FLUID INJECTION SYSTEM

The present invention relates to a fluid injection system suitable for use in injection of gas into a wellbore, typically an offshore wellbore for petroleum production.

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 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 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 pocket mandrels.

A publication which may be useful to understand the background is EP1682351.

This prior art document discloses a gas lift system which includes a retrievable one-way valve mounted in the side pocket of a side pocket mandrel, and one or more additional one-way valve mounted outside the side pocket which are connected to the interior of the side pocket. The system is configured such that gas in the annulus flows through the or each additional one-way valve into an inlet port of the retrievable one-way valve via the interior of the side pocket, through the retrievable one-way valve and into the main bore of the production tubing. The retrievable one-way valve and the or each additional one-way valve are configured to prevent reverse fluid flow through the gas lift system, i.e. to prevent flow of fluid from the main bore of the production tubing into the annulus. The or each additional one-way valve may be provided with a screen which is configured to filter the gas before it passes through the additional one-way valve. The screen comprises a tubular body with a closed end and an open end by means of which the screen is secured to the additional one-way valve. The tubular body is perforated, and prevents solid

particles which are larger than the perforations from entering the additional one-way valve.

The present application relates to an alternative configuration of fluid injection system.

SUMMARY

According to first aspect of the invention we provide a fluid injection system comprising at least one side pocket mandrel having a tubular side wall which encloses a main passage and side pocket, the tubular side wall having an interior surface and an exterior surface, the system further comprising a one-way valve mounted in the side pocket, wherein the side pocket mandrel has a first inlet passage which provides a first flow path for flow of fluid between the exterior surface of the tubular side wall and an inlet of the one-way valve, a second inlet passage which provides a second flow path for flow of fluid between the exterior surface of the tubular side wall and the inlet of the one-way valve, a screen which is configured to prevent solid particles from entering the inlet of the one-way valve via the first inlet passage, and a closure device which is arranged to block the second inlet passage when fluid pressure at the exterior surface of the tubular side wall is below a pre-determined level and which is configured to move to an open configuration to allow flow of fluid along the second inlet passage when fluid pressure at the exterior surface of the tubular side wall is at or above the pre-determined level.

In one embodiment, the closure device comprises a non-reclosing pressure relief device such as a burst disc / rupture disc / pressure safety disc / bursting disc / burst diaphragm.

In one embodiment, the closure device comprises a one-way valve.

In one embodiment, the closure device comprises a plug which is retained in the second inlet passage by a frangible retaining mechanism.

In one embodiment, the screen comprises an elongate filament.

In one embodiment, the screen comprises a mesh or perforated sheet.

In one embodiment, the screen is mounted on the exterior surface of the tubular side wall. As such, fluid at the exterior of the side pocket mandrel must pass through the screen before entering the first inlet passage. Advantageously, the screen

extends around at least a portion of the circumference of a portion of the tubular side wall. It may extend around the entire circumference of a portion of the tubular side wall

In one embodiment, the side pocket mandrel comprises a main part which includes the side pocket and a first portion of the main passage, and an auxiliary part which comprises a second portion of the main passage, the main part and the auxiliary part being releasably connected together by means of corresponding connection formations, such as correspondingly threaded end portions, so that the first portion and second portion of the main passage form a continuous path for flow of fluid through the side pocket mandrel. In this case, the screen may be mounted on the auxiliary part.

In one embodiment, the second inlet passage is connected to the first inlet passage, so that fluid flowing from the exterior surface of the tubular side wall to the inlet of the one-way valve via the second inlet passage first passes along the second inlet passage, then along a portion of the first inlet passage to the inlet of the one-way valve.

In one embodiment, the one-way valve in the side pocket is a main one-way valve, and the system is provided with an auxiliary one-way valve which is mounted in the first inlet passage so that fluid flowing along the first inlet passage to the inlet of the main one-way valve passes through the screen before entering the auxiliary one-way valve. Advantageously, the auxiliary one-way valve is mounted on the side pocket mandrel outside of the side pocket.

Where the second inlet passage is connected to the first inlet passage, the auxiliary one-way valve may be located in the first inlet passage such that fluid flowing from the exterior surface of the tubular side wall to the inlet of the main one-way valve via the second inlet passage first passes along the second inlet passage, then into the first inlet passage, though the auxiliary one-way valve and then to the inlet of the main one-way valve.

According to a second aspect of the invention we provide a fluid injection system comprising at least one side pocket mandrel having a tubular side wall which encloses a main passage and side pocket, the tubular side wall having an interior surface and an exterior surface, the system further comprising a one-way valve mounted in the side pocket, wherein the side pocket mandrel has an inlet passage

which provides a flow path for flow of fluid between the exterior surface of the tubular side wall and the inlet of the one-way valve, a screen which is configured to prevent solid particles from entering the inlet of the one-way valve via the inlet passage, and which is mounted on the exterior surface of the tubular side wall of the side pocket mandrel and extends around at least a portion of the circumference thereof. As such, fluid at the exterior of the side pocket mandrel must pass through the screen before entering the first inlet passage.

The screen may extend around the entire circumference of a portion of the tubular side wall.

In one embodiment, the screen comprises an elongate filament.

In one embodiment, the screen comprises a mesh or perforated sheet.

In one embodiment, the side pocket mandrel comprises a main part which includes the side pocket and a first portion of the main passage, and an auxiliary part which comprises a second portion of the main passage, the main part and the auxiliary part being releasably connected together by means of corresponding connection formations, such as correspondingly threaded end portions, so that the first portion and second portion of the main passage form a continuous path for flow of fluid through the side pocket mandrel. In this case, the screen may be mounted on the auxiliary part.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIGURE 1 is a schematic illustration of a longitudinal cross-section through a fluid injection system according to a first aspect of the invention,

FIGURE 2 is a schematic illustration of a transverse cross-section through the fluid injection system illustrated in Figure 1 along line X,

FIGURE 3 is a schematic illustration of the longitudinal cross-section through the fluid injection system illustrated in Figure 1 with the screen blocked by solid particles and the closure device opened to allow flow of fluid into the one-way valve via the second inlet passage,

FIGURE 4 is a schematic illustration of a longitudinal cross-section through an alternative embodiment of fluid injection system according to a first aspect of the invention,

FIGURE 5 is a schematic illustration of a longitudinal cross-section through a further alternative embodiment of fluid injection system according to a first aspect of the invention,

FIGURE 6 is a schematic illustration of a longitudinal cross-section through a further alternative embodiment of fluid injection system according to a first aspect of the invention,

FIGURE 7 is a schematic illustration of a longitudinal cross-section through a fluid injection system according to a second aspect of the invention,

FIGURE 8 is a schematic illustration of a longitudinal cross-section through an alternative embodiment of fluid injection system according to the second aspect of the invention,

FIGURE 9 is a schematic illustration of a longitudinal cross-section through a well production system including a plurality of fluid injection systems according to the first and second aspects of the invention,

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 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.

Figures 1 & 2 shows a first embodiment of fluid injection system 10 comprising at least one side pocket mandrel 12 having a tubular side wall 14 which encloses a main passage 16 and a laterally offset side pocket 18, the tubular side wall 14 having an interior surface 14a and an exterior surface 14b. There is an internal wall 14c separating the side pocket 18 and the main passage 16.

The main passage 16 of the side pocket mandrel 12 has a longitudinal axis A, and the side pocket 18 as a longitudinal axis B which is generally parallel to and offset from the longitudinal axis A of the main passage 16.

In this embodiment, the main passage 16 has a generally uniform cross-sectional area along its entire length, and the side pocket 18 is located in an intermediate portion of the side pocket mandrel 12 which is located between end portions of the tubular side wall 14. In the intermediate portion of the side pocket mandrel 12, the tubular body 14 has a larger outer diameter than at the end portions.

The end portions of the tubular body 14 are provided with connection formations 20 by means of which each end portion may be releasably connected to another tubular element, such as a stand of production tubing. Typically, the connection formations 20 comprise a screw thread.

The system 10 further comprises a one-way valve 22 mounted in the side pocket 18. The one-way valve 22 has a housing 24, an inlet port 26, an outlet port 28 and a valve member 30 which is mounted in the housing 24 and which is movable between an open position in which flow of fluid though the housing between the inlet port 26 and the outlet port 28 is permitted, and a closed position in which the valve member 30 engages with a valve seat 32 to block flow of fluid between the inlet port 26 and the outlet port 28. Typically, the one-way valve 22 also comprises a resilient biasing element such as a spring (not shown) which urges the valve member 30 into its closed position. The valve member 30 is arranged relative to the valve seat 32 such that the valve member 30 is moved out of engagement with the valve seat 32 to move to its open position when fluid pressure at the inlet port 26 exceeds fluid pressure at the outlet port 28, and moves to its closed position to block reverse flow of fluid from the outlet port 28 to the inlet port 26.

In this embodiment, the housing 24 of the one-way valve 22 is tubular, having a side wall 24a which extends generally parallel to the longitudinal axis B of the side pocket 18, and first and second end faces 24b, 24c, which close the housing at either end of the side wall 24a. The inlet port 26 is provided in the side wall 24a close to the first end face 24b, whilst the outlet port 28 is provided in the second end face 24c. Two seals 33a, 33b are provided between the side wall 24a of the housing 24 and the interior surface 14b of the portion of the tubular side wall 14 of the side pocket mandrel 12 forming the side pocket 18, a first one of the seals 33a being close to the first end face 33a and a second one of the seals 33b being close to the second end face 33b. The inlet port 26 is located between the two seals 33a, 33b. It will be appreciated that one or both of the seals 33a, 33b may be a seal assembly comprising a plurality of separate sealing elements.

The side pocket 18 has a first inlet passage 34 which provides a first flow path for flow of fluid between the exterior surface 14b of the tubular side wall 14 and the inlet 26 of the one-way valve 22, a second inlet passage 36 which provides a second flow path for flow of fluid between the exterior surface 14b of the tubular side wall 14 and the inlet 26 of the one-way valve 22.

In this embodiment, the first inlet passage 34 has a first internal portion 34a which extends through the tubular side wall 14 generally parallel with the longitudinal access B of the side pocket 18, and a second internal portion 34b which extends generally perpendicular to the longitudinal axis B of the side pocket 18 from an end of the first internal portion 34a into the side pocket 18. These are best illustrated in Figure 2.

In this embodiment, the second inlet passage 36 extends through the tubular side wall 14 of the side pocket mandrel 12 generally perpendicular to the longitudinal axis B of the side pocket 18 directly from the exterior surface 14b to the interior surface 14a of the tubular side wall 14.

The second internal portion 34b of the first inlet passage 34 and the second inlet passage 36 both extend into the side pocket 18 at the interior surface 14a of the tubular side wall 14 between the two seals 33a, 33b. The seals 33a, 33b provide a substantially fluid tight seal between the housing 24 and the tubular side wall 14, and so fluid passing along the first and second inlet passages 34, 36 is trapped between the seals 33a, 33b and is forced into the housing 24 of the one-way valve 22 via the inlet port 26. In this embodiment, the second inlet passage 36 is generally aligned with the inlet port 26 of the one-way valve 22, but this is not essential, as there would still be fluid communication between the two via the space between the two seals 33a, 33b even if the two were misaligned. It will be appreciated that the inlet port 26 of the one-way valve 22 could equally be aligned with the second portion 34b of the first inlet passage 34.

The system further comprises a screen 38 which is configured to prevent solid particles from entering the inlet port 26 of the one-way valve 22 via the first inlet passage 34, and a closure device 40 which is arranged to block the second inlet passage 36 when fluid pressure at the exterior surface 14b of the tubular side wall 14 is below a pre-determined level and which is configured to move to an open configuration to allow flow of fluid along the second inlet passage 36 when fluid

pressure at the exterior surface 14b of the tubular side wall 14 is at or above the pre-determined level. The screen 38 is mounted on the exterior surface of the tubular side wall 14 of the side pocket mandrel 12 so that fluid at the exterior of the side pocket mandrel 12 must pass through the screen 38 before entering the first inlet passage 34. Advantageously, the screen 38 extends around a portion of the circumference of the tubular side wall (14). In the embodiments described below, the screen 38 extends around the entire circumference of a portion of the tubular side wall 14.

In this embodiment, the closure device 40 comprises a non-reclosing pressure relief device known as a burst disc / rupture disc / pressure safety disc / bursting disc / burst diaphragm, but it could equally comprise an alternative pressure actuated relief mechanism such as a one-way valve, or a plug which is retained in the second inlet passage 36 by a frangible retaining mechanism.

In this embodiment, the screen 38 comprises an elongate filament, such as a wire, which is wrapped multiple times around a portion of the tubular side wall 14 of the side pocket mandrel 12 between one of the connectors 20 and the side pocket 18. In other words, in this embodiment, the screen 38 is wrapped around a portion of the tubular side wall 14 that encloses only the main passage 16 of the side pocket mandrel 12 – it is not also wrapped round the side pocket 18. The screen 38 need not comprises an elongate filament, however. The screen 38 may, for example, comprise a tubular mesh or perforated tube, or a mesh or perforated sheet bent to form a tube around the tubular side wall 14 of the side pocket mandrel 12. It will be appreciated that the screen 38 will not necessary remove **all** solid particles from the fluid – it will only catch solid particles which are greater in size than the spaces between adjacent portions of the elongate filament (or where a mesh or perforated tube / sheet is used greater in size than the apertures or perforations in the mesh or perforated tube or sheet). Smaller solid particles may pass through the screen 38 and enter the one-way valve 22. Advantageously, however, the spaces between adjacent portions of the elongate filament (or where a mesh or perforated tube / sheet is used the apertures or perforations in the mesh or perforated tube or sheet) are sized appropriately to catch all solid particles that are large enough to cause significant damage if they are permitted to enter the first inlet passage 34.

The screen 38 is supported on the tubular side wall 14 by means of a first collar 42a which is connected to a first end 38a of the screen 38, and a second collar 42b

which is connected to a second end 38b of the screen 38. The collars 42a, 42b are secured to the exterior surface 14b of the tubular side wall, for example, by means of a screw thread.

The first collar 42a is provided with a collar passage 44 which extends from the space between the screen 38 and the exterior surface 14b of the tubular side wall 14 to the first portion 34a of the first inlet passage 34 so that the collar passage 44 forms part of the first inlet passage 34. In this embodiment, the first inlet passage 34 also includes an external pipe portion 34c, in the form of a pipe or tube, which connects the collar passage 44 to the first portion 34a.

As such, fluid can flow through the screen 38, into the collar passage 44, along the external pipe portion 34c, along the first internal portion 34a, along the second internal portion 34b and into the housing 24 of the one-way valve 22 via the inlet port 26. Solid particles present in this fluid which are greater in size than the spaces between adjacent portions of the elongate filament (or where a mesh or perforated tube / sheet is used greater in size than the apertures or perforations in the mesh or perforated tube or sheet) are caught by the screen 38 and prevented from entering the first inlet passage 34, and thus also from entering the inlet port 26 of the one-way valve 22.

The side pocket mandrel 12 is also provided with an injection port 46 which extends between the side pocket 18 and the main passage 16, which is arranged to connect the outlet port 28 of the one-way valve 22 to the main passage 16. In this embodiment, the injection port 46 is provided in a portion of the internal wall 14c. As such, when fluid pressure at the exterior of the side pocket mandrel 12 is higher than fluid pressure in the main passage 16 by an amount which is sufficient to move the valve member 30 to its open position, fluid can flow from the exterior of the side pocket mandrel 12, through the screen 38, along the first inlet passage 34, through the inlet port 26, through the outlet port 28 and through the injection port into the main passage 16, solid particles having been removed from the fluid by the screen 38.

If the screen 38 becomes blocked so that flow of fluid into the first inlet passage 34 is prevented or at least significantly restricted, and fluid pressure at the exterior of the side pocket mandrel 12 increases to a level which causes the closure device 40 to open, unscreened fluid can then pass from the exterior of the side pocket mandrel

12 though the one way valve 22 and into the main passage 16 via the second inlet passage 36, as illustrated in Figure 3. In other words, the second inlet passage 36 provides an alternative route for injection of fluid into the main passage 16.

The one-way valve 22 blocks reverse flow of fluid from the main passage 16 to the exterior of the side pocket mandrel 12 via either the first or second inlet passage 34, 36.

An alternative embodiment of fluid injection system 10a is illustrated in Figure 4. This embodiment has many features in common with the embodiment illustrated in Figures 1 – 3, and the same reference numerals are used to designate the common features.

In this embodiment, the side pocket mandrel 12 comprises a main part 12a which includes the side pocket 18 and a first portion 16a of the main passage 16, and an auxiliary part 47 which encloses a second portion 16b of the main passage 16. The main part 12a and the auxiliary part 47 are releasably connected together by means of corresponding connection formations, such as correspondingly threaded end portions, so that the first portion 16a and second portion 16a of the main passage form a continuous path for flow of fluid through the side pocket mandrel. The auxiliary part 47 may, for example be a pup or sub. In this case, the screen 38 is mounted on the auxiliary part 47.

A further alternative embodiment of fluid injection system 10b is illustrated in Figure 5. This embodiment also has many features in common with the embodiment illustrated in Figures 1 – 3, and the same reference numerals are used to designate the common features.

In this embodiment, the second inlet passage 36 is connected to the first inlet passage 34, so that fluid flowing from the exterior surface 14b of the tubular side wall 14 to the inlet port 26 of the one-way valve 22 via the second inlet passage 36 first passes along the second inlet passage 36, then along a portion of the first inlet passage 34 to the inlet port 26 of the one-way valve 22. In this particular embodiment, the second inlet passage 36 is provided in the first collar 42, and joins the collar passage 44.

A further alternative embodiment of fluid injection system 10c is illustrated in Figure 6. This embodiment also has many features in common with the embodiment

illustrated in Figures 1 – 3, and the same reference numerals are used to designate the common features.

This embodiment differs in that the system 10'' additionally comprises an auxiliary one-way valve 50 which is mounted in the first inlet passage 34 so that fluid flowing along the first inlet passage 34 to the inlet port 26 of the main one-way valve 22 passes through the screen 38 and the auxiliary one-way valve 50 before entering the one-way valve 22 in the side pocket 18 (hereinafter referred to as the main one-way valve 22).

Whilst the auxiliary one-way valve 50 could be located anywhere in the first inlet passage 34, in this embodiment it is mounted on the side pocket mandrel 12 outside of the side pocket 18. Specifically, in this embodiment, the auxiliary one-way valve 50 is provided in the external pipe portion 34c of the first inlet passage 34.

The auxiliary one-way valve 50 has a housing, an inlet port, an outlet port and a valve member which is mounted in the housing and which is movable between an open position in which flow of fluid though the housing between the inlet port and the outlet port is permitted, and a closed position in which the valve member engages with a valve seat to block flow of fluid between the inlet port and the outlet port. Typically, the auxiliary one-way valve also comprises a resilient biasing element such as a spring (not shown) which urges the valve member into its closed position. The valve member is arranged relative to the valve seat such that the valve member is moved out of engagement with the valve seat to move to its open position when fluid pressure at the inlet port exceeds fluid pressure at the outlet port, and moves to its closed position to block reverse flow of fluid from the outlet port to the inlet port.

The auxiliary one-way valve 50 thus acts as a back-up to prevent reverse flow of fluid from the main passage 16 to the exterior of the side pocket mandrel via the first inlet passage 34 in the event that the main one-way valve 22 fails open or if the main one-way valve 22 is retrieved for repair, servicing or replacement.

Where the second inlet passage 36 is connected to the first inlet passage 34, the auxiliary one-way valve 50 may be located in the first inlet passage 34 in such a position that fluid flowing from the exterior surface 14b of the tubular side wall 14 to the inlet 26 of the main one-way valve 22 via the second inlet passage 36 first passes along the second inlet passage 36, then along a portion of the first inlet

passage 34, through the auxiliary one-way valve 50 and then to the inlet of the main one-way valve 22.

It will be appreciated that, alternatively, an additional auxiliary one-way valve could equally be provided in the second inlet passage 36.

It should be appreciated that by wrapping the screen 38 around the circumference of the exterior surface of the tubular side wall of the side pocket mandrel 12, a substantial surface area for filtering solid particles from the incoming fluid can be provided without significantly affecting the overall dimensions of the system. This is particularly true if the screen 38 is mounted on an auxiliary part 47 as illustrated in Figure 4. The auxiliary part 47 may, for example comprise a 7m long pup, and the screen 38 may be wrapped around a significant proportion, if not all, of the length of this part. A significant amount of debris would have to accumulate on such a large area of screen to completely block flow of fluid to the one-way valve (2).

As such, with such a large surface area of screen, the risk of the screen 38 becoming blocked may be sufficiently low that it is not necessary to provide a second inlet passage.

An alternative embodiment of fluid injection system 10d is illustrated in Figure 7. This embodiment also has many features in common with the embodiment illustrated in Figures 4, and the same reference numerals are used to designate the common features. In this embodiment, however, no second inlet passage is provided. The first inlet passage 34 provides the only path for flow of fluid from the exterior of the side pocket mandrel 12 into the one-way valve 22.

It should be appreciated that the second inlet passage 36 could equally be omitted from the embodiments illustrated in Figures 1 – 3 (where the side pocket mandrel 12 does not comprise a main and auxiliary part) or Figure 6 (where the system is provided with an auxiliary one-way valve).

A further alternative embodiment of fluid injection system 10e is illustrated in Figure 8. This embodiment also has many features in common with the embodiment illustrated in Figures 1 - 7, and the same reference numerals are used to designate the common features.

In this embodiment, there is also no second inlet passage, and the first inlet passage 34 provides the only path for flow of fluid from the exterior of the side

pocket mandrel 12 into the one-way valve 22. In this embodiment, however, the first inlet passage 34 is located in the same position as the second inlet passage 36 in the embodiments illustrated in Figures 1 – 4 and 6. That is to say, the first inlet passage 34 extends through the tubular side wall 14 of the side pocket mandrel 12 generally perpendicular to the longitudinal axis B of the side pocket 18 directly from the exterior surface 14b to the interior surface 14a of the tubular side wall 14. In this embodiment, the first inlet passage 34 is generally aligned with the inlet port 26 of the one-way valve 22, but this is not essential, as there would still be fluid communication between the two via the space between the two seals 33a, 33b even if the two were misaligned. Also in this embodiment, the screen 38 is mounted around the portion of the tubular side wall 14 of the side pocket mandrel 12 that encloses the side pocket 18, the first inlet passage 34 extending to the portion of the exterior surface 14b of the tubular side wall 14 between the first and second collars 42a, 42b by means which the screen is mounted on the side pocket mandrel 18.

It should be appreciated that an auxiliary one-way valve could also be provided in the inlet passage 34 in this embodiment 10e of fluid injection system 10e.

The fluid injection systems 10, 10a, 10b, 10c, 10d are advantageously used to control the flow of an injection fluid from a well annulus into a well conduit of a hydrocarbon well, and any of the fluid injection systems 10, 10a, 10b, 10c, 10d, 10e described above may be incorporated into a well production system as illustrated in Figure 9. The injection fluid may be a gas, and the fluid injection system 10, 10a, 10b, 10c, 10d, 10d a gas lift system.

Figure 9 shows a well casing 95 which lines a wellbore which extends towards a subterranean reservoir (not shown). A production tubing 90 extends down the wellbore inside the well casing 95 from a wellhead 93 located at the top of the wellbore on a land surface 94. The wellhead 93 may alternatively be located on a subsea surface, or a platform deck. There is an annular volume around the production tubing 90, between the production tubing 90 and the casing 95, which is generally referred to as the well annulus 96. The production tubing 90 has a main passage 97, and when the well is producing, fluid from the subterranean reservoir flows up the main passage 97 of the production tubing 90 to the wellhead 93.

The production tubing 90 comprises a pipe or tubular 91 in which is provided at least one of the fluid injection systems 10, 10a, 10b, 10c, 10d. 10e. The fluid at the

exterior of the tubular side wall 14 of the side pocket mandrel 12 referred to in the description above is therefore the fluid in the well annulus 96. The side pocket mandrel 18 of each fluid injection system 10, 10a, 10b, 10c, 10d, 10e is located between adjacent lengths or stands of production tubing, and is connected to the ends of the adjacent lengths of production tubing by means of the connectors 20. The main passage 16 of the side pocket mandrel 12 is aligned with the main passage 97 of the production tubing 90.

Injection fluid may therefore be pumped into the well annulus 96, and when the fluid pressure in the well annulus 96 is sufficiently high, will flow into the main passage 97 of the production tubing 90 via the screen 38, the first inlet passage 34, the auxiliary one-way valve 50 if provided, the (main) one-way valve 22, and the main passage 16 of the side pocket mandrel 12. The screen 38 prevents solid particles in the injection fluid above a certain size from entering the main one-way valve 22 (and the auxiliary one-way valve 50 where provided). Where a second inlet passage 36 is provided, if the screen is blocked, and, as a result, the fluid pressure in the well annulus increases to the predetermined level (specifically the predetermined level at which the closure device 40 is configured to open), the closure device 40 will move to its open position, so that flow of injection fluid into the main passage 97 of the production tubing 90 can resume.

The invention is not limited by the embodiments described above; reference should be had to the appended claims.

Reference numerals list:

10 – first embodiment of fluid injection system

12 – side pocket mandrel

14 – tubular side wall

14a – interior surface of tubular side wall

14b – exterior surface of tubular side wall

14c – internal wall

16 – main passage

18 – side pocket

20 – connection formations

22 – one-way valve

24 – housing

26 – inlet port

28 – outlet port

30 – valve member

32 – valve seat

34 – first inlet passage

34a – first internal portion

34b – second internal portion

34c – external pipe portion

36 – second inlet passage

38 – screen

38a – first end of the screen

38b – second end of the screen

40 – closure device

42a – first collar

42b – second collar

44 – collar passage

46 – injection port

47 – auxiliary part

48 – connectors

50 – auxiliary one-way valve

CLAIMS

1. A fluid injection system (10, 10a, 10b, 10c) comprising at least one side pocket mandrel (12) having a tubular side wall (14) which encloses a main passage (16) and side pocket (18), the tubular side wall (14) having an interior surface (14a) and an exterior surface (14b), the system (10, 10a, 10b, 10c) further comprising a one-way valve (22) mounted in the side pocket (18), wherein the side pocket mandrel (12) has a first inlet passage (34) which provides a first flow path for flow of fluid between the exterior surface (14b) of the tubular side wall (14) and an inlet (26) of the one-way valve (22), a second inlet passage (36) which provides a second flow path for flow of fluid between the exterior surface (14b) of the tubular side wall (14) and the inlet (26) of the one-way valve (22), a screen (38) which is configured to prevent solid particles from entering the inlet (26) of the one-way valve (22) via the first inlet passage (34), and a closure device (40) which is arranged to block the second inlet passage (36) when fluid pressure at the exterior surface (14b) of the tubular side wall (14) is below a predetermined level and which is configured to move to an open configuration to allow flow of fluid along the second inlet passage (36) when fluid pressure at the exterior surface (14b) of the tubular side wall (14) is at or above the predetermined level.
2. A fluid injection system (10, 10a, 10b, 10c) according to claim 1 wherein the closure device (40) comprises a non-reclosing pressure relief device.
3. A fluid injection system (10, 10a, 10b, 10c) according to claim 1 wherein the closure device (40) comprises a one-way valve.
4. A fluid injection system (10, 10a, 10b, 10c) according to claim 1 wherein the closure device (40) comprises a plug which is retained in the second inlet passage by a frangible retaining mechanism.
5. A fluid injection system (10, 10a, 10b, 10c) according to any preceding claim wherein the screen (38) comprises an elongate filament.
6. A fluid injection system (10, 10a, 10b, 10c) according to any preceding claim wherein the screen (38) comprises a mesh or perforated sheet.
7. A fluid injection system (10, 10a, 10b, 10c) according to any preceding claim wherein the screen (38) is mounted on the exterior surface (14b) of the tubular side wall (14).

8. A fluid injection system (10a) according to any preceding claim wherein the side pocket mandrel (12) comprises a main part (12a) which includes the side pocket (18) and a first portion (16a) of the main passage (16), and an auxiliary part (47) which comprises a second portion (16b) of the main passage (16), the main part (12a) and the auxiliary part (47) being releasably connected together by means of corresponding connection formations (48) so that the first portion (16a) and second portion (16b) of the main passage (16) form a continuous path for flow of fluid through the side pocket mandrel (18).
9. A fluid injection system (10a) according to claim 8 wherein the screen (38) is mounted on the auxiliary part (47).
10. A fluid injection system (10c) according to any preceding claim wherein the second inlet passage (36) is connected to the first inlet passage (34), so that fluid flowing from the exterior surface (14b) of the tubular side wall (14) to the inlet (26) of the one-way valve (22) via the second inlet passage (36) first passes along the second inlet passage (36), then along a portion of the first inlet passage (34) to the inlet (26) of the one-way valve (22).
11. A fluid injection system (10c) according to any preceding claim wherein the one-way valve (22) in the side pocket (18) is a main one-way valve (22), and the system (10, 10a, 10b, 10c) is provided with an auxiliary one-way valve (50) in the first inlet passage (34) so that fluid flowing along the first inlet passage (34) to the inlet (26) of the main one-way valve (22) passes through the screen (38) before entering the auxiliary one-way valve (50).
12. A fluid injection system (10c) according to claim 11 wherein the auxiliary one-way valve (50) is mounted on the side pocket mandrel (12) outside of the side pocket (12).
13. A fluid injection system (10c) according to claims 10 and 11 or 12 wherein the auxiliary one-way valve (50) is located in the first inlet passage (34) such that fluid flowing from the exterior surface (14b) of the tubular side wall (14) to the inlet (26) of the main one-way valve (22) via the second inlet passage (36) first passes along the second inlet passage (36), then into the first inlet passage (34), though the auxiliary one-way valve (50) and then to the inlet (26) of the main one-way valve (22).
14. A fluid injection system (10, 10a, 10b, 10c, 10d, 10e) comprising at least one side pocket mandrel (12) having a tubular side wall (14) which encloses a

main passage (16) and a side pocket (18), the tubular side wall (14) having an interior surface (14a) and an exterior surface (14b), the system (10, 10a, 10b, 10c, 10d, 10e) further comprising a one-way valve (22) mounted in the side pocket (18), wherein the side pocket mandrel (12) has an inlet passage (34) which provides a flow path for flow of fluid between the exterior surface (14b) of the tubular side wall (14) and the inlet (26) of the one-way valve (22), and a screen (38) which is configured to prevent solid particles from entering the inlet (26) of the one-way valve (22) via the inlet passage (34), and which is mounted on the exterior surface of the tubular side wall (14) of the side pocket mandrel (12) and extends around at least a portion of the circumference thereof.

15. A fluid injection system (10, 10a, 10b, 10c,10d, 10e) according to claim 14 wherein the screen (38) comprises an elongate filament.
16. A fluid injection system (10, 10a, 10b, 10c, 10d, 10e) according to claim 14 wherein the screen (38) comprises a mesh or perforated sheet.
17. A fluid injection system (10b, 10d) according to any one of claims 14 - 16 wherein the side pocket mandrel (12) comprises a main part (12a) which includes the side pocket (18) and a first portion (16a) of the main passage (16), and an auxiliary part (47) which comprises a second portion (16b) of the main passage (16), the main part (12a) and the auxiliary part (47) being releasably connected together by means of corresponding connection formations (48) so that the first portion (16a) and second portion (16b) of the main passage (16) form a continuous path for flow of fluid through the side pocket mandrel (12).
18. A fluid injection system (10b, 10d) according to claim 17 wherein the screen (38) is mounted on the auxiliary part (47).