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Equalize Method: A New Method for Optimizing Gas Lift Spacing Design

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Equalized Method: A New Method for Optimizing Gas Lift Spacing Design

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Abstract

In gas lift unloading process, killing fluid depth is often represented using static fluid model. An innovative method is proposed to optimize gas lift design by considering the fluid movement into the reservoir. The objective of this paper is to present this new equalized method in order to minimize the number of unloader valve and optimize the gas lift design.

The equalized gas lift spacing design method is started by determining reservoir parameters, reservoir pressure, and productivity index. Well testing data provides necessary data to determine static bottomhole pressure, indicating reservoir pressure in a static condition, as well as productivity index. Afterwards, combining Darcy law and hydrostatic pressure equation, actual killing fluid depth for a set of time can be obtained until it reached equalized condition. This equalized condition is the starting point for gas lift spacing design.

The following study used well-X in ONWJ field which plans to target depleted reservoir. To enhance the production, a gas lift system is required to maintain oil production. The conventional gas lift spacing method yields a total of eight unloaders. By utilizing this new method until the pressure reached equilibrium condition, the number of unloaders used can be reduced significantly to a total of four unloaders. In addition, the equalized method will allow higher test rack opening pressure that result in higher gas lift operating pressure and higher injected gas capacity. In the end, equalized method will achieve higher oil productivity and will generate greater profit compared to conventional method.

The novelty of this paper involves the application of a new method for gas lift spacing design. For future implementation, most well cases with gas lift system can use this method for higher well production capacity and better economic feasibility.

Keywords: gas lift, equalized, killing fluid

1. Introduction

ONWJ is an offshore field located in North West Java. More than 80% of the wells using gas lift as artificial lift therefore optimum gas lift design is essentials to achieve desire production. As a mature field with old facilities, it faces many challenges regarding to production, one of which is limited casing pressure. Discharge compressors from several areas vary with range between 600 psi to 700 psi. Meanwhile reservoir pressure varies from 600 psi to 1500 psi and well depth varies from 3000 ft TVD to 4000 ft TVD.

All this time, conventional gas lift design are used for infill and recompletion wells which calculates gas lift mandrel spacing from surface. This conventional design resulted in many gas lift mandrels must be installed which caused operating gas lift pressure much lower than kick off pressure.

In many cases, gas lift re-design was conducted to change gas lift valve with dummy. It is found that the well only require 2 or 3 gas lift valve, while dummies are installed in other upper gas lift mandrels. Even sometimes only orifice is needed if reservoir pressure is lower than available gas lift pressure.

While gas lift re-design is best practice for low trajectory well, it is risky and very difficult to conduct in high deviated well. Therefore new method for gas lift mandrel spacing is needed.

2. Basic Theory

Flowing mechanism in a medium is often annotated by the total energy difference between two points of interest. In a closed system with static boundary, the difference is thus, potential energy difference acting in the form of hydrostatic pressure. According to Pascal, hydrostatic pressure emphasizes the fundamental principle of fluid mechanics, by which the pressure applied to the surface of a fluid is transmitted uniformly throughout the fluid; resulting the term "incompressible fluid" where pressure difference is transmitted uniformly.

Incompressible fluid flow is, as well, frequently represented by a potential difference, as described by Bernoulli's fluid dynamic principle. Such example in petroleum industry is the denser fluid invasion from the well into reservoir productive zones during completion or workover process (Bedrikovetsky, 2003). While prone to be negligible, the situation can be crucial while substantial pressure difference persists between the inflow zones; namely existing zone between reservoir and wellbore. This is due to the fact that within a specific amount of time, killing fluid will undergo level reduction, forcing the needs to reevaluate and reoptimize the proposed completion design while killing fluid column exist in the well.

As mentioned before, killing fluid level, having more pressure than formation pressure will induce flowing mechanism to the formation. This matter can be simply explained by taking into account, Le Chatelier principle of corresponding pressure, in which an addition in pressure will shift the equilibrium towards the opposite condition; that is the pressure and volume will decrease towards the reservoir (Chatelier, 1898).

3. Methodology

Basic principle is using fluid flow in porous media. However, before the explanation progresses further, a deciding factor to be considered is that equilibrium method will only work on a depleted reservoir. This is caused by the fact that equilibrium method needs some space to accommodate killing fluid entrance, which is provided by the depleted reservoir which contains several partially-filled spaces.

In this procedure, a calculation is conducted by emphasizing killing fluid flow in porous media, presuming that killing fluid will behave as a one-phase incompressible fluid. One phase, incompressible fluid flow in porous media equation, with the flow occurring from the well to the reservoir is shown as Eq. 1. Note that injectivity index term is used here rather than productivity index to affirm injection flow from well to reservoir, though both terms will be used interchangeably since its value is identical.

$$Q_{inj} = K(P_{wf} - P_{res}) \qquad (1)$$

where

Q_{inj} : injected killing fluid rates (bbl/day)

K : injectivity index constant (bbl/day/psi)

P_{wf} : bottomhole pressure (psi)

P_{res} : reservoir pressure (psi)

By assuming that bottomhole pressure is denoted by only one type of killing fluid; consisting of single density, the equation is emphasized using hydrostatic pressure equation. The equation is shown by **Eq. 2**.

$$Q_{inj} = K(\gamma_l h - P_{res}) \qquad (2)$$

where

γ_l: specific weight of killing fluid (psi/ft)

h: fluid column height (ft)

For the purpose of sensitivity and for achieving a better result, the calculation was done using an hour base. Therefore, the equation turns into **Eq. 3**.

$$Q_{inj} = \frac{K(\gamma_l h - P_{res})}{24} \quad (3)$$

Using the above equation, the rate of killing fluid reduction from the well into the reservoir per unit hour can be determined. Thus, height reduction of the fluid column (in MD) can be calculated using simple volumetric equation as shown in **Eq. 4**. (assuming injected rate unit base is bbl)

$$\frac{dh_{dep}}{dt} = -\frac{5.615\, Q_{inj}}{A_{tot}} \quad (4)$$

where

h_{dep} : height of fluid column that is gone in one hour in MD (ft)

A_{tot} : total area of the tubing and annulus (ft^2)

Then, the iteration is conducted until equilibrium condition achieved, indicated by the relatively unchanged value of fluid column height. As a result, the equalized height of fluid column can be used as our starting point in the gas lift spacing design. To further confirm that the method is applicable in the field, a plot of fluid withdrawal rate and fluid level drop rate against equalized time; time required to reach equilibrium condition should be done to emphasize the length of the period required to conduct the following method.

3.1 Gas Lift Design

Methodology for conducting gas lift design includes determination of gas lift valve spacing design and PTRO (Test Rack Opening Pressure) design. The analytical solution procedure for gas lift valve spacing design is outlined as follow. Starting from wellhead pressure p_{hf} at surface, computation and plot of a flowing tubing-pressure traverse is conducted under fully unloaded condition using Hagedorn-Brown correlation. From a desired injection operating pressure p_c at surface, injection operating pressure line is constructed using **Eq. 5**.

$$P_{c,v} = P_{c,s}\, e^{0.01875 \frac{\gamma_g h_{dep}}{\bar{z}\bar{T}}} \quad (5)$$

where

$P_{c,v}$: casing pressure at valve depth (psi)

$P_{c,s}$: casing pressure at surface (psi)

z : gas deviation factor (dimensionless)

T : temperature (^oR)

From flowing tubing pressure line and injection operating pressure line against depth, the gas lift spacing design is conducted from the surface to mid perforation depth. Kickoff casing pressure line is calculated and drawn to ensure unloading process initiation. By intersecting the surface depth to the kickoff line using the killing fluid gradient as a slope, the first gas lift valve depth is obtained. A line is drawn after, adding a safety factor to the next flowing tubing pressure depth. The process is then repeated by intersecting this flowing tubing pressure depth to injection operating line constructed earlier until it reaches mid perforation depth. The following method will yield several depth values, which will be the valve designed depth for gas lift spacing design.

In comparison, while using the equalized method, the intersection between flowing tubing pressure line and operating casing pressure line is estimated at a lower depth; the equalized depth calculated earlier. The rest of the step is the same, but the results will be slightly or much different depending on the pressure difference between the inflow zones.

To conduct PTRO design, force balance analysis is conducted based on well pressure, consisting of both casing and tubing pressure, and valve pressure, represented by dome pressure. Force balance equation used in the calculation can be seen at **Eq. 6**.

$$FB = P_{c,v}(1-R) + P_{t,v}(R) - P_d \qquad (6)$$

where

$P_{t,v}$: tubing pressure at valve depth (psi)

P_d : dome pressure of valve (psi)

R : area ratio, A_p/A_b, where A_p is valve seat area and A_b is total effective bellows area

To support the applicability of this method, the amount of gas passage; the maximum theoretical amount of gas possible to be injected will also be compared between conventional method and equalized method. Calculation of the amount of gas passage through the choke will use modified subsonic flow equation proposed by Thornhill-Craver (Cook, 1946) at **Eq. 7**.

$$Q = 155 \times C_d \times A_P \times P_{c,v} \times \sqrt{\frac{248.4 \times \left(\left(\frac{P_{t,v}}{P_{c,v}}\right)^{1.48} - \left(\frac{P_{t,v}}{P_{c,v}}\right)^{1.741}\right)}{\gamma_g \times T_v}} \qquad (7)$$

where

C_d : discharge/ choke flow coefficient of 0.865

γ_g : gas specific weight related to air (psi/ft)

T_v : temperature at valve depth (^oR)

In the end, gas lift performance curve is used to compare theoretical gain of the rate that can be achieved using the conventional method and equalized method. The whole calculation and comparison steps are presented in **Fig. 1**.

4. Case Study

Well-X is a producing well from a depleted reservoir. Its low reservoir pressure needs some assistance in order to be produced commercially. Gas lift as an artificial lift is suggested to be implemented in the well. Considering its reservoir pressure condition fulfills one of the requirements to effectively run this new equalized method. A case study on Well-X is conducted using the conventional method and equalized method. The well and reservoir data, as well as its supporting data, are presented by Table 1.

5. Result and Discussion

The result of the following case study regarding the application of equalized method will compare both conventional methods and equalized method base on several important factors mentioned in methodology, including the number of GLM (Gas Lift Mandrel) to be used, gas passage rate, as well as possibly attained rate from GLPC (Gas Lift Performance Curve). To start the discussion, the elapsed time needed to perform equalized method will be initially evaluated to emphasize the applicability of this method. For further analysis purposes, several injectivity index values will be displayed to compare the results, as shown in Fig. 2 & Fig. 3.

In the Figure 2 & 3, Well-X data with injectivity index of 1.0 stb/day/psi yield equalized time less than 10 hours to satisfy relative error ε_s value of 0.1. Compared to some higher-pressure formation with less injectivity index of 0.5 stb/day/psi only yield equalized time as much as 24 hours to satisfy the same condition. Hence, the equalized method does prove its applicability, considering less than 1 day is needed to increase its gas lift efficiency effectively.

The number of GLM to be used can be estimated from the flow diagram of gas lift spacing design as shown below in Fig 4.

From the figure 4, it can be interpreted that conventional method with killing fluid depth level assumption at the surface yields a total of eight GLM, while equalized method yields much less number, of four GLM. This is caused by a significant difference in pressure between inflow zones, causing the number of pressure range and GLM used to differ greatly.

Another analysis of PTRO and gas passage based on force balance calculation can be seen at Table 2 and Table 3.

From further calculation, it can be seen that not only the number of GLM used is being reduced by the equalized method, but also the amount of possible casing pressure and gas passage are being increased significantly. Higher surface operating pressure will give more benefit in injecting more gas and reducing more fluid weight, which will tend to increase the amount of recoverable oil. It can also be seen by the GLPC, as shown in Fig.5.

From the GLPC with operating pressure of 580 psi using equalized method yields liquid production rate of about 1180 STB/day, or around 708 STB/day of oil production rate, compared to conventional method with operating pressure of 493 psi, which only yields production rate of about 870 STB/day, or around 522 STB/day of oil production rate. This increment is significant enough that total production is increase ~35% of the original production rate, which shows a significant improvement in generated profit due to this new method.

6. Conclusion

From the case study result, this method has been successful in the attempt of increasing liquid production rate from 870 STB/day to about 1180 STB/day for relatively low-pressure reservoir.

The equalized method is better than conventional method because the number of unloaders will be reduced significantly. Thus, allowing a maximum value of operating injection pressure which contributes to the amount of gas passage that can be passed in order to increase the production rate.

7. Recommendation

The equalized method is most suitable for well with criteria deep reservoir, relatively low reservoir pressure, high deviated and limited gas lift pressure since first GLM will be much deeper than the conventional method therefore it will reduce number of unloaders.

8. References

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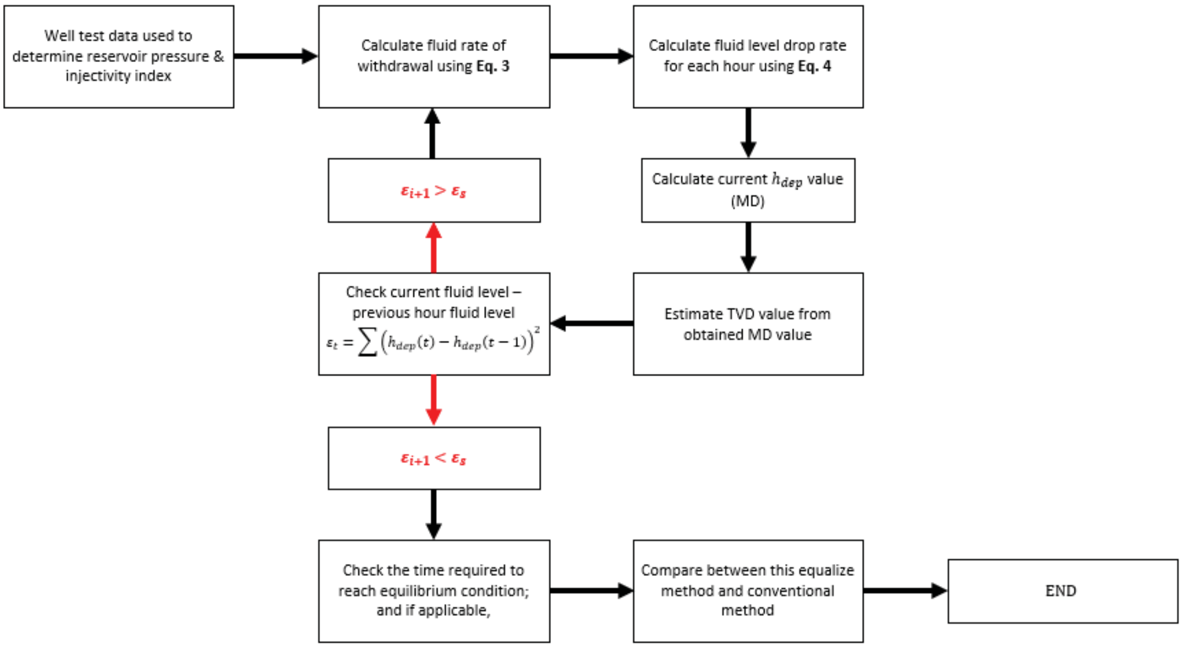

Figure 1. Schematic Algorithm

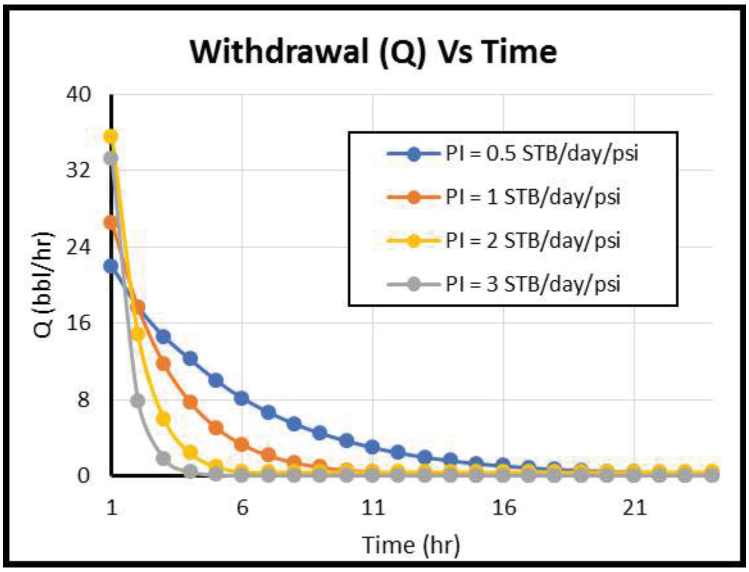

Figure 2. Plot of Withdrawal Rate to Evaluate Equalized Time

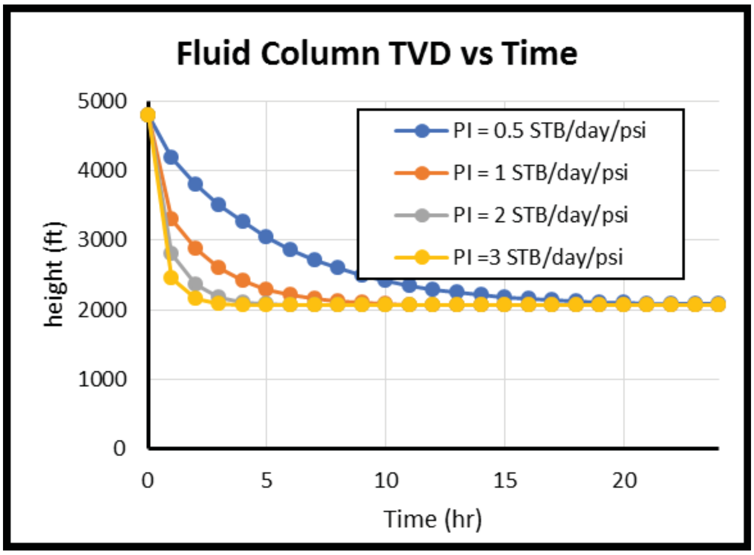

Figure 3. Plot of Killing Fluid Depth to Evaluate Equalized Time

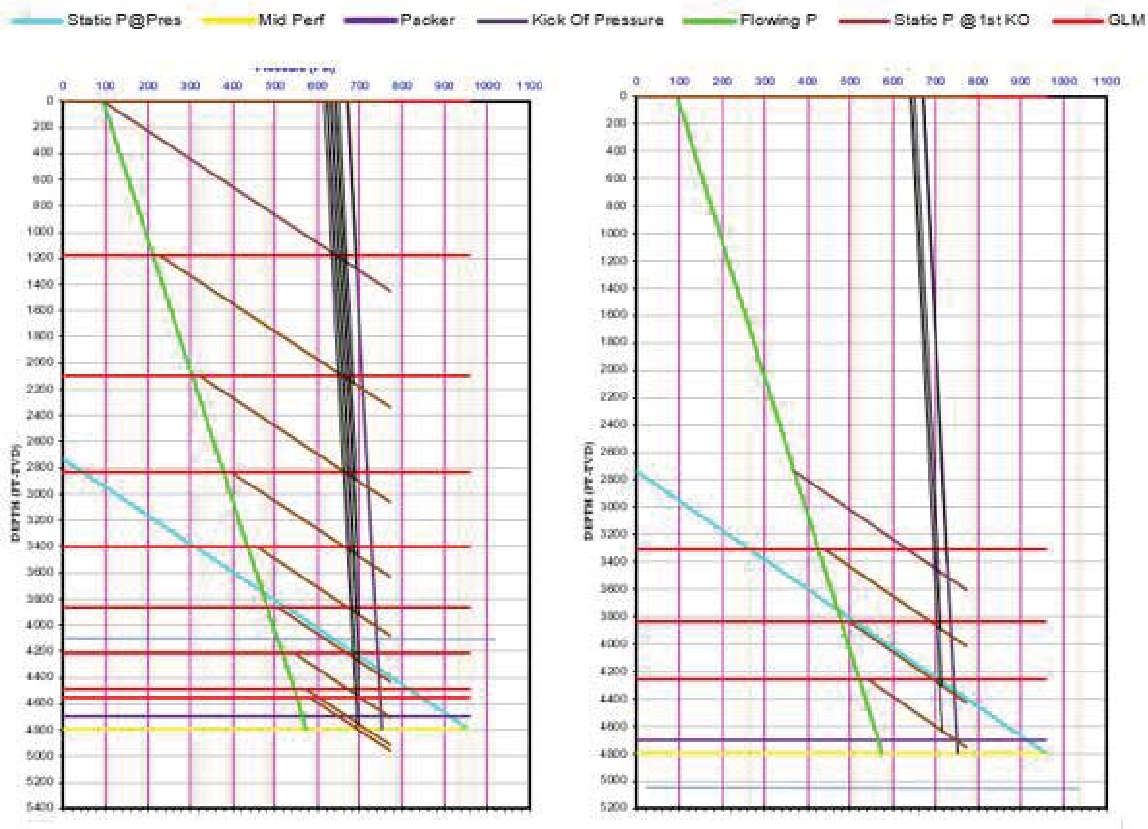

Figure 4. Comparison between Gas Lift Spacing Design Flow Diagram of Conventional Method (left) and Equalized Method (right)

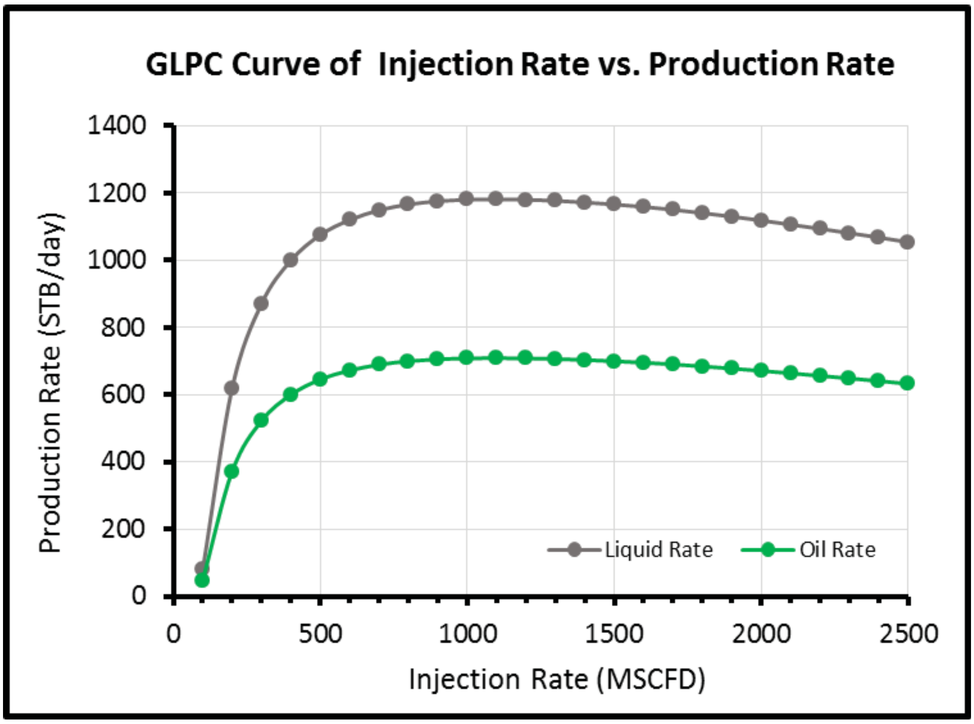

Figure 5. GLPC of Injection Rate against Production Rate

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Table 1. Case Study Data for Well-X

	Parameter	Value
1	Reservoir Pressure (psi)	956
2	Injectivity Index (stb/day/psi)	3
3	Killing Fluid Gradient (psi/ft)	0.465
4	TVD of mid perf (ft)	4794
5	MD of mid perf (ft)	5700
6	Production Casing Outer/Inner Diameter (in)	7/6.538
7	Tubing Outer/Inner Diameter (in)	3.5/2.991
8	Maximum Kick Off Pressure (psi)	670
9	Water cut (%)	20
10	Available Port Size of Gas Lift Valve	0.1875, 0.25, 0.3125

Table 2. Gas Lift Design Results of Well-X using Conventional Method

	Valves	TVD (ft)	Port Size (in)	PTRO 80F (psia)	Force Balance (psia)	Valve Position	Gas Passage (MSCFD)
1	Unloader	1174	0.1875	601	-146	Closed	
2	Unloader	2094	0.1875	586	-128	Closed	
3	Unloader	2827	0.1875	569	-109	Closed	
4	Unloader	3407	0.1875	552	-89	Closed	
5	Unloader	3862	0.1875	535	-69	Closed	
6	Unloader	4216	0.1875	518	-48	Closed	
7	Unloader	4489	0.1875	503	-29	Closed	
8	Orifice	4558	0.3125	orifice	14	-	310

Table 3. Gas Lift Design Results of Well-X using Equalized Method

	Valves	TVD (ft)	Port Size (in)	PTRO 80F (psia)	Force Balance (psia)	Valve Position	Gas Passage (MSCFD)
1	Unloader	3301	0.1875	602	-70	Closed	
2	Unloader	3835	0.1875	584	-52	Closed	
3	Unloader	4253	0.1875	573	-30	Closed	
4	Orifice	4558	0.3125	orifice	104	-	1113