift system" in which a high pressure gas is injected into a production tubing which extends down the wellbore to the formation. The high pressure gas may be supplied through the annulus between the production
15 tubing and the wellbore casing, and injected into the production tubing via one or more gas lift valves which are arranged on the production tubing at the required depth in the wellbore. The gas lift valve(s) may be arranged in the production tubing itself, or they may be arranged in side pockets mandrels.

Publications which may be useful to understand the background include
20 WO2007091898, WO2019/004838, and WO2019/074374. WO2004/092537, CA 02461485

Typically such valves include a valve member which is linearly moveable into and out of engagement with a valve seat to control flow of fluid from the annulus into the production tubing, and are configured to be pressure actuated, i.e. to open when the
25 pressure the annulus exceeds a pre-determined level. Often a spring or other resilient biasing element is provided to urge the valve member into engagement with the valve seat, the valve being configured such that the valve member will move out of engagement with the valve seat when the fluid pressure in the annulus is sufficient to overcome the biasing force of the spring. Such valves are, however,
30 prone to "chattering", when the valve member repeatedly moves into and out of engagement with the valve seat. This "bouncing" of the valve member on the valve seat can, over time, cause damage to the valve device, for example fatigue failure of

the spring or wear of the valve seat or valve member which prevents the valve member from providing a fluid tight seal when engaged with the valve seat.

The present application relates to a new configuration of valve suitable for use in a gas lift system, which may reduce or alleviate the problem of the valve "chattering" when in use.

SUMMARY

According to a first embodiment we provide a valve comprising a housing which has an exterior and which encloses an interior space, the housing being provided with an inlet port and an outlet port, both of which provide a conduit between the exterior and interior space of the housing, the valve further comprising a main valve seat and a main valve member which is located in the interior space of the valve housing, the main valve member being movable between a closed position in which it engages with the main valve seat and blocks flow of fluid between the inlet port and the outlet port, and an open position in which it is not engaged with the main valve seat and the inlet port is fluidly connected to the outlet port, and having a passage which fluidly connects the inlet port and the outlet port when the main valve member is in the open position, characterised in that the valve further comprises an auxiliary valve member which is movable relative to the main valve member between a closed position in which the auxiliary valve member blocks the passage thereby restricting flow of fluid along the passage, and an open position in which substantially unrestricted flow of fluid along the passage is permitted.

The main valve member advantageously further comprises an auxiliary valve seat with which the auxiliary valve member engages when in the closed position to block flow of fluid along the passage, the auxiliary valve seat being integral with or secured to the main valve member.

The auxiliary valve member may be provided in the passage.

The valve may further comprise a main resilient biasing element, such as a spring, which acts on the valve member to urge the valve member to the closed position. In this case, the main resilient biasing element may extend between the housing and the valve member.

The valve may further comprise an auxiliary biasing element which urges the auxiliary valve member to the closed position. Where the valve has a main resilient biasing element, the auxiliary biasing element is advantageously configured to provide a greater biasing force than the main resilient biasing element.

- 5 The main valve member may be linearly moveable between the open and closed positions.

The main valve member may have a longitudinal axis and move generally parallel to the longitudinal axis between the open and closed positions. In this case, the passage, or at least part of the passage may extend from a first end of the main
10 valve member generally parallel to the longitudinal axis.

The main valve member may divide the interior space of the housing into an inlet volume and an outlet volume, the inlet volume comprising the portion of the interior volume of the housing to which the inlet port is connected when the main valve member is in its closed position, and the outlet volume comprising the portion of the
15 interior volume of the housing to which the outlet port is connected when the main valve member is in its closed position.

The valve may further comprise a choke part which is moveable between a fully open position in which the cross-sectional area available for flow of fluid along the inlet port is maximised, and a variety of active positions in which the choke part
20 restricts flow of fluid along the inlet port. The choke part may also be movable to a fully closed position in which the choke part blocks the inlet port, and therefore substantially prevents flow of fluid between the exterior of the valve housing and the interior volume of the valve housing via the inlet port.

The housing may comprise choke part may be located in the inlet volume.
25 Moreover, the auxiliary valve member may be connected to the choke part so that the auxiliary valve member moves relative to the valve housing with the choke part. In this case, advantageously, the choke part and auxiliary valve member are configured such that the auxiliary valve member moves away from the main valve member as the choke part moves towards its fully open position.

30 Advantageously, the auxiliary valve part is tapered in such a way that its cross-sectional area increases from a proximal end thereof towards a distal end, the proximal end being closer to the main valve member than the distal end.

The valve may be provided in a fluid injection system for use in a hydrocarbon well.

According to another embodiment we provide a fluid injection system comprising a valve having any feature or combination of features described above, and tube having a side wall which encloses a main passage and an side passage which
5 extends through the side wall to the main passage, the valve being mounted on the tube so that the outlet volume of the valve is in fluid communication with the side passage.

According to another embodiment we provide a fluid injection system comprising a valve having any feature or combination of features described above and a side
10 pocket mandrel having a main passage which is aligned with the main passage of the tube, and a laterally offset side pocket bore, the main bore and the laterally offset side pocket bore being separated by an internal wall, wherein the valve is arranged in the side pocket bore, the inlet port of the valve being in fluid communication with the exterior of the side pocket mandrel via an inlet opening, and
15 the outlet port of the valve being in communication with the main passage via an outlet conduit.

The outlet conduit may be provided in the internal wall.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other characteristics will become clear from the following description of
20 illustrative embodiments, given as non-restrictive examples, with reference to the attached drawings, in which

FIGURE 1 is an illustration of a longitudinal cross-section through an embodiment of valve according to the invention with the main valve member and auxiliary valve member both in the closed position,

25 FIGURE 2 is an illustration of a longitudinal cross-section through the valve illustrated in Figure 1 with the main valve member in the open position and the auxiliary valve member in its closed position,

FIGURE 3 is an illustration of a longitudinal cross-section through the valve illustrated in Figure 1 with the main valve member and auxiliary valve member both
30 in their open positions,

FIGURE 4 is an illustration of a longitudinal cross-section through an alternative embodiment of valve according to the invention with the choke part, main valve member and auxiliary valve member in their closed positions,

FIGURE 5 is an illustration of a longitudinal cross-section through the valve
5 illustrated in Figure 4 with the choke part, main valve member and auxiliary valve member in their open positions,

FIGURE 6 is an illustration of a longitudinal cross-section through a further alternative embodiment of valve according to the invention with the choke part, main valve member and auxiliary valve member all in their closed positions,

10 FIGURE 7 is an illustration of a longitudinal cross-section through the valve illustrated in Figure 6 with the choke part and main valve member in their open positions and the auxiliary valve member in the closed position,

FIGURE 8 is an illustration of a longitudinal cross-section through the valve illustrated in Figure 6 with the choke part, main valve member and auxiliary valve
15 member all in their fully open positions,

FIGURE 9 is an illustration of an enlarged portion of the valve illustrated in Figure 8,

FIGURE 10 is a schematic illustration of a fluid injection system for a hydrocarbon well including valve according to the invention,

FIGURE 11 is a schematic illustration of a side pocket mandrel of the fluid injection
20 system illustrated in Figure 10.

DETAILED DESCRIPTION

The following description may use terms such as "horizontal", "vertical", "lateral", "back and forth", "up and down", "upper", "lower", "inner", "outer", "forward", "rear", etc. These terms generally refer to the views and orientations as shown in the
25 drawings and that are associated with a normal use of the invention. The terms are used for the reader's convenience only and shall not be limiting.

Referring now to Figures 1 - 3, there is shown a valve 10 which is suitable for use in a gas lift valve in a hydrocarbon production system. The valve 10 comprises a housing 12 which has an exterior and which encloses an interior space. In this

embodiment, the housing 12 and interior space are generally cylindrical and have a longitudinal axis A.

The valve 10 further comprises a main valve seat 14 and a main valve member 16 which is located in the interior space of the valve housing 12 and which divides the interior space into an inlet volume 18a and an outlet volume 18b. The main valve seat 14 is fixed relative to the valve housing 12. In this example, the main valve seat 14 is provided on a shoulder 20 which is integral with the housing 12, and which extends radially inwardly of the housing 12 into the interior space thereof. The main valve seat 14 comprises a seating surface which faces towards the outlet volume 18b, and in this example is inclined at an angle of approximately 45° to the longitudinal axis A.

The main valve member 16 is movable between a closed position in which it engages with the main valve seat 14 and blocks flow of fluid between the inlet volume 18a and the outlet volume 18b, and an open position in which it is not engaged with the main valve seat 14 and the inlet volume 18a is fluidly connected to the outlet volume 18b. In this embodiment, a seal 22 is provided to ensure a fluid-tight, or substantially fluid-tight seal between the main valve member 16 and the main valve seat 14 when the main valve member 16 is in the closed position. The valve 10 is illustrated with the main valve member in the closed position in Figure 1 and in the open position in Figures 2 and 3.

In this embodiment, the movement of the main valve member 16 between the open position and the closed position comprises linear movement generally parallel to the longitudinal axis A.

In this example, the main valve member 16 is generally cylindrical.

The main valve member 16 has a working area which is contact with fluid in the inlet volume 18a, the working area being arranged such that the force exerted by pressurised fluid in the inlet volume 18a urges the main valve member 16 away from the main valve seat 14.

In this embodiment, the main valve member 16 has an exterior surface 26, and a first end of the main valve member 16 has an enlarged outer diameter head portion 16a, a reduced outer diameter intermediate portion 16b, and an enlarged outer diameter tail portion 16c. The portion of the exterior surface 26 which connects the

head portion 16a and the intermediate portion 16b forms a sealing surface 26a which engages with the main valve seat 14 when the main valve member 16 is in the closed position, and the main valve member 16 is arranged such that the head portion 16a extends into the outlet volume 18b. The angle of inclination of the
5 sealing surface 26a relative to the longitudinal axis A corresponds to the angle of inclination of the seating surface of the valve seat 14. The tail portion 16c of the main valve member 16 extends into the inlet volume 18a.

It will be appreciated, therefore, that the main valve member 16 is configured and arranged relative to the main valve seat 14 such that if the pressure in the outlet
10 volume 18b exceeds the pressure in the inlet volume 18a, the main valve member 16 is pushed by the fluid pressure in the outlet volume 18b into its closed position.

The valve device 10 further comprises a main resilient biasing element, which in this example is a helical spring 23 (hereinafter referred to as the main spring 23), which acts on the main valve member 16 to urge it into the closed position. The main
15 spring 23 is arranged around the intermediate portion 16b of the main valve member 16, and extends between the shoulder 20 of the valve housing 12 and a shoulder 26b on the exterior surface 26 of the main valve member 26 which connects the intermediate portion 16b to the tail portion 16c.

In this example, the valve 10 is provided with a stop 25 which engages with the main
20 valve member 16 to limit movement of the sealing surface 26a away from the main valve seat 14. When the main valve member 16 engages with the stop 25, the main valve member 16 is thus in its fully open position. In this particular embodiment, the head portion 16a engages with the stop 25, and the stop 25 is an end face of the housing 12.

25 In this embodiment, the fluid connection between the inlet volume 18a and outlet volume 18b is achieved via a passage 24 which extends through the main valve member 16. The passage 24 fluidly connects the inlet volume 18a and the outlet volume 18b when the main valve member 16 is in the open position. In this example, a first part 24a of the passage 24 extends from the tail portion 16c of the
30 main valve member 16 generally parallel to the longitudinal axis A.

Also in this embodiment, a second part 24b of the passage 24 extends from the first part 24a of the passage 24 radially outwardly of the first part 24a, to connect the first

part 24a of the passage to the exterior surface 26 of the intermediate portion 16b of the main valve member 16. The second part 24b of the passage 24 could extend at any angle up to 90° to the longitudinal axis A, but in this example extends at an angle of around 45° to the longitudinal axis A. Moreover, whilst the main valve member 16 could be provided with a single passage 24, in this embodiment, there are multiple second parts 24b of the passage 24 which are spaced around the circumference of the main valve member 16.

The valve 10 is further provided with an inlet port (not shown in Figures 1 – 3) which extends through the housing 12 to connect the inlet volume 18a with the exterior of the housing 12, and an outlet port 29 which extends through the housing 12 to connect the outlet volume 18b with the exterior of the housing 12.

A valve having all the features described above can function as a gas lift valve. When there is no supply of pressurised fluid to the inlet volume 18a via the inlet port 28, the main spring 23 urges the main valve member 16 to the closed position. When pressurised fluid is supplied to the inlet volume 18a at a pressure which is sufficient to overcome the biasing force of the main spring 23 and the force acting on the head portion 16a of the main valve member 16 from and pressurised fluid in the outlet volume 18b urging the main valve member 16 into engagement with the main valve seat 14, the pressure of the fluid in the inlet volume 18a acts on working area of the the main valve member 16 to move it into the open position so that the seating surface 26a moves out of contact with the valve seat 14. Fluid can therefore flow from the inlet volume 18a to the outlet volume 18b via the passage 24, and the space between the seating surface 26a and the valve seat 14.

The resulting drop in pressure in the inlet volume 18a on opening of the main valve member 16 may, however, allow the main spring 23 to push the main valve member 16 back to the closed position. Then, once the pressure builds up in the inlet volume 18a, the main valve member 16 opens, and the cycle repeats. The resulting repeated hammering of the main valve member 16 on the main valve seat 14 is known as chattering, and is most likely to occur when the rate of flow of fluid into the inlet volume 18a via the inlet port is low. Such chattering of the valve is problematic, as it can cause fatigue failure of the spring and / or damage to the sealing surface 26a of the main valve member 16 and/or the seal element 22, both of which can result in a loss of effective sealing function and leakage of fluid between the inlet

volume 18a and the outlet volume 18b when the valve member 16 is in the closed position.

In order to address this problem, the valve 10 further comprises an auxiliary valve 30 comprising an auxiliary valve member 31 which is movable relative to the main valve member 16 between a closed position in which the auxiliary valve member 16 blocks the passage 24 thereby preventing flow of fluid along the passage 24, and an open position in which flow of fluid along the passage 24 is permitted. The auxiliary valve 30 is configured such a working area of the main valve member 16 is still in contact with fluid in the inlet volume 18a even when the auxiliary valve 30 is closed, the working area of the main valve member 16 being arranged such that the force exerted by pressurised fluid on the working area urges the main valve member 16 away from the valve seat 14.

In this embodiment, the auxiliary valve 30 is provided in the passage 24, (in this embodiment in the first portion 24a of the passage 24) and the main valve member 16 further comprises an auxiliary valve seat 32 with which the auxiliary valve member 31 engages when in the closed position to block flow of fluid along the passage 24. The auxiliary valve seat 32 may be secured to the main valve member 16, but in this example is integral with the main valve member 16. Specifically, in this example, the auxiliary valve seat 32 comprises an annular shoulder which extends from the tail portion 16c of the main valve member 16, radially inwardly into the first portion 24a of the passage 24.

The auxiliary valve member 31 is supported in the first portion 24a of the passage 24 via an auxiliary valve support 34, which is also located in the first part 24a of the passage 24 and secured to the tail portion 16c of the main valve member 16.

In this embodiment, the auxiliary valve 30 is a poppet valve, and the auxiliary valve member 31 is configured to moved linearly along the passage 24 in a direction generally parallel to the longitudinal axis A between its open and closed positions. The auxiliary valve member 31 has a disc 31a and a stem 31b. The disc 31a engages with the auxiliary valve seat 32 when the valve member 31 is in its closed position to block the passage 24. The stem 31b is located in an aperture provided in the auxiliary valve support 34 which allows the auxiliary valve member 31 to move linearly along the passage 24.

It should be appreciated, that whilst in this embodiment, the auxiliary valve member 31 is located in the passage 24, this need not be the case. The auxiliary valve seat 32 could be provided at one end of the main valve member 16 around the end of the passage 24. In this case, the auxiliary valve member 31 could be located in the inlet
5 volume adjacent the end of the main valve member 16 and movable into engagement with the auxiliary valve seat 32 whilst remaining outside of the passage 24.

In this embodiment, the auxiliary valve 30 further comprises an auxiliary biasing element, in this example a helical spring 36 (hereinafter referred to as the auxiliary
10 spring), which urges the auxiliary valve member 31 to the closed position. In this example, the spring 36 is located around the stem 31b and extends between the auxiliary valve support 34 and the disc 31a of the auxiliary valve member 31.

When the auxiliary valve member 31 is in its closed position, a portion of the surface of the disc 31a bounded by the line of contact between the disc 31a and the
15 auxiliary valve seat 32 (hereinafter referred to as the working area of the auxiliary valve), is exposed to fluid in the inlet volume 18a. The pressure of fluid in the inlet volume 18a acts on this working area to overcome the biasing force of the auxiliary spring 36 and to push the auxiliary valve member 31 away from the auxiliary seat 32.

20 The valve 10 operates as follows.

When the pressure in the inlet volume 18a is low, the springs 23, 36 urge the main and auxiliary valve members 16, 31 respectively into their closed positions, as illustrated in Figure 1. In this configuration, flow of fluid between the inlet volume 18a and the outlet volume 18b is blocked by both the main valve member 16 and
25 the auxiliary valve member 31. The working area of the auxiliary valve 30 and an end face of the tail portion 16c of the main valve member 16 are in direct contact with fluid in the inlet volume 18a, and therefore form a combined valve working area.

As the pressure in the inlet volume 18a increases, the force on the valve member 16 resulting from the contact between the fluid in the inlet volume 18a the combined
30 valve working area increase until it is sufficiently high to overcome the biasing force of the main spring 23 and the force of the pressurised fluid in the outlet volume 18b acting on the head portion 16a of the main valve member 16. When this occurs, the

main valve member 16 moves from its closed position to its open position. The auxiliary valve 30 moves with the main valve member 16, however, and remains in its closed position. This configuration is illustrated in Figure 2. In this configuration, flow of fluid between the inlet volume 18a and the outlet volume 18b is blocked by the auxiliary valve 30 only, as this prevents the flow of fluid along the passage 24.

The springs 23, 36 are configured so that the biasing force of the main spring 23 is overcome before the biasing force of the auxiliary spring 36. It will be appreciated that the working area of the auxiliary valve 30 is smaller than the combined valve working area, the force exerted by the fluid pressure in the inlet volume 18a on the auxiliary valve member 31 only is less than the force on the main valve member 16. As such, this could be achieved by configuring the auxiliary spring 36 to have a spring force which is greater than, equal to, or slightly less than the spring force of the main spring 23.

As the pressure in the inlet volume 18a increases further, eventually, the force from the fluid pressure in the inlet volume 18a on the working area of the auxiliary valve 30 is sufficient to overcome the biasing force of the auxiliary spring 36. When this occurs, the auxiliary valve member 31 moves from its closed position to its open position. This configuration is illustrated in Figure 3. In this configuration, flow of fluid between the inlet volume 18a and the outlet volume 18b along the passage 24 is permitted.

This process is reversed if the pressure in the inlet volume 18a decreases.

An alternative embodiment of valve according to the invention is illustrated in Figure 4 and 5.

This embodiment of valve 10' is very similar to the embodiment illustrated in Figures 1 to 3, and the equivalent parts are labelled with the same reference numerals. The only difference is that, in this embodiment, the valve 10' further comprises a choke part 40 which is moveable between a fully open position in which the cross-sectional area available for flow of fluid along the inlet port 28 is maximised, and a variety of active positions in which the choke part 40 restricts flow of fluid along the inlet port 28. In this embodiment, the choke part 40 is also movable to a fully closed position in which the choke part 40 blocks the inlet port 28, and therefore substantially prevents flow of fluid between the exterior of the valve housing 12 and the inlet

volume 18a via the inlet port 28. The valve 10' is illustrated with the choke part 40 in the fully closed position in Figure 4 and the fully open position in Figure 5.

In this embodiment, the choke part 40 is located in the inlet volume 18a.

The choke part 40 can comprise a tubular sleeve which is either mounted around
5 the exterior of the housing 12 and which is slidable along the exterior of the housing 12 to cover the inlet port 28 to a greater or lesser extent.

In this example, however, the choke part 40 is a tubular sleeve which lines the interior of the valve housing 12 and which is slidable along the interior of the housing 12 to cover the inlet port 28 to a greater or lesser extent. A seat 42 is provided
10 around the inner circumference of the valve housing 12, and the choke part 40 is configured to engage with the seat 42 when in the fully closed position to substantially prevent leakage of fluid from the inlet port 28 into the inlet volume 18a..

The valve 10' further comprises an actuator (not shown) which is operable to move the choke part 40 between the fully open and fully closed positions. Typically the
15 actuator comprises an electric motor, but this need not be the case. It could, for example, be a hydraulically or pneumatically operated actuator.

The choke part 40 may be used to vary the rate of flow of fluid from the exterior of the valve housing 12 into the inlet volume 18a, or to close the connection between the exterior of the housing 12 and the inlet volume 18a completely.

20 A further alternative embodiment of valve according to the invention is illustrated in Figures 6 – 8. This embodiment of valve 10'' again has many similarities to the valve 10' described above and as shown in Figures 4 and 5, and, again, the equivalent parts have the same reference numerals. In this case, the difference lies in the configuration of the auxiliary valve 30'', principally in that the auxiliary valve
25 member 31'' is connected to the choke part 40 so that the auxiliary valve member 31'' moves relative to the valve housing 12 with the choke part 40. As such, rather than being secured to the main valve member 16, the auxiliary valve support 34'' extends between the auxiliary valve member 31'' and the choke part 40. Also in this example, the auxiliary valve member 31'' is fixed relative to the choke 40, i.e. there
30 is no possibility of relative movement between these two parts. In this example, the auxiliary valve support 34'' comprises a tube which extends from an end of the actuator 40 to the auxiliary valve member 31''.

In this example, the choke part 40 and auxiliary valve member 31'' are configured such that the auxiliary valve member 31'' moves away from the head portion 16a of the main valve member 16 as the choke part 40 moves from its fully closed position towards its fully open position.

- 5 The choke part 40 is connected to a piston part 44, the piston part 44 being connected to the actuator (not shown) by means of which movement of the choke part 40 is effected. The piston part 44 is configured to support the choke part 40, auxiliary valve member 31'' and auxiliary valve support 34'' in the housing 12, whilst
- 10 mentioned above, the actuator could comprises an electric motor, or means of supplying pressurised fluid to bear on the piston part 44 to move the piston part 44 along the axis A. A seal 46 is mounted in the interior surface of the housing 12 to provide a substantially fluid tight seal between the housing 12 and the exterior surface of the piston part 44. This seal therefore acts to prevent or at least
- 15 substantially prevent leakage of fluid from the inlet volume 18a along the space between the piston part 44 and the housing 12 whilst allowing the piston part 44 to slide relative to the housing.

- The auxiliary valve support 34'' is configured such that when the main valve member 16 is in its closed position, the auxiliary valve member 31'' is located in the passage
- 20 24, specifically in the part of the first portion 24a of the passage 24 enclosed by the tail portion 16c of the main valve member 16. The largest outer diameter of the auxiliary valve member 31'' is just slightly smaller than the interior diameter of the passage 24 in the tail portion 16c of the main valve member 16, so that there is no contact between the auxiliary valve member 31'' and the main valve member 16, but
- 25 the gap between the two parts is so small that only very limited flow of fluid between the two can occur. As such, the auxiliary valve member 31'' substantially blocks the passage 24. This is the case over the entire range of movement of the choke part 40. In other words, whilst the main valve member 16 is in its closed position, the passage 24 is blocked by the auxiliary valve member 31'' when the choke is in its
- 30 fully closed and fully open positions, and all positions in between, and both the main valve member 16 and the auxiliary valve member 31'' provide a barrier to significant flow of fluid between the inlet volume 18a and the outlet volume 18b.

The auxiliary valve support 34'' is, however, configured such that when the main valve member 16 moves to its open position, the auxiliary valve member 31'' no longer blocks the passage 24, and flow of fluid between the inlet volume 18a and the outlet volume 18b is permitted. This could occur when the main valve member

5 16 has moved far enough towards its fully open position for the auxiliary valve member 31'' to no longer be located in the passage 24. In this embodiment, however, the passage 24 has a substantially constant transverse cross-sectional area along most of the tail portion 16c of the main valve member 16, and but increases (in this example generally linearly) in a flared end portion 24a at the very

10 end of the tail portion 16c of the main valve member 16. When the auxiliary valve member 31'' is located in the flared end portion, the gap between the auxiliary valve member 31'' and the interior surface of the main valve member 16 increases to allow significant flow of fluid along the passage 24. The size of this gap increases as the main valve member 16 moves closer to its fully open position.

15 The valve 10'' operates as follows.

When the pressure in the inlet volume 18a is low, the main spring 23 urges the main valve member 16 into its closed positions, as illustrated in Figure 6. In Figure 6, the choke part 40 is shown in its fully closed position. As such flow of fluid between the inlet volume 18a and the outlet volume 18b is blocked by both the main valve

20 member 16 and the auxiliary valve member 31''.

As the choke part 40 is opened, and pressurised fluid allowed to enter the inlet volume 18a via the inlet portion 28, the pressure in the inlet volume 18a increases, the force on the valve member 16 resulting from the contact between the fluid in the inlet volume 18a the main valve member 16 increases until it is sufficiently high to

25 overcome the biasing force of the main spring 23 and the force of the pressurised fluid in the outlet volume 18b acting on the head portion 16a of the main valve member 16. When this occurs, the main valve member 16 moves from its closed position to its open position. The auxiliary valve 31'' moves along the passage 24 away from the head portion 16a of the main valve member 16, but initially remains

30 very close to the interior surface of the main valve member 16, thus effectively blocking the passage 24. This configuration is illustrated in Figure 7. In this configuration, flow of fluid between the inlet volume 18a and the outlet volume 18b is

blocked by the auxiliary valve 30'' only, as this prevents significant flow of fluid along the passage 24.

As the pressure in the inlet volume 18a increases further, eventually, the force from the fluid pressure in the inlet volume 18a on the working area of the auxiliary valve
5 30 is sufficient to overcome the biasing force of the main spring 23 to such an extent that the main valve member 16 moves sufficiently far towards its fully open position that the auxiliary valve member 31'' is no longer blocking the passage 24. This could occur because the auxiliary valve member 31'' is no longer in the passage 24. In this example, however, this occurs whilst the auxiliary valve member 31'' is still in
10 the passage 24, but has entered the flared portion of the passage 24. The diameter of the passage 24 is, at this point, significantly greater than the outer diameter of the auxiliary valve member 31'', and, as such there is a large enough gap between the auxiliary valve member 31'' and the interior surface of the main valve member 16, and the auxiliary valve 30'' is open. Fluid can therefore flow from the inlet volume
15 18a into the outlet volume 18b via the gap between the auxiliary valve member 31'' and the main valve member 16 and the passage 24. This configuration is illustrated in Figure 8.

This process is reversed if the pressure in the inlet volume 18a decreases.

It will be appreciated that, when the auxiliary valve 30'' opens, the resulting drop in
20 pressure in the inlet volume 18a may cause the main valve member 16 to move back towards its closed position. As soon as the auxiliary valve member 31'' blocks the passage 24 again, the pressure in the inlet volume 18a will stabilise, and the main valve member 16 will therefore not move all the way back to its closed position. As such, the main valve member 16 will not hit and damage the valve seat
25 14.

Although not essential, in this embodiment, the auxiliary valve part 31'' is tapered in such a way that its transverse cross-sectional area increases from a proximal end 31a'' thereof towards a distal end 31b'', the proximal end 31a'' being closer to the main valve member 16 than the distal end 31b''.

30 In the embodiment illustrated in Figures 6 – 8, the auxiliary valve member 31'' is tear-drop shaped. This is best illustrated in Figure 9. Its proximal end 31a'' is pointed, so the transverse cross-sectional area is minimal at the proximal end 31a'',

increases towards the distal end 31b'', and is maximum at an intermediate portion 31c'' thereof. The cross-sectional area decreases again from the intermediate portion 31c'' to the distal portion 31b''. It is the intermediate portion, that interacts with the valve member 16 to block the passage 24.

- 5 Shaping the auxiliary valve member 31'' in this way may provide a more streamlined flow of fluid from the inlet volume 18a into the passage 24, and therefore may reduce the resistance to fluid flow of the valve 10''. It may allow for a fluid flow regime similar a convergent-divergent plug nozzle, thus providing a more stable choked flow which is substantially independent of differential pressure fluctuations
10 across the valve.

Advantageously, the area enclosed by the intermediate portion 31c'' of the auxiliary valve member 31'' is the same as the area enclosed by the line of contact between the seal 46 and the piston part 44. In this embodiment, the transverse cross-section of both the piston part 40 and the auxiliary valve member 31'' is circular, and so this
15 means that the largest outer diameter of the auxiliary valve member 31'' is the same as (or at least very similar to) the diameter of the line of contact between the seal 46 and the piston part 44 (labelled OD in Figure 9). This means that the choke assembly (comprising the choke part 40, auxiliary valve support 34'' and auxiliary valve member 31'') is pressure balanced when the choke part 40 is in its open
20 position. In other words, the force acting on the choke part 40 from pressurised fluid in the inlet volume 18a is counter-balanced by the force acting on the distal end 31b'' of the auxiliary valve member 31''. This may assist in reducing the forces acting on the choke part assembly as a result of fluid flow into the inlet volume 18a.

Similarly, the choke part 40 and seat 42 are configured such that when the choke
25 part 40 is in its closed position, engaged with seat 42, the area enclosed by the line of contact between the seat 42 and the choke part 40 is the same as or very similar to the area enclosed by the intermediate portion 31c'' of the auxiliary valve member 31'', and also to the area enclosed by the line of contact between the seal 46 and the piston part 44. The choke part assembly 31'', 34'', 40 is therefore pressure
30 balanced when the choke part 40 is in its closed position also.

It should be appreciated that the auxiliary valve member 31'' need not be connected to the choke part 40. For example, the auxiliary valve support 34'' could be secured to the valve housing 12 to hold the auxiliary valve member 31'' in the inlet volume

18a in such a position that when the main valve member 16 is in its closed position, the auxiliary valve member 31'' is located in the passage 24 so that the auxiliary valve member 31'' blocks the passage 24. In other words, whilst the main valve member 16 is in its closed position, the passage 24 is blocked by the auxiliary valve member 31'', and both the main valve member 16 and the auxiliary valve member 31'' provide a barrier to flow of fluid between the inlet volume 18a and the outlet volume 18b.

The auxiliary valve support 34'' would, however, be positioned such that when the main valve member 16 is close to its fully open position, the auxiliary valve member 31'' no longer blocks the passage 24, and flow of fluid between the inlet volume 18a and the outlet volume 18b is permitted. This could occur when the main valve member 16 has moved far enough towards its fully open position for the auxiliary valve member 31'' to no longer be located in the passage 24, or it could occur in the same way as described in relation to the embodiment illustrated in Figures 6 – 8 when the auxiliary valve member 31'' enters the flared part of the tail portion 16c, and the gap between the auxiliary valve member 31''' and the main valve member 16 increases.

In this embodiment, the auxiliary valve support 34'' is configured to support the auxiliary valve member 31'' in the inlet volume 18a so that its longitudinal axis generally coincides with the axis A. It is also configured so that it does not form a barrier to flow of fluid along the inlet volume 18a. It may, for example, comprise a plurality of spokes which extend radially inwardly from the valve housing 12 to the auxiliary valve member 31''.

This embodiment of valve 10'' may be provided with a choke part 40, but this need not be the case.

This embodiment of valve 10'' operates as follows:

When the pressure in the inlet volume 18a is low, the main spring 23 urges the main valve member 16 into its closed position. As such flow of fluid between the inlet volume 18a and the outlet volume 18b is blocked by both the main valve member 16 and the auxiliary valve member 31''.

As pressurised fluid allowed to enter the inlet volume 18a via the inlet portion 28, the pressure in the inlet volume 18a increases, the force on the valve member 16

resulting from the contact between the fluid in the inlet volume 18a the main valve member 16 increases until it is sufficiently high to overcome the biasing force of the main spring 23 and the force of the pressurised fluid in the outlet volume 18b acting on the head portion 16a of the main valve member 16. When this occurs, the main valve member 16 moves from its closed position to its open position. The auxiliary valve 31''' moves along the passage 24 away from the head portion 16a of the main valve member 16, but initially remains in its closed position in which it prevents significant flow of fluid along the passage 24.

As the pressure in the inlet volume 18a increases further, eventually, the force from the fluid pressure in the inlet volume 18a on the working area of the auxiliary valve 30 is sufficient to overcome the biasing force of the main spring 23 to such an extent that the main valve member 16 moves sufficiently far towards its fully open position that the auxiliary valve member 31'' is no longer blocking the passage 24. Fluid can therefore flow from the inlet volume 18a into the outlet volume 18b via the gap between the auxiliary valve member 31''' and the main valve member 16 and along the passage 24.

This process is reversed if the pressure in the inlet volume 18a decreases.

It will be appreciated that, in all the disclosed embodiments, as the pressure rises in the inlet volume 18a, there is significant movement of the main valve member 16 away from the valve seat 14 before the auxiliary valve 30, 30'' opens to allow flow of fluid from the inlet volume 18a to the outlet volume 18b.

In the embodiments illustrated in Figures 1 - 5, when the auxiliary valve 30 opens, the resulting drop in pressure in the inlet volume 18a may allow the auxiliary spring 36 to push the auxiliary valve member 31 back to the closed position. As such, there may be chattering of the auxiliary valve 30. However, as the auxiliary valve 30 does not provide the main barrier for flow of fluid between the inlet volume and the outlet volume, any resulting damage is not so critical, as it will not result in leakage of fluid between the the inlet volume 18a the outlet volume 18b.

In the embodiments illustrated in Figures 6 - 8, whilst the drop in pressure in the inlet volume 18a that occurs when the flow of fluid from the inlet volume 18a to the outlet volume 18b commences may cause the main valve member 16 to move back towards its closed position, as soon as the auxiliary valve member 31'' blocks the

passage 24 again, the pressure in the inlet volume 18a will stabilise, and the main valve member 16 will therefore not move all the way back to its closed position. As such, the main valve member 16 will not hit and damage the valve seat 14.

The valves 10, 10', 10'' are advantageously provided used to control the flow of an injection fluid from a well annulus into a well conduit of a hydrocarbon well. The injection fluid may be a gas, and the valve a gas lift valve. In this case, the inlet volume 18a of the valve 10, 10', 10'' is fluidly connected to the well annulus and the outlet volume 18b of the valve 10, 10', 10'' is fluidly connected to the well conduit. The well conduit typically comprises the main passage of a section of production tubing.

Such a fluid injection system is illustrated in Figure 10. This shows a production tubing 90 which extends from a wellhead 93 located on a land surface 94. The wellhead 93 may alternatively be located on a subsea surface, or a platform deck. A well casing 95 extends towards a subterranean reservoir (not shown). The production tubing 90 comprises a pipe 91 having at least one side pocket mandrel 92a-c. Each side pocket mandrel 92a-c has an opening which permits fluid communication between the inside 97 of the production tubing 90 and an annulus 96 between the well casing 95 and the production tubing 90. At least one tool, in this embodiment, a valve 10, 10', 10'' according to the invention, is arranged in each respective side pocket mandrel 92a-c.

One such side pocket mandrel 92 is illustrated in Figure 11. The side pocket mandrel 92 can be installed in the pipe 91 of the production tubing 90 in a well bore by means of end connectors 104 and 105. The side pocket mandrel 92 has a main passage 102 which, when installed, is aligned with the main passage of the production tubing 90. This allows production fluids to pass through the side pocket mandrel 92, and it allows access to the inside of the side pocket mandrel 92 through the inside of the production tubing 90.

The side pocket mandrel 92 also has a laterally offset side pocket bore 107, the main passage 102 and the laterally offset side pocket bore 107 being separated by an internal wall 109. An inlet opening 106 (or, alternatively, several inlet openings)

is provided on the outside surface of the side pocket mandrel 92 to connect the annulus 96 with the side pocket bore 107.

- The valve 10, 10', 10'' (illustrated schematically in Figure 11) is arranged in the side pocket bore (107), the inlet volume 18a of the valve 10, 10', 10'', being in fluid communication with the exterior of the side pocket mandrel (92) via the inlet opening or openings 106, and the outlet volume 18b of the valve 18 being in communication with the main passage 102 via an outlet port 108 provided in the internal wall 109.
- 10 The invention is not limited by the embodiments described above; reference should be had to the appended claims.

CLAIMS

1. A valve comprising a housing which has an exterior and which encloses an interior space, the housing being provided with an inlet port and an outlet port, both of which provide a conduit between the exterior and interior space of the housing, the valve further comprising a main valve seat and a main valve member which is located in the interior space of the valve housing, the main valve member being movable relative to the valve housing between a closed position in which it engages with the main valve seat and blocks flow of fluid between the inlet port and the outlet port, and an open position in which it is not engaged with the main valve seat and the inlet port is fluidly connected to the outlet port via the interior space, the main valve member having a passage which extends through the main valve member and provides a conduit for flow of fluid between the inlet port and the outlet port when the main valve member is in the open position, characterised in that the valve further comprises an auxiliary valve member which is movable relative to the main valve member between a closed position in which the auxiliary valve member blocks the passage thereby restricting flow of fluid along the passage, and an open position in which substantially unrestricted flow of fluid along the passage is permitted.
2. A valve according to claim 1 wherein the main valve member further comprises an auxiliary valve seat with which the auxiliary valve member engages when in the closed position to block flow of fluid along the passage, the auxiliary valve seat being integral with or secured to the main valve member.
3. A valve according to any preceding claim wherein the auxiliary valve member is provided in the passage.
4. A valve according to any preceding claim further comprising a main resilient biasing element which acts on the main valve member to urge the main valve member to the closed position.
5. A valve according to claim 4 wherein the main resilient biasing element extends between the housing and the main valve member.
6. A valve according to any preceding claim further comprising an auxiliary biasing element which urges the auxiliary valve member to the closed position.

7. A valve according to claims 4 and 6 wherein the auxiliary biasing element is configured to provide a greater biasing force than the main resilient biasing element.
8. A valve according to any preceding claim wherein the main valve member is linearly moveable between the open and closed positions.
9. A valve according to claim 8 wherein the main valve member has a longitudinal axis and moves generally parallel to the longitudinal axis between the open and closed positions.
10. A valve according to claim 9 wherein the passage, or at least part of the passage extends from a first end of the main valve member generally parallel to the longitudinal axis.
11. A valve according to any preceding claim wherein the main valve member divides the interior space of the housing into an inlet volume and an outlet volume, the inlet volume comprising the portion of the interior volume of the housing to which the inlet port is connected when the main valve member is in its closed position, and the outlet volume comprising the portion of the interior volume of the housing to which the outlet port is connected when the main valve member is in its closed position.
12. A valve according to any preceding claim further comprising a choke part which is moveable between a fully open position in which the cross-sectional area available for flow of fluid through the inlet port is maximised, and a variety of active positions in which the choke part restricts flow of fluid through the inlet port.
13. A valve according to claim 12 wherein the choke part is movable to a fully closed position in which the choke part blocks the inlet port, and therefore substantially prevents flow of fluid between the exterior of the valve housing and the interior volume of the housing via the inlet port.
14. A valve according to claims 12 or 13 wherein housing comprises an inlet volume which comprises the portion of the interior volume of the housing to which the inlet port is connected when the main valve member is in its closed position, and the the choke part is located in the inlet volume.
15. A valve according to any of claims 12 to 14 wherein the auxiliary valve member is connected to the choke part so that the auxiliary valve member moves relative to the valve housing with the choke part.

16. A valve according to claim 15 wherein the choke part and auxiliary valve member are configured such that the auxiliary valve member moves away from the main valve member as the choke part moves towards its fully open position.
- 5 17. A valve according to any preceding claim wherein the auxiliary valve member is tapered in such a way that its cross-sectional area increases from a proximal end thereof towards a distal end, the proximal end being closer to the main valve member than the distal end.
- 10 18. A fluid injection system for use in a hydrocarbon well comprising a valve according to any one of claims 1 – 17.
- 15 19. A fluid injection system comprising a valve according to any one of claims 1 – 17, and tube having a side wall which encloses a main passage and an side passage which extends through the side wall to the main passage, the valve being mounted on the tube so that the outlet volume of the valve is in fluid communication with the side passage.
- 20 20. A fluid injection system for a hydrocarbon well comprising a valve according to any one of claims 1 – 17, a tubular and a side pocket mandrel having a main passage which is aligned with a main passage of the tubular, and a laterally offset side pocket bore, the main bore and the laterally offset side pocket bore being separated by an internal wall, wherein the valve is arranged in the side pocket bore, the inlet port of the valve being in fluid communication with the exterior of the side pocket mandrel via an inlet opening, and the outlet port of the valve being in communication with the main passage via an outlet conduit.
- 25 21. A fluid injection system according to claim 20 wherein the outlet conduit is provided in the internal wall.