IMPACT OF GAS LIFT INJECTION RATE ON OIL PRODUCTION RATE

Dr. Mohamed A. GH. Abdalsadig

Petroleum Engineering department, Facility of Petroleum and Gas Engineering, University of Zawia, Libya

mohamed682003@yahoo.com

Abstract

As worldwide energy demand continues to grow, oil and gas fields have spent hundreds of billions of dollars to build the substructures of smart fields. Management of smart fields requires integrating knowledge and methods in order to automatically and autonomously handle a great frequency of real-time information streams gathered from those wells. Furthermore, oil businesses movement towards enhancing everyday production skills to meet global energy demands signifies the importance of adapting to the latest smart tools that assist them in running their daily work.

A laboratory experiment was carried out to evaluate gas lift wells performance under realistic operations in determining reservoir pressure, production operation point, injection gas pressure, port size, and the influence of injection pressure on well performance. Lab VIEW software was used to determine gas passage through the Smart Gas Lift valve (SGL) for the real-time data gathering. The results showed that the wellhead pressure has a large influence on the gas lift performance and showed that the utilized smart gas lift valve can be used to enhanced gas Lift performance by regulating gas injection from down hole.

Keywords: Gas injection rate effect; Gas injection effect on well head pressure and Gas lift port size effect,

Introduction

Purpose of Artificial Lift

The purpose of artificial lift is to maintain a reduced producing BHP so the formation can give up the desired reservoir fluids. A well may be capable of performing this task under its own power. In its latter stages of flowing life, a well is capable of producing only a portion of the desired fluids. During this stage of a well flowing life and particularly after the well dies, a suitable means of artificial lift must be installed so the required flowing BHP can be maintained; Figures (1) and (2) Illustrate the Inflow/outflow performance of a dead well and flowing lifted well by using artificial lift techniques. Keeping the required flowing BHP is the basis for the design of any artificial lift installation; if a predetermined pressure drawdown can be maintained, the well will produce the desired fluids. This is true regardless of the type of lift installed.

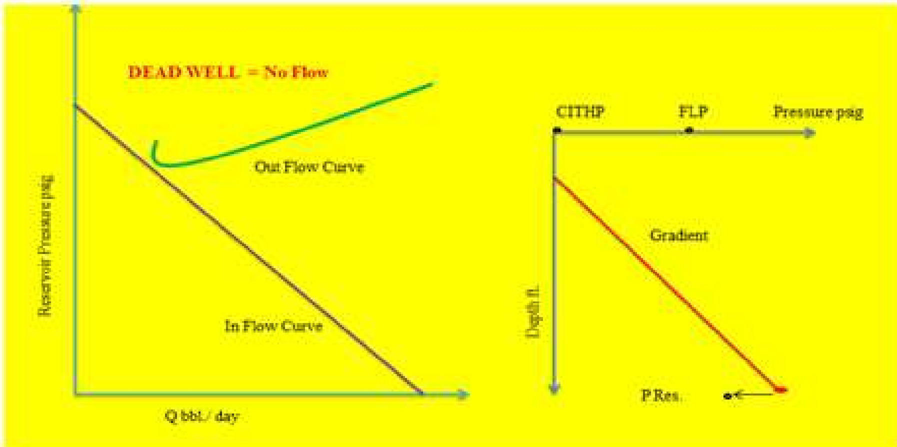


Figure (1): Illustrate the Inflow/Outflow Performance.

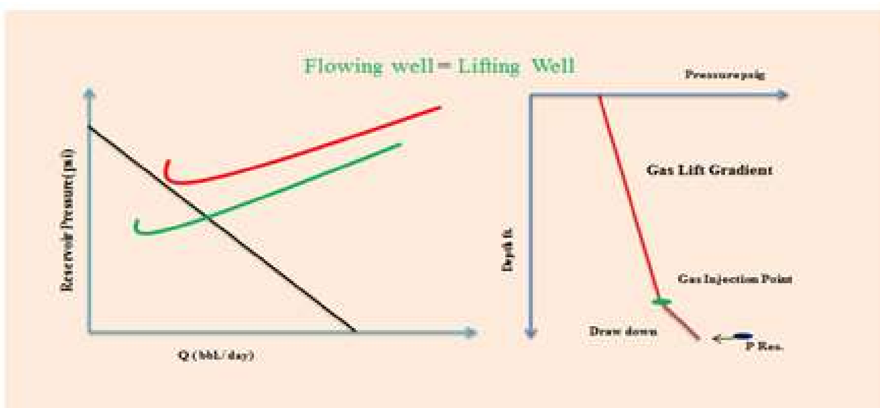


Figure (2): Illustrate Flowing Lifted Well by Using Artificial Lift Methods.

Statement of the Problems

Recent testing has specified that the gas lift valve regularly does not open completely in real operations. Subsequently, actual flow through the gas lift valve is significantly smaller than what would be expected when using full-open models. Unloading valves are spaced and sized to allow stepwise injection of gas at lower valves. This is accomplished by dropping the flowing tubing pressure reverse of these lower valves to a pressure less than the lower valves' casing pressure. The injection of gas at the upper valve reasons the flowing tubing gradient to be lightened and the tubing pressure to be reduced. Normally, the more gas that is injected at an upper valve, the lower the tubing pressure will be. If a valve is incapable of transporting sufficient gas to cause the tubing pressure at the following lower valve to be reduced below the casing pressure at that valve, transmission to the following lower valve will not happen. The importance of performance investigation of gas lift valve was demonstrated, in capitalize on production from gas lifted wells, by Laing (Laing, 1989). Stewart, etal. decreased orifice sizes of the gas lift valves and redesigned the gas lift headers to remove the problems of slugging and hydrate formation (Stewart, Goodacre and Cruicksank, 1989). Lagerlef informed that the gas lift valve quality assurance program was in place for Eastern Operation Area since 1981 (Lagerlef, 1993).Capucci etal. developed a true transient unloading model(Guerrero-Sarabia and Fairuzov, 2005). Bertovic, etal. described a theoretical analysis supported by experiments to determine a practical model for gas lift valve performance (Bertovic *et al.*, 1997).Yula et al. developed a novel transient model and dynamic simulator that describe the complicated appearances of the gas lift unloading process (Yula *et al.*, 1999). Faustinelli.et al.studied a new unified model that predicts the flow performance of nitrogen charged injection pressure that operated gas lift valves (Faustinelli, Epm and Doty, 2001). Shahri applied a method for measurement of injection gas throughput of gas lift valve before the well connection(Shahri and Winkler, 2011). Laboratory gas dynamic throughput shows that each injection worked GLV repeatedly does not open completely in real operated based on (Elldakli *et al.*, 2014).

Experiment setup

Figure (3) demonstrates the schematic diagram of the experimental setup which shows the major experimental components used in this investigation.

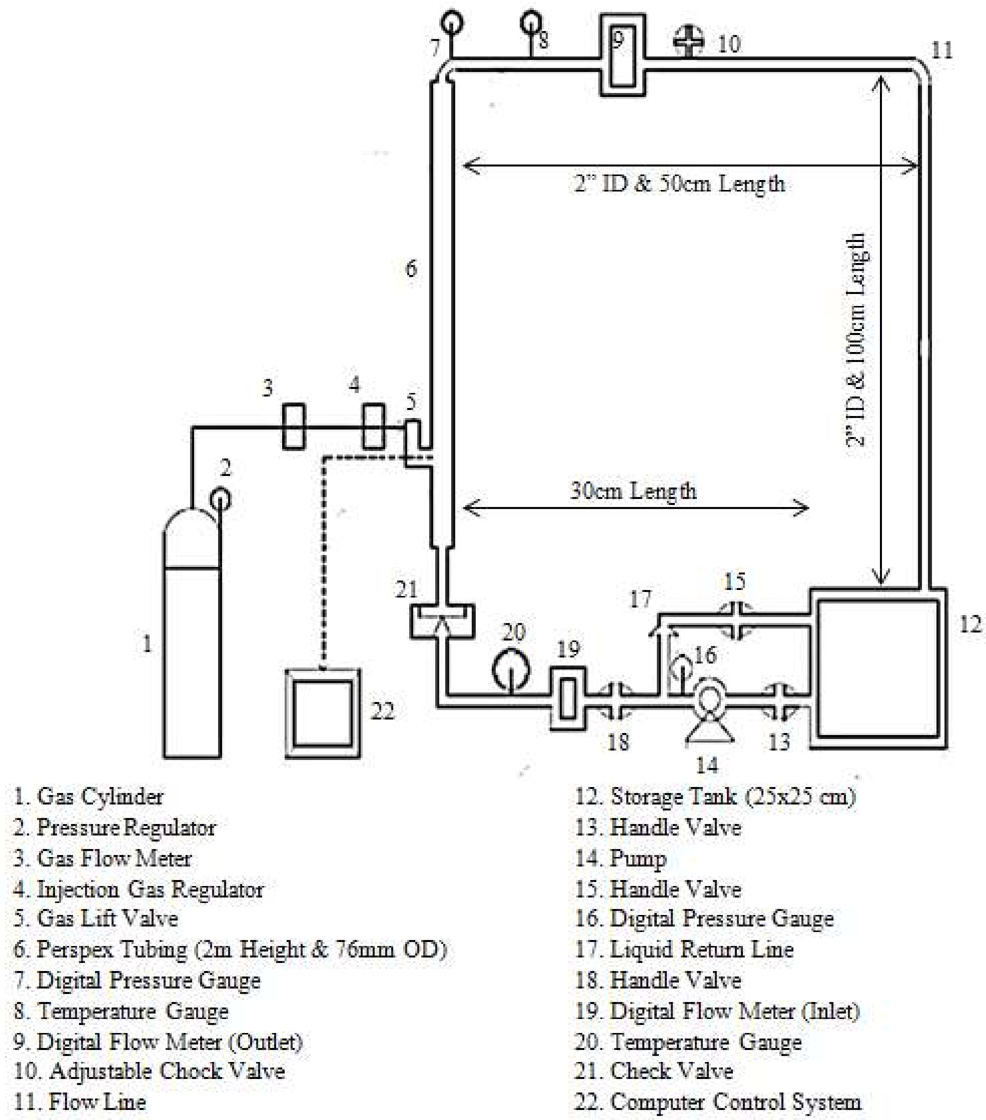


Figure (3): Schematic Diagram of the Experimental Flow.

Construction of the Experimental Setup

Connect the storage tank with the pump suction.

i. Connect hand valves at the tank and at the end and top of the rig.
ii. Install the return line from the discharge pump to the tank to control the pump discharge rate.
iii. Connect the pump to the bottom of the apparent pipe.
iv. Connect the measurement gauges (i.e. Pressure gauges, Temperature Gauges and Flow Meters) at the bottom and the top of the production string pipe to regulate the inflow and outflow rate.
v. Install the pressure devices at the pump suction and at the top of the rig.

vi. Connect the flow line from the well head to the storage tank.
vii. Make a hole with the size of the bottom of production pipe to apply it as injection point
viii. Connect the smart gas lift valve at the injection point
ix. Connect the smart valve with controller system
x. Fix the controller method with the processer database
xi. Connect the valve to electricity.

Measurement and Control Variables

There are numbers of potentials to regulate the entire system operation, such as:

i. Measurement and control the air injection volume to determine the optimum injection rate.
ii. Control and record the air injection pressure to obtain the optimum injection enter to the system.
iii. Record and observation the well head pressure is required to study the effect of injection rate pressure then volume on the well operation
iv. Record the inlet and outlet pressure of the system
v. Record the inlet and outlet flow rate to determine the efficiency of the gas injection operation.
vi. Operate the smart gas lift valve with different port size to study the effect of increasing or decreasing the port size on the production performance
vii. Investigation and evaluate the results.
viii. Adjustment of the pump speed so as to emulate different reservoir pressure situations
ix. Adjustment of the liquid feeding valve so as to affect the (well) down-hole pressure and water inflow.
x. Regulation of the gas injection valve so as to affect the gas injection rate.
xi. Controller of the choke valve at the top of the rig so as to control the two-phase flow out of the rig.

The Major Components of the Above Diagram are Described Below

Gas Cylinder, Pressure Regulator, and Gas Flow Meter

Operation of the gas energy is accomplished by the continuous injection of a controlled stream of gas into the liquid column to provide the lifting energy. In this study, a gas cylinder (or a compressor) was used to provide air as an injection media and the injection pressure and flow rate were controlled by a pressure regulator and manometer.

Automation Gas Lift Valve

The gas lift valve is a motorized control valve calculated to control the flow of air inside the transplant tube. A DC motor controls the opening width to regulate the flow. A potentiometer is integrated into the electrical actuator to imprisonment the position. A microcontroller enables numerical regulator. Double switches provide the physical control. The set point is displayed in percentage from 0-100%.

The valve was linked with a control line to provide actual opening or closing and could be run with an adaptable opening flow proportional rate with a computer program. The airflow rate that fed into the tubing could be controlled at a different flow rate and different injection pressure by using air, an injection regulator and air flow meter. A control valve is a power operated a device, which is capable of modulating the flow at variable degrees among minimal flow and full capacity in response to a signal from the computer program. A control valve is capable of changing the position of the flow controlling part in the valve. The valve moderates flow through the movement of a valve plug in relation to the port(s) located inside the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. The actuator is electrically operated; it directs the movement of the stem as dictated by the external control device. Figure (4) shows the Smart Gas Lift Valve and the injection point where the valve was connected and Figure (5) shows the experimental loop control system. As described earlier, the aim of this investigation is to control the injection port size remotely from the top surface. In this study, the valve port size varies from 4% to 100%.

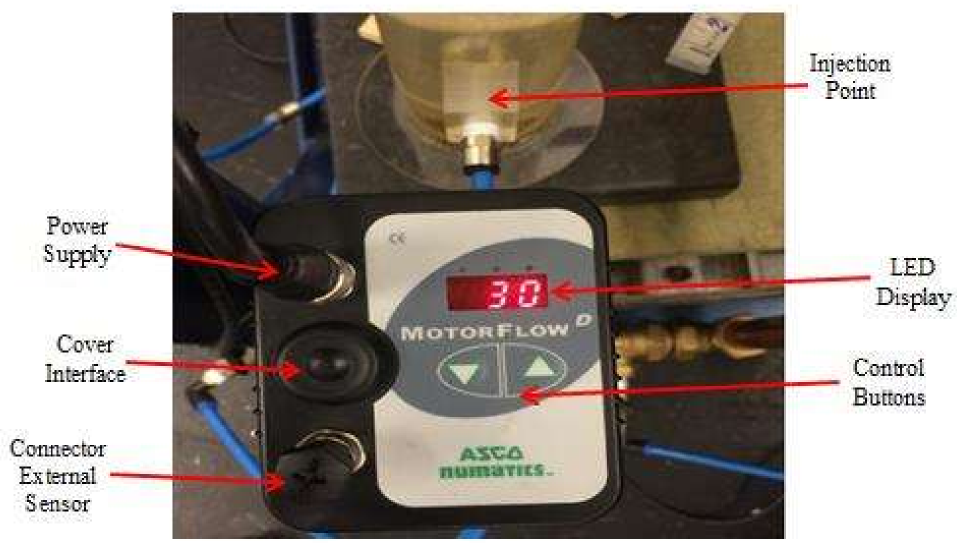


Figure (4): Automation Gas Lift Valve.

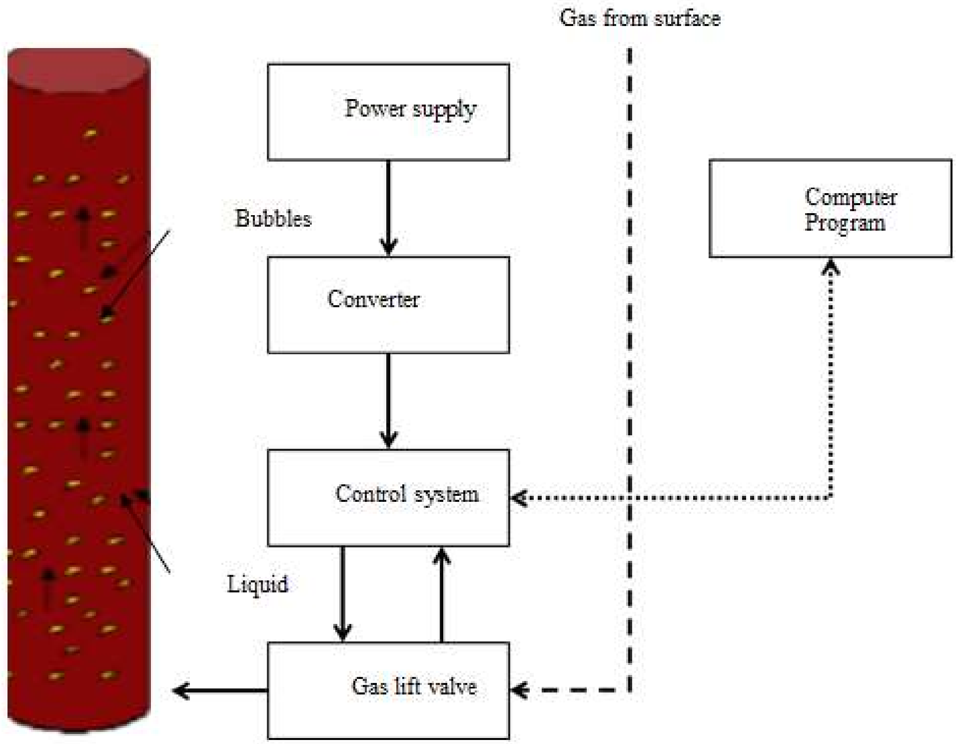


Figure (5): Gas Lift Control System.

A DC motor controls the opening port size to maintain the injection pressure and flow rate of the air into the system. A potentiometer was integrated into the electrical actuator to capture the opening position. A control valve is a power operated a device capable of modulating the flow at varying degrees between the minimal flow and full capacity in response to a signal from the computer program. A control valve is capable of changing the position of the flow controlling element in the valve. The valve modulates the flow through the movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. The actuator is electrically operated to direct the movement of the stem as dictated by the external control device. Figure 5 shows the experimental loop control system.

Practical electronic converters use switching techniques. By storing the input energy temporarily and then releasing that energy to the output at a different voltage, switched-mode DC-to-DC converters convert one DC voltage level to another, which may be higher or lower. The power converter that was used in the experiment to provide the constant voltage to the smart gas lift valve which has the following features:

Input AC voltage range: AC 100 – 240 V

- AC Input Frequency: 47 – 63 Hz.
- Productivity: $\leq$ 78%.
- Power factor: $\leq$ 0.9.

Constant voltage and current range selection:

- (16 V/ 5A) selection I.
- (27.6 V/3A) selection II.
- (0 – 36 V/ 2.2 A selection III.
- Characteristics: load regulation (0-100%).
- Line regulation $\pm$ 10%.
- Dimensions: 53.5 × 127 × 330 mm (2× 5×13 inch).
- Figure (6) illustrations the power converter that was used in the experiment to provide the constant voltage to the smart gas lift valve.
- Figure (7) illustrates the control loop which was used to control the smart gas lift operation. The control consists of a controller, a final control element process, and the sensor. This controller was connected with the computer program by utilizing USB connection.

Figure (6): Power Converter.

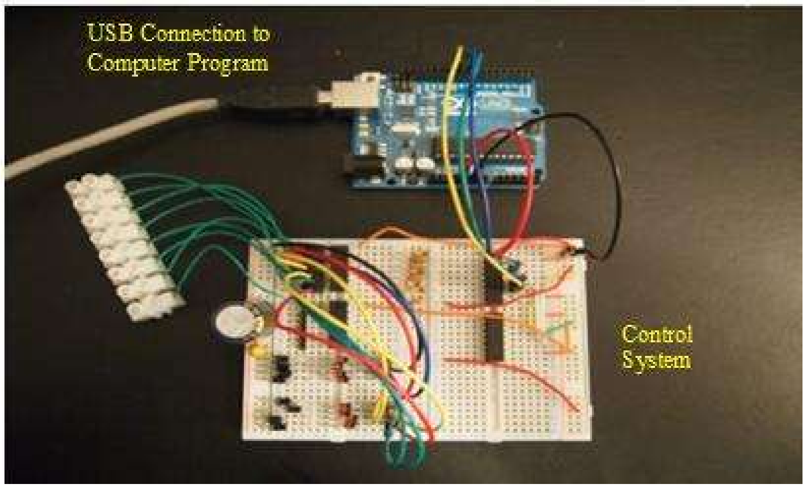


Figure (7): Experimental Control Loop

Perspex Tubing (2m Height & 76mm OD)

In an oil field, the production tubing includes several pipelines linked together in order to achieve the reservoir and reach the production target. The design of this tubing, mainly, depended on the reservoir geometric configurations. In this experimental study, the production well tube was simulated by using a 2 m PVC tube to have better visualization and see the flow regimes and fluctuations at different locations that could be visually detected.

Pressure Gauges (Inlet and Outlet)

As can be seen in Figure (3), there are two pressure gauges installed in this experimental work as indicated #7 and #16. The first gauge is to measure the pressure of the flow coming out of the well tube (which is called pressure head) and the second gauge is located after the pump to measure the inlet flow going to the system which is simulating the reservoir pressure.

Digital Temperature Gauge

The oil coming from the reservoir has normally high temperature (about 240°C). Therefore, this experimental setup consisted of two digital temperature gauges to monitor any changes from the reservoir to the top surface (see #8 and #20 in Figure (3)). The first temperature gauge had been located after the pump to show the reservoir temperate and the second one was installed at the top of the PVC tube to monitor the flow temperature in the top surface.

Digital Flow Meter (Outlet)

In this paper, two different well reservoirs were considered: (i) Natural Flow Well, in which the fluid flow rate was almost constant from the reservoir up to the top surface. This was due to having high pressure of the reservoir. (ii) Gas Lift Well, in which the reservoir pressure was not enough to push the fluid coming out of the production tubing which means that the outlet flow was almost zero. Therefore, an external energy needed to be applied to assist the production. In this experimental setup, the first digital flow meter was installed after the pump to record the reservoir flow rate (see #19 in Figure (3)) and the second digital flow meter was located at the top to presents the flow rate coming out of the production tubing (see #9 in Figure (3)).

Storage Tank (25x25 cm)

The petroleum reservoir is a subsurface pool of hydrocarbons contained in permeable or cracked rock formations. The naturally occurring hydrocarbons, such as crude oil or natural gas, are surrounded by overlying rock formations with lower permeability. In this experiment, a 25x25 cm plastic storage tank was used to simulate an oil reservoir.

Pump (Reservoir Pressure)

An adjustable speed pump system (see Figure (3) and (6)) was used to stimulate the real reservoir pressure. The well endpoint (down-hole) was linked to the pump and was controlled to produce proper pressure (referred to as reservoir pressure) at the discharge of the pump system. A manual valve downstream of the pump system was used to match the difference in pressure between the reservoir and the down-hole pressure. The discharge pump system was measured by a flow meter.

Check Valve

The prime function of a check valve is to protect mechanical equipment in a piping system by preventing reversal of flow by the fluid. This is particularly important in the case of a pump, where backflow can damage the internals of the equipment and cause an unnecessary shutdown of the system.

Computer Program

Smart completion technology permits engineers to enhance production or injection programs, develop reservoir performance, reach higher extraction ratios, and decrease field growth and interference charges. The technologies dependability has been established in high-productivity wells are appropriate for determining smart completions that are today being connected in wells with lower efficiency to assist in safeguarding against reservoir uncertainties and deliver incremental production. To control the injection of air with lift valve a computer program was connected to the valve with databases. The gas lift valve was opened at different percentages with a range from 0 – 100.

Experiment Results

The gas lift technique can be used for both type of wells explained above. This technique keeps the bottom-hole pressure low enough to provide a high-pressure difference between the reservoir and the bottom-hole. Reduction of the bottom-hole pressure will normally increase the liquid production rate. However, injecting too much gas into the system may cause increasing of the bottom-hole pressure which will lead to declining the production rate due to the back pressure. In order to achieve the optimum production rate, the port size of the gas lift valve and the gas injection pressure (bottom hole) must be controlled to provide a certain amount of gas to improve the productivity. This investigation, therefore, focused on the effect of three different gas injection pressures namely low (29 psi), medium (58 psi) and high (87 psi) (due to limitation of the experiment) on Production Rate and Well-Head Pressure for both Natural Flow Wells and Gas Lift Wells (or dead wells).

Using the modified simulated apparatus described in the paper, a number of configurations with respect to Natural Flow Wells and Gas Lift Well together with ‘Smart Gas Left Valve’ were tested.

Table (1) summaries of these the results of configurations the following discussed of:

Table (1): The Details Information of the Natural Flow Wells and the Gas Lift Wells.

Well Number	Type of Well	Initial Pump Pressure (psi)	Initial Flow Rate (l/min)
NFW-1	Natural Flow	4.0	25
NFW-2	Natural Flow	2.5	10
GLW-1	Gas Lift (Dead)	1.0	0
GLW-2	Gas Lift (Dead)	0.5	0

Effect of Gas Injection Pressure on to the Production Rate and Well-Head Pressure

As mentioned previously, the gas lift technique can be used for both types of wells (Natural flow wells and the Gas lift wells). This technique keeps the bottom-hole pressure low enough to provide a high-pressure difference between the reservoir and the bottom-hole. In this study, the effect of the injection pressure on to production flow rate was carried out.

The pressure that spikes higher can indicate a problem but the more typical ones will be a cause for concern about damage. A high-pressure event can rupture the wellhead, flow line, a valve or other component, damaging a separator, compressor, or other equipment. It is critical to monitor all pressure conditions at the well head pressure as part of the standard safe operating procedure.

It has been mentioned above that the traditional gas lift technologies have design limitations on gas lift valve such as multi-point of injection, nitrogen charge and, pressure operated valve is very sensitive to well performance condition such as pressure, temperature and casing pressure. Also, the gas injection rate cannot be controlled (Forero *et al.*, 1993). Furthermore, operating a gas-lift under low or high gas-lift injection rate has some disadvantages. First, the full lift potential in the gas is not accurately used, resulting in a very inefficient operation. Secondly, pressure surges in production facilities may be so huge that severe operational problems can happen (Use and Analysis, 1988). Furthermore, lift gas flow is not completely controlled. Nevertheless, it was suspected that stability might be brought to the unsteady well by using a control valve to adjust its gas flow. The best gas lift applications used an injection pressured operation valve to regulator lift gas to the well. This means that most engineers can only guess the flow rate being delivered to the bottom of the well. They are not able to control it properly (Avest and Oudeman, 1995). In this research, smart gas lift valve was used to examine the effect of valve port size and none of the difficulties mentioned above were experienced.

Gas lift valves are considered the heart of the gas lift system of controlling the amount of the gas that enters in the tubing string. In this smart gas lift valve, the gas was injected continually and monitored from the surface in order to prevent any dynamic changes that might happen; if well performance changed, gas lifting injection rate could be increased or decreased depending on well performance.

Well Natural flow: NFW -1

As shown in Table (2), the well NFW-1 was assumed to have 4-psi reservoir pressure and producing 25 lit/min before applying gas injection technique. Although the well was flowing naturally, gas-lifting system could be applied to achieve higher production rates. Table (2) presents the results of low gas injection pressure (29 psi) onto the NFW-1 and Figure 8 demonstrates these results graphically.

Table (2): The Results Summary of Low Gas Injection Pressure onto the NFW-1.

Valve Description		Production Rate (l/min)	% of Increase in Production Rate	Well-Head Pressure (psi)
% of Opening	Port Size (mm)			
4	0.25	26.1	4	1.3
15	0.95	26.6	6	0.9
30	1.91	27.0	8	0.9
50	**3.18**	**27.6**	**10**	**0.9**
65	4.13	27.0	8	0.9
80	5.08	26.5	6	0.9
100	6.35	26.0	4	1.4

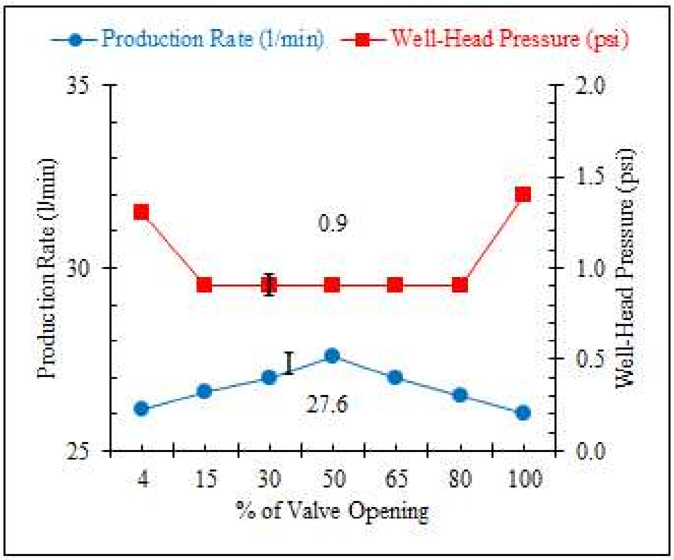


Figure (8): Effect of Low Gas Injection Pressure (29 psi) for NFW-1.

As shown in Figure (8), the overall result indicates that the production rate for NFW-1 well increases from 25 lit/min from the baseline with the application of low gas injection pressure of 29 psi. Figure (8) also shows that the improvement on production rate is made at about 4% on the commencement of the gas injection process. This can be aligned to 4% of the valve port size opening (or 0.25 mm port size diameter) in which the wellhead pressure is at the maximum level of 1.3 psi (as shown in Figure (8)). The production rate will then rise to the maximum value of 27.6 lit/min with the 50% opening of the valve port size (or 3.18 mm port size diameter). This increase is due to the reduction of the wellhead pressure from 1.3 psi to 0.9 psi that provides more pressure drop in order to push the liquid to the surface. The production rate eventually declines to 26 lit/min when the valve is fully open and the wellhead pressure increases to the maximum value. This reduction of flow rate is due to the more gas being injected onto the system, which generates gas bubbles within the liquid column. These gas bubbles tend to combine and form the slug characteristics within the production tubing thus it will partially block the production tubing. Injecting high amounts of gas raised the bottom-hole pressure that led to a reduction of the production rate. This was due to the high gas injection rate that caused slippage. In this case, the gas phase moved quicker than the liquid phase, leaving the liquid phase behind and a smaller amount of liquid flowed along the tubing. Therefore, there should be an optimum gas-injection rate. Although the control of pore-size could be cumbersome with smart valve system, this problem can be mitigated.

Table (3) summarizes the results of medium gas injection pressure (58psi) onto the NFW-1 and Figure (9) presents these results graphically.

Table (3): The Results Summary of Medium Gas Injection Pressure onto the NFW-1.

Valve Description		Production Rate (lit/min)	% of Increase in Production Rate	Well-Head Pressure (psi)
% of Opening	Port Size (mm)			
4	0.25	29.0	16	1.2
15	0.95	29.5	18	1.0
30	**1.91**	**31.0**	**24**	**1.0**
50	3.18	30.2	21	1.0
65	4.13	30.0	20	1.0
80	5.08	29.5	18	1.0
100	6.35	29.1	16	1.3

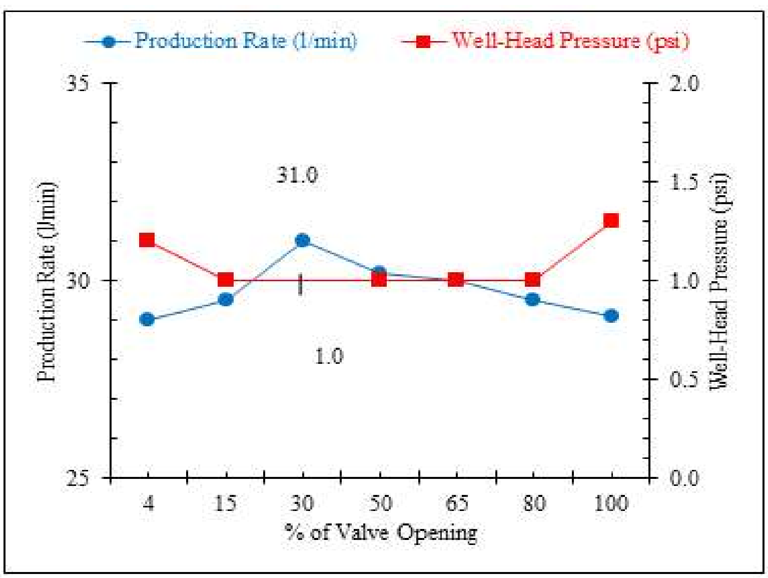


Figure (9): Effect of Medium Gas Injection Pressure (58 psi) for NFW-1.

Figure (9) shows the overall improvement of the production rate on NFW-1 with medium gas injection pressure at 58 psi. The result indicates that the flow rate increased to 29 lit/min (about 16% improvement on flow rate) from the baseline of 25 lit/min at the beginning of gas injection when the valve port size was partially open at 4% (or 0.25mm port size diameter). The wellhead pressure is also 1.2 psi which is the highest value. The production rate rose gradually to the optimum level of 31.0 lit/min with the 30% opening of the valve port size (or 1.91mm port size diameter). This increase shows an improvement of 24% in the production rate. Furthermore, the wellhead pressure was reduced to 1.0 psi which provided higher-pressure drop and hence a better improvement on production rate. The wellhead pressure then remained constant whereas the flow rate slightly decreased to 29.5 lit/min when the valve port size was 80% open (or 5.08 mm port size diameter). Fully opening the valve increased wellhead pressure up to 1.3 psi at the minimum production rate, 29.1 lit/min . Comparing the maximum flow rate level at medium gas injection pressure with those at low gas injection pressure shows a better achievement in production; it is about 3.4 lit/min in difference (27.6 lit/min with low gas injection pressure and 31 lit/min when the medium gas injection pressure used).

Table (4) summarizes the results of high gas injection pressure (87 psi) onto the NFW-1 and Figure 11 presents these results graphically.

Table (4): The Results Summary of High Gas Injection Pressure onto the NFW-1.

Valve Description		Production Rate (lit/min)	% of Increase in Production Rate	Well-Head Pressure (psi)
% of Opening	Port Size (mm)			
4	0.25	29.3	17	1.0
15	**0.95**	**31.0**	**24**	**1.0**
30	1.91	28.7	15	1.0
50	3.18	27.6	10	1.2
65	4.13	27.2	9	1.2
80	5.08	26.0	4	1.4
100	6.35	25.5	2	1.5

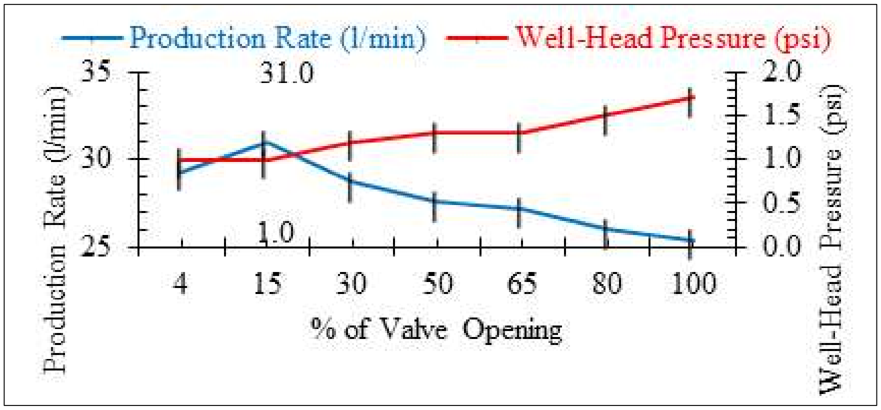
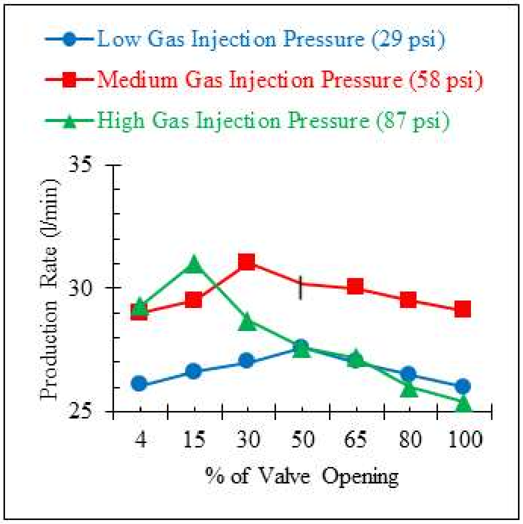


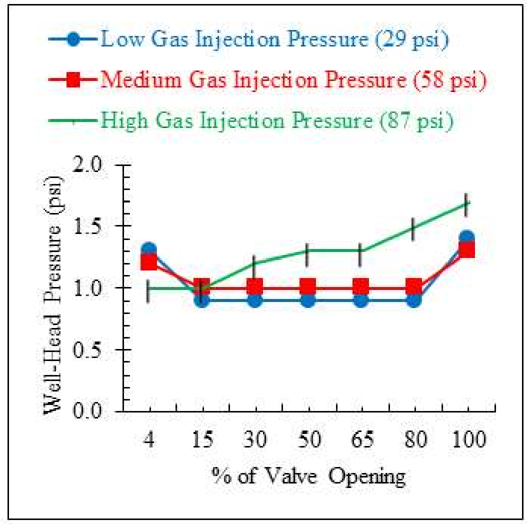
Figure (10): Effect of High Gas Injection Pressure (87 psi) for NFW-1.

Results shown in Figure 10, presents the maximum production rate of 31.0 lit/min (or 24% improvement on production). It could be achieved when the high gas injection pressure at 87 psi was used and when the valve was 15% open (or 0.95mm port size diameter). The flow rate then decreased sharply to the minimum level of 25.5 lit/min. Comparing this value with the 25 lit/min at the baseline shows that the production stopped. At gas injection commencing, the wellhead pressure was at 1.0 psi, and it remained constant until the production rate reached the maximum level. Then it rose dramatically to 1.7 psi when the valve was fully open. This issue was caused by injecting too much gas into the system in which the gas bubbles within the production tubing generated rapidly. Since the injection of the pressure was higher, the bubbles combined faster than when injecting gas at low pressure. Thus the complete blockage will occur and the production will stop.

Figure (11) shows the comparison of the all three gas injection pressures onto the NFW-1.



(a) Production Rate



(b) Well-Head Pressure

Figure (11): Summary of Different Gas Injection Pressures on Production Rate for NFW-1.

Although NFW-1 flows naturally however as shown in Figure 4, the application of gas lifting system with different gas injection pressures helps to increase the production rate (see Figure (11a)) , and maintains well-head pressures (see also Figure (11b)). Injecting the gas at low and medium pressures increases the production rate constantly and the wellhead pressures differ slightly.

When using these two injection pressures, gas bubbles generation within the liquid column can be controlled better than when injecting the gas at high pressure. When the gas is injected at high pressure, the slight increase in the valve port size can block the production tubing due to the generating of the too much gas bubbles and rapid increase of wellhead pressure. Therefore using the novel method of gas injection using a smart gas lift valve can assure the user to control and monitor the valve port size from the surface at all the time and reduce or increase the valve port size as required.

Conclusion

- It can be concluded that smart gas lift valve is capable of aiding faster continuous flow gas lift optimization process as it can be used to determine the optimum flow rate in gas lift system.
- Obtaining the optimum gas-injection rate is important because oil production increases as gas injection increases. However, injecting excessive gas will reduce production rate and increase the operation cost due to the high gas prices and compressing costs.

- Wellhead pressure is transmitted to the bottom of the hole, reducing the differential into the wellbore thereby reducing production and, at the same time, increasing injection gas requirements. So low wellhead backpressure is of a prime importance as it allows increased draw down, enhanced gas lift efficiency and thereby production can be increased, and lift power decreased.

- The results prove that the wellhead pressure has a major influence on gas lift performance and that a smart gas lift valve can help to improve gas lift performance by controlling gas injection from downhole. Obtaining the optimum gas-injection rate is important because excessive gas injection declines the production rate and increases the operational cost.

- When the gas is injected at high pressure, the slight increase in the valve port size can block the production tubing due to the generation of the too much gas bubbles and the rapid increase of wellhead pressure. Therefore using the novel method of gas injection, the smart gas lift valve, can assure that the user can control and monitor the valve port size from the surface at all the time and can decrease or increase the valve port size as required.

Reference

- Avest, D. and Oudeman, P. (1995) 'A Dynamic Simulator to Analyse and Remedy Gas Lift Problems.', *SPE,30639*.

- Bertovic, D. *et al.* (1997) 'Calculating Accurate Gas Lift Flow Rate Incorporating Temperture Effects'. Oklahome.

- Capucci, E. C. and Serra, K. V. (1991) 'Transient Aspects of Unloading Oil Wells Through Gas-Lift Valves', *SPE Annual Technical Conference and Exhibition*. doi: 10.2118/22791-MS.

- Elldakli, F. *et al.* (2014) 'Improved Gas Lift Valve Performance using a Modified Design for GLV', (Winkler 1987).

- Faustinelli, J. G., Epm, P. and Doty, D. R. (2001) 'SPE 69406 Dynamic Flow Performance Modeling of a Gas-Lift Valve'.

- Forero, G. *et al.* (1993) *Artificial Lift Manual Part 2A*. Hague.

- Guerrero-Sarabia, I. and Fairuzov, Y. V (2005) 'Effect of Operating Valve Performance on Stability of Gas Lift Wells', *SPE Annual Technical Conference and Exhibition*, p. 7. doi: 10.2118/97275-MS.

- Jahanshahi, E. *et al.* (2008) 'Modeling and Simulation of Instabilities in Gas- L ifted Oil Wells', *Spe*, 112108(March), pp. 12–14.

- Lagerlef, D. L. (1993) ‘Quality Assurance: Bellows-Operated Gas-Lift Valves’, *Proceedings of SPE Western Regional Meeting*. doi: 10.2523/26100-MS.

- Laing, C. (1989) ‘Gas-Lift Design and Production Optimization Offshore Trinidad’, *SPE Production Engineering*, 4(2), pp. 135–141. doi: 10.2118/15428-PA.

- Shahri, M. A. and Winkler, H. W. (2011) ‘SPE 141055 Practical Method for Measurement of Injection-gas Throughput of Each Gas-Lift Valve before Well Installation’, pp. 1–7.

- Stewart, D. J., Goodacre, J. and Cruicksank, C. (1989) ‘Bass Strait: Production Decline Mitigation’, *SPE, 19467*.

- Use, T. and Analysis, S. (1988) ‘WE 17584 The Use of Systems Analysis in the Design of a Gas-Lift System’.

- Yula, T. *et al.* (1999) ‘Transient Dynamic Characteristics of the Gas-Lift Unloading Process(includes associated papers 57662 and 57711)’, *SPE Journal*, 4(3). doi: 10.2118/57659-PA.