SPE 69402

New Gas-Lift Pilot Valve Increases Gas-Lift Efficiency

Ali Hernandez, SPE, PDVSA Intevep; Cesar Perez, Balmiro Villalobos, Analis Romero, PDVSA EP; Sam Wildman, Altec Inc.

Abstract

The most important component in an intermittent gas lift installation is the pilot valve. Its selection and proper calibration determine the success of the gas lift design. Recent tests performed in a field scale installation equipped with an experimental well and careful observations of the performance of real wells on intermittent gas lift in Lake Maracaibo have shown the importance of the proper selection of the area ratio of the pilot section and the main port diameter. Usually, the designer has a variety of area ratios of the pilot section to choose from and its selection will depend on the type of gas lift operation, choke controlled or use of time-cycle controllers, and the volume of gas needed per cycle. In some cases, the lowest commercially available area ratio will still be too large with the result of not being able to inject below a certain volume of gas per cycle. The over-injection per cycle takes place because the minimum spread attainable is greater than needed. This situation occurs when the tubing-casing annulus is large and the valve size that can be installed in the well is smaller than the 1 ½-inch valve. Hundreds of wells in Lake Maracaibo with 7-inch casings and 2 7/8-inch tubing can not be efficiently lifted because of the lack of commercially available pilot valves with small area ratios.

The diameter of the main gas injection orifice is a fixed value for a particular valve model. The size of this orifice is important for two reasons:

The size of the injection orifice, together with the injection pressure and tubing load, determines the velocity of the liquid slug being lifted. If the size of the orifice is too small, which is usually the case for 1-inch size valves, the liquid fallback is increased due to low liquid slug velocities.

Small injection orifice diameters increase gas injection time and therefore limit the liquid production of the well, especially if the optimum cycle time is of short duration.

Tests performed in an experimental well, and presented in this paper, show how a new 1-inch pilot valve design was able to increase the gas lift efficiency. The main features of the new gas lift valve, its calibration procedure and its performance in several real wells are also presented in this paper.

Introduction

The main components of a gas lift pilot valve are shown in **Fig. 1**. There are two main sections in a pilot valve: the pilot section and the power section. The pilot section controls the opening and closing pressure of the valve. The difference between the opening and closing pressure is called the spread of the valve and it is determined by the area ratio of the pilot section. The area ratio of the pilot section is defined as the ratio of the pilot section seat area and the bellows area. The value of the opening pressure is determined by the tubing production pressure and the pressure of the nitrogen inside the bellows for bellows charged valves, or the setting of the spring for a spring loaded valves, or a combination of both spring and bellows pressure. Once the pilot section opens, the power section is activated and the power piston is lowered allowing the gas in the casing annulus to enter the production tubing. The power section seat determines to a large degree the gas flow rate that the valve can pass.

Even with the use of surface cycle controllers, subsurface gas lift pilot valves are highly recommended for a well on intermittent gas lift. Pilot valves provide a variety of area ratios independently of the main port or power seat diameter. On the other hand, for single element valves, the valve area ratio determines the size of the injection orifice and this might lead to an unwanted situation: if the required area ratio is small, then the gas would have to pass through a small seat area. This affects the efficiency of the lifting process for two reasons:

- It has been found that the fall back losses increase as the injection orifice diameter decreases, ref. 1 and 2.
- The required time for the injection of a certain volume of gas might be increased to a point that the daily production of the well might fall. This is specially true for wells requiring a high cycle frequency.

A force balance perform on a valve just before it opens will result in the following equation:

$$R = \frac{spread}{pvo - pt} \tag{1}$$

For fixed tubing and casing opening pressure, the spread is increased only if the area ratio is increased. On the other hand, for fixed area ratio and casing opening pressure, the spread can only be increased, to some extend, if the tubing pressure decreases. The area ratio is then a very important design parameter since it determines the volume of gas to be injected for choke controlled intermittent gas lift. If the lowest available area ratio is too large compared to the area ratio needed, gas will be over injected. This is specially trued in wells with large casing diameters, small tubing o.d. and gas lift mandrels for small valves. Through careful observation in a controlled environment, ref. 1, it was found that the real spread of the valve deviates from what equation 1 predicts. Spring-loaded valves tend to close at a higher pressure giving smaller spreads. Nitrogen charged valves tend to close at a lower pressure giving a larger spread. More research is needed on this subject to gain understanding of the dynamic behavior of pilot valves.

While the spread determines the total volume of gas to be injected per cycle, the main injection orifice determines the rate at which the gas will flow, which in turn determines the gas injection time. The gas flow rate has to be high enough so as to maintain a liquid slug velocity at about 1000 ft/min. This means that a pilot valve should remain open for a period of time, in minutes, approximately equal to the measured depth of the well in 1000 ft. A mass balance of the gas in the annulus yields an expression for the gas injection time, tinj:

$$tinj = \frac{\left(\frac{V}{2}\left(\frac{MW}{z1 * Ru * T1} + \frac{MW * \exp(.01875(dv)Gg/(\bar{z}\bar{T}))}{z2 * Ru * T2}\right)\right)(spread)}{m2 - m1} \tag{2}$$

So the gas injection time is directly proportional to the spread of the valve and the annulus volume, and it is inversely proportional to the mass flow rate through the gas lift valve, m2, minus the gas flow rate through the surface injection choke. Additionally, m2 depends on the gas injection pressure minus the tubing pressure and the valve's internal restrictions to the gas flow. One way then to reduce the gas injection time is to increase the gas flow rate through the valve by reducing flow restrictions through it as much as possible.

The influence of the spread of the valve and its internal flow restrictions on the lift efficiency is illustrated in this paper by several field experiences described below.

New Pilot Valve Main Features

The new 1-inch pilot valve is designed utilizing non-traditional packing, seals, and materials. This approach made it possible to produce a 1-inch pilot valve that features improved performance and durability.

Utilizing larger inside diameter packing allows for the area through the packing barrels to be increased. This makes it possible to use a more desirable dome spring and increase flow area through lower packing barrel without compromising strength. These features enhance the repeatability and internal flow path of the valve.

The upper reciprocating piston seal is of different design and self-lubricating. This replaces a reciprocating o-ring piston seal that is lubricated by a Teflon ® extrusion ring. The new type seal contributes to the durability of the valve.

The lower end of the power section piston and piston cap is the most susceptible to damage due to being situated in the flow path of the injection gas. To minimize this susceptibility, low pressure or non-metal seals are removed from piston cap and placed out of flow path. The seal is captured and held securely in place by the piston body as components are assembled.

A double heat-treated stainless material is utilized for the piston, piston cap, piston housing, seat housing and stem. With this material, the internal dimensions are increased.

The benefits are; improved injection gas performance and allows for a larger bellows. The large bellows significantly increases the range of area ratios.

The reverse flow check design is found in some brands of 1½-inch pilot valves but not commonly found in 1-inch pilot valves. Reverse flow is prevented by a ball and seat combination being placed in the lower end of the power section piston. This allows for an unobstructed injection gas flow path beyond power section seat.

The new valve features a combination of spring force and nitrogen pressure in the dome. The combination contributes to the predictability of the operating pressure of the valve. The nitrogen charge is added to supplement the spring force and make the valve's calibration easier to perform. The combination adds steps to the calculation process when solving for the test rack opening of the valve, see equations a.1 and a.2 in the Appendix.

Field Scale Tests

The new pilot valve was tested in 1999 in a test well located in Western Venezuela, ref. 1 and 3. The gas lift mandrel was located in a 2 7/8 in tubing at a depth of 2500 ft. The production casing size was 7 in (23 #/ft). The injection pressure was approximately 900 psi. Columns of 500 ft in length of 23 API oil were lifted. The tubing opening load was 260 psi.

Prior to the tests described here, several commercially available valves were tested. The performance of the new pilot valve was compared with the commercially available valve that showed the best performance. **Fig. 2** shows the performance of the new valve compared with the performance of the other valve. The fall back plotted in **Fig. 2** is the percentage of the initial slug that could not be lifted per thousand ft of point of injection depth. The new valve size was of only 1 inch o.d. and the comparison was made with another valve of 1 ½ in o.d. It was not possible to test the new valve against another 1 in valve because the lowest volume of gas that could be injected per cycle with a 1 in valve was 800 standard ft^3 above the gas required to achieve the minimum fall back. This was due to the fact that the lowest area ratio of the commercially available valve was still too large. This would have implied an over injection in a real well.

As can be seen in **Fig. 2**, the gas required per cycle, for a given fall back, is about the same for both valves.

Table 1 shows that the new 1 in valve can achieve a greater gas flow rate with less pressure drop than the other 1 in commercially available valve.

Pilot Valve Performance in Real Wells

The new valve has been tested in three wells in Lake Maracaibo. The operational performance of each well, before and after the installation of the valve, is presented and analyzed here. The operational characteristics of each well are presented in **Table 2**. Well A and B were on choke controlled intermittent gas lift. Well C had a surface controller installed at the well head to control the cycle time and the volume of gas injected per cycle.

Well A

This well was producing 65 Br/d when it was on continuous gas lift. The production increased to 90 Br/d after a pilot valve was installed. The pilot valve installed was a commercially available valve with the minimum area ratio.

The casing injection pressure trend before and after the installation of the new valve is presented in **Fig. 3**. The injection time before the installation of the new valve was 15 minutes. For the valve depth of this well, the gas injection time should be around 5 or 6 minutes. So the injection time was about twice the required injection time. After the installation of the new valve, the gas injection time was reduced to 7 minutes passing about the same total volume of gas per cycle. The total gas injection per day was reduced because the cycle time was increased. The volume of gas injected per cycle was around 11000 ft^3 at standard conditions. Tests performed at the experimental well in Western Venezuela indicated that the volume of gas needed for this well was of only 6000 standard ft^3 per cycle. But since the area ratio of the new valve was not the lowest possible, there is still a chance of reducing the daily gas injection even further. A pressure survey conducted according to a procedure described in ref. 4 indicated that the fall back losses were below 3% per thousand ft of valve depth.

Well B

This well was producing 70 Br/d with a nitrogen charged pilot valve. The production increased to 84 Br/d after the installation of the new valve. The volume of gas injected per cycle was reduced from 5380 to 3500 standard ft^3, but the daily injection volume stayed about the same because the cycle time was reduced when the new valve was installed. A pressure survey was run after the installation and it was found that the fall back per thousand ft of valve depth was only 1,6%. The survey also indicated that the optimum cycle time was 45 min. This means that the daily gas injection could be reduced to 112000 standard ft^3 per day and increase the liquid production at the same time. Tests performed at the experimental well in Western Venezuela indicated that the volume of gas needed for this well was of only 2200 standard ft^3 per cycle. Since the area ratio of the valve installed was 0.164, which is well above the minimum available ratio, the daily gas injection could be further reduced to 70000 standard ft^3 per day.

The increase in liquid production has to do with the fact that the gas injection time was reduced from 9 to 3.5 minutes.

Well C

Well C was put on intermittent gas lift with the use of a surface controller and a spring loaded pilot valve that gave a minimum spread of 50 psi. Because of the size of the injection annulus, the volume of gas injected per cycle for a 50 psi spread was 8000 standard ft^3. The volume of gas needed per cycle was only 3200 ft^3. This problem was resolved with the installation of the new pilot valve, which was able to reduce the spread to 20 psi. The volume of gas per cycle with the new valve was reduced to 4000 standard ft^3. The daily gas injection volume was reduced from 692,000 to 200,000 standard ft3, not only because of the reduction of the gas injection per cycle, but also because the cycle frequency was reduced.

The gas injection time was reduced from 8 to 4 minutes. This contributed to the increase of the daily production from 171 to 300 Br/d but it was not the most important reazon. The major reason for the increase in daily production was the reduction of the cycle frequency, which was too high before.

Conclusions

1. A new gas lift pilot valve has been successfully designed and tested for intermittent gas lift.
2. Field scale tests performed at a controlled environment demonstrated that the design of valve area ratio and the gas injection orifice diameter have an important influence on the efficiency of the lifting process.
3. The new valve has been tested in real wells with the result of increasing the liquid production with less gas injected per cycle.
4. More research work needs to be done on the dynamic behavior of pilot valves in order to gain understanding on this subject.

Nomenclature

Dv= valve depth
Gg= gas specific gravity
m1= gas flow rate through the surface choke
m2= gas flow rate through the gas lift valve
MW= molecular weight
pd= pressure required in dome to close valve at depth
pdt= Pd with nitrogen charge corrected to calibration temperature
pto= tubing opening pressure
pvo= valve opening pressure
ptro= test rack opening pressure
R= pilot port area to bellow area ratio
Ru= universal gas constant
Sp= spring pressure
Spread= opening pressure minus closing pressure

tinj= gas injection time
T1= injection gas temperature at the surface
T2= injection gas temperature at valve depth
V= annulus volume
Z1= injection gas compressibility at the surface
Z2= injection gas compressibility at valve depth

Acknowledgements

The design and construction of the new pilot valve was possible thanks to the knowledge and experience of Ashby Breaux Jr. with JMI Manufacturing and the late Boyd Airs, the research work performed at PDVSA Intevep and the effort made by Altec Inc. to manufacture it.

References

1. Hernandez A., Gasbarri S., Machado M, Marcano L., Manzanilla R., Guevara J.: "Field-Scale Research on Intermittent Gas Lift," paper SPE 52124 prepared for presentation at the 1999 Mid-Continent Operations Symposium held in Oklahoma City, Oklahoma, 28-31 March 1999.
2. Brown K., Jessen F.: "Evaluation of Valve Port Size, Surface Chokes and Fluid Fall-Back in Intermittent Gas-Lift Installations," JPT (March 1962) 315.
3. Hernandez A., Castillo P., Marcano L., Reyna M. ; "Intermittent Gas Lift Test Results". PDVSA Intevep Technical Report # INT-6558, 1999.
4. Hernandez, A., Garcia G., Concho M., Garcia R., Navarro U.: "Down-hole Pressure and Temperature Survey Analysis for Wells on Intermittent Gas Lift," paper SPE 39853 presented at SPE Int. Pet. Conference and Exhibition held in Villahermosa, Mexico, 3-5 March 1998.

Appendix

The new 1-inch pilot valve is an injection pressure operated valve with a combination of spring force and nitrogen pressuring the dome. Equations solving for Pvc, Pd, Psc, Pso, and OP are the same as for any other injection pressure operated valve. Pdt and Ptro have to be adjusted for the pressure contributed by the spring. Spring force is applied during the assembly of the valve and the travel is not consistent. For accuracy, it is recommended that the pressure applied by the spring be measured rather than calculated.

The following equations solve for the Pdt and Ptro respectively:

$$Pdt = (Pd - Sp) * Tcf + Sp \quad (a.1)$$

$$Ptro = Pdt / R \quad (a.2)$$

Table 1. Valve performance comparison

Type of valve	Instantaneous gas flow rate ft^3/d	Pressure drop across the val., psi
New valve (1 in)	2500	475
Other valve (1 in)	2300	520

Table 2. Completion and production characteristics

Well	A	B	C
Casing diameter (in)	7x23	5 ½	7x23
Tubing id (in)	2 7/8	2 7/8	2 7/8
Valve depth (ft)	6577	2907	3200
Crude API	32	25	27
Gas inj. before (ft^3/d)	650	173	692
Gas inj. after (ft^3/d)	420	172	200
Prod. Before (Br/d)	90	70	171
Prod. after (Br/d)	90	85	300
tinj before (min)	15	9	8
tinj after (min)	7	3,5	4

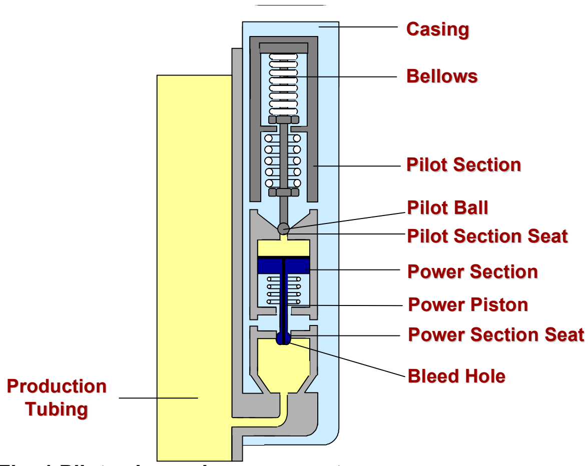

Fig. 1 Pilot valve main components

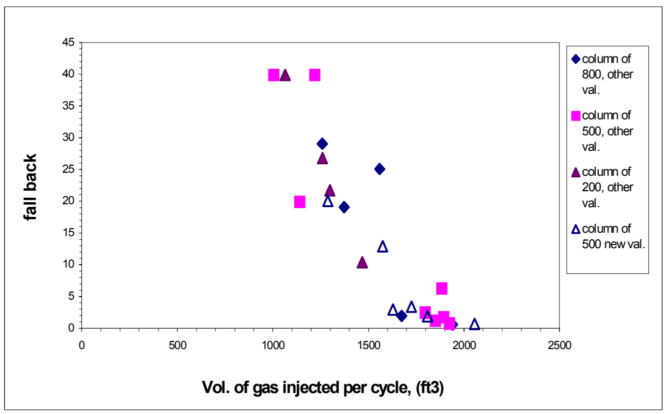

Fig. 2 Fall back losses vs. volume of gas injected per cycle.

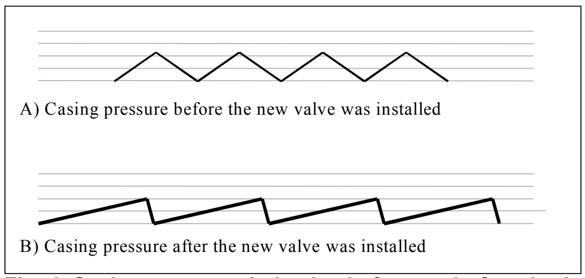

Fig. 3 Casing pressure behavior before and after the installation of the new pilot valve in well A