An Experimental Comparison Between Actual Valve and Benchmark Valve Using Modified Design and Optimized Design

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Abstract
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 compares the performance of actual valve and Benchmark valve using different seats and ball sizes atinjection pressure of 600 psi.

Twoseat designs were investigated in this experimental study: modified and optimized seat designs. The effects of ball diameters, Port Top Diameter (PTD) and Port Bottom Diameter (PBD) for modified and optimized seat designs were examined. 16 seat sizes and 6 different ball sizes were used for both actual valve and benchmark valve to investigate the best gas throughput.

The results of lab studiesshow that actual valve is better than benchmark valve in terms of gas throughput. The gas flow rate using actual valve was higher than using benchmark valve by between 35% to 40% for the optimized and modified designs respectively. The results also show that the best case in modified and optimized design using Benchmarkvalve and actual valve individuallyis when Port Bottom Diameter (PBD) 6/16inch, Port Top Diameter (PTD) 8/16 inch with ball size 7/16 inch (1/16 in smaller than PTD).

The best ball and seat design of the optimized design using actual gas lift valve could be implemented in field application to improve the oil production.

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

I. Introduction

Gas lift is considered as one of the artificial lift methods, which has been applied extensively for several decades and used by 10% of the artificial lift methods in oil industry. In 1797, Carl Loscherinitially conducted laboratory experiments using compressed air to lift liquids. This technique was later used to lift water from pit swing. Air was injected into liquid at the bottom of tubing through a valve. Later, it was known as the gas lift method whenairlift was used in the oil industry to obtain oil from wells (John W. Booth 1864). An American engineer named Cockford used an air-filled pipe connected to the tubing to decrease hydrostatic pressure by reducing oil density, allowing the well to produce more. In the 1920's, air was replaced by natural gas to be used to lift oil for safety reasons and this application was successfully applied in the Seminole field in Oklahoma.

Spring-operated differential GLV was invented in the 1930's. The valve works only when the injected pressure (casing pressure) is greater than tubing pressure. Brown,1984 developed another GLVs model, which mechanically operated from the surface, using tubing string. Due to the difficulty and unreliability of tubing retrievable GLVs, wireline retrievable GLVs were introduced instead of the mechanical one.

(Winkler and Blann, 2007) defined the gas lift as a simple and flexible artificial lift method in which external gas is injected continuously or intermittently from the casing-tubing annulus into the tubing string through specially designed valves (GLV). Although sophisticated gas lift technologies such as smart GLV (Xu et al., 2013) and advanced Gas-Lift Insert System (GLIS) (Aliyeva and Novruzaliyev, 2015) have been developed, all GLVs are still being manufactured based on King 's design (King, 1940). This design consists of a nitrogen-charged dome section and bellows assembly. Currently in United States, it is estimated that around 40% of the unconventional wells with artificial lift systems installed use gas lift, 36% use ElectricalSubmersible Pump, 13% use rod lift, 7% use plunger lift and 4% jet pumps (Pankaj et al., 2018).

Another type of GLV in which the nitrogen-charged dome and bellows assembly are absent is called Benchmark GLV. Laboratory testing is the primary use of this type of GLV. However, Winkler and Camp (1987) successfully usedbenchmarkvalve in field applications. The basic components of both types of GLV are shown in figure 1.

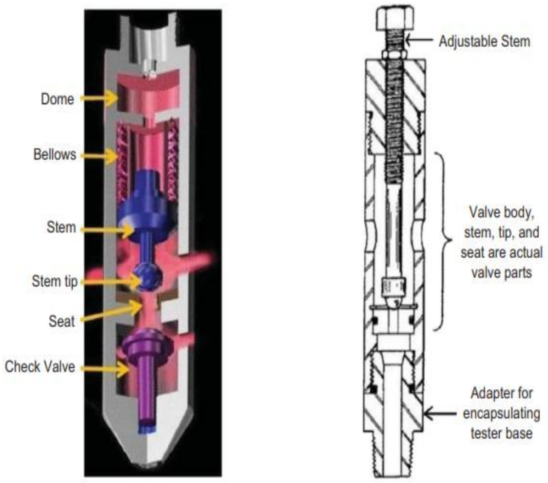

Fig 1: Basic components of an actual (left) and a benchmark (right) GLV. (Elldakli 2017)

(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 ballsizes were found to significantly improve the gas throughput of actual GLV. This improvement was as high as 179% for large PBD seats.

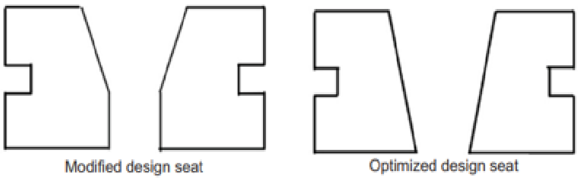

Fig 2: Types of seat designs

II. 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:

A. Aging:

Aging or hydraulic stabilization is done to reduce the hysteresis effect associated with the bellows assembly. Thesetup of this aging test contains an air-driven water pump, aGLV holder, and some pop joints. Figure 3 and figure 4(Kabir, 2018) illustrate the schematic diagram and an actualdiagram of the apparatus respectively. This apparatus iscalled ager or GLV hydro tester. The stepwise procedures are given below:

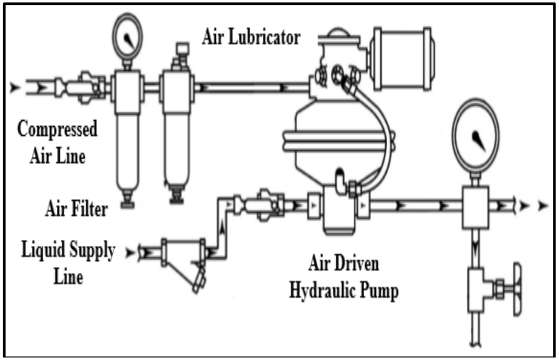

Fig 3: Schematic diagram of the ager

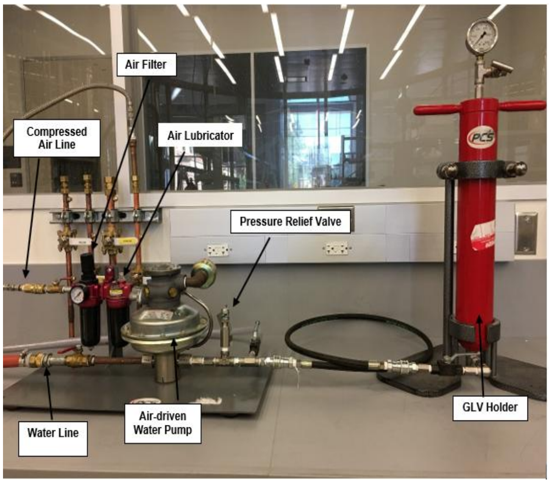

Fig 4: Actual ager

1. After the opening pressure of the GLV is set using static testing, the GLV is put into a 60^{o}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 freeflow 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 lid of the GLV Chamber is opened to remove the GLV.
7. The GLV is immersed in the water bath again for at least 15 minutes
8. The GLV is removed from the water bath and using static testing, the test rack opening pressure is measured.
9. 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.

B. 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 5.

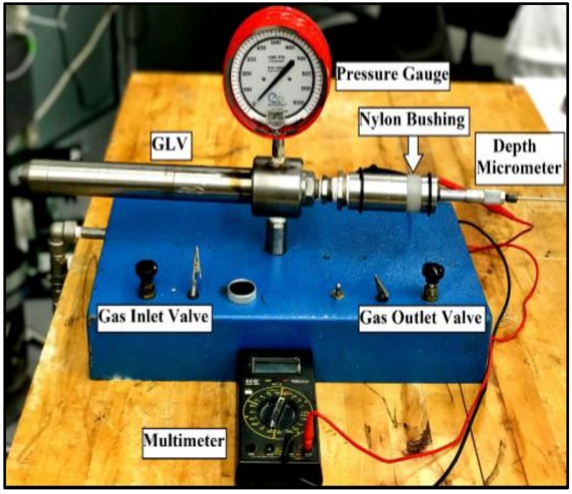

Fig 5: Actual probe teste (Kabir, 2018)

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 lineis 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 loadrate, 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.
9. There will be two regions in the plot: a left region with lower slope and a right region with higher slope. Some best fit lines are drawn through the data points in the region with lower slope. A typical graph from probe testing is presented in Figure 6.

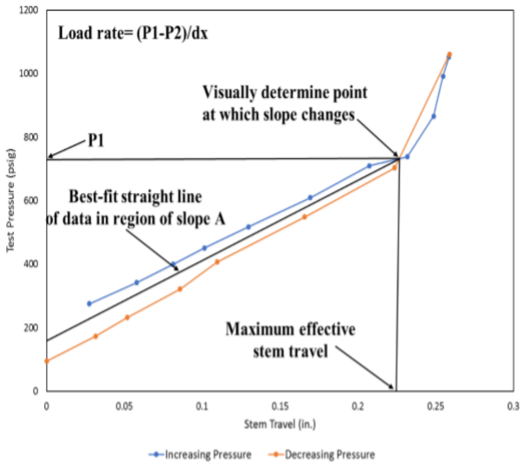

Fig 6: Typical data from probe test (Kabir, 2018)

C. Blowdown Test

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 volumewith known internal capacity, an encapsulatedvessel which holds the GLV, the GLV,high-speed pressure transducers,high speedtemperature recorder, and a data-acquisition system (DAQ)

which might be integrated with the pressure transducer. An actual diagram of the blowdown tester is given in figure 7 (Kabir, 2018).

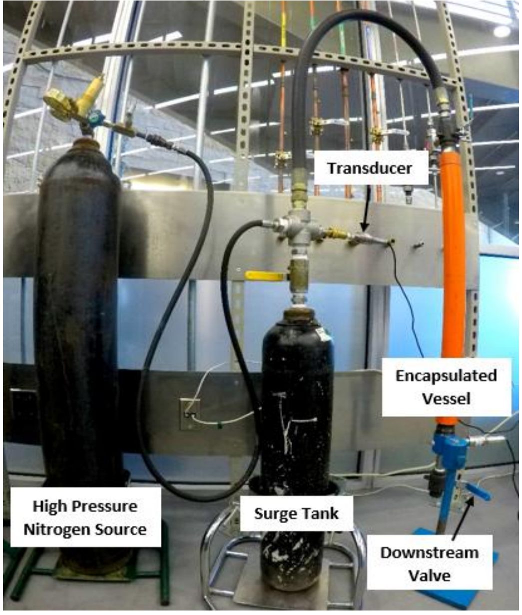

Fig. 7: Actual Blowdown Tester

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 recording using laser temperature gun.
6. The pressure and corresponding time recording are 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 both actual valve and benchmark valve.

III. Results and discussion

The results of the experimental work were very interesting and promising. The blowdown test results show that the actual valve is better than benchmark valve in terms of gas throughput for both the modified design and optimized design. The gas flow rate using actual valve was higher than using benchmark valve by between 35 % to 40% for the optimized and modified designs.The following results of the blowdown test for both benchmark and actual valves support the above conclusion.

A. Results of blowdown test using Benchmark valve:

a) Modified design seat results:

Ten different seats and six ball sizes were used in this experiment. PBD (3/16in to 6/16in), PTD (5/16in to8/16in), and ball sizes (4/16in to 9/16in). The following Tables (1-10) show the results of the blowdown test using the different sizes of seat and ball of the modified design.

Table 1: PBD 3/16in andPTD 5/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	5/16	4/16	594
3/16	5/16	5/16	528
3/16	5/16	6/16	371
3/16	5/16	7/16	381
3/16	5/16	8/16	300

Table 2: PBD 3/16in andPTD 6/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	6/16	4/16	578
3/16	6/16	5/16	561
3/16	6/16	6/16	363
3/16	6/16	7/16	348
3/16	6/16	8/16	319

Table 3: PBD 3/16in andPTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	7/16	4/16	567
3/16	7/16	5/16	571
3/16	7/16	6/16	565
3/16	7/16	7/16	555
3/16	7/16	8/16	381
3/16	7/16	9/16	364

Table 4: PBD 3/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	8/16	4/16	565
3/16	8/16	5/16	566
3/16	8/16	6/16	565
3/16	8/16	7/16	566
3/16	8/16	8/16	502
3/16	8/16	9/16	488

Table 5: PBD 4/16in andPTD 6/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	6/16	5/16	1031
4/16	6/16	6/16	1030
4/16	6/16	7/16	693
4/16	6/16	8/16	712

Table 6: PBD 4/16in andPTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	7/16	5/16	1026
4/16	7/16	6/16	1015
4/16	7/16	7/16	1018
4/16	7/16	8/16	693
4/16	7/16	9/16	656

Table 7: PBD 4/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	8/16	5/16	1007
4/16	8/16	6/16	1004
4/16	8/16	7/16	994
4/16	8/16	8/16	988
4/16	8/16	9/16	692

Table 8: PBD 5/16 in and PTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	7/16	6/16	1602
5/16	7/16	7/16	1428
5/16	7/16	8/16	1025
5/16	7/16	9/16	1055

Table 9: PBD 5/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	8/16	6/16	1613
5/16	8/16	7/16	1587
5/16	8/16	8/16	1503
5/16	8/16	9/16	1003

Table 10: PBD 6/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	8/16	7/16	2207
6/16	8/16	8/16	1859
6/16	8/16	9/16	1498

It can be seen from the tables (1-10) that the PTD size has no effect on the gas throughput whereas the PBDsize show significant and direct effect on the gas throughput. For example, the PBD 3/16 and 4/16in, the gasthroughput was 566 MSCF/D and 1007 MSCF/D respectively at fixed PTD and Ball size. On the other hand, the ball size shows an inversely proportional relation to the gas throughput. For example, the ball sizes 6/16in and 7/16in, the gas throughput was 1030 MSCF/D and 693 MSCF/D respectively at fixed PBD and PTD sizes.

b) Optimized design seat results:

Six different seats and five ball sizes were used in this experiment. PBD (4/16in to 6/16in), PTD (8/16in to 9/16in),

and ball sizes (5/16in to 9/16in). The following Tables (11-16) show the results of the blowdown test using different sizes of seat and ball of the optimized design.

Table 11: PBD 4/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	8/16	5/16	1007
4/16	8/16	6/16	1012
4/16	8/16	7/16	964
4/16	8/16	8/16	1005
4/16	8/16	9/16	651

Table 12: PBD 4/16in andPTD 9/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	9/16	5/16	988
4/16	9/16	6/16	993
4/16	9/16	7/16	974
4/16	9/16	8/16	917
4/16	9/16	9/16	888

Table 13: PBD 5/16in andPTD 9/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	9/16	6/16	1550
5/16	9/16	7/16	1538
5/16	9/16	8/16	1470
5/16	9/16	9/16	1525

Table 14: PBD 5/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	8/16	6/16	1562
5/16	8/16	7/16	1560
5/16	8/16	8/16	1503
5/16	8/16	9/16	1039

Table 15: PBD 6/16in andPTD 9/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	9/16	7/16	2153
6/16	9/16	8/16	2137
6/16	9/16	9/16	2156

Table 16: PBD 6/16 and PTD 9/16 at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	8/16	7/16	2196.5
6/16	8/16	8/16	2184
6/16	8/16	9/16	1522

Similar tothe modified design seat results, the optimized design results revealed that the PTD size almost has no effect on the gas throughput whereas the PBD sizehas proportional effect on the gas throughput. For example,the PBD 4/16 and 5/16in, the gas throughput was 1012 MSCF/D and 1562 MSCF/D respectively at fixed PTD and Ball size. Thus, the ball size shows an inversely proportional relation to the gas throughput. For example, the ball sizes 5/16in and 9/16in, the gas throughput was 988 MSCF/D and 888 MSCF/D respectively at fixed PBD and PTD sizes.

B. Results of blowdown test using Actual valve:

a) Modified design seat results:

Ten different seats and six ball sizes were used in this experiment. PBD (3/16in to 6/16in), PTD (5/16in to 8/16in), and ball sizes (4/16in to 9/16in). The following Tables (17-26) show the results of the blowdown test using the different sizes of seat and ball of the modified design.

Table 17: PBD 3/16in andPTD 5/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	5/16	4/16	857
3/16	5/16	5/16	803
3/16	5/16	6/16	740
3/16	5/16	7/16	708
3/16	5/16	8/16	623

Table 18: PBD 3/16in and PTD 6/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	6/16	4/16	864
3/16	6/16	5/16	817
3/16	6/16	6/16	727
3/16	6/16	7/16	687
3/16	6/16	8/16	580

Table 19: PBD 3/16in andPTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	7/16	4/16	860
3/16	7/16	5/16	820
3/16	7/16	6/16	821
3/16	7/16	7/16	712
3/16	7/16	8/16	683
3/16	7/16	9/16	564

Table 20: PBD 3/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
3/16	8/16	4/16	824
3/16	8/16	5/16	815
3/16	8/16	6/16	800
3/16	8/16	7/16	831
3/16	8/16	8/16	747
3/16	8/16	9/16	597

Table 21: PBD 4/16in andPTD 6/16in at different ball sizes.

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	6/16	5/16	1302
4/16	6/16	6/16	1115
4/16	6/16	7/16	1017
4/16	6/16	8/16	999

Table 22: PBD 4/16in andPTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	7/16	5/16	1210
4/16	7/16	6/16	1301
4/16	7/16	7/16	1001
4/16	7/16	8/16	870
4/16	7/16	9/16	755

Table 23: PBD 4/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	8/16	5/16	1135
4/16	8/16	6/16	1112
4/16	8/16	7/16	1200
4/16	8/16	8/16	1000
4/16	8/16	9/16	854

Table 24: PBD 5/16in andPTD 7/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	7/16	6/16	1740
5/16	7/16	7/16	1602
5/16	7/16	8/16	1422
5/16	7/16	9/16	1394

Table 25 PBD 5/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	8/16	6/16	1700
5/16	8/16	7/16	1732
5/16	8/16	8/16	1502
5/16	8/16	9/16	1303

Table 26: PBD 6/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	8/16	7/16	2405
6/16	8/16	8/16	2222
6/16	8/16	9/16	1995

The effect of port bottom diameter, port top diameter, and ball size of the modified design on the gas throughput of the actual valve is similar to the Benchmark valve. The results revealed that the PTD size has no effect on the gas throughput whereas the PBD size show significant and direct effect on the gas throughput. For example, the PBD 4/16 and 5/16in, the gas throughput was 1112 MSCF/D and 1700 MSCF/D respectively at fixed PTD and Ball size. On the other hand, the ball size shows an inverselyproportional relation to the gas throughput. Forexample, the ball sizes 6/16in and 7/16in, the gas throughput was 1300 MSCF/D and 1000 MSCF/D respectively at fixed PBD and PTD sizes.

b) Optimized design seat results:

Six different seats and five ball sizes were used in this experiment. PBD (4/16in to 6/16in), PTD (8/16in to9/16in), and ball sizes (5/16in to 9/16in). The following Tables (27-32) show the results of the blowdowntest using the different sizes of seat and ball of the optimized design.

Table:27 PBD 4/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	8/16	5/16	1135
4/16	8/16	6/16	1239
4/16	8/16	7/16	1231
4/16	8/16	8/16	1022
4/16	8/16	9/16	864

Table 28: PBD 4/16in andPTD 9/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
4/16	9/16	5/16	1001
4/16	9/16	6/16	1010
4/16	9/16	7/16	993
4/16	9/16	8/16	1203
4/16	9/16	9/16	984

Table 29: PBD 5/16in andPTD 9/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	9/16	6/16	1575
5/16	9/16	7/16	1550
5/16	9/16	8/16	1561
5/16	9/16	9/16	1555

Table 30: PBD 5/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
5/16	8/16	6/16	1569
5/16	8/16	7/16	1600
5/16	8/16	8/16	1560
5/16	8/16	9/16	1120

Table 31: PBD 6/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	9/16	7/16	2200
6/16	9/16	8/16	2245
6/16	9/16	9/16	2173

Table 32: PBD 6/16in andPTD 8/16in at different ball sizes

PBD, in	PTD, in	Ball, in	Q, Mscf/d
6/16	8/16	7/16	2300
6/16	8/16	8/16	2221.5
6/16	8/16	9/16	1671

Like the modified design seat results, the optimized design results revealed that the PTD size almost has no effect on the gas throughput whereas the PBD size has proportional effect on the gas throughput, for example, for the PBD 5/16 and 6/16in, the gas throughput was 1600 MSCF/D and 2300 MSCF/D respectively at fixed PTD and Ball size. Moreover, the ball size shows an inversely proportional relation to the gas throughput. For example, for the ball sizes 6/16in and 9/16in, the gas throughput was 1569 MSCF/D and 1120 MSCF/D respectively at fixed PBD and PTD sizes.

IV. Comparison between Benchmark valve and actual valve using modified and optimized design:

A. Modified seat design:

All cases of different seat and ball sizes show that the actual valve is much better than the benchmark valve in terms of gas flow rate which results in more oil production. Examples of PBD, PTD, and ball sizes for both benchmark and actual valves are presented in the following figures.

Figures 7, 8 and 9, display higher gas flow rate for the actual valve as compared to the benchmark valve for allseat and ball sizes. Particularly, PBD 5/16in and PTD 8/16in seat design resulted in the highest gas throughput.

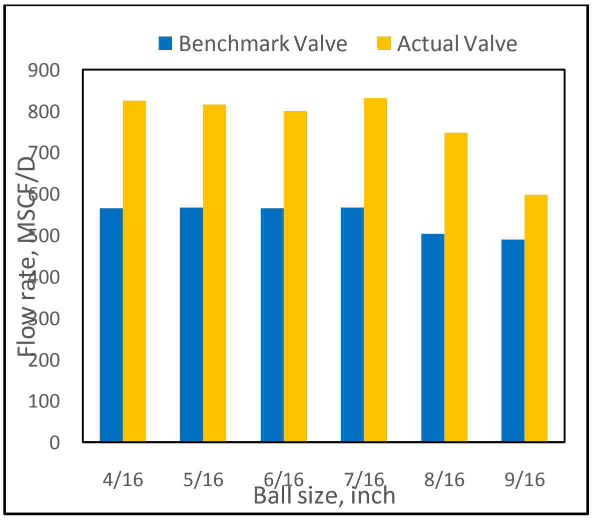

Fig 8: Effect of ball size on the gas throughputat PBD 3/16in and PTD 8/16in

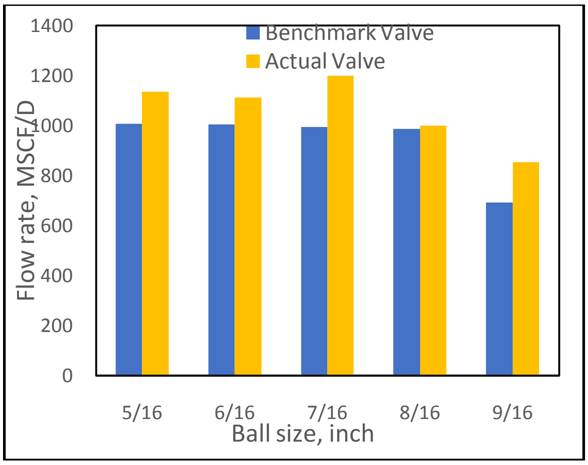

Fig 9: Effect of ball size on the gas throughput at PBD 4/16in and PTD 8/16in

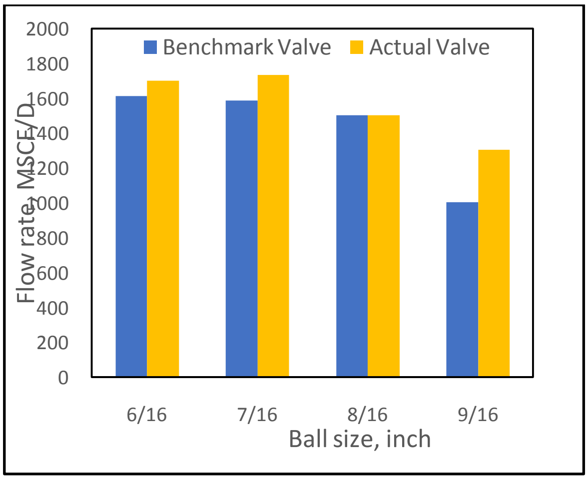

Fig 10: Effect of ball size on the gas throughput at PBD 5/16 in and PTD 8/16 in

B. Optimized Seat Design:

The results of optimized design were the same as the modified design for all different seat and ball sizes. These results demonstrate that using the actual valve gives higher gas flow rate than using the benchmark valve. Examples of PBD, PTD, andball sizes for both benchmark and actual valves are presented in the following figures 10, 11 and 12.

Among the different seat and ball size of the optimized design, PBD 6/16in and PTD 8/16inwere the best design that gave the highest gas flow rate.

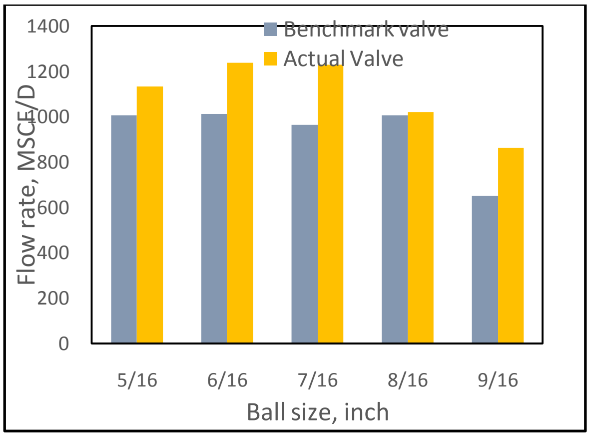

Fig 11: Effect of ball size on the gas throughput at PBD 4/16in and PTD 8/16 in

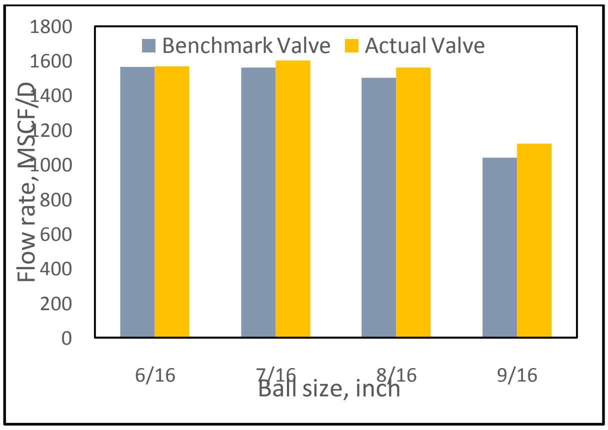

Fig 12: Effect of ball size on the gas throughput at PBD 5/16 in and PTD 8/16 in

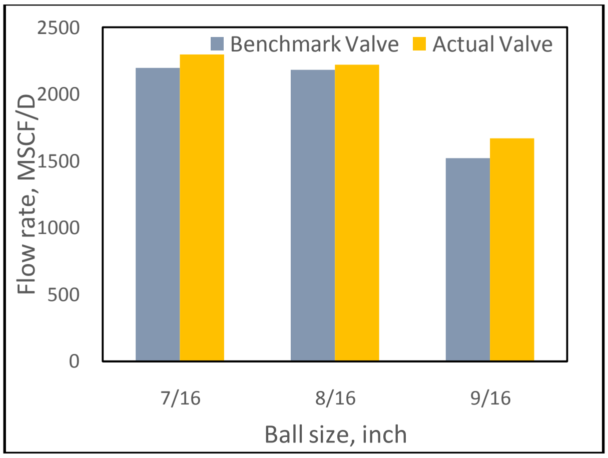

Fig 13: Effect of ball size on the gas throughput at PBD 6/16 in and PTD 8/16 in

To summarize the results of the all cases of the blowdown test, the optimized design is much better than the modified design using the actual valve. An example of the comparison between the modified design and optimizeddesign is shown in figure 13 where the flow rate obtained from the optimized design is higher by up to 11.4% than the modified design.

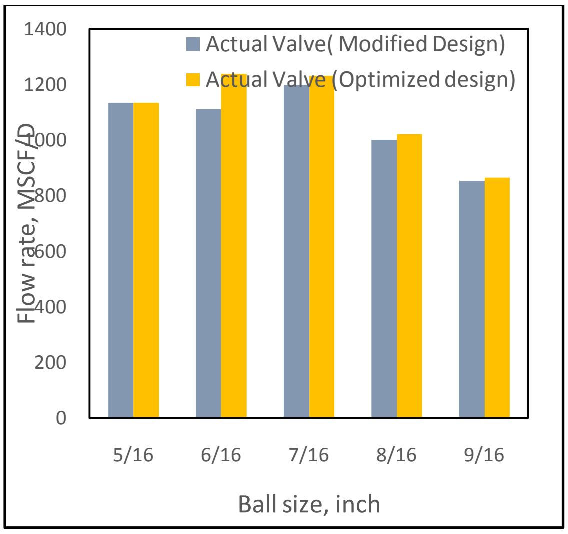

Fig 14: PBD 4/16 in and PTD 8/16 in

V. Conclusion

Two seat designs were investigated in this experimental study: modified and optimized seat designs using Benchmark valve and actual valve. The effects of ball diameter, Port Top Diameter (PTD) and Port Bottom Diameter (PBD) for modified and optimized seat designs were examined. 16 seat sizes and 6different ball sizes were used for both actual valve and benchmark valve to investigate the best gas throughput.

1. The results of the experiment demonstrate that the actual valve is better than benchmark valve because it gives higher gas throughput.
2. The gas flow rate using actual valve was higher than using benchmark valve by between 35% to 40% for both optimized and modified designs.
3. The experimental results also show that PTD size has no effect on the gas throughput whereas the PBD size show significant and direct effect on the gas throughput. In addition, the ball size is inversely proportional to the gas throughput.
4. The results also show that the best case in modified and optimized design using actual valve when Port Bottom Diameter (PBD) 6/16 in, Port Top Diameter (PTD) 8/16 inch with ball size 7/16. In this case the gas flow rate was 2300 MSCF/D and 2403 MSCF/D for modified and optimized designs respectively.
5. The best ball and seat design of the optimized design using actual gas lift valve could be implemented in field application to improve the oil production rate in gas lift wells.

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