ROBUST GAS LIFT VALVE WITH MULTIPLE SEALS SUITABLE FOR HARSH ENVIRONMENTS

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ABSTRACT

The Eagle Ford, Bakken and other operating areas often prove to be challenging areas for the successful, long-term operation of gas lift valves due to numerous factors which may compromise the efficiency of the installation and reduce production and life expectancy of the valve.

These factors may include well bore heat, well bore fluids and gases, well bore contaminants and debris, offset fracturing activity, natural formation pressure and introduced, non-naturally occurring pressure. Wellbore heat and wellbore fluids act to degrade sealing components by causing expansion and contraction or other deformities of the elastomer, while wellbore gases can also cause degradation of sealing components by permeating into the sealing elastomers. Wellbore contaminants and debris may find their way into the dome bore thus contaminating the valve core causing sticking and/or find their way into the charged chamber. Offset fracturing activity can damage the elastomer or can increase the set pressure in the bellows reducing integrity of the valve.

The robust gas lift valve, suitable for harsh environments, provides a series of multi-layer protection from the negative effects associated with these factors, thus serving to increase the operational success and runtime longevity of the gas lift valve(s) utilized in the system.

This paper discusses current issues seen with traditional, injection pressure operated gas lift valves. Additionally, this paper explains both the similarities and differences between common gas lift valves and the robust Warden valve highlighting the benefits of the Warden gas lift valve. Results showing improvements in gas lift system operation, a decrease in operator interventions and increased longevity of equipment in these challenging environments are presented.

INTRODUCTION

For decades, operators have utilized conventional injection pressure operated (IPO) valves in gas lift installations in all operating basins. Often, these valves operate effectively and for prolonged periods of time without the need for replacement or other intervention. The primary goal of a gas lift system is to lift as deep as possible through a single point of injection with as little injection gas as possible. If one or more valves are compromised or fail completely due to unintended bellows pressure loss or pressure gain, the gas lift system can be more complicated, partially compromised, or rendered entirely useless—all of which may involve increased downtime, operator intervention, reduced production, and increased costs for the operator.

The Eagle Ford, Bakken and other operating areas often prove to be challenging areas for the successful, long-term operation of gas lift valves due to numerous factors which may compromise the efficiency of the installation and reduce production and life expectancy of the valve.

These factors may include well bore heat, well bore fluids and gases, well bore contaminants and debris, offset fracturing activity, natural formation pressure and introduced, non-naturally occurring pressure. Wellbore heat, fluids and gases may all act to degrade sealing components by causing expansion and contraction or other deformities of the elastomers. Wellbore contaminants and debris may find their way into the dome bore, thus contaminating the valve core and causing sticking. These contaminates may also find their way into the charged chamber and mix with the dampening fluid, causing further physical changes and variations in a once controlled environment. Offset fracturing activity can damage the elastomers or can increase the set pressure in the bellows, thus reducing integrity of the valve.

COMPONENTS OF A TRADIONAL INJECTION PRESSURE OPERATED GAS LIFT VALVE

A traditional injection pressure operated (IPO) gas lift valve is comprised of several components which aid in its successful operation and intended set pressure containment. Figure 1 below, from [1] serves to depict these associated structures. At the top of the valve and depicted at the dark blue arrow point is the valve's tail plug with elastomeric O-Ring. This plug serves as the primary method of barrier against unintended pressure introduction from the well bore and the last line of defense against nitrogen pressure loss from the valve's charged bellows chamber.

Depicted at the red arrow point is the copper or brass crush gasket or washer. This component serves as a secondary backup seal intended to prevent pressure introduction from the well bore or pressure loss from the nitrogen charged bellows chamber. It is crushed by torquing the threaded tail plug into the valve's dome bore since it is sandwiched between the bottom ledge of the tail plug and an inner, internal ledge of the valve's dome housing.

Situated below the tail plug and crush gasket is the valve core, depicted at the green arrow point. This assembly contains two sealing elastomers—one on the outermost body and another in a dish-like structure at the distal end of a spring-loaded stem that runs through its center. The sealing elastomer on the outer body of the valve core creates a seal within the valve’s dome bore or top internal housing as it is screwed into its bore and is intended to prevent pressure from escaping the valve’s bellows charge chamber.

The elastomer contained on the distal end of the valve core’s spring-loaded stem creates a seal as bellows charge pressure acts against the stem, forcing the stem and its dish-like structure to seat against the main body of the valve core. This sealing elastomer is also intended to protect against the loss of pressure from the valve’s bellows charge chamber. It is important to consider that the introduction of outside differential pressure is not prevented by the valve core alone. Should differential pressure greater than that contained within the valve’s charged bellows chamber find its way to the valve core, the pressure can be introduced to the charge chamber through the valve core, as it functions solely as a one-way check valve.

Directly below the valve core and depicted at the yellow arrow point is the valve’s bellows charge chamber. This chamber contains the set value of nitrogen pressure desired in the valve per the associated gas lift design at sixty degrees Fahrenheit per API protocol. This set nitrogen pressure can be manipulated by lightly tapping the valve core’s spring-loaded stem to release pressure incrementally. The set nitrogen value can also be increased as needed through use of a threaded charging apparatus affixed to the dome bore housing. Differential nitrogen pressure may be introduced through the valve core and subsequently into the bellows charge chamber.

Below the bellows charge chamber and affixed to it, is the triple ply Monel bellows assembly, depicted at the purple arrow point. This assembly resembles an accordion in function and expands and contracts in relation to the presence or absence of opposing differential forces greater than the nitrogen pressure contained withing the bellows charge chamber—these forces being casing and tubing pressure.

Affixed to the bellows assembly is the valve’s stem and tungsten carbide ball, shown at the orange arrow point. As the bellows assembly expands or contracts due to opposing forces or lack thereof, the stem and seat either mate with or rise off the structure found below it—the valve’s seat, shown at the light blue arrow point. The seat is composed of Monel or tungsten carbide and has a bore hole running through its center which is size matched to the tungsten carbide ball affixed to the distal end of the stem. The relationship of the valve’s stem to the seat dictates whether the valve is in an open or closed state. If the ball of the stem is off seat, there is no seal created, and injection gas may pass through the seat and be introduced to aerate the fluid column it communicates with. If the ball is on seat, a seal is created, and no injection gas may pass through the seat.

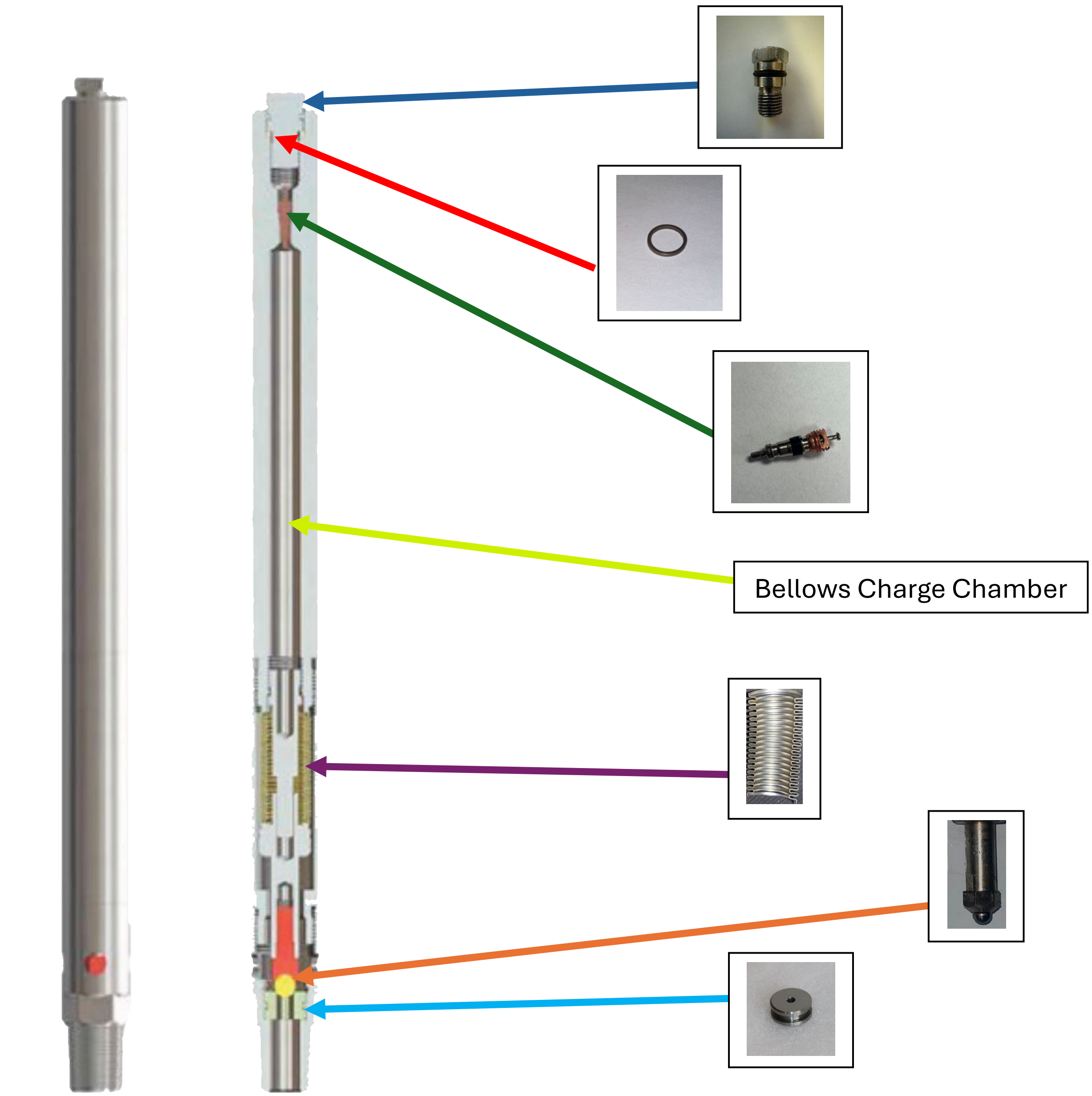

Figure 1 – Component Arrangement of a Traditional Injection Pressure Operated (IPO) Gas Lift Valve

SAFEGUARDS AGAINST BELLOWS PRESSURE LOSS OR GAIN FOR A STANDARD INJECTION PRESSURE OPERATED (IPO) GAS LIFT VALVE

A standard injection pressure valve typically relies on four methods of protection from loss of intended and contained bellows pressure or unintended gain of outside differential pressure—three elastomeric seals and one metallic gasket or washer. One elastomeric seal, depicted in Figure 2 below at the red arrow point, is contained inside the dish-like structure at the distal end of the valve core. This elastomeric seal is affixed to the spring-loaded stem of the valve core and is meant to provide seal when the internal bellows charge pressure charge acts against it, thus placing it in a sealing position against its blunt end stop, which is the main outer metallic body of the valve core. This seal is meant to prevent the escape of bellows charge pressure.

The second elastomeric seal is also found on the valve core and is depicted at the green arrow point. This sealing elastomer achieves its seal by mating with a conical internal bore machined into the valve's dome housing. Above this conical bore is a threaded portion which receives the valve core's upper threaded exterior, allowing for specified torque which aides in the mating of the sealing elastomer into the conical bore—thus providing seal. As explained earlier, it is important to consider that both sealing elastomers on the valve core only protect against pressure loss from the valve's charged bellows chamber and do nothing to protect against outside differential pressure should it find its way past the other two subsequent safeguards.

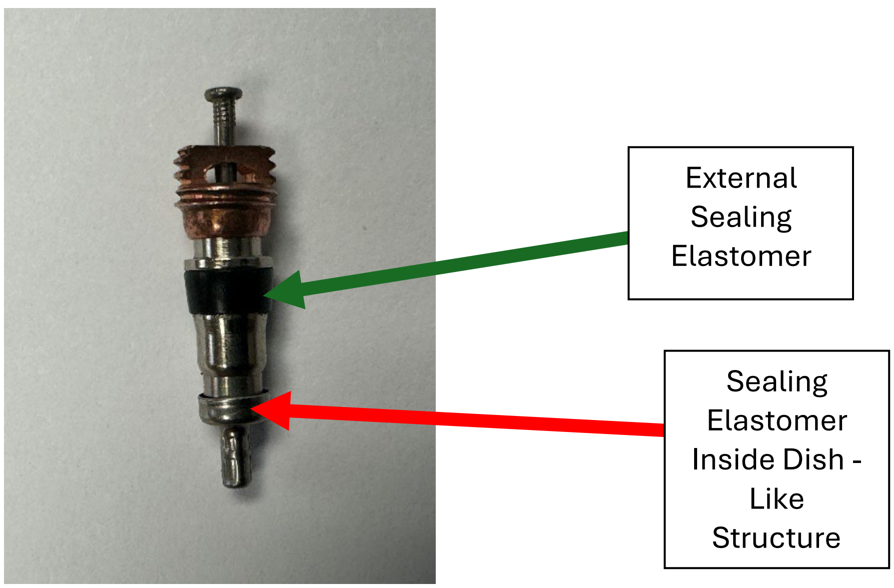

Figure 2 – Sealing Component Arrangement of Valve Core Found in Traditional IPO Valve

The next method of intended pressure protection is created by the valve's copper or brass crush gasket or washer and its engagement with the valve's dome bore, depicted below in Figure 3. This crush gasket or washer is meant to provide a method of backup seal against both pressure loss from the valve's charged bellows chamber should the valve core become compromised as well as a method of protection from outside differential pressure from the well bore. This component is crushed by the mechanical torque applied to the tail plug as it is screwed into the valve's internally threaded dome bore. Since it is sandwiched between the bottom face of the tail plug and valve's dome bore ledge, applied force associated with the torquing of the tail plug's external threads and the dome bore's internal threads cause the crush gasket or washer to be smashed or crushed, thus creating an intended seal.

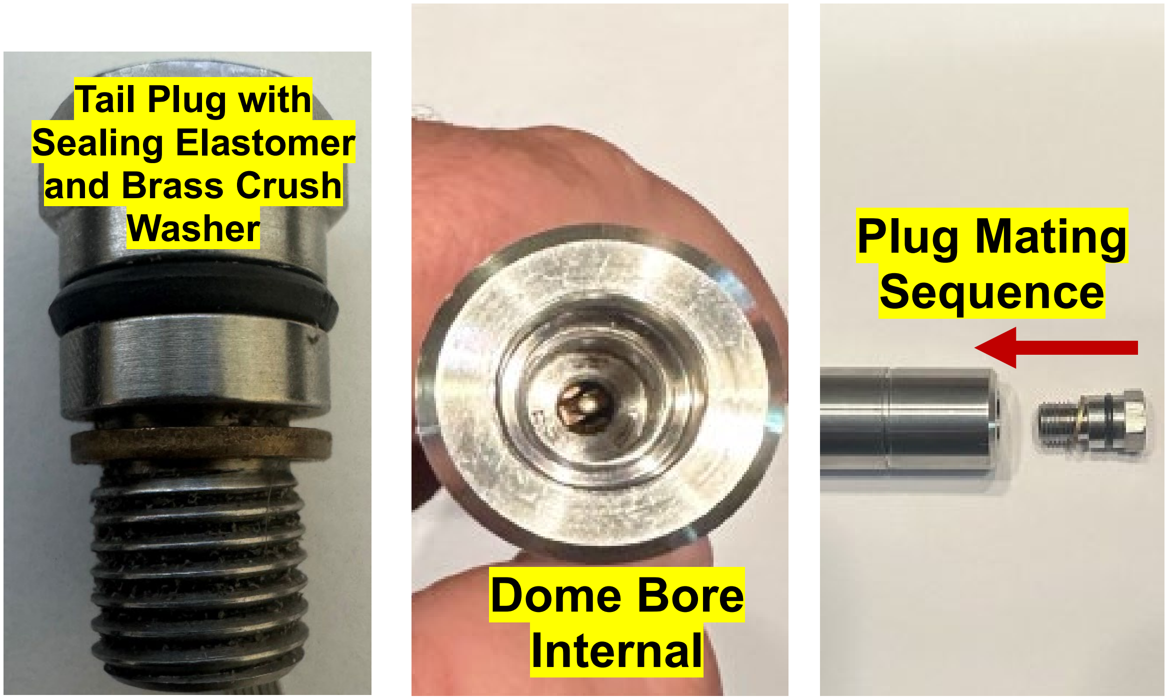

Figure 3 – Brass Crush Washer Arrangement on Tail Plug and Mating Sequence into Dome Bore

The final pressure barrier, which protects against both charged bellows pressure loss and outside differential pressure intrusion is the elastomer on the valve's tail plug—depicted in figure four below and shown at the light blue arrow point. This sealing elastomer mates with the upper polished bore of the valve's dome housing internal to provide its seal.

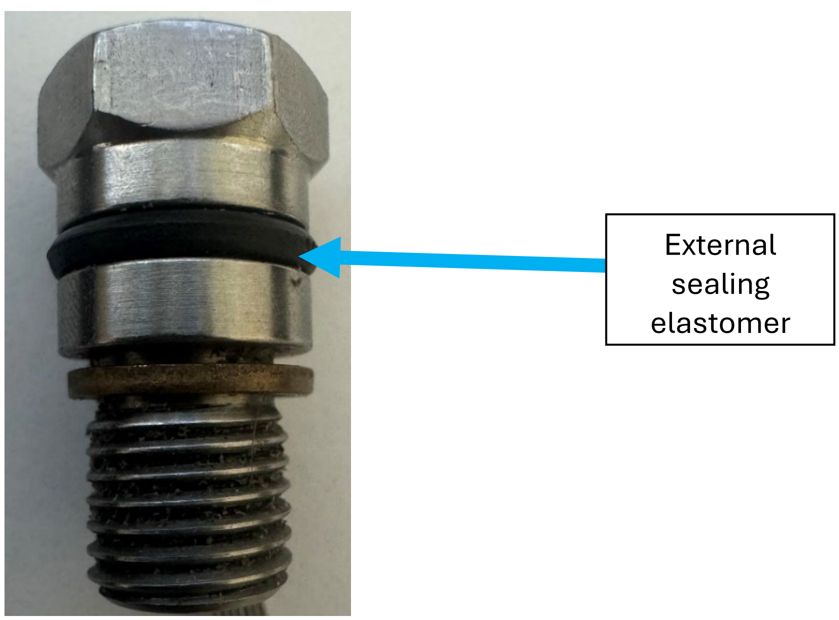

Figure 4 – External Sealing Elastomer Contained on Tail Plug

INTENDED FUNCTION OF A TRADITIONAL IPO GAS LIFT VALVE

A traditional injection pressure operated (IPO) valve is designed to introduce high pressure injection gas from the annular side of the wellbore into the tubing string in conventional flow scenarios, or from the tubing string into the annulus in annular flow applications. This introduction of injection gas serves to aerate the produced fluid and reduce its flowing density to surface. As this occurs, the flowing bottom hole pressure of the well is reduced, thus allowing greater feed in from the reservoir.

This process creates what we refer to as drawdown, which aids in flow of produced formation fluids. The gas lift valve functions as a back pressure regulator. The set charge pressure of the gas lift valve(s) in a designed system are manipulated manually and correspond to designated pressures calculated through a gas lift design process. The bellows charge pressures are arranged in a decreasing arrangement from the uppermost valve placed in the well bore to the bottommost valve in the well bore. The gas lift system is designed so that as well bore pressures decrease and draw down occurs, gas lift valves will close as the associated design closing pressures are reached.

Figure 5 below provides an example of this pressure decrease for a traditional tubing flow gas lift design. The surface closing pressures (PSCs) of the gas lift valves outlined in red are arranged in decreasing value from the uppermost valve in the string to the lowest valve in the string. The PSC value is the pressure read on surface measuring equipment (i.e.: a gauge).

#	Valve Desc.	Depth TVD ft	Depth MD ft	TV F	TCF	Port Size 64th	R	PT psi	DPC psi	PSC psi	PVC psi	OP psi	PSO psi	PD @60 psi	PTRO psi
10	L-CIPO-2	2000	2029	126	0.8721	12	0.038	297	52	924	976	1003	951	851	885
9	L-CIPO-2	3650	3704	157	0.8227	12	0.038	315	96	898	994	1021	925	818	850
8	L-CIPO-2	5300	5380	187	0.7799	12	0.038	414	139	872	1011	1035	896	789	820
7	L-CIPO-2	6750	6853	213	0.7463	12	0.038	488	177	848	1025	1046	869	765	795
6	L-CIPO-2	8050	8173	237	0.7177	12	0.038	578	211	821	1032	1050	839	741	770
5	L-CIPO-2	9150	9290	257	0.6956	12	0.038	643	239	798	1037	1053	814	722	750
4	L-CIPO-2	10100	10255	274	0.6778	12	0.038	704	264	772	1036	1049	785	702	730
3	L-CIPO-2	10900	11067	288	0.6638	12	0.038	761	285	751	1036	1047	762	688	715
2	L-CIPO-2	11550	11727	299	0.6532	12	0.038	773	302	722	1024	1034	732	669	695
1	L-CIPO-2	12150	12336	307	0.6457	12	0.038	764	318	695	1013	1023	705	654	680

TV: Temperature of Valve
TCF: Temperature Correction Factor
R: Ap/Ab
DPC: Gas Weight = Casing Pres at Depth - CP at Surface
PT: Tubing Pressure
PSC: Closing Pressure at Surface
PVC: Closing Pressure at Depth
OP: Opening Pressure at Depth
PSO: Surface Opening Pressure
PD at 60F: Bellows Press at Base Temperature = TCF x PVC
PTRO: Test Rack Opening Pressure

Figure 5 – Example of Decreasing Valve Pressure Values Corresponding to Well Drawdown

These values would correspond to the relative casing pressure of the well bore. As the system operates and injection gas is introduced, the static bottom hole pressure at the reservoir is reduced, and drawn down occurs. As casing pressure decreases below the PSC of valve ten, in this scenario 924 PSI, the top valve would close, and the point of gas injection would then transfer to valve nine. This process would continue, dictated by pressure reduction and well drawdown, until the casing pressure becomes low enough to reach the bottommost available point of injection—in this case being the end of tubing.

WHAT HAPPENS IF THE INTENDED OPERATION OF AN IPO VALVE IS COMPROMISED?

Any drastic interruption to the intended pressures contained in one or more valve's bellows charge value can impact the intended operation and integrity of the designed gas lift system. An example of such interruption is depicted in Figure 6 below. As we see in Figure 6, unintended variation from set and intended parameters can have detrimental effects on the success of a gas lift system.

Figure 6 shows a hypothetical scenario for a gas lift system containing seven IPO valves for traditional tubing flow. The top pressure value presentation set in Figure 6 depicts a seven-valve gas lift system in which valve number six has a corresponding pressure test rack opening pressure (PTRO) of 985 PSI. This is the pressure at which the valve was set at sixty degrees Fahrenheit per API protocol in a controlled shop environment. This pressure test rack opening (PTRO) pressure of 985 PSI would correspond to a closing pressure at surface (PSC) value of 985 PSI, meaning this valve would close once casing pressure reaches a value of 985 PSI read at a surface gauge. This valves surface opening pressure (PSO) would correspond to a value of 1016 PSI, meaning the valve would not reopen once closed until casing pressure reached a value of 1016 PSI on a surface gauge.

All valves below valve six are arranged so that their corresponding closing pressures at surface decrease in value from top to bottom, which corresponds to the draw down sequence of the well bore. Moreover, the surface opening pressures (PSOs) are arranged in decreasing value as well. Once the intended closing pressure at surface (PSC) is reached for each valve and it closes, it would not gain reopen unless casing pressure reached the corresponding surface opening pressure value. This system would function as intended assuming no additional issues or constraints.

#	Valve Desc.	Depth TVD ft	Depth MD ft	TV F	TCF	Port Size 64th	R	PT psi	DPC psi	PSC psi	PVC psi	OP psi	PSO psi	PD @60 psi	PTRO psi
7	L-CIPO-2	2200	2203	113	0.8969	12	0.038	270	76	1013	1089	1121	1045	976	1015
6	L-CIPO-2	4200	4204	149	0.8383	12	0.038	356	145	985	1130	1161	1016	948	985
5	L-CIPO-2	6100	6105	183	0.7899	12	0.038	522	211	958	1169	1195	984	924	960
4	L-CIPO-2	7700	7705	212	0.7531	12	0.038	594	267	927	1194	1218	951	899	935
3	L-CIPO-2	9200	9205	238	0.7232	12	0.038	692	319	898	1217	1238	919	880	915
2	L-CIPO-2	10530	10535	262	0.6980	12	0.038	572	365	869	1234	1260	895	861	895
1	Orifice	12200	12211	292	0.6693	12	OV								

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5	L-CIPO-2	6100	6105	183	0.7899	12	0.038	522	211	958	1169	1195	984	924	960
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Figure 6 – Example of Compromised Valve PSC Affecting Successful System Operation

Examining the bottom pressure value set in Figure 6, we are exposed to a hypothetical scenario in which this intended test rack opening pressure (PTRO) for valve six is compromised due to a tail plug elastomeric failure. Depicted here is the same seven-valve gas lift system, but the test rack opening pressure (PTRO) of valve six in the system, originally intended as 985 PSI, has been reduced to 925 PSI. Thus, the closing pressure at surface (PSC) value for this valve becomes 916 PSI, and system operating pressure also becomes 916 PSI. This is detrimental to the successful operation of the system. Injection gas circulates at valve six in an infinite loop, and the system is compromised and stuck at this valve station for point of injection since a subsequent transfer cannot be achieved. Since the regulated system pressure is now 916 PSI, valves five and four are in a closed state, and intended transfer to lower subsequent valves cannot be achieved.

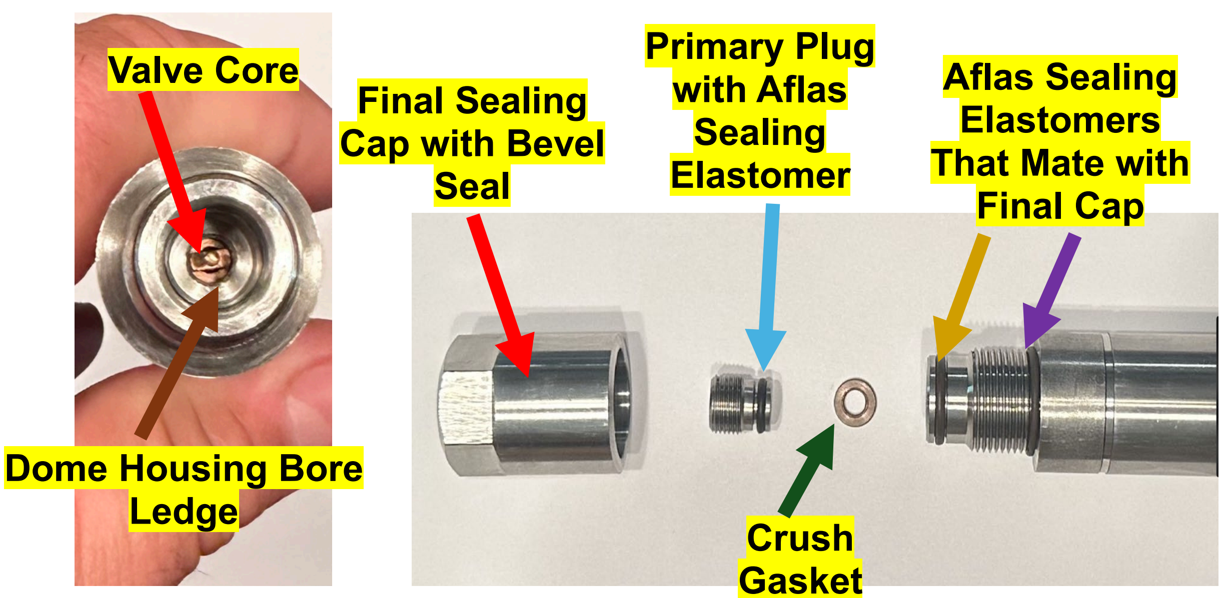
WHAT HAS BEEN DONE TO MITIGATE THE RISKS OF BELLOWS PRESSURE FLUCTUATIONS?

The standard injection pressure operated (IPO) valve has long stood as the go to valve for gas lift completions in the continental United States and abroad. Although associated risks always exist, they do not present themselves in all applications—especially in areas where contributing factors are less or not prevalent at all. As the oil and gas industry continues to make great strides in engineering controls, it becomes more in tune with digging deeper into root cause analysis of valve failures—particularly in areas where gas lift is the preferred method of artificial lift.

Through these stringent analysis, operators and vendors have placed greater focus on working in partnerships to develop solutions to issues being seen. Gas lift vendors in more complicated areas must adapt their equipment to meet operating areas demands and greatly reduce or eliminate valve failures. Some research has led vendors to adapt certain aspects of gas lift valves with the intention of increasing valve integrity and longevity. Some of these adaptions include elastomer selection, specified torque specifications for tail plug crush gaskets, adaptations to crush gasket properties, alterations to O-Ring sizing, thread relationships, and even multiple seal redundancies. As working relationships between vendors and operators continue to strengthen and more emphasis is placed on closing the gap on overall failure rates, effective solutions should become more prevalent.

WHAT SETS THE REDSIGNED GAS LIFT VALVE WITH MULTIPLE SEALS SUITABLE FOR HARSH ENVIRONMENTS APART?

The improved gas lift valve with multiple seals suitable for harsh environments is unique in that it incorporates a system of multiple sealing redundancies designed to mitigate the risk of both bellows pressure loss and gain. As depicted in Figure 7 below, this improved valve integrates five elastomeric seals, one metallic gasket or washer, and one final metal to metal seal incorporated into a final encapsulation.



(a) (b)

Figure 7 – Sealing Components of Valve with Multiple Seals Suitable for Harsh Environments

Since the traditional IPO valve and the redesigned valve with multiple seals utilize the same valve core, the first two methods of elastomeric seal mirror those of the traditional IPO valve previously detailed in Figure 2. The valve core is depicted in Figure 7 (a) at the red arrow point and is the first line of defense against charged bellows chamber pressure loss.

The third elastomeric seal is depicted in Figure 7 (b) at the blue arrow point. This seal is an O-Ring placed into a machined groove at the base of the primary plug, which is affixed above the valve core and crush gasket in the dome housing bore. This seal is fourth line of defense against outside differential pressure intrusion and third line of defense against charged bellows chamber pressure loss.

The fourth elastomeric seal, which is depicted in Figure 7 (b) at the gold arrow point is an O-Ring positioned into a machined grove at the distal end of the dome housing adapter and seals against the upper interior bore of the final encapsulation. This elastomer serves as the third line of defense against outside differential pressure intrusion and fourth line of defense against charged bellows chamber pressure loss.

The fifth elastomeric seal, which is depicted in Figure 7 (b) at the purple arrow point, serves as a crush style O-Ring and seals inside the distal end bore ledge of the final encapsulation. This elastomer serves as the second line of defense against outside differential pressure intrusion and the fifth defense against charged bellows chamber pressure loss.

The metallic gasket or washer, depicted in Figure 7 (b) at the dark green arrow point is situated between the primary plug which houses the third elastomeric seal and the bore ledge above the valve core, as depicted in Figure 7 (a) and shown at the brown arrow point. This component serves as the fifth line of defense against outside differential pressure intrusion and second line of defense against charged bellows chamber pressure loss. As a specific torque value is applied to the primary plug and its external male threads engage with the internal threads of the dome housing bore, the metallic gasket or washer is crushed between the blunt end of the tail plug and the machined internal ledge inside the dome housing bore. The intended purpose of this crush or physical change is to provide another seal.

After the primary plug has been installed and torqued, the final encapsulation with interior female thread and interior sealing surfaces, depicted in Figure 7 (b) and shown at the red arrow point, is threadedly coupled to the valve dome housing with exterior male threads. This structure, with its machined characteristics, serves as the primary line of defense against outside differential pressure intrusion and the final defense barrier against charged bellows chamber pressure loss. This encapsulation is machined with a convex bevel slant at the distal end. In opposing fashion, the ledge of the dome bore housing is machined with a concave bevel slant. The result at final applied makeup torque is a metal-to-metal mesh, which serves to provide yet another backup redundancy seal. As seen and explained, the improved valve provides many more backup redundancies which act as safeguards against both charged bellows chamber pressure loss and intrusion of outside differential pressure gain, thus increasing the likelihood of valve integrity and alignment with intended operation when placed into the well bore for gas lift system operation.

CONTROLLED ENVIRONMENT TESTING

The more resilient valve described herein was tested by a contracted third party in March 2023. The test was coordinated to include three (3) test valves of each size (1.0” and 1.5”) improved gas valves with multiple seals, along with one (1) test valve of each size (1.0” and 1.5”) in standard IPO valve configuration with a standard tail-plug design. Eight valves were tested in total. Each valve was carefully assembled before the testing started and set with an internal test rack opening (TRO) charge at 60 degrees Fahrenheit around +/- 1200 psig. The initial test pressures for each valve (before testing) were recorded after multiple aging steps. Once they were set, the valves were brought over to the testing facility where they were carefully loaded into two separate pressure chambers (four valves per chamber). Figure 9 below depicts the valves loaded into their respective test chambers.

Figure 9 – Valves for Test Loaded into Their Respective Chambers

Once these test chambers were loaded and secured for testing, they were pressured up to 5000 psig, before being heated to 325 degrees Fahrenheit, which is beyond the typical bottom hole temperature in well bore applications. The two chambers were kept at these conditions for ten hours. Figure 10 below depicts the test chart from the pressure and temperature hold for the longevity of the testing operation.

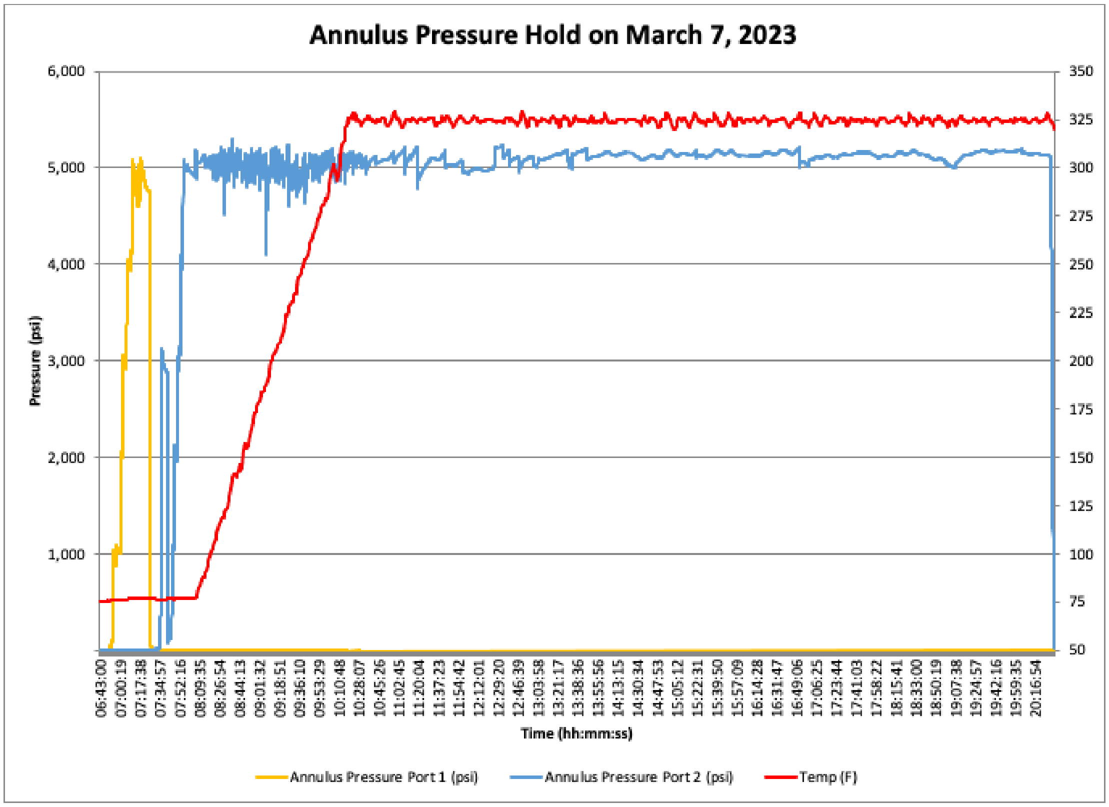


Figure 10 – Pressure and Temperature Chart from Testing Operation

After ten hours at test conditions, the pressure and heat were slowly reduced. The valves were allowed to sit at ambient conditions overnight before they were carefully removed from each test chamber the next day and returned for comparative test rack opening pressure testing. Figure 11 below shows the valves after removal from their respective testing chambers.

Figure 11 – Valves After Removal from Their Respective Testing Chambers

The overall goal of the test was to evaluate the resiliency of the new tail-plug seal design and make sure it would not leak, or fail, under extreme pressure and temperature conditions for a defined period. The verification for this test would include a before and after valve test rack opening pressure analysis and comparison as well as a post inspection of the interior bellows fluid and charge chamber conditions. The standard valve samples were included as comparison controls.

Table 1 below details the pressure test data for the valves pre and post the testing operation. As seen, there was one valve with zero pressure and one with 265 PSI post-test. The valve containing zero pressure was due to a failed bellows solder joint and was excluded other than for inspection of elastomer condition. The valve containing 265 PSI was inspected for root cause of failure.

Table 1 – Pressure Test Data for Valves Pre and Post Testing Operations

Test Chamber Number	Description	TRO Ambient	TRO Shelf @ 60 Degrees F	TRO After First Age	TRO After Second Age	TRO After Third Age	Final TRO Before Third-Party Testing	TRO After Third-Party Testing	Notes
1	1" Valve	1273	1233	1223	1227	1221	1221	1260	Robust Valve
2	1" Valve	1244	1245	1238	1236	1236	1236	1270	Robust Valve
1	1" Valve	1211	1202	1193	1202	1203	1205	1218	Robust Valve
2	1" Valve	1270	1220	1210	1210	1210	1210	1253	Standard IPO Valve
2	1.5" Valve	1186	1176	1173	1172	1160	1155	0	Robust Valve
2	1.5" Valve	1237	1118	1117	1117	1117	1117	1075	Robust Valve
1	1.5" Valve	1211	1159	1157	1157	1157	1157	1113	Robust Valve
1	1.5" Valve	1293	1264	1268	1266	1263	1258	265	Standard IPO Valve

***NOTE: 1.5" valve with no pressure was the result of a failed bellows solder joint, not a seal failure

RESULTS OF THE THIRD-PARTY TESTING

As a result of the third-party testing operation, we were able to draw several conclusions. First, the reengineered valve with multiple seals suitable for harsh environments was able to withstand a test pressure of 5,000 psig and a test temperature of 325 degrees Fahrenheit. Second, the elastomers contained in the gas lift valves with multiple seals suitable for harsh environments faired very well throughout the testing—particularly as compared to the traditional IPO valve controls. Figure 12 below depicts the elastomer condition of the standard 1.0" IPO valve found to contain 265 psi of bellows charge pressure post testing operations. As depicted in the figure and pointed out by the red arrow, the valve's tail plug elastomer was extremely compromised, and a portion of it was left behind in the dome bore upon removal of the tail plug assembly.

Figure 12 – Elastomer Condition of Standard 1.0” IPO Valve Post Testing

Figure 13 below depicts the 1.0” valve with multiple seals and the state of its elastomers post testing operations. As seen, the elastomers in this valve fared well and did not exhibit signs of degradation or failure.

Figure 13 - Elastomer Condition of 1.0” Robust Valve Post Testing

Figure 14 below depicts the elastomer condition of the standard 1.5” IPO valve found to contain 1253 psi of bellows charge pressure post testing operations. As depicted in the figure and pointed out by the red arrow, the valve's tail plug elastomer experienced some slight degradation in the form of peeling.

Figure 14 – Elastomer Condition of Standard 1.5" IPO Valve Post Testing

Figure 15 below depicts the 1.5" improved gas lift valve and the state of its elastomers post testing operations. As seen, the elastomers in this valve fared well and did not exhibit signs of degradation or failure.

Figure 15 - Elastomer Condition of 1.5" Robust Valve Post Testing

Upon further examination of the gas lift valves with multiple seals, there was no evidence of outside pressure or fluid into the bellows charge chambers of the test sample valves. Moreover, no identifiable trapped pressure existed within any sealing voids other than between the valve core and primary sealing plug.

<u>HAS THE POTENTIAL PRESSURE LOSS FOR THE IMPROVED GAS LIFT VALVE BEEN IDENTIFIED?</u>

Calculations have been run for the potential pressure loss at each void area within the improved gas lift valve. Below, in Figure 16 are the calculated pressure loss volumes at each void area.

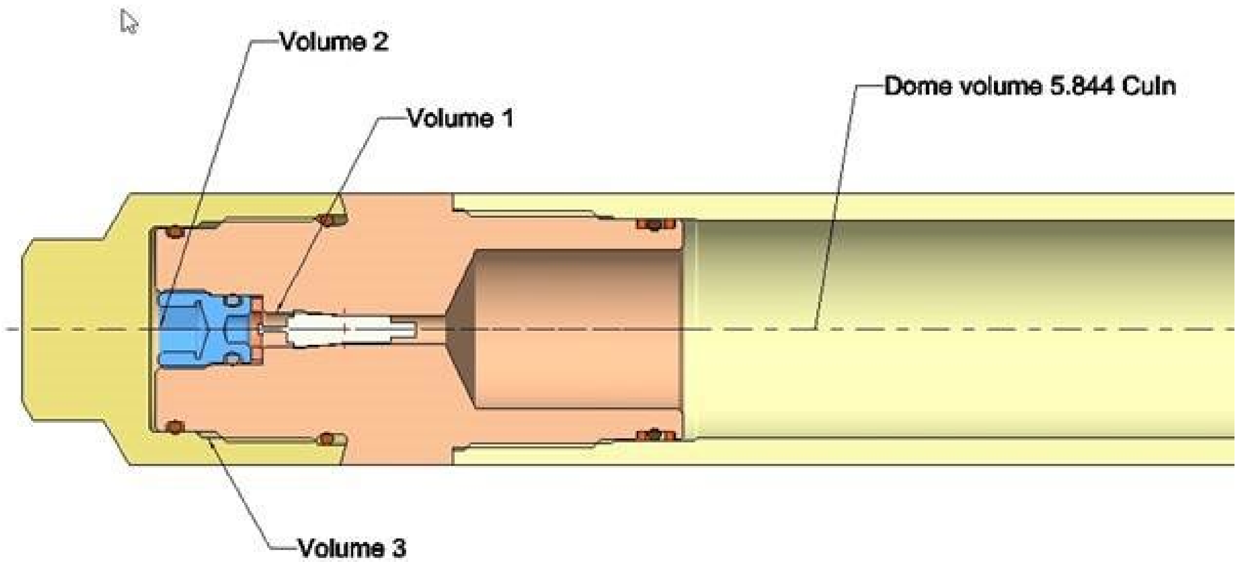
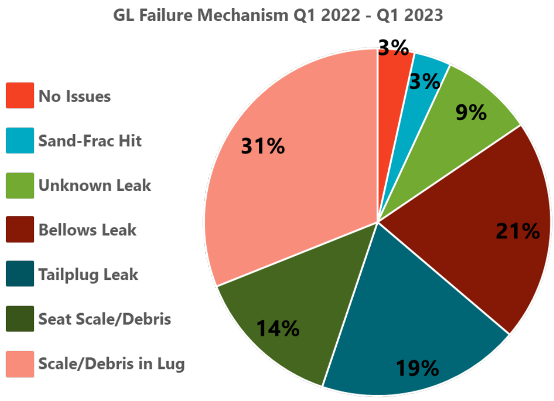


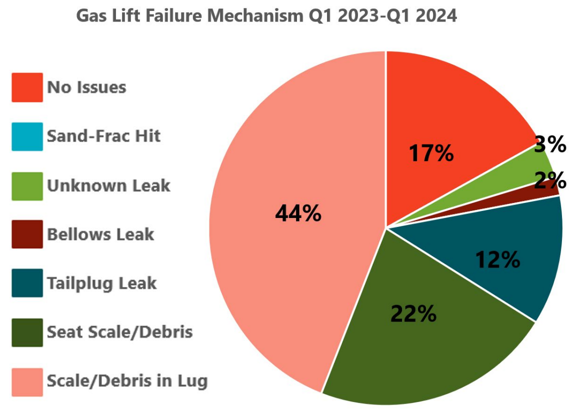
Figure 16 – Pressure Void Area Volumes Identified (1.0" Robust Valve)

For a one-inch valve with an initial set bellows charge chamber pressure of 1000 PSI, the pressure loss for volume one (valve core leak contained by the primary plug) is approximately 2 PSI. The potential loss for volume one and volume two combined (compromised valve core and primary plug seal) would be approximately 7 PSI. If all barriers up to the final elastomeric seal were to be compromised, the total loss for volume one, two, and three combined would be approximately 9 PSI. That said, a gas lift design typically provides for a 20 to 25 PSI safety factor. Therefore, considering the safety allotted, the gas lift system should still function properly even with a slight pressure loss seen in the more advanced valve, assuming the final barrier contained pressure under a worst-case scenario. Comparatively speaking, a traditional injection pressure operated valve without additional backup redundancies to contain lost pressure from the bellows charge chamber could suffer far greater pressure loss, thus compromising the gas lift system beyond the bounds of built in safety considerations.

<u>POSITIVE FEEDBACK</u>

One major operator in the Eagle Ford agreed to share failure mechanism data providing real data regarding success associated with running the alternative gas lift valve. This data is shown below in Figure 17 and depicts comparative data percentages of failure mechanisms for quarter one of 2022 through quarter one of 2023 as opposed to quarter one of 2023 through quarter one of 2024. As shown, there has been drastic reduction in percentages of all failure mechanisms except that labeled as scale/debris in the lug of the gas lift mandrel.





GAS LIFT FAILURE MECHANISM Q1 2022 - Q1 2023	GAS LIFT FAILURE MECHANISM Q1 2023 - Q1 2024
	• Identified bellows leaks have been reduced from 21% to 2% • Tail plug leaks have been reduced from 19% to 12%

Figure 17 - Comparative data percentages of failure mechanisms Q1 2022 through Q1 2023 as opposed to Q1 2023 through Q1 2024

Although this data does not limit failure percentages to one sole gas lift equipment provider, the operator did provide an additional comment regarding the shift to utilizing the alternate valve—"*The transition to redesign has shifted the failure mechanism, reducing pulls that are leak prone.”*

ACTUAL RUN AND SUCCESS NUMBERS

The field success of the improved gas lift valve has spoken for itself. Since the first unit was installed in the ground in May 2023, there have been 5,379 deployed into wells in various operating areas as of March 15, 2025. Table 2 below details total units deployed in the field along with the respective quantity deployed in each operating play.

Table 2 – Units Deployed Per Operating Play May 2023 Through March 15, 2025

Operating Play	Quantity Deployed
Eagle Ford	4,951
Permian	223
Bakken	106
DJ Basin	99
Total	**5,379**

To date, there have been no reported operator pulls of the redesigned gas lift valve with multiple seals due to a valve failure.

Patent number US 12,241,347 B2 was issued by the United States Patent and Trademark Office for the improved valve.

CONCLUSION

As operators strive to maximize production while minimizing costs and downtime for troubled wells, it is imperative that equipment installed in wells provides integrity and successful long-term operation. In recent years, as more focus has been placed on identifying definitive failure mechanisms, an increased push has been made for concrete solutions to challenges that plague artificial lift installations in unconventional plays—particularly those characterized by more harsh conditions. These may include well bore heat, introduced chemical programs, offset fracturing activity, corrosive properties, and numerous other factors. By identifying viable solutions to well-known and continuous issues, operators can reduce failures which translates to decreased downtime and less need for operational workover expenditures. The more durable gas lift valve has proven itself as an answer to problems experienced with gas lift valve installations and is expected to continue to be an invaluable asset to the world of gas lift.

REFERENCES

1. "Orion GV Conventional IPO Valve - Saz Oilfield Services." *SAZOIL*, 28 June 2024, sazoil.com/orion-gv-conventional-gas-lift-valve-ipo/.