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(54) **ROBUST GAS LIFT VALVE SUITABLE FOR USE IN HARSH ENVIRONMENTS**

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(51) **Int. Cl.**
E21B 43/12 (2006.01)

(52) **U.S. Cl.**
CPC ***E21B 43/123*** (2013.01); *Y10T 137/2934* (2015.04)

(58) **Field of Classification Search**
CPC Y10T 137/2934; E21B 43/123
See application file for complete search history.

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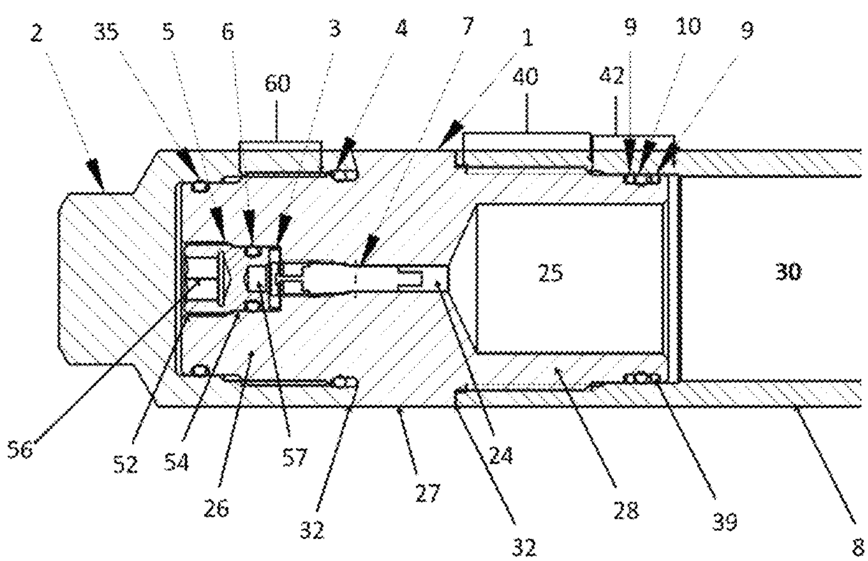
Primary Examiner — Hailey K. Do

(57) **ABSTRACT**

A gas lift valve including a body with interior charging chamber; a housing defining a bore in fluid communication with the charging chamber; a plug positioned within the bore and an a first O-ring forming a seal between an external surface of the plug and an interior surface of the bore, a crush washer is positioned between the plug and a surface of the housing; and a cap positioned with respect to the housing such that the plug is positioned within the cap interior bore and a second O-ring forms a seal between a first external surface of the housing and a first interior surface of the cap.

19 Claims, 3 Drawing Sheets



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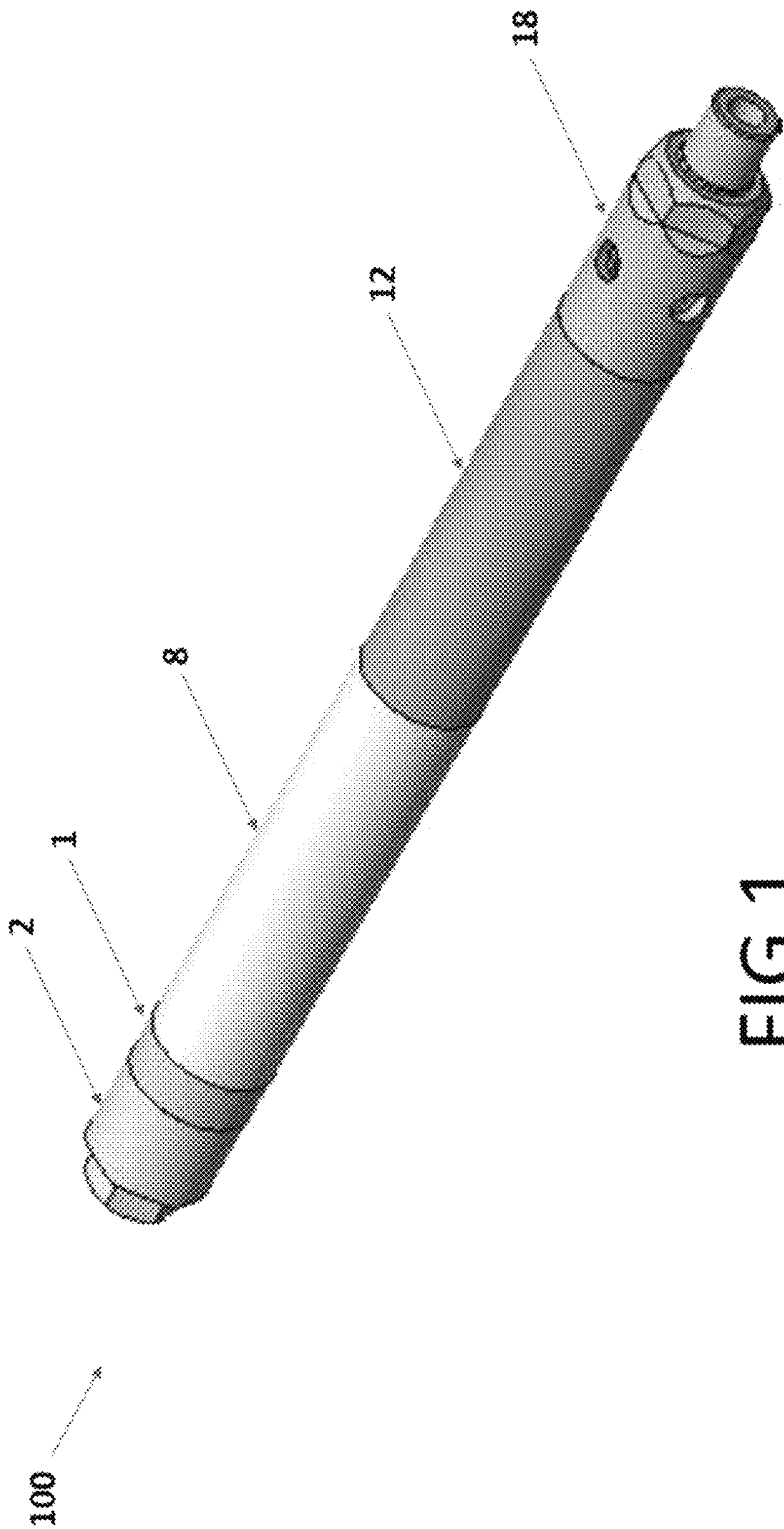

FIG 1

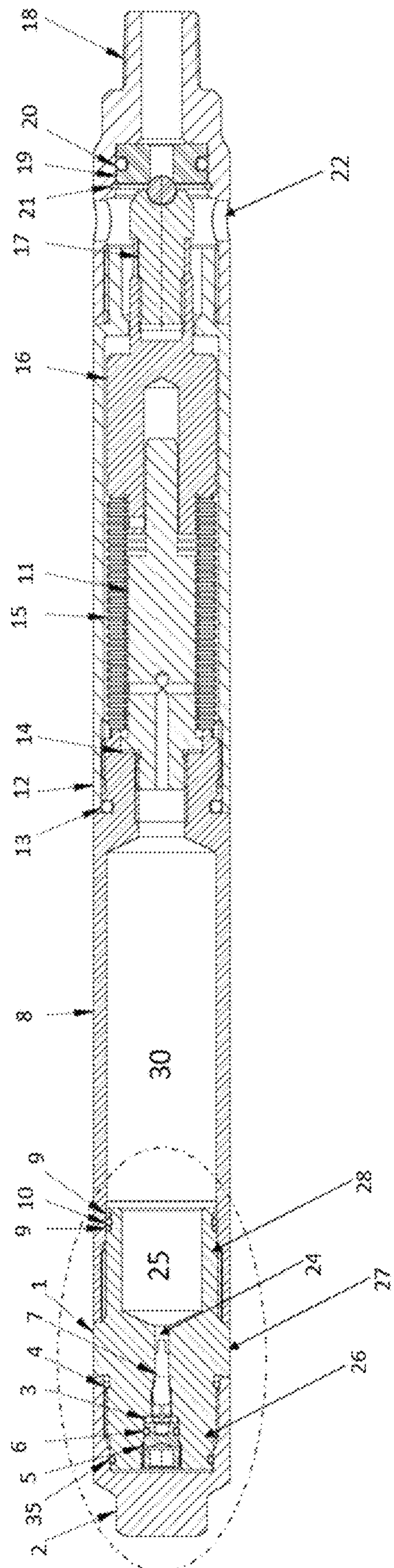
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FIG 2

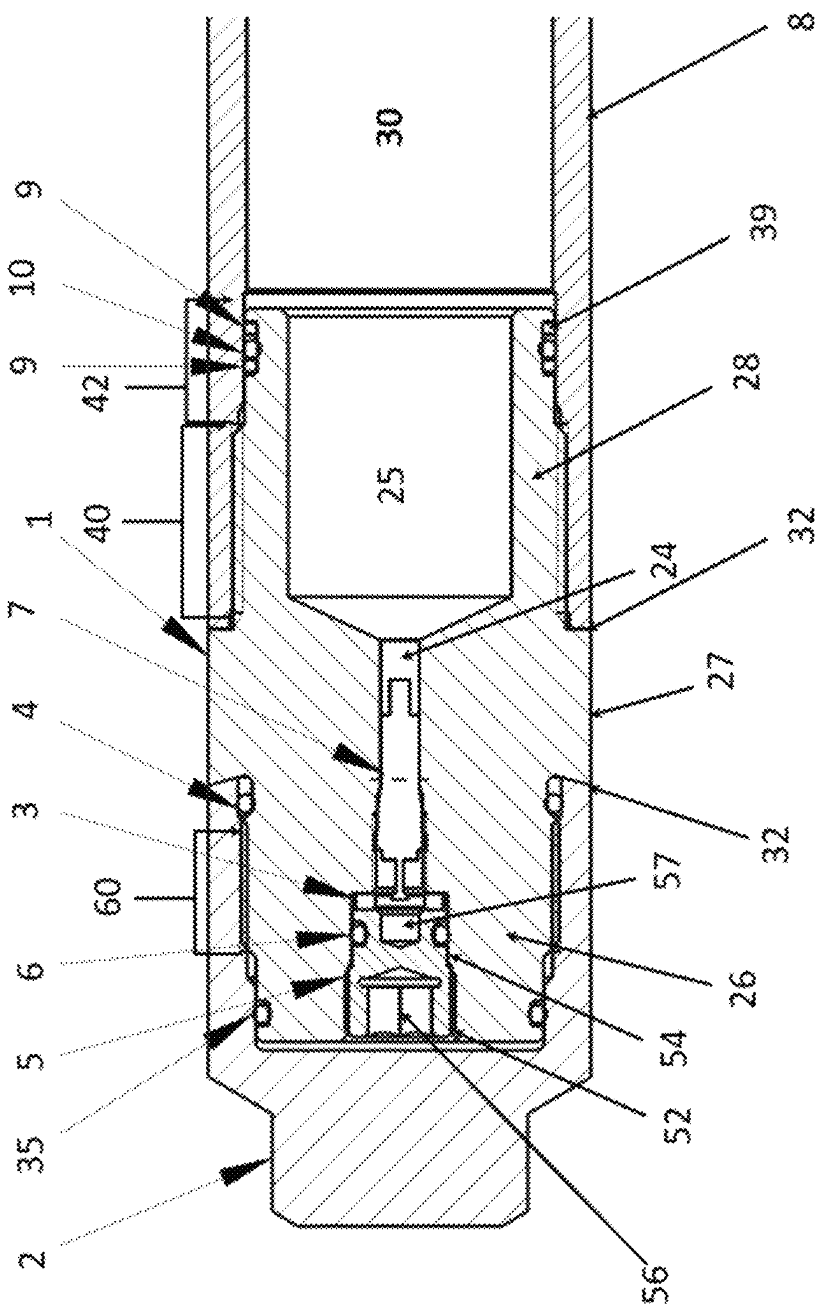

FIG. 3

ROBUST GAS LIFT VALVE SUITABLE FOR USE IN HARSH ENVIRONMENTS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Application No. 63/483,988 filed on Feb. 9, 2023 and entitled "Robust Gas Lift Value Suitable for Use in Harsh Environments."

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not applicable.

REFERENCE TO APPENDIX

Not applicable.

BACKGROUND OF THE INVENTION

The present disclosure relates to gas lift valves for use in artificial gas lift applications. In certain such applications, pressurized gas is used to form or supplement gas within production fluids to promote the production of, for example, oil and gas from a well.

In many artificial gas lift applications one or more gas lift valves are used to control the injection of gas into reservoir fluids. In such applications, pressurized gas is applied to the input of the one or more gas lift valves and each gas lift valve can be set to open when the pressure of the applied gas reaches a certain set pressure, sometimes referred to as a charge pressure. This charge pressure also correlates to a relative closing pressure of the valve.

In many of such applications, the pressure setting at which a given gas lift valve will open is set by the injection of a gas (typically nitrogen) through a valve element (typically a dill or Schrader-type valve) into a cavity within the gas lift valve (often referred to as a dome). In operation, the pressurized gas within the cavity or chamber acts against a biasing member within the valve, typically in the form of a bellow, that, in turn, acts against a movable valve element. In such applications, when the pressure within the reservoir meets or exceeds the set point pressure for a given valve, the valve will be forced open and a gas applied at the input of the valve will be injected into the reservoir fluids.

A long standing problem in the field of artificial gas lift is that conventional gas lift valves often do not operate properly (or over a desired length of time) in certain environments and/or that such gas lift valves are subject to damage if uncommon well conditions are encountered.

For example, in applications where a gas lift valve is used in a high temperature environment, it is not uncommon for one or more of the internal gasketing materials maintaining the gas pressure within the dome in the valve to either degrade, expand, or adjust to the point that a seal maintaining the pressure containment within the dome fails in part or in total. When such an event occurs, some or all of the pressurized gas within the dome will exit the gas lift valve, resulting in either complete failure of the gas lift valve or sub-optimum performance of the valve as a result of the undesired change in the internal charge pressure in the valve.

A further long standing problem in the field of artificial gas lift valves is that conventional valves are prone to failure in the event that the reservoir in which the valve is operating is subjected to an unanticipated spike in pressure. Such an unexpected pressure spike can occur, for example, when a well adject to a producing well in which a gas lift valve is positioned, is undergoing a hydraulic fracturing operation. In such applications, very high-pressure fluids are injected into the well undergoing the hydraulic fracturing operation with the goal of creating or expanding fractures within the rock surfaces or other formations adjacent the treated well. In such operations, it is possible that a fracture will be created that can extend from the treated reservoir to the producing reservoirs in which the gas lift valve is positioned which can result in a significant spike in the reservoir pressure of the producing well. It is known that such an undesired pressure spike (or "frac hit") can damage conventional gas lift valves, either rendering the valve—and typically more than one gas lift valves within the producing well—inoperable, or causing an adjustment in the pressure setting of the valve (or multiple valves) resulting in non-optimal valve operations.

One object of the embodiments discussed herein is to reduce or overcome the above-identified and other problems associated with conventional gas lift valve constructions.

It is to be understood that the discussion above is provided for illustrative purposes only and is not intended to and does not limit the scope or subject matter of the appended or ultimately issued claims or those of any related patent application or patent. Thus, none of the appended claims, ultimately issued claims or claims of any related application or patent are to be limited by the above discussion or construed to address, include, or exclude each or any of the above-cited features or disadvantages merely because such were mentioned herein.

BRIEF SUMMARY OF THE INVENTION

A brief non-limiting summary of one of the many possible embodiments of the inventions disclosed herein is a gas lift valve including a body defining an interior charging chamber, the interior charging chamber defining a volume; a housing defining a bore in fluid communication with the charging chamber where the bore has a maximum internal diameter; a plug positioned within the bore, where the plug has a maximum outer diameter greater than the maximum internal diameter of the bore in the housing; a first O-ring forming a seal between an external surface of the plug and an interior surface of the bore; a crush washer positioned between the plug and a surface of the housing which serves as a sealing component; and a cap defining an interior bore, the cap being positioned with respect to the housing such that the plug is positioned within the cap interior bore; and a second resilient element forming a seal between a first external surface of the housing and a first interior surface of the cap.

Additionally or alternately, the positioning of the plug and the crush washer can form a cavity between the valve assembly and the plug and wherein the volume of the cavity is less than 0.007% of the total volume of the charging chamber.

None of these brief summaries of the inventions is intended to limit or otherwise affect the scope of what has been disclosed and enabled or the appended claims, and nothing stated in this Brief Summary of the Invention is intended as a definition of a claim term or phrase or as a disavowal or disclaimer of claim scope.

BRIEF DESCRIPTION OF THE DRAWINGS

The following figures form part of the disclosure of inventions and are included to demonstrate further certain aspects of the inventions. The inventions may be better understood by reference to one or more of these figures in combination with the detailed description of certain embodiments presented herein.

FIG. **1** illustrates an exemplary embodiment of a robust gas lift valve **100** constructed in accordance with certain teachings of this disclosure that is suitable for use in harsh environments.

FIG. **2** illustrates additional details of the exemplary gas lift valve **100** and which depicts the exemplary valve **100** of FIG. **1** in cross section.

FIG. **3** illustrates further additional details of an exemplary embodiment constructed in accordance with the teachings of this disclosure and shows certain of the elements in FIG. **2** in greater detail.

While the inventions disclosed herein are susceptible to various modifications and alternative forms, only a few specific embodiments have been shown by way of example in the drawings and are described in more detail below. The figures and detailed descriptions of these embodiments are not intended to limit the breadth or scope of the inventive concepts or the appended claims in any manner. Rather, the figures and detailed written descriptions are provided to illustrate the inventive concepts to a person of ordinary skill in the art and to enable such person to make and use the inventive concepts illustrated and taught by the specific embodiments.

DETAILED DESCRIPTION

The Figures described above, and the written description of specific structures and functions below, are not presented to limit the scope of the inventions disclosed or the scope of the appended claims. Rather, the Figures and written description are provided to teach a person skilled in this art to make and use the inventions for which patent protection is sought.

A person of skill in this art having benefit of this disclosure will understand that the inventions are disclosed and taught herein by reference to specific embodiments, and that these specific embodiments are susceptible to numerous and various modifications and alternative forms without departing from the inventions we possess. For example, and not limitation, a person of skill in this art having benefit of this disclosure will understand that Figures and/or embodiments that use one or more common structures or elements, such as a structure or an element identified by a common reference number, are linked together for all purposes of supporting and enabling our inventions, and that such individual Figures or embodiments are not disparate disclosures. A person of skill in this art having benefit of this disclosure immediately will recognize and understand the various other embodiments of our inventions having one or more of the structures or elements illustrated and/or described in the various linked embodiments. In other words, not all possible embodiments of our inventions are described or illustrated in this application, and one or more of the claims to our inventions may not be directed to a specific, disclosed example. Nonetheless, a person of skill in this art having benefit of this disclosure will understand that the claims are fully supported by the entirety of this disclosure.

Those persons skilled in this art will appreciate that not all features of a commercial embodiment of the inventions are described or shown for the sake of clarity and understanding. Persons of skill in this art will also appreciate that the development of an actual commercial embodiment incorporating aspects of the present inventions will require numerous implementation-specific decisions to achieve the developer's ultimate goal for the commercial embodiment. Such implementation-specific decisions may include, and likely are not limited to, compliance with system-related, business-related, government-related, and other constraints, which may vary by specific implementation, location and from time to time. While a developer's efforts might be complex and time-consuming in an absolute sense, such efforts would be, nevertheless, a routine undertaking for those of skill in this art having benefit of this disclosure.

Further, the use of a singular term, such as, but not limited to, "a," is not intended as limiting of the number of items. Also, the use of relational terms, such as, but not limited to, "top," "bottom," "left," "right," "upper," "lower," "down," "up," "side," and the like are used in the written description for clarity in specific reference to the Figures and are not intended to limit the scope of the invention or the scope of what is claimed.

Reference throughout this disclosure to "one embodiment," "an embodiment," or similar language means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one of the many possible embodiments of the present inventions. The terms "including," "comprising," "having," and variations thereof mean "including but not limited to" unless expressly specified otherwise. An enumerated listing of items does not imply that any or all of the items are mutually exclusive and/or mutually inclusive, unless expressly specified otherwise. The terms "a," "an," and "the" also refer to "one or more" unless expressly specified otherwise.

The description of elements in each Figure may refer to elements of proceeding Figures. Like numbers refer to like elements in all figures, including alternate embodiments of like elements. In some possible embodiments, the functions/actions/structures noted in the figures may occur out of the order noted in the block diagrams and/or operational illustrations. For example, two operations shown as occurring in succession, in fact, may be executed substantially concurrently or the operations may be executed in the reverse order, depending upon the functionality/acts/structure involved.

Turning now to several descriptions, with reference to figures, or particular embodiments incorporating one or more aspects of the disclosed inventions, FIG. **1** illustrates an exemplary embodiment of a robust gas lift valve **100** constructed in accordance with certain teachings of this disclosure that is suitable for use in harsh environments. Such harsh environments include, but are not limited to, downhole environments where the gas lift valve will be subject to high temperatures; environments (downhole or otherwise) where the gas lift valve may be subject to impacts and/or vibrations after it is set; environments where the gas lift valve may be subjected to potentially harmful chemicals and/or well bore fluids, gases, and foreign wellbore materials from a reservoir, and/or environments where there is a possibility of malicious adjustment of a set gas lift valve before it is positioned downhole.

In the illustrated embodiment of FIG. **1**, the main externally visible body of the gas lift valve **100** gas lift valve includes, from right to left in the figure a valve seat housing **18**, a bellow housing **12**, a dome housing **8**, and a valve core housing **1**.

Although not illustrated in FIG. **1**, in different implementations additional housings or mechanisms may be coupled to the gas lift valve **100** prior to its installation for use downhole. For example, in some embodiments a check valve assembly and/or a latching assembly may be coupled (via threads or otherwise) to the distal end of the valve seat housing **18**.

The described housing elements may be formed from any material suitable for use in the intended or potential operation environments in which the valve **100** may be used. Such materials include, but are not limited to 316 stainless steel, other grades of stainless steel, various metal alloys including MONEL® metal alloys, heat, or chemical steel such as steel treated with a nitriding process; or any other suitable material. In some embodiments, each of the housings will be formed from the same material. In other embodiments, the housing components may each be formed from different materials and/or only some of the housing elements may be formed from the same material. The various housing elements may be formed through a machining process, a casting process, a 3D printing process, combinations of the foregoing, or any other suitable construction process or combination of processes.

In the embodiment of FIG. **1** each of the housing elements is coupled to an adjacent element via a threaded connection, although alternative connection methods could be used without departing from the teachings of this disclosure. Such alternate connection methods include friction welding, press fitting, brazing, soldering, gas-tight quick connect connection and other suitable types of connections.

In the embodiment of FIG. **1**. The dome housing **8** is depicted as a component separate from the valve core housing **1** and the dome housing **8** and the valve core housing **1** are shown as being connected via a threaded connection. This is only one example of a valve constructed according to the teachings of this disclosure. Alternative embodiments are envisioned, wherein other coupling methods are used (as discussed above). Still further alternative embodiments are envisioned wherein the valve housing **1** and the dome housing **8** are formed as a single, integral component.

Additional details of the exemplary gas lift valve **100** are reflected in FIG. **2**, which depicts the exemplary valve **100** in cross section.

As reflected in FIG. **2**, the valve seat housing **18** defines a plurality of openings **22** (only one of which is through which injection gas may pass).

As also shown, in the figure a valve seat **19** is positioned within a recess formed in the seat housing **18**, and a resilient sealing element in the form of an O-ring **20** is positioned within a grove formed in the seat housing to form seal between valve seat **19**/O-ring **20** assembly and the seat housing **18**. The O-ring **20** may be formed of any suitable material, including elastomeric materials such as VITON® 90D synthetic rubber, a FFKM base material such as CHEMRAZ® elastomer, a harsh environment material such as KALREZ® synthetic rubber, or any other suitable O-Ring material. In some embodiments, the elastomeric material may be selected to have a high temperature rating for example, in some embodiments, a temperature rating of 350° Fahrenheit or greater. It will be appreciated that the material used to form the O-Ring **20** may be used to form any of the O-Rings or other resilient structures disclosed herein.

A retaining clip **21** may be used to help retain the valve seat **19**/O-ring **20** assembly within the valve seat **19**. The retaining clip **21** may be constructed of brass, stainless steel, alloy steel, INCONEL® nickel alloy, or any other suitable material.

As shown in FIG. **2**, the valve seat **19** includes an interior bore that, when not blocked, creates a path for fluid (e.g., injection gas) to flow from the outside of the gas lift valve **100**, through the openings **22** in the valve seat housing **18**, through the bore in the valve seat, and out of a discharge port of the valve or through the discharge port of the gas lift valve **100** into an affixed check valve or other additional affixed feature. Any such additional affixed features may be attached to the valve **100** using threads, a latching mechanism, O-Ring sealing fixture, or any other suitable method of attachment.

In the exemplary valve **100** of FIG. **2**, a movable bellow assembly is positioned in the interior of the bellow housing **12** that includes a guide rod **11**, a bellow **15** positioned about the guide rod **11**, and a ball stem assembly **17**. In the example of FIG. **2**, the ball stem assembly **17** includes a stem and a valve ball positioned within the stem. It will be appreciated that in alternate embodiments, the valve stem assembly **17** could be formed as an integral component including a stem portion and a valve sealing portion.

In the example of FIG. **2**, a bellow adapter **16** is positioned between the bellow **15** and the ball stem assembly **17**. The bellow adapter **16** may be coupled to the bellow **15** at a first end of the bellow adapter **16** (the left end in FIG. **2**) end and to the ball stem assembly **17** a second end of the bellow adapter **16** (the right end in FIG. **2**) through any suitable process. Such connecting processes can include brazing, welding, or any other suitable process.

The end of the bellow **15** not coupled to the bellow adapter **16** may be coupled to a projecting surface of the guide rod **11**, as further shown in FIG. **2**.

In the example of FIG. **2**, the construction of the dome housing **8** is such that a surface of the dome housing **8** generally abuts a surface of the guide rod **11**. A washer element **14**, which may take the form of a crush washer, may be positioned between the guide rod **11** and the generally abutting surface of the dome housing **8**. In embodiments where the washer element **14** takes the form of a crush washer, the crush washer may be formed from copper, stainless steel, or any other suitable material. It will be appreciated that such materials can be used to form any or all crush washers disclosed herein.

In the example, of FIG. **2**, the bellow adapter includes a recess in which a projecting portion of the guide rod **11** is positioned. It will be appreciated that, because of this arrangement, the bellow adapter **16** (and therefore the ball stem assembly **17** coupled to one end of the bellow adapter **16**) can move relative to the guide rod **11** as the bellow **15** compresses and de-compresses. It will be further appreciated that as the bellow **15** compresses and/or decompresses (and moves relative to the guide rod **11**) the valve ball (or sealing surface) of the valve stem assembly **17** will move into and out of engagement with the valve seat **19**, thus blocking or permitting the flow of injection gas from outside the gas lift valve, through the openings **22** in the valve seat housing, and through the opening in the valve seat **19** and out of the discharge port of the valve.

In the example of FIG. **2**, the bellow housing **12** is coupled at one end to an end of the dome housing **8** and an and a resilient sealing element in the form of O-ring **13** (positioned within a recess in the dome housing **8**) is used to provide a seal between the two housing elements. The O-ring may be formed from the same material, or a different material, as O-Ring **20**, discussed above.

For the exemplary gas lift valve **100** of FIG. **2**, the end of the dome housing **8** not coupled to the bellow housing **12** is coupled to the valve core housing **1**. It will be appreciated that, in embodiments, where the dome housing **8** and the valve core housing **1** are formed as an integral component, there will be no such coupling.

In the example of FIG. **2**, the dome housing **8** defines a first interior bore that serves to at least partially define an interior charging chamber **30** that exists at least partially within the dome housing **8**. In the example of FIG. **2**, the interior charging chamber **30** is partially (although primarily in the example) defined by the first interior bore, which is bounded by interior surfaces of the dome housing **8** and partially defined by a second interior bore **25** bounded by interior surfaces of a recess in the valve core housing **1** (discussed below). Thus, in the illustrated example, the charging chamber exists partially within the dome housing and partially within the valve core housing. It will be appreciated that, in alternate embodiments the interior charging chamber **30** may be defined by interior surfaces of the valve core housing **1** or, in embodiments where the valve core housing **1** is integrally formed with the dome housing **8**, by the interior of the integral component alone.

It will be appreciated that the first interior bore within the dome housing will have a first internal or interior cross sectional diameter and that the second interior bore **25** within the valve core housing will have a second internal or interior cross sectional diameter.

As reflected in FIG. **2**, in the exemplary embodiment, the valve core housing **1** includes and defines, in addition to the second interior bore **25** discussed above, a third bore of a third internal or interior cross-sectional diameter or dimension, and a fourth bore **24** of a fourth internal or interior cross sectional dimension in fluid communication with each other. In the example of FIG. **2**, the fourth interior bore **24** is positioned between the second and the third interior bores.

In the example, of FIG. **2** a portion of the third interior bore is threaded.

The third bore is not separately labeled in FIG. **2** but will be understood to be the bore in valve core housing **1** in which the intermediate sealing element **5** (discussed below) is positioned. As reflected in the figures, the first, second, third and fourth bores are—in the absence of any elements positioned within the bores—in fluid communication with one another.

As reflected in the figures, both the third interior bore and the fourth interior bore have, respectively, third and fourth internal or interior cross sectional diameters.

As may be noted, in FIG. **2**, the first bore, second bore, third bore, and fourth bores all pass axially through the valve core housing **1**. As reflected in the figure, the interior cross-sectional diameter dimension of the fourth bore **24** is smaller than the interior cross-sectional diameter dimensions of both the first bore **30** and the second bore **25**, and the interior cross sectional dimension of the first bore **30** is greater than the interior cross-sectional dimension of the second bore **25**. In the example of FIG. **2**, the interior cross sectional diameter of the third bore is greater than the interior cross sectional diameter of the fourth bore **24**, but less than the interior cross-sectional diameter of the second bore **25**.

It will be appreciated that, in the example of FIG. **2** and other anticipated embodiments, the interior cross-sections of the bores corresponding to the first, second and third bores may not be exactly constant throughout the corresponding bore structures. For example, in FIG. **2** the interior cross section of the bore corresponding to the third bore varies slightly across its axial length. In such instances, the references herein to the interior cross sectional diameter should be understood to refer to the maximum interior cross sectional diameters of the corresponding bore sections.

In the illustrated example, a valve assembly **7** is positioned within the bore **24**. The valve assembly **7** may take the form of a Schrader type valve core and, more particular, a valve core of the type that includes nitrile sealing elements, such as a nitrile valve core available from Dill Air Control Products or a sealing element comprising any other suitable material such as VITON® synthetic rubber, FFKM, KALREZ® synthetic rubber, CHEMRAZ® elastomer, or any other suitable elastomeric or sealing material. In the example of FIG. **2**, the valve assembly **7** is positioned such that it is substantially completely within the fourth bore **24**. Alternate embodiments are envisioned, however, wherein portions of the valve assembly **7** extend into one or both of the second bore **25** or the third bore. For example, as shown in FIG. **3**, in one embodiment, the valve assembly **7** can comprise a main body and a stem wherein only the main body portion is positioned completely within the fourth bore.

In the example of FIG. **2**, the valve core housing **1** includes a first exterior surface or section **27** having a first external diameter, a second exterior surface or section **26** having a second external diameter, and a third exterior surface or section **28** having a third external diameter. In the example, of FIG. **2**, the second external diameter of the second exterior surface **26** is less than the first external diameter of the first exterior surface **27**.

In the example of FIG. **2**, at least portions of the outer surfaces of the second section **26** and the third section **28** are threaded, and the outer surface of the first exterior section **27** is substantially smooth. As depicted in FIG. **2**, the outer diameter of the first section **27** is greater than the outer diameters of the second and third sections **26** and **28**. In the example of FIG. **2**, the outer diameter of the second section **26** is less than the outer diameter of third section **28**. This is exemplary as the diameters of the second and third sections **26**, **28** may be the same, or substantially the same, or the outer diameter of the third section **28** may be greater than the outer diameter of the second section **26**.

In the example of FIG. **2**, the interior of the third bore defines a threaded surface that may extend across all or a position of the third bore. As shown in the figure, an intermediate sealing structure **5**—in the form of a partially threaded plug—is depicted as being positioned within the third interior bore. As reflected in the figure, the plug **5** includes a threaded exterior surface threadably coupled to a portion of an internally threaded section of the third bore within the valve core housing.

As further shown in FIGS. **1** and **2** in the illustrated example, the illustrated embodiment further includes a secondary sealing structure **2**, in the form of a cap element. In the illustrated example, the cap element **2** defines a solid distal end (on the left of FIG. **1**) and a proximal end. As shown, in the example, the cap **2** includes a recess defining a fifth interior bore having an interior surface that is at least partially threaded. In the example of FIG. **2**, the cap is threadedly coupled to the second exterior surface or section **26** of the valve core housing **1** such that the proximal end of the cap abuts a lip surface extending from the valve core housing **1**.

As will be appreciated from an inspection of FIG. **2**, when the secondary sealing structure **2** and the intermediate sealing structure **5** are removed, depending on the open/close state of the valve assembly **7**, a fluid path may be created thorough which a fluid (such as a charging gas) may pass through the valve assembly **7** into (or out of) the charging chamber **30** at least partially defined by the interior of the dome housing **8**. This fluid path is beneficial, at least in that it provide a fluid path through which a charging gas (e.g., nitrogen) may be passed through the valve assembly **7** into the charge chamber **30** to build up pressure within the cavity so as to adjust and control the force required to compress the bellow **15** and open the sealing mechanism formed by the valve stem **17** and the valve seat **19**. This fluid path is potentially detrimental, however, in that it provides a fluid path through which pressurized gas within the charge chamber **30** may leak from the interior of chamber **30** outside of the gas lift valve **100**, thus producing an undesired change in the pressure setting at which the gas lift valve **100** would open or close should one or more of the described intended sealing mechanisms be partially compromised or fail completely.

As will be appreciated, the arrangement and combination of elements and components disclosed herein and reflected in FIGS. **1** and **2** provide a novel structure that, among other things:

(a) provides protection for the components of the system: (I) before charging, (ii) after a rough charging but before fine adjustment; (iii) and after fine adjustment;
(b) provides for efficient and effective charging; and
(c) avoids and/or minimizes the prospect of undesirable leakage after the disclosed gas lift valve is charged to the desired level.

Additional details of an exemplary embodiment constructed in accordance with the teachings of this disclosure are reflected in FIG. **3**, which depicts certain of the elements in FIG. **2** in greater detail.

FIG. **3** illustrates one way the valve core housing **1** may be coupled to the dome housing **8**. In FIG. **3**, the valve core housing **1** is coupled to the dome housing **8** through a threaded connection and an annular seal is formed between the two elements. In the illustrated example the seal is formed through the use of a sandwich seal structure in which a resilient sealing element in the form of O-Ring **10** is sandwiched between two split rings **9**, and the sandwich structure is positioned within an annular groove **39** formed in an outer surface of the valve core housing **1**.

The O-Ring **10** and split rings **9** may be formed from the same material—or a different material—as the O-Ring **20** discussed above.

In the example of FIG. **3**, the outer surface of the second end of the valve core housing **1** is threaded across a first axial length **40** and is substantially smooth (except for the groove **39**) across a second axial length **42**. It will be appreciate that this is exemplary only and that the outer surface of such end may be threaded across substantially its entire axial length. In the embodiment of FIG. **3**, the interaction of the sandwich sealing assembly with the surfaces of the valve core housing **1** and the dome housing **8** form a gas-tight seal between the valve core housing **1** and the dome housing **8**.

As further shown in FIG. **3**, in the illustrated embodiment an end surface of the dome housing **8** mates with a surface of the valve core housing **1** to form a metal-to-metal seal across the annual region **32**. In the example of FIG. **3**, this seal at region **32** is formed by an abutment between relatively flat, generally perpendicular surfaces, of the valve core housing **1** and the dome housing **8**. In the example of FIG. **3**, It will be appreciated that this form of abutment is exemplary only and that one or both of the abutting surfaces could be angled to the same or to different degrees.

While not depicted in FIG. **3**, alternate embodiments are envisioned wherein one or more elements are used to enhance the seal formed at region **32** between the valve core housing **1** and the dome housing **8**. For example, embodiments are envisioned wherein a suitable engaging or gasket structure is positioned between the two housings at region. One structure that may be used is a washer of a malleable material, such as, for example, a copper crush washer **3**.

In the example of FIG. **3**, an exemplary intermediate sealing element **5** is positioned within the first bore of the valve core housing. In the illustrated embodiment, the intermediate sealing element is threadedly coupled to the valve core housing **1** through a threaded engagement. In FIG. **3**, the threaded engagement of the intermediate sealing element **5** and the valve core housing **1** is accomplished through the engagement of an externally threaded section **52** of element **5** with an internally threaded section of the valve core housing (not labeled in FIG. **3**).

In the example of FIG. **3**, the sealing or plug element **5** defines an unthreaded, substantially smooth outer section **54**. In the illustrated example, this unthreaded section defines an annular recess in which an O-ring **6** is positioned. As shown in the figure the unthreaded section **54** of the intermediate sealing element **5** is received within a smooth interior bore section of the valve core housing **1**. Other embodiments of sealing plug **5** are envisioned in which the O-Ring **6** could be situated somewhat lower or higher on smooth outer section **54**, or where additional O-Rings in addition to O-Ring **6** could be added to smooth outer section **54** to promote redundant seals.

In the exemplary embodiment multiple seals are formed between the intermediate sealing element **5** and the valve core housing **1** including a seal formed via and a resilient sealing element in the form of an O-ring **6** positioned within a groove formed in the smooth outer surface **54** of the intermediate sealing surface. The O-Ring **6** may be formed from the same material—or a different material—as the O-Ring **20** discussed above.

In FIG. **3**, an additional seal is formed through the positioning of a sealing element **3**, which may take the form of copper crush washer **3**, between an outer annular end surface of the intermediate sealing member **5** and an annular surface of the valve core housing **1**. Such a crush washer **3** will deform, and create sealing surfaces, as the intermediate sealing member **5** is screwed into the valve core housing **1** and torque is applied. As will be appreciated, the combination of the interior sealing element **5**, the O-Ring **6** and the sealing element **3** form multiple seals that will tend to prevent or inhibit the flow of gas from the charging chamber **30** out of the valve **100**, even if the seal(s) within the valve assembly **7** fail. As will be appreciated, the crush washer can be formed from materials other than copper.

As will also be appreciated, the combination of the intermediate sealing member **5**, and the sealing element **3** form a cavity between the valve assembly **7** and the intermediate sealing member **5** where the volume of the cavity is small relative to the overall volume of the charging chamber **30**. For example, in the embodiment of FIG. **3**, the total volume of the cavity between the valve assembly **7** and intermediate sealing member **5** is less than 1%, and in some embodiments, less than 0.25% of the total volume of the charging chamber **30**, such that any leakage through the valve assembly **7** into such cavity will result in a minimal change of the charge pressure within chamber **30** and any outward pressure source would not intrude on the intended pressure of the chamber **30** as well. In some embodiments, the volume of the cavity between the valve assembly **7** and intermediate sealing member **5** is less than or equal to 0.007% of the total volume of chamber **30**.

Still further, in the illustrated embodiment a further intermediate cavity is defined by a surface of the cap **2**, a surface of the valve core housing **1**, a surface of the plug **5**, and a surface of the resilient member **6**. Such intermediate cavity is of a relatively small volume and, in the example a volume less than 2% and, in some embodiments, less than 0.25 of the volume of the charging chamber. As will be appreciated, in such embodiments failure of the sealing elements within the valve assembly **7** and/or the seal created by resilient sealing member **6** will result in a non-significant drop of the overall charging pressure, such that such failures will not materially affect the proper operation of the gas lift valve.

As reflected in FIG. **3**, in the illustrated example, the dimensions of the plug **5** are such that no portion of the plug extends into the described intermediate volume.

In addition to reducing the potential for degraded or undesired performance of the disclosed gas lift valve, the disclosed structure will protect the internal valve components from undesired forces that could be created as the result of an undesired rapid change in the reservoir pressures external to the valve. For example, if a valve as described herein is subject to a "frac hit," the disclosed structures will tend to protect the components of the valve from damage.

In the embodiment of FIG. **3**, the intermediate sealing element **5** defines a first axially extending cavity **56** at one end (the leftmost end in FIG. **3**) and a second axially extending cavity **57** at the other end. Both cavities are optional.

In the embodiment of FIG. **3** the first cavity **56** is shaped so as to receive an end of a hex wrench to enable proper positioning of the element **5** within the valve housing **1**. It will be appreciated that other approaches could be used to facilitate such positioning including the formation of alternately shaped recesses within the cavity **56** (e.g., a recess designed to receive the end of a TORX® threaded fastening device wrench) or bolt-like extension from the end of the element **5**.

In the embodiment of FIG. **3** the second cavity **57** provides a clearance volume to ensure that no surface of the intermediate sealing element **5** contacts—and potentially damages or activates—the valve assembly **7**. Again, this recess is optional, and the end of the element **5** closest to the valve assembly **7** can be flat or flush.

In the arrangement of FIG. **3**, the secondary sealing element **2** is threadedly coupled to the first end of the valve core housing **1** via a threaded connection between an internally threaded portion **60** of the secondary sealing element **2** and an externally threaded portion of the valve core housing. In the illustrated embodiment of FIG. **3**, the interior portions of the secondary sealing element **2** other than portion **60** are substantially smooth and non-threaded, as are the exterior portions of the first end of the valve core housing **1** other than the threaded portion coupled to the threaded portion of the intermediate sealing member.

In the example of FIG. **3** there are at least three seals created between secondary sealing element **2** and the valve core housing **1** which useful in protecting against unintended or undesired pressure intrusion or extrusion through the valve assembly **7**.

A first seal is created by a metal-metal abutment of a surface on the secondary sealing element **2** and a surface of the valve core housing **1** at the region **32**. In the example of FIG. **3**, the surface of the valve core housing at which such metal-to-metal contact occurs is a lip surface formed at or by the transition between the first exterior surface **27** of the valve core housing and the second exterior surface **26**. In the specifically illustrated embodiment, the abutting surfaces are angled relative to the axial axis of the gas lift valve **100**, although this is exemplary only.

A second seal is created through the use of and a resilient sealing element in the form of an O-Ring **4** positioned about an exterior surface of the valve core housing **1** near the metal-metal abutment region **32**. The O-Ring **4** may before from the same—or a different—material as the O-Ring **20** and may be positioned within a grove formed in the outer surface of the valve core housing **1**, or—as depicted in FIG. **3**—within an area bounded by a raised bump (or lip) on the outer surface of the first section of housing **1** on one side and one of the surfaces forming the metal-metal seal at region **32** on the other.

In FIG. **3**, a third seal is created through the use of an and a resilient sealing element in the form of O-Ring **35** positioned within a grove formed in the outer surface of the valve core housing **1** at a point where an imaginary line passing from one point on the O-Ring **35** through the center of the O-Ring **35** to the opposite side of the O-Ring **35** will pass through the intermediate sealing member **5**. The O-Ring **35** may be formed from the same material—or a different material—as the O-Rings discussed above.

More specifically, in the example of FIG. **3**, each of the resilient sealing elements (or O-rings in the example) **4**, **6** and **35** is in the form of a structure that defines an open central area, with the open central are being the area surrounded by the element. In the illustrated example, at least a portion of the valve assembly **7** is within the open central area of the resilient sealing element **4**, and at least a portion of the plug **5** is within the open central area of the resilient sealing element **35**. As will be reflected, in the illustrated example, the resilient sealing element **6** is positioned along the longitudinal axis of the illustrated gas lift valve at a position between the resilient sealing elements **35** and **4**.

In the embodiment of FIG. **3** the secondary sealing element **2** is formed as a component separate from the intermediate sealing element **5**. Alternate embodiments are envisioned where both elements are formed, e.g., through 3-D printing, as a single integral element.

As will be appreciated when the intermediate sealing element **5** and the secondary sealing element **2** are not coupled to the valve core housing **1**, charging of the charging chamber **30** can be easily accomplished by coupling a suitable charging apparatus to the assembly and charging the charge chamber **30** through the valve assembly.

The coupling of the secondary sealing element **2** and/or the intermediate sealing element **5**, individually or simultaneously to the valve core housing **1** can enhance, among other things, the protection, charging, transport, and use of the illustrated exemplary gas lift valve **100**.

For example, prior to charging of the gas lift valve **100**, the secondary sealing element **2** can be loosely coupled to the valve core housing **1** to protect exposed threads of the valve core housing **1** from damage and to protect the valve assembly **7** from being contaminated by dust or other potentially fouling materials. The loose coupling can thus provide protection as described above, yet permit easy removal for charging of the valve **100**. In such a configuration, no intermediate protection element **5** needs to be coupled to the valve core housing **1**.

In terms of pre-charge protection it will be appreciated that the same secondary sealing element **2** to be used when the gas lift valve is placed in operation (e.g., an element **2** formed of metal) need not be used for pre-charge protection. For such pre-charge protection, an alternately constructed element, such as one formed from plastic, could be used. In such implementations, the color of the protective element **2** could be used to indicate, for example, that the valve has not yet been charged and/or the pressure level to which the valve is desired to be charge.

In alternate embodiments, the valve **100**—or a number of similar valves **100**—can be initially roughly charged to a rough set pressure and then the secondary sealing **2** member (but not the intermediate sealing element **5**) can be coupled to the valve core housing **1** during a period before such rough charged valves are finally charged through fine adjustment of the pressure within the charging chamber **30**. Such use of the secondary sealing member **2** can provide a level of protection against leakage of charge gas from the valve (and protection of the threads and the valve assembly **7** against fouling) but also provides a structure that can readily be removed for fine tuning of the charge.

Still further, the disclosed valve **100** can be used in a configuration where it is charged to a desired level, the intermediate sealing element **5** is coupled to the valve core housing **1**, and the secondary sealing element **2** is also coupled to the valve core housing **1**. In such configurations substantial, multiple, and redundant layers of protection and protection against gas and/or fluid leakage or intrusion are provided to protect and ensure proper usage of the gas valve **100** over an extended period and in various applications and usages. Such multiple, redundant layers of production can both avoid or minimize the changes of an undesirable leak of gas from the charging chamber **30** and/or intrusion of gas and/or fluids from outside sources (e.g., wellbore gases and fluids) into the charging chamber and reduce the risk of any unwanted or malicious discharge of charge gas (since a significant number of components will need to be removed to access the valve assembly **7**).

In instances, where unwanted or malicious adjustment of the pressure setting within the charging chamber is desired to be avoided, the exposed end of the intermediate sealing member **5** could be formed in a unique shape, such that only a correspondingly shaped tool can made with the exposed shape and permit removal of the intermediate sealing element **5** form the valve core assembly **1**. In such an embodiment, the "key" required to remove the intermediate sealing member **5** (which would be required to adjust the pressure within the charge chamber **30**) can be made available only to those individuals authorized to adjust the charge setting of the valve **100**.

Other and further embodiments utilizing one or more aspects of the inventions described above can be devised without departing from the spirit of Applicant's invention. Further, the various methods and embodiments of the methods of manufacture and assembly of the system, as well as location specifications, can be included in combination with each other to produce variations of the disclosed methods and embodiments. Discussion of singular elements can include plural elements and vice-versa. Similarly, elements have been described functionally and can be embodied as separate components or can be combined into components having multiple functions.

The inventions have been described in the context of preferred and other embodiments and not every embodiment of the invention has been described. Obvious modifications and alterations to the described embodiments are available to those of ordinary skill in the art. The disclosed and undisclosed embodiments are not intended to limit or restrict the scope or applicability of the invention conceived of by the Applicants, but rather, in conformity with the patent laws, Applicants intend to protect fully all such modifications and improvements that come within the scope or range of equivalent of the following claims.

What is claimed is:

1. A gas lift valve comprising:

a valve seat housing;

a bellow housing;

a dome housing, the dome housing defining a first interior bore, the first interior bore having a first interior cross sectional diameter and partially defining an interior charging chamber existing at least partially within the dome housing; and

a valve core housing, the valve core housing defining:

a second interior bore partially defining the interior charging chamber, the second interior bore having a second interior cross-sectional diameter:

a third interior bore having a third interior cross-sectional diameter, wherein the third interior cross-sectional diameter is less than the second interior cross-sectional diameter, and wherein the third interior bore has an internally threaded section, and

a fourth interior bore, wherein the fourth interior bore is positioned in fluid communication with, and between, the second and the third interior bores;

a first exterior surface having a first external diameter,

a second exterior surface having a second external diameter, wherein the second external diameter is less than the first external diameter, and wherein at least a portion of the second exterior surface is threaded; and

a lip surface formed by the transition between the first exterior surface and the second exterior surface;

a valve assembly positioned at least partially within the fourth interior bore;

a plug positioned within the third interior bore, the plug including a threaded exterior surface threadably coupled to at least a portion of the internally threaded section of the third interior bore;

a cap element, the cap element defining a proximal end and a distal end, the cap element further defining a fifth interior bore, wherein at least a portion of the interior surface of the fifth interior bore is threaded and wherein the cap element is threadably coupled to the second exterior surface of the valve core housing such that the proximal end of the cap element abuts the lip surface of the valve core housing; and

a first resilient sealing element positioned between at least a portion of the interior surface of the fifth interior bore and the second exterior surface, the first resilient sealing element defining a first open central area;

a second resilient sealing element positioned between an outer surface of the plug and at least a portion of the interior surface of the third interior bore, the second resilient sealing element defining a second open central area;

a third resilient sealing element positioned between an inner surface of the fifth interior bore and the second exterior surface of the valve core housing, the third resilient sealing element defining a third open central area, and

wherein:

at least a portion of the valve assembly is within the third open central area;

at least a position of the threaded plug is within the first open central area; and

the second resilient sealing element is positioned along the longitudinal axis of the gas lift valve at a position between the first resilient sealing element and the third resilient element.

2. The gas lift valve of claim **1**, further comprising a check valve coupled to the valve seat housing.

3. The gas lift valve of claim **1**, wherein the bellow housing and the dome housing are formed as an integral component.

4. The gas lift valve of claim **1**, wherein the valve assembly is a Schrader valve core.

5. The gas lift valve of claim **1**, wherein the valve assembly comprises a main body and a stem, and wherein the main body of the valve assembly is positioned completely within the fourth interior bore.

6. The gas lift valve of claim **1**, wherein the first, second and third resilient sealing elements are O-Rings.

7. The gas lift valve of claim **1**, wherein the third interior bore defines an unthreaded section, wherein the plug includes an outer unthreaded section that defines an annular recess, and wherein the second resilient member is positioned within the plug annular recess.

8. A gas lift valve comprising:

a body, the body defining an interior charging chamber;

a valve core housing, the valve core housing having a distal end and defining:

a valve receiving bore in fluid communication with the interior charging chamber, the valve receiving bore being configured to receive a valve assembly; and

a plug receiving bore in fluid communication with the valve receiving bore, the plug receiving bore having a maximum interior diameter and being configured to receive a plug;

an outer exterior annular surface, the outer exterior annular surface including a threaded exterior section having a first outer diameter and a non-threaded exterior section having a second outer diameter, where the first outer diameter is less than the second outer diameter; and

a plug, the plug having a maximum outer diameter that is less than the maximum interior diameter of the plug receiving bore, the plug being positioned within the plug receiving bore; and

a cap defining a distal section and a proximal bore, the proximal bore defining a first bore section having a first internal diameter and a second bore section having a second internal diameter, wherein the second internal diameter is greater than the first internal diameter, wherein the cap is threadedly connected to the valve core housing such that at least a portion of the threaded external section of the valve core housing is within the second bore section of the cap and at least a portion of the non-threaded external section of the valve core housing is within the first bore section of the cap; and

a valve assembly positioned within the valve receiving bore; and

an O-ring positioned between a portion of the non-threaded exterior section of the valve core housing and interior portion of the distal interior bore within the cap.

9. The gas lift valve of claim **8** wherein an exterior surface of the valve core housing defines an annular recess, and wherein the O-ring is positioned within the annular recess.

10. The gas lift valve of claim **8** further comprising a crush washer positioned between the plug and a surface of the valve core housing.

11. The gas lift valve of claim **8**, wherein no portion of the plug extends outside the plug receiving bore.

12. The gas lift valve of claim **8**, wherein the valve core housing further comprises an annular lip, and wherein the cap defines a proximal end surface that abuts the annular lip.

13. The gas lift valve of claim **8** wherein the plug includes a distal end, and wherein the distal end defines a cavity sized to receive a tool for positioning the plug within the plug receiving cavity.

14. A gas lift valve comprising:

a body defining an interior charging chamber, the interior charging chamber defining a volume;

a housing defining a bore in fluid communication with the charging chamber, the bore having a maximum internal diameter;

a plug positioned within the bore, the plug having a maximum outer diameter that is less than the maximum internal diameter of the bore in the housing;

a first resilient element forming a seal between an external surface of the plug and an interior surface of the bore;

a crush washer positioned between the plug and a surface of the housing; and

a cap defining an interior bore, the cap being positioned with respect to the housing such that the plug is positioned within the cap interior bore; and

a second resilient element forming a seal between a first external surface of the housing and a first interior surface of the cap; and

a valve assembly positioned within the bore,

wherein the valve assembly includes a stem,

wherein the crush washer defines a disc-shaped cavity, and

wherein at least a portion of the stem is within the disc-shaped cavity.

15. The gas lift valve of claim **14** further comprising a third resilient element forming a seal between a second external surface of the housing and a second interior surface of the cap.

16. The gas lift valve of claim **14** wherein the crush washer comprises copper.

17. The gas lift valve of claim **14** further comprising an intermediate cavity partially defined by a surface of the cap, a surface of the housing, a surface of the plug, and a surface of the second resilient member, wherein no portion of the plug extends into the intermediate volume.

18. The gas lift valve of claim **14** wherein the positioning of the plug and the crush washer form a cavity between the valve assembly and the plug.

19. The gas lift valve of claim **18** wherein the volume of the cavity is less than 0.007% of the total volume of the charging chamber.

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