The International Journal of Engineering and Science (IJES)
|| Volume || 10 || Issue || 5 || Series I || Pages || PP 36-47|| 2021 ||
ISSN (e): 2319-1813 ISSN (p): 20-24-1805

Optimizing Gas Throughput of Actual Valve Using Different Seat Designs, Seat Sizes, and Ball Sizes – An Experimental Study

Saleh Ahmed[1*], Hossein Emadi[1], Lloyd Heinze[1], Rayan Khalil[1], Fathi Elldakli[2], Khalid Elwegaa[3]

[1]*Bob L. Herd Department of Petroleum Engineering, Texas Tech University, Lubbock, TX 79409, USA*
[2]*Priority Artificial Lift Services, LLC. Houston, TX 77041, USA*
[3]*Department of Petroleum Engineering, Faculty of Engineering, Sabratha University, Libya*
**Corresponding author: Saleh Ahmed*

ABSTRACT

Gas lift is considered the most important artificial method in the oil and gas industry. Although, there are several components in the Gas Lift Valve (GLV), the ball and the seats are the only two adjustable components. The objective of this study is to maximize the gas flow rate (throughput) using different seat designs, seat sizes, and ball sizes to increase oil production.

Blowdown test has been conducted using actual valve and nitrogen gas at 600 psi injection pressure. In total, five main seat designs were experimentally tested to investigate the highest gas throughput. The first three seat designs (sharp edge, modified design, and optimized design) have previously been evaluated using low gas injection pressure. Developing on this study, these seat-deigns have now been tested using 600 psi injection pressure. Additionally, two new seat designs were invented in this research including partially curved design (PCD) and wholly curved design (WCD). To optimize the gas throughput, thirty-four seat sizes and five ball sizes were used.

The results of the experimental work revealed that WCD promised the highest gas throughput comparing to the other seat designs. Each seat has a port top diameter (PTD) and a port bottom diameter (PBD). The results showed that PTD size almost has no effect on the gas throughput whereas the PBD size proportionally affects the gas throughput. When the PTD was increased from 6/16 in to 9/16 the gas throughput had an insignificant change. On the other hand, the gas throughput increased by 46% when the PBD increased from 4/16 in to 6/16 in. The results also demonstrated that the ball size has an inversely proportional relationship with the gas throughput. When the ball size was decreased from 9/16 in to 5/16 in, the gas throughput was increased by 19% (fixing the PTD and PBD). The results show that the optimal seat size is when PBD and PTD are 6/16 inch and 8/16 inch. Also, when the ball size is 7/16 inch (1/16 in smaller than PTD) giving a gas throughput of 2.015 MSCF/D, which matches the simulation results with an error of 4-11%.

The novelty of this experimental research is describing five different GLV designs, two of which were invented. Additionally, the results show the effect of each of the adjustable GLV components: PBD, PTD, and ball size.

Keywords: *Artificial Gas Lift, Gas Lift Valve, Ball Configuration, Seat Size, Gas Throughput.*

Date of Submission: 01-05-2021 Date of Acceptance: 15-05-2021

I. INTRODUCTION

In 1797 Carl Loscher carried out laboratory experiments that used compressed air to lift liquids in tubes. This technique was so effective that it is now considered the most efficient artificial method to lift liquids in oilfields. It is known as the “gas” lift method. A tube is inserted into the ground and filled with compressed air, so the compressed air is injected through a valve at a single point. This method was initially used to lift water from a pit swing. In 1864 this method was used in the oil industry to obtain oil from wells that were no longer gushing oil. Thus, they called it a “well-blower” (Brantly, 1961). Cockford, an American engineer, modified the technique by adding an air-filled pipe to the tubing of compressed air (Cloud, 1937). The air-filled pipe allowed the hydrostatic pressure to decrease by reducing the oil density, which allowed the well to produce more oil. Cockford used his system to obtain more oil from wells in Pennsylvania. His method was widely used from 1920 to 1929. However, the oxygen in the air presented a safety hazard, so the industry switched to natural gas. Using natural gas proved to be a safer technique. It was applied extensively in the Seminole oilfield in Oklahoma. Initially, the natural gas was just injected into the bottom of the well. The method was limited to shallow wells because the injection pressure was so low. Over time the method underwent modifications to improve the gas-lift method. Thus, the downhole equipment was replaced with packer and standing valve. In the1930’s this led to the invention of the spring-operated differential gas-lift valve (GLV).

This method allowed the injected pressure to be variable. Thus, if the injected pressure (casing pressure) becomes greater than the tubing pressure, the valve will open in order to maintain the oil flow. In the 1980's (Brown 1984) developed a GLV model that could be operated from ground-level. In Brown's model the valve is operated in the well using tubing string. Unfortunately, if a valve needed to be replaced, all of the string tubing had to be removed from the well. This led to wireline retrievable valves. Thus, when a GLV needed to be replaced, it could be pulled out of the well without pulling out the entire tubing string. Thus, using wireline retrievable equipment made running GLV and out downhole devices easier and therefore more cost effective.

Elldakli, 2014 conducted experimental work to optimize the GLV performance by measuring dynamic gas throughput performance of each GLV using a modified seat design of benchmark valve. The results of the study showed that GLV performance using the modified seat was between 5 to 30% more than the gas throughput capacity of GLVs using a sharp-edge seat.

Kabir, 2018), conducted an experimental work to analyze the effects of smaller ball size on the GLV gas throughput using both modified and optimized seat designs of actual GLV. The ball was 1/16 inch smaller than the PTD of the seats. The results show that the smaller ball sizes were found to significantly improve the gas throughput of actual GLV. This improvement was as high as 179% for large PBD seats.

It should be noted that the gas lift GLV method is not the best option for very low production wells. Thus, for wells with low liquid capacity there are some newer lifting methods that have been developed, such as the chamber and plunger lift method.

The objective of this study is to optimize the GLV performance by measuring the dynamic gas throughput of each GLV using the new design seats of Partially curved (PCD) and Wholly curved (WCD) in lab experimental to match it with Computational Fluid Dynamics technique (CFD) which used to simulate the flow behavior through GLV. The results of the experimental work of the new designs were compared to the previous designs (Sharp-Edge, Modified and optimized designs).

II. EXPERIMENTAL STUDY

Actual gas lift valve and Benchmark valve are both being used in gas lift to inject gas and maximize the oil production. These valves contain several components and the only adjustable components are the ball and the seat. Previous experimental studies on gas lift performance have examined only a few parameters at a time. To provide a more complete overview of the process, this study optimizes the performance of actual GLV using different seats and ball sizes at injection pressure of 600 psi. The basic components of both types of GLV are shown in figure 1.

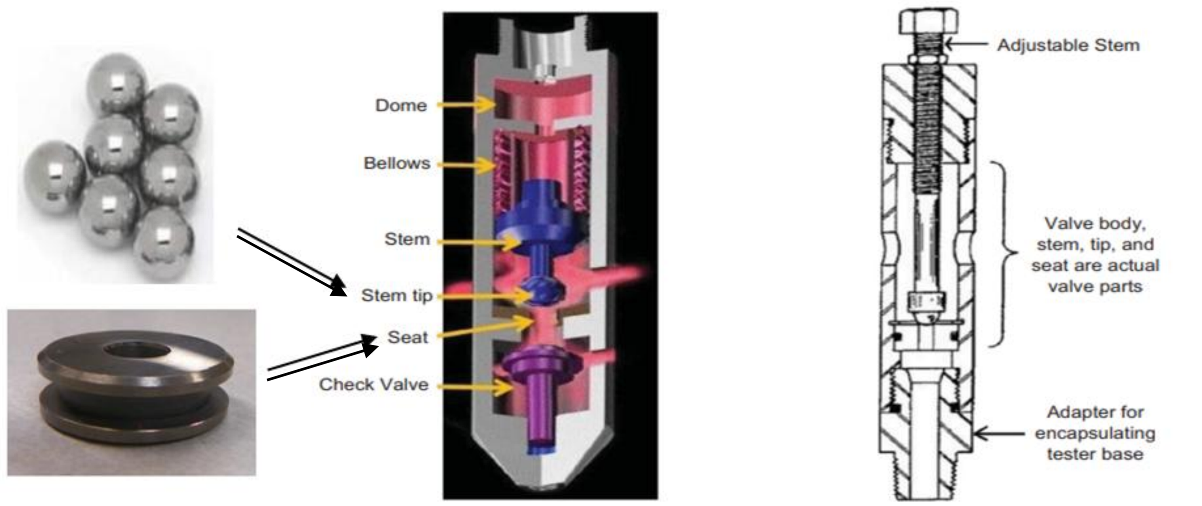

Figure 1.1 Basic components of an actual (left) and a benchmark (right) GLV.

Two seat designs were investigated in this experimental study: Partially curved design (PCD) and Wholly curved design (WCD) seats. The effects of ball diameters, Port Top Diameter (PTD) and Port Bottom Diameter (PBD) for PCD and WCD seat designs were examined. 14 seat sizes and 5 different ball sizes were used for actual valve to investigate the best gas throughput. Figure 1.2 shows the five seat types of the GLV.

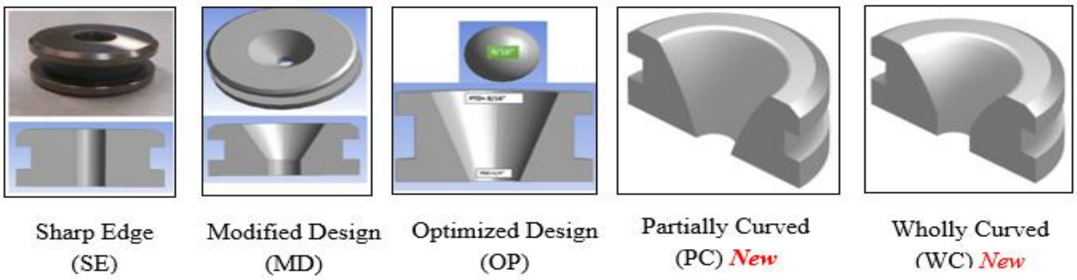

Figure 1.2: Five different types of seat designs.

The experimental results of running 54 scenarios of PCD and WCD showed that PCD has

15% higher gas throughput than the modified design at the ball size 6/16 inches, PBD 5/16 inches and PTD 7/16 inches. Also, WCD has 10% higher gas throughput than the optimized design at the ball size 7/16 inches, PBD 6/16 inches and PTD 8/16 inches. The results also demonstrated that the best design seat is the Wholly Curved Design compared to the others when the PBD, PTD and the ball are 6/16 in, 8/16 in and 7/16 in, respectively resulting in the highest gas flow rate of 2220 MSCF/D. Also, the results of the experimental work revealed that WCD promised the highest gas throughput comparing to the other seat designs.

Each seat has a port top diameter (PTD) and a port bottom diameter (PBD). The results showed that PTD size almost has no effect on the gas throughput whereas the PBD size proportionally affects the gas throughput. When the PTD was increased from 6/16 in to 9/16 the gas throughput had an insignificant change. On the other hand, the gas throughput increased by 48% when the PBD increased from 4/16 in to 6/16 in. The results also demonstrated that the ball size has an inversely proportional relationship with the gas throughput. When the ball size was decreased from 9/16 in to 5/16 in, the gas throughput was increased by 23% (fixing the PTD and PBD). The results show that the optimal seat size is when PBD and PTD are 6/16 inch and 8/16 inch. Also, when the ball size is 7/16 inch (1/16 in smaller than PTD) giving a gas throughput of 2220 MSCF/D, which matches the simulation results with an error of 4%.

2.1 Experimental Work

The main objective of the entire experimental program is to test the gas lift valve under dynamic conditions by employing “blowdown” or “pressure decay” test. The experimental work consists of three main tests, Aging, Probe test and Dynamic testing (Blowdown). Two types of gas lift valve were used in this experiment (Actual valve and Benchmark valve), however, aging test is used only for the actual gas lift valve. The three tests procedure are explained below:

2.1.1 Ager

Aging or hydraulic stabilization is done to reduce the hysteresis effect associated with the bellows assembly. The setup of this aging test contains an air-driven water pump, a GLV holder, and some pop joints. Figure 1.3 (Kabir, 2018) illustrate the schematic diagram and an actual diagram of the apparatus respectively. This apparatus is called ager or GLV hydro tester.

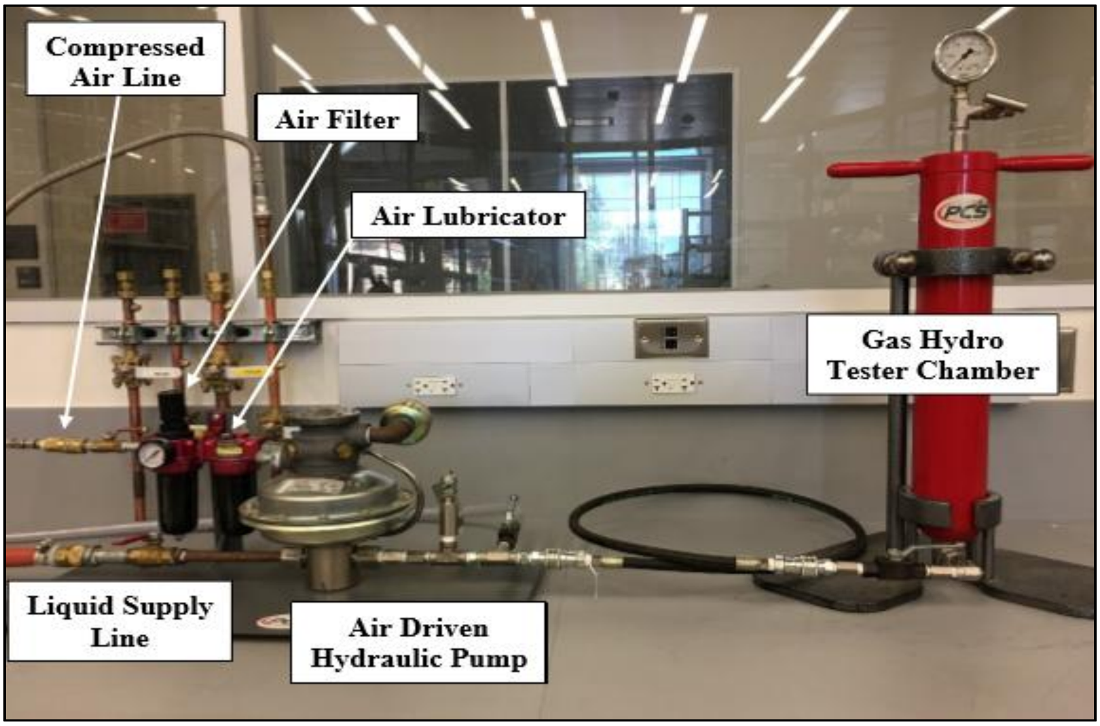

Figure 1.3: Actual ager

Aging test procedure:
1. After the opening pressure of the GLV is set using static testing, the GLV is put into a 60°F water bath for at least 15 minutes.
2. The GLV is then placed inside the ager GLV chamber. Meanwhile, the GLV should not be hold from the dome section to avoid the heat transfer from hand.
3. Then the lid of the GLV chamber is closed.
4. The pump is turned on using the following procedure:
a. All the lines must be depressurized.
b. Air shut-off valve is then closed.
c. Driving air supply is turned on.
d. Air pressure regulator is adjusted to 25 psi starting pressure.
e. The valve in the hydraulic circuit and the water shut-off valve are opened to allow free flow of water from reservoir.
f. Slowly the air shut-off valve is opened to start the pump operating.
g. Then valve is closed in hydraulic circuit.
h. pump and air circuit are monitored for leaks in lines, fittings, etc.
i. With pump and circuit operating properly, air pressure regulator is readjusted until desired pump discharge pressure (5000 psi) is reached.
j. The gauge pressure attached to the GLV chamber is recorded.
5. The GLV is kept inside the GLV chamber under 5000 psi pressure for at least 15 minutes.
6. The pump is turned off using the following procedure:
7. The lid of the GLV Chamber is opened to remove the GLV.
8. The GLV is immersed in the water bath again for at least 15 minutes
9. The GLV is removed from the water bath and using static testing, the test rack opening pressure is measured.
10. If the test rack opening pressure has been changed by 5 psi or more, then steps 2 through 9 are repeated until the pressure does not change by maximum of 5 psi.

2.1.2 Probe testing

The purpose of the GLV probe test is used to determine the relative "stiffness" of a gas-lift valve and to determine the maximum effective stem travel. When gas pressure is admitted to the tester, it must act on the full area of the valve bellows to lift the stem off the seat. When this pressure is increased, the stem lifts further from the seat. By using the probe tester, an accurate measure of the stem travel versus pressure can be determined and the results are tabulated and plotted. An actual diagram of the probe tester is given in Figure 1.4.

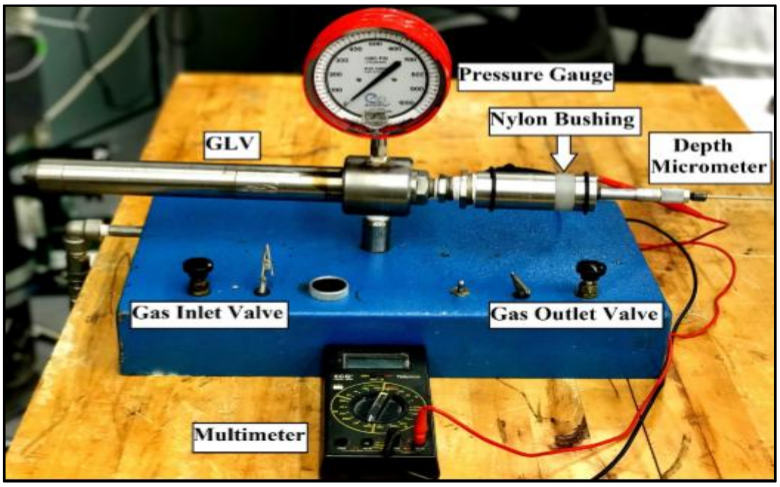

Figure 1.4: Actual probe teste (Kabir, 2018)

When the pressure is plotted as the ordinate and the stem travel as the abscissa, a relatively straight line will be generated for the effective stem travel. The slope of this line is an indication of the "stiffness" of the valve. The numerical value of the slope is called the Bellows Assembly Load Rate and is measured in psig/inch. The higher the load rate, the "stiffer" the valve and inversely, the lower the load rate, the "softer" the valve. The stepwise procedure is given below:

1. After setting the test rack opening pressure using the static testing and aging, the valve is inserted in the test sleeve and a micrometer is added to the downstream side of the valve.
2. By adjusting the knob attached to the micrometer, the micrometer probe is positioned such that it barely touches the ball. The corresponding micrometer reading is recorded.
3. A multimeter is attached to the two sides of the nylon bushing. A resistance reading of zero ensures the continuity of the circuit.
4. The pressure is increased until the probe no longer touches the stem tip. A drastic increase in resistance in the multimeter reading ensures this. This is the pressure at which the valve opens when test pressure is applied over the full bellows area.
5. The micrometer probe is positioned using the knob such that it barely touches the ball again which is demonstrated by zero resistance in the multimeter reading again. The corresponding micrometer reading is recorded.
6. Steps 2 through 5 are repeated for several increasing pressures until the stem no longer moves with increasing pressure.
7. Steps 2 through 5 are repeated for several decreasing pressures until the initial micrometer reading is reached.
8. The pressures vs stem travels are plotted on the same graph for both increasing and decreasing pressures.

The objective of blowdown test is to measure the flow rate capabilities of the valves under simulated well conditions. The methodology behind this technique is simply discharging a certain volume of gas at a certain time until the upstream pressure reaches the final downstream pressure which is ambient pressure. The initial pressure is largely greater than the test rack opening pressure to ensure a fully open GLV.

The apparatus for this test includes some compartments such as source of high pressure nitrogen gas, upstream and downstream regulators attached to the high-pressured source of gas, an extra empty volume with known internal capacity, an encapsulated vessel which holds the GLV, the GLV, high-speed pressure transducers, high speed temperature recorder, and a data-acquisition system (DAQ) which might be integrated with the pressure transducers. An actual diagram of the blowdown tester is given in Figure 1.5.

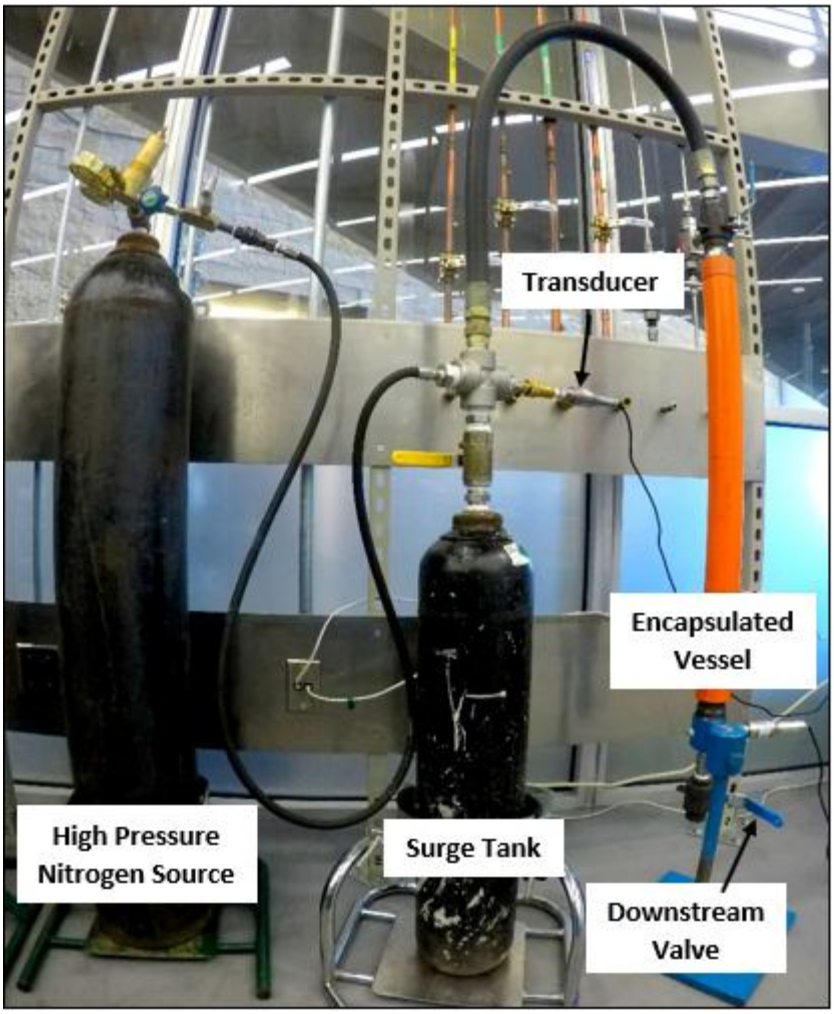

Figure 1.5: Actual blowdown tester

The procedure for running the dynamic testing is as follows:
1. The GLV is attached inside the encapsulating vessel and the vessel is closed.
2. The upstream pressure is set at a very high value compared to the test rack opening pressure.
3. The main feeding valve that is attached to the high-pressure nitrogen source is shut in.
4. Wait until the upstream pressure is stabilized.
5. The temperature is recorded using laser temperature gun.
6. The pressure and corresponding time recording is started.
7. The downstream valve is kicked open as fast as possible.
8. The temperature is recorded again using laser temperature gun.
Blowdown test procedure is implemented for actual valve.

2.3 Results and Discussion

The results of the partially curved and Wholly curved design seats were very promising and demonstrated that the gas throughput was higher using the new designs than using the previous ones. Specifically, wholly curved design seat showed the best results among all the design seats in terms of gas flow rate.

2.3.1 Ball Size and Seat Type Optimization

The results of the experimental work of the PC and WC seats demonstrated that the ball size has an inversely proportional relationship with the gas throughput. When the ball size was decreased by 38% (from 9/16 in to 5/16 in), the gas throughput was increased by 20% (fixing the PTD and PBD).
Furthermore, when the PTD was increased by 33% (from 6/16 in to 9/16 in), the gas throughput did not increase much (fixing the ball and the PBD). On the other hand, the gas throughput was doubled when the PBD was increased 50% (fixing the ball and the PTD).
The above results support the previous work conducted by (Kabir, 2018) when Modified and optimized seats were investigated.

The following figures present the effect of the ball and seat sizes of Modified Design (MD), Optimum Design (OD), PCD and WCD on the performance of GLV.

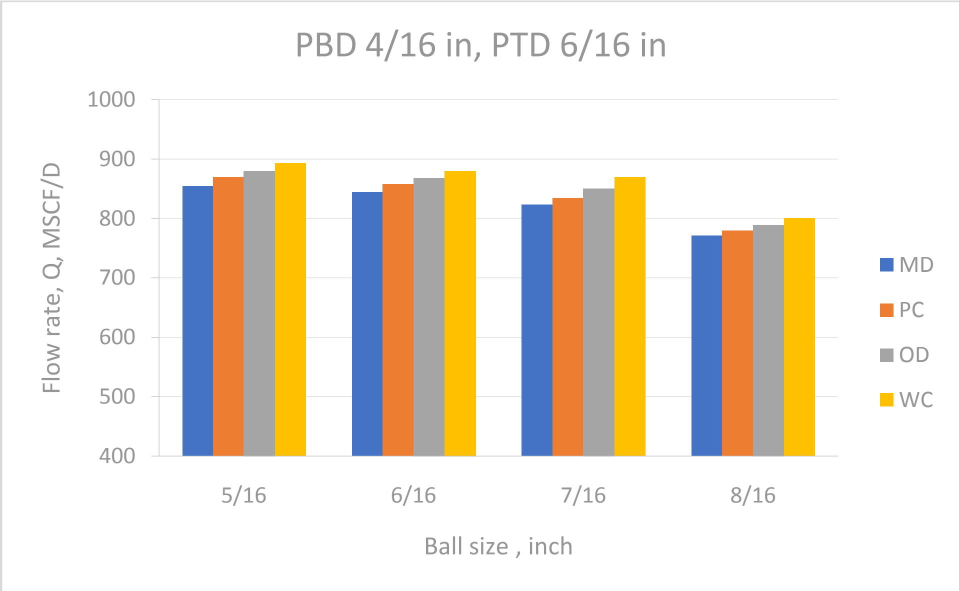

Figure 1.6 Effect of ball size on the gas throughput at PBD 4/16 in and PTD 6/16 in

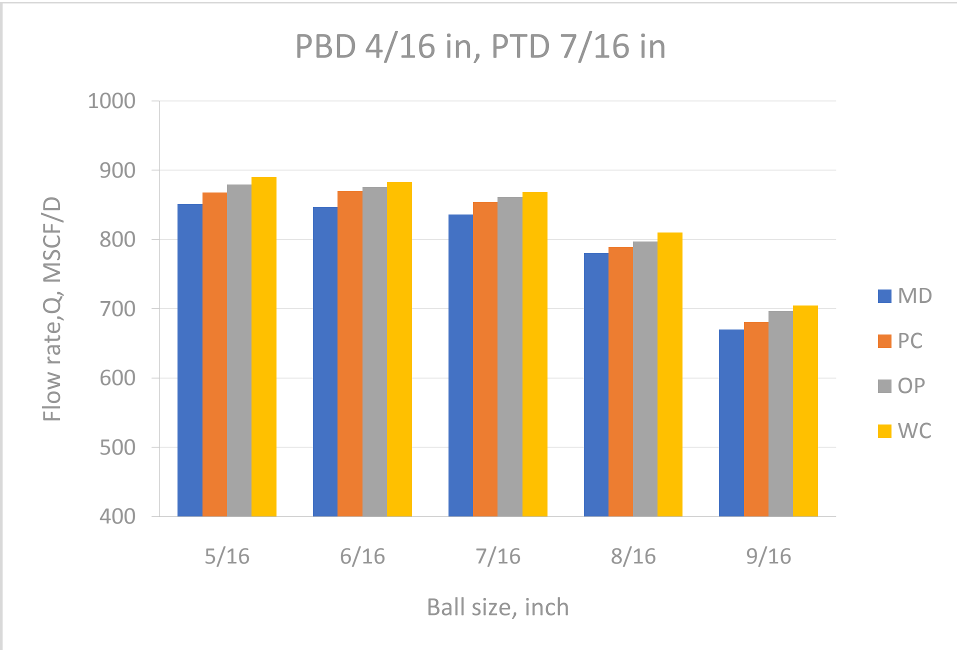

Figure 1.7 Effect of ball size on the gas throughput at PBD 4/16 in and PTD 7/16 in

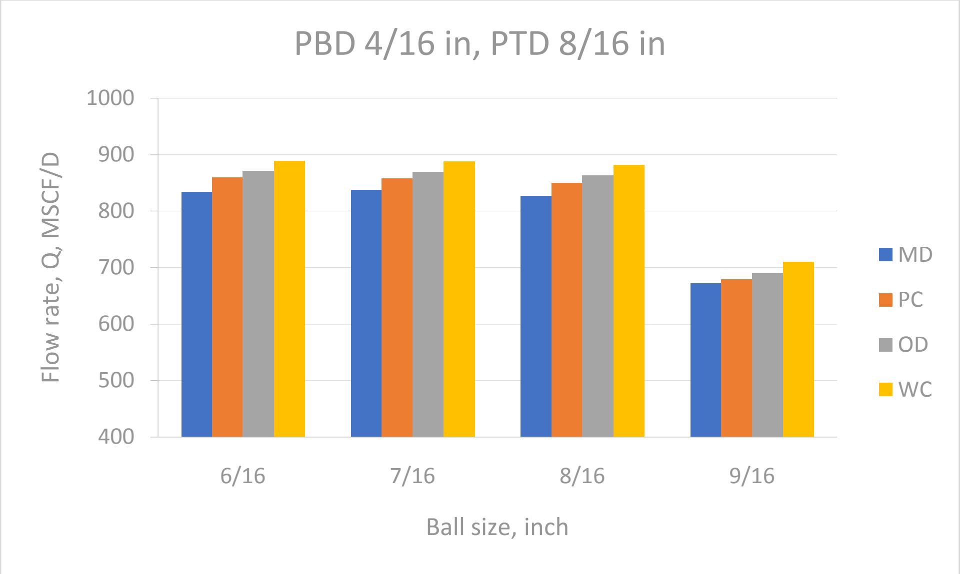

Figure 1.8 Effect of ball size on the gas throughput at PBD 4/16 in and PTD 8/16 in

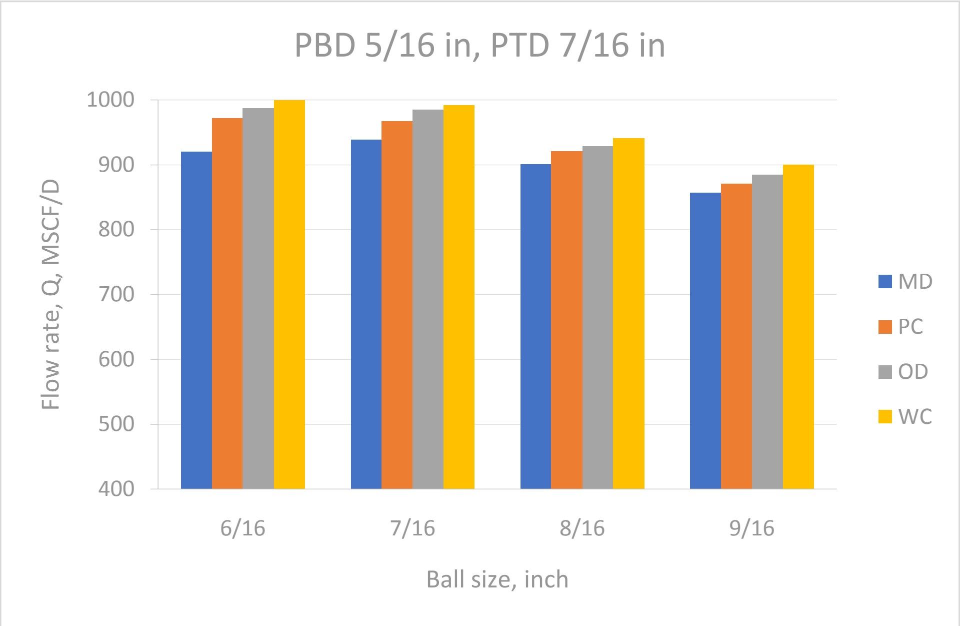

Figure 1.9 Effect of ball size on the gas throughput at PBD 5/16 in and PTD 7/16 in

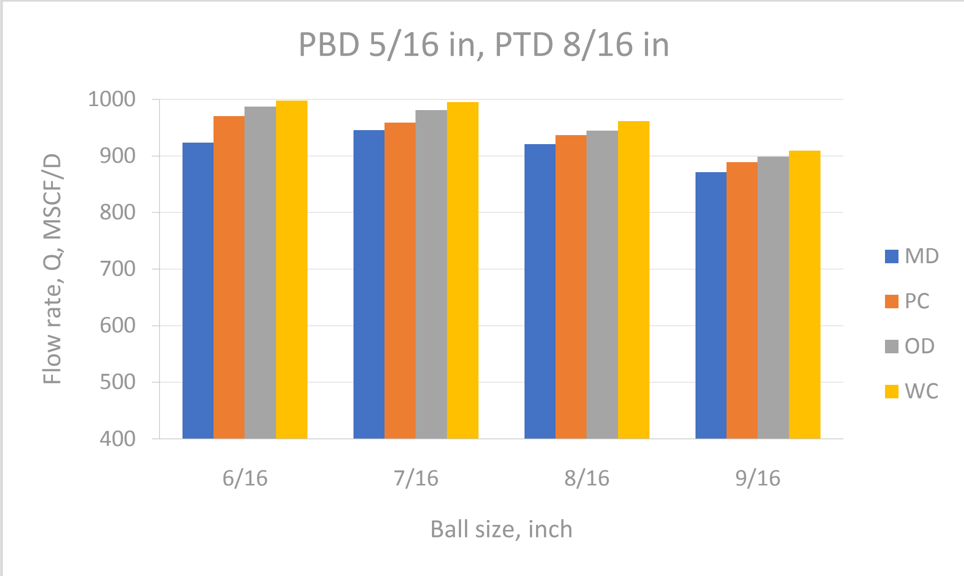

Figure 1.10 Effect of ball size on the gas throughput at PBD 5/16 in and PTD 8/16 in

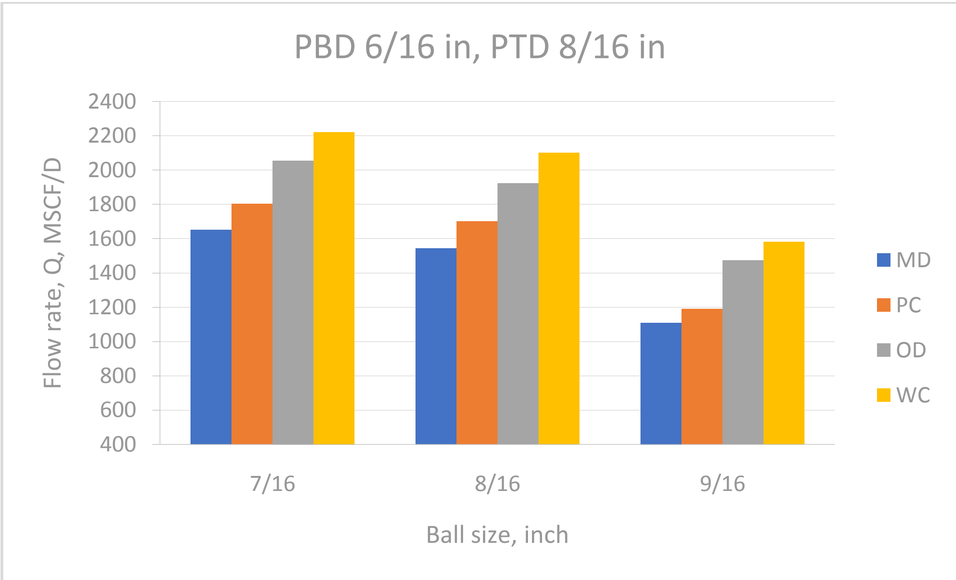

Figure 1.11 Effect of ball size on the gas throughput at PBD 6/16 in and PTD 8/16 in

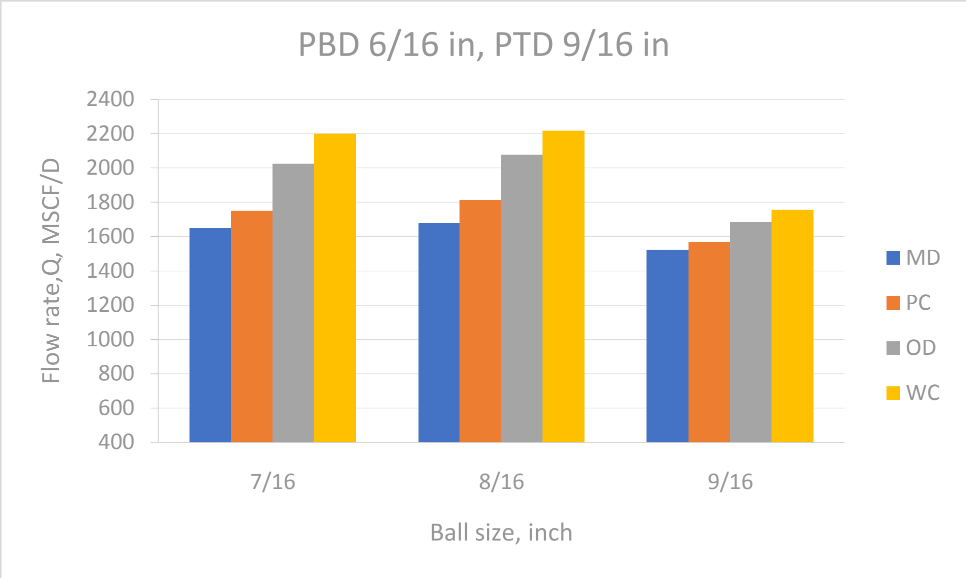

Figure 1.12 Effect of ball size on the gas throughput at PBD 6/16 in and PTD 9/16 in

2.3.2 The Best Seat Type at Various Ball Sizes

Table 1, table 2, table 3 and table 4 show that the best scenario when analyzing the PBD and PTD is WCD seat at various ball sizes of 5/16 in, 6/16 in, 7/16 in and 8/16 in respectively.

Table 1: The best seat at ball size 5/16 in

PBD, in	PTD, in	*Ball, in*	Q, MSCF/D	Seat Type
4/16	6/16	***5/16***	893	WC
4/16	7/16	***5/16***	890	WC
4/16	8/16	***5/16***	889	WC

Table 2: The best seat at ball size 6/16

PBD, in	PTD, in	*Ball, in*	Q, MSCF/D	Seat Type
4/16	6/16	***6/16***	880	WCD
4/16	7/16	***6/16***	883	WCD
4/16	8/16	***6/16***	889	WCD
5/16	7/16	***6/16***	1000	WCD
5/16	8/16	***6/16***	997	WCD

Table 3: The best seat at ball size 7/16 in

PBD, in	PTD, in	*Ball, in*	Q, MSCF/D	Seat Type
4/16	6/16	***7/16***	869	WCD
4/16	7/16	***7/16***	869	WCD
4/16	8/16	***7/16***	888	WCD
5/16	7/16	***7/16***	992	WCD
5/16	8/16	***7/16***	995	WCD
6/16	8/16	***7/16***	2220	WCD
6/16	9/16	***7/16***	2198	WCD

Table 4: The best seat at ball size 8/16

PBD, in	PTD, in	*Ball, in*	Q, MSCF/D	Seat Type
4/16	6/16	***8/16***	800	WCD
4/16	7/16	***8/16***	810	WCD
4/16	8/16	***8/16***	881	WCD
5/16	7/16	***8/16***	941	WCD
5/16	8/16	***8/16***	961	WCD
6/16	8/16	***8/16***	2100	WCD
6/16	9/16	***8/16***	2217	WCD

Table 5 shows the best seat and ball size of Wholly curved design which results in the highest gas throughput of 2220 MSCF/D

Table 5: The best seat of Wholly Curved Design

PBD, in	***PTD, in***	***Ball Size, in***	***Q, MSCF/D***	***Seat Type***
4/16	6/16	5/16	893	WCD
5/16	7/16	6/16	1000	WCD
6/16	8/16	7/16	2220	WCD
6/16	8/16	8/16	2217	WCD

Table 6 demonstrates the comparison between the Wholly curved design and Sharp edge design (SE). The new design of wholly curved was not only the best among the PC, MD and OP, but it was also better than the Sharp edge design. The gas throughput obtained by the wholly curved design is almost twice the amount of the sharp edge design, which is currently approved and used in the oil industry.

Table 6: The comparison between Wholly curved design and Sharp edge design

Seat Type	PBD, in	PTD, in	Ball Size, in	Q, MSCF/D
Wholly Curved	6/16	8/16	7/16	2220
Sharp Edge	6/16	6/16	7/16	1114

III. CONCLUSION

In this experimental study, five main seat designs were evaluated using Actual GLV: The Sharp edge (SE), modified design (MD), the optimized design (OD), Partially Curved Design (PCD) and Wholly Curved Design (WCD). Twenty-nine seat sizes and five different ball sizes have been selected to maximize the gas throughput implementing the five designs (SE, MD, OP, PC, and WC).

- The results of the partially curved and Wholly curved design seats were very promising and demonstrated that the gas throughput was higher using the new designs than using the previous ones (SE, MD, and OP).
- Wholly curved seat is considered the best design compared to the others because it gives the highest flow rate 2220 MSCF/D.
- The results also demonstrated that all seat designs have a uniform pressure distribution, however, wholly curved design has the highest gas throughput according to the pressure profile.
- The results of the experimental work of the PCD and WCD seats demonstrated that the ball size has an inversely proportional relationship with the gas throughput. When the ball size was decreased from 9/16 in to 5/16 in, the gas throughput was increased by 20% (fixing the PTD and PBD).
- It was also observed that there is an insignificant effect when increasing the PTD.
- Wholly curved seat design could be potentially implemented in the oil industry to improve the efficiency of the current gas lift operation and ultimately oil production.

REFERENCES

[1]. Ehsanul Kabir, (2017), Investigating effects of ball size on the performance of gas lift valve for both modified and optimized seats, Oil & Gas Science and Technology 73(1):15

[2]. Ehsanul Kabir, (2018), Optimizing Seat and Ball Combination of Actual Gas Lift Valve: An Experimental and CFD Simulation Study. Texas Tech University

[3]. Elldakli, F., Soliman, M., Shahri, M., 2014a. Enhanced Gas Lift Valve Performance With Sharp Edged Seat Using Larger Balls, in: Southwestern Petroleum Short Course. Lubbock, Texas, USA.

[4]. Elldakli, F., Soliman, M.Y., Shahri, M., Winkler, H.W., Gamadi, T.D., 2014b. Improved Gas Lift Valve Performance Using a Modified Design for GLV Seat, in: SPE Artificial Lift Conference & Exhibition-North America. Society of Petroleum Engineers, Houston, Texas, USA. https://doi.org/10.2118/171342-MS

[5]. Decker, A. L., et al. (1976). Analytical methods for determining pressure response of bellows operated valves.

[6]. Decker, K., et al. (1986). Computer modeling of gas-lift valve performance. In Offshore technology conference.

[7]. Kulkarni, M. (2005). Gas lift valve modeling with orifice effects. (Unpublished master's thesis). Texas Tech University., Lubbock

[8]. Shahri, M. A. (2011). Simplified and rapid method for determining flow characteristics of every gas-lift valve (glv) (Unpublished doctoral dissertation). Texas Tech University.

[9]. Winkler, H., Camp, G., et al. (1987). Dynamic performance testing of single-element unbalanced gas-lift valves. SPE Production Engineering, 2(03), 183–190.

[10]. Brown, K. 1973. Gas Lift Theory and Practice. P.202

[11]. Winkler, W., & Blann, J. (2007). Petroleum engineering handbook, chapter 11. Society of Petroleum Engineers.

[12]. Aliyeva, F., & Novruzaliyev, B. 2015. Gas Lift – Fast and Furious. In proceedings of the SPE Annual Caspian Technical Conference & Exhibition.

[13]. King, W. (1944, January 18). Time and volume control for gas. Google Patents. (US Patent 2,339,487).

[14]. Xu, Z., Richard, B. M., & Kritzler, J. H. (2013, September 30). Smart Gas Lift Valves Enhance Operation Efficiency of Offshore Wells. In proceedings of the Annual Technical Conference & Exhibition.

[15]. Acuna, H.G., 1989. Normalization of One-Inch Nitrogen Charged Pressure Operated GasLift Valves. Tulsa University.

[16]. Kolawole O., Gamadi T., and Bullard D. (2019). Artificial Lift System Applications in Tight Formations: The State of Knowledge. SPE Production & Operations, SPE-196592-PA.

[17]. Almeida, A.R., 2011. A Model to Calculate the Theoretical Critical Flow Rate Through Venturi Gas Lift Valves (includes Addendum). SPE J. 16, 134–147. https://doi.org/10.2118/126184-PA

[18]. Kolawole O., and Ispas I. (2019). Interaction Between Hydraulic Fractures and Natural Fractures: Current Status and Prospective Directions. Journal of Petroleum Exploration and Production Technology. https://doi.org/10.1007/s13202-019-00778-3.

[19]. Fathi Elldakli (2017) Testing, Modeling and Optimizing a Modified Design of Gas Lift Valve Seat. (Unpublished doctoral dissertation). Texas Tech University.

[20]. Bertovic, D., 1995. A Unified Model for Gas-Lift Valve Performance Incorporating Temperature Effects. Tulsa University.

[21]. Kolawole O., Kovács-Federer G., and Szabo I. (2018). Formation Susceptibility to Wellbore Instability and Sand Production in the Pannonian Basin, Hungary. American Rock Mechanics Association, ARMA-2018-221.

[22]. Elldakli, F., Soliman, M., 2017. Optimum design for new gas lift valve seat. J. Pet. Sci. Eng. 149, 456–464. https://doi.org/https://doi.org/10.1016/j.petrol.2016.10.062

[23]. Gas-Lift Valve Performance Testing API RP 11V2, 2nd ed, 2008. American Petroleum Institute (API).

[24]. Nieberding, M.A., 1988. Normalization of Nitrogen-loaded Gas-Lift Valve Performance. University of Tulsa

[25]. Sagar, R., 1991. Improved Dynamic Model of Gas-Lift Valve Performance. University of Tulsa.

[26]. Shahri, M., Winkler, H.W., 2011. Practical Method for Measurement of Injection-gas Throughput of Each Gas-Lift Valve before Well Installation, in: SPE Production and Operations Symposium. Society of Petroleum Engineers, Oklahoma City, Oklahoma, USA https://doi.org/10.2118/141055-MS

Saleh Ahmed, et. al. "Optimizing Gas Throughput of Actual Valve Using Different Seat Designs, Seat Sizes, and Ball Sizes – An Experimental Study."*The International Journal of Engineering and Science (IJES)*, 10(05), (2021): pp. 36-47.