

## EQUILIBRIUM-CURVE-BASED GAS LIFT DESIGN FOR ENHANCING PRODUCTION IN AN OIL WELL

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**ABSTRACT:** During mid-to late-life of producing wells, depletion of reservoir pressure and liquid loading is inevitable. Artificial lift methods such as electrical submersible pumping, sucker rod pumping, plunger lift or gas lift, to name a few can be applied to address these issues. A 9000 ft-deep oil Well has experienced a decline in flow rate, prompting the decision to implement gas lift method. This paper aims to design gas lift method using combination of graphical and analytical methods, and to calculate and analyze the depths of unloading bracketing valves for this specific well. The primary purpose of unloading valves is to initially remove spacer fluid from the annulus, allowing the gas lift system to operate. Bracketing valves, on the other hand, serve as future production valves when production liquid level decreases. By constructing an equilibrium-curve which serves as the basis for determining unloading valve depths, this study identifies four unloading valves at depth of 2800 ft, 5220 ft, 5950 ft, 7550 ft respectively, and 2 extended bracketing valves at depths of 8050 ft and 8550 ft. The operational gas lift valve depth point for this Well is determined to be 7550 ft, which yield a production flow rate of 703 B/D.

**Keywords:** *Gas Lift, Equilibrium Curve, Unloading & Operational Valves*

### INTRODUCTION

An oil well with a total depth of 9,000 feet, which previously produced fluids naturally, has experienced a significant decline in productivity, resulting in its inability to deliver fluids to the separator. This condition not only affects the company's operational performance but also reduces regional revenue derived from oil profit-sharing. To address this issue, the application of an artificial lift system is necessary. Given the existing gas lift infrastructure in several wells within the same field and the availability of a sufficient gas supply, the gas lift method is identified as the most technically and economically viable solution. Prior to initiating gas lift operations, it is essential to unload the spacer fluid present in the annular space, which will subsequently be replaced by the injected gas.

In an effort to increase production capacity, wells in oil and gas field typically undergo modifications. These modifications such as changes in production methods, pump parameters, and other operational adjustments require specific conditions and are applied based on the particular field situation, which often varies. The gas lift artificial lift method is commonly used in fields with adequate gas availability, relatively high fluid levels, and a high productivity index (PI). According to Brown (1980), in practice, gas lift using conventional tubing flow can achieve flow rates of approximately 200 to 20,000 B/D, whereas production through the annulus may exceed 80,000 B/D.

Gas lift is an artificial lifting method that utilizes the natural properties of gas, namely its low density and the ability to be dissolved into production fluids. The overall hydrostatic pressure within the tubing

decreases as more gas dissolves into the production fluid. Consequently, the deeper the gas injection point, the more effective the pressure reduction, making deeper injection generally more ideal. The gas lift mechanism begins with the injection of high-pressure gas through the annulus, which then enters the tubing through the operating valve. There, it mixes with the production fluid, reducing the fluid's density and lowering the bottomhole flowing pressure, thereby enhancing flow to the surface. While a drop in reservoir pressure can be difficult to manage and often requires large-scale solution, gas lift is generally easy to remedy on-site.

According to Dunham (1973), an "equilibrium curve" is the locus of points representing the intersection of flowing pressure gradient curves (above the gas-lift injection valve) for varying production rates at a constant gas injection rate. Therefore, for a specific gas injection rate, the well must operate along the equilibrium curve. The equilibrium point between the flow in the tubing and the gas injection inflow must be determined prior to designing the installation of the gas lift valve. The pressure conditions at the depth where the gas lift valves are to be installed can be quickly estimated using the equilibrium curve.

This study aims to determine the optimal setting depths of the unloading valves, production valves, and bracketing valves through an equilibrium-curve-based analysis methodology.

**METHODS**

This analysis was conducted using an approach that combines analytical and graphical techniques. The analysis is conducted using common tools such as Microsoft Excel to construct the equilibrium curve and determine the valve depths.

The flowchart in Figure 1 below illustrates the workflow involved in designing a gas lift well. Meanwhile, Table

1 presents the parameter data required for this analysis.

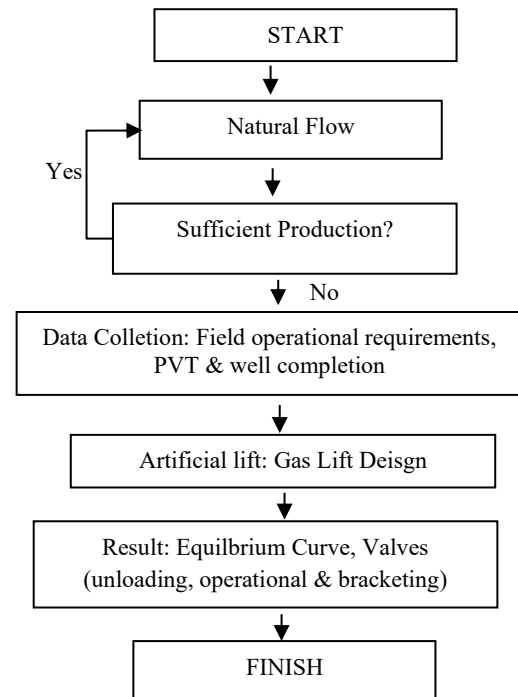


Figure 1 Flow Chart

Table 1 Well "X" data

Gas Injection Pressure	1300	psig
Gas Injection Capacity	450,000	scf/d
$\rho$ (Density Spacer Fluids)	0.465	psi/ft
Well Depth	9000	ft
Reservoir Pressure	3500	psi
PI	0.45	b/d/psi
WC	0.25	
$\rho_o$ (Oil Density)	35	API
$\rho_{fp}$ (Average Production Fluid Density)	0.426	psi/ft
Gas SG	0.65	
Pwh	100	psi
ID Tubing	2	Inch
ID Casing	7	Inch
Surface Temperature	105	$^{\circ}$ F
Downhole Temperature	180	$^{\circ}$ F

Determining the flow rate resulting from gas injection at various depths is a necessary step prior to constructing the equilibrium curve. As previously mentioned, the flow

rate increases with deeper valve installation. The selection of flow rates is adjusted to match the specific conditions and production fluid characteristics of this well. Several pressure traverse charts are available in Brown (1984), Volume 4, Appendix 4.2. By evaluating variations in flow rate, the corresponding bottomhole flowing pressure (Pwf) at each equilibrium point can be estimated using Equation 1. Based on this approach, the equilibrium line curve which serves as the foundation for the gas lift design can be constructed. Since the well flow is in single-phase, the single-phase flow equation can be applied to calculate the bottomhole flowing pressure.

$$P_{wf} = P_R - \frac{Q}{PI} \dots\dots\dots 1$$

Where:

Pwf : bottomhole flowing pressure (psi)

PR : Reservoir Pressure (psi)

Q : Flow Rate (B/D)

PI : Production Indeks (B/D/psi)

Calculations from both the top and the bottom of the well are required to determine the equilibrium point. The wellhead serves as the starting point for the top-down calculation, while the bottom of the well specifically the center of the perforated interval serves as the starting point for the bottom-up calculation.

$$\text{Pressure at } D_t = P_{wh} + \rho_{mix} D_t \dots\dots\dots 2$$

$$\text{Pressure at } D_t = P_{wf} - \rho_{fp} (D - D_t) \dots\dots 3$$

Thus, by combining the "top" and "bottom" equations, the following equation is obtained:

$$D_t = \frac{P_{wh} - (P_{wf} - \rho_{fp} D)}{\rho_{fp} - \rho_{mix}} \dots\dots\dots 4$$

Using the following equation, the value of Pt can be determined once the value of Dt has been established.

$$P_t = P_{wh} + \rho_{mix} D_t \dots\dots\dots 5$$

Where:

D, Dt : Depth (ft)

Pwh : Well Head Pressure (psi)

$\rho_{mix}$  : Injection gas-Production fluid mixed pressure gradient (psi/ft)

Pt : Flowing pressure at certain depth (psi)

It is essential to design an injection gas pressure gradient profile that intersects the equilibrium line during the unloading stage, when the spacer fluid (the fluid occupying the annulus) is displaced by the injected gas. It is important to note that a safety margin of 50 psi is commonly incorporated into the calculations when determining the setting depth of the unloading valve. By reducing the injection pressure by 50 psi, the unloading process can be maintained consistently, even in the event of fluctuations in compressor output pressure. This pressure reduction also compensates for pressure losses occurring in the gas flow through the unloading valves and the annulus (Davies, 2016).

**RESULT AND DISCUSSION**

**Well Initial conditions (the dead well)**

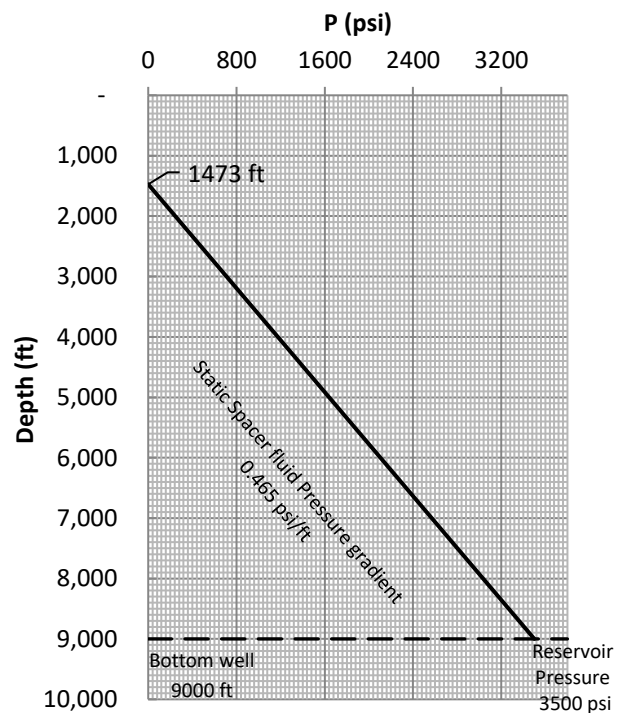


Figure 2 Pressure-depth profile of initial condition

After the well completion, the annular space between the tubing and casing is filled with spacer fluid having a density of 0.465 psi/ft to balance the formation pressure. Figure 2 illustrates the initial conditions of the Well prior to the unloading and gas lift operations. The figure demonstrates that the spacer fluid can only be supported to a depth of 1,473 feet at a reservoir pressure of 3,500 psi. Beyond this point, the fluid will be unloaded out from the well and replaced by injection gas.

**Equilibrium Curve Construction**

The first step in constructing the equilibrium curve is performing a nodal analysis (pressure traverse curve) at various production rates: 200, 400, 600, 800, and 1,000 B/D. The pressure traverse curve is illustrated by Brown (1984) in *Volume 4, Appendix 4.2*. This analysis is carried out to obtain the gas-liquid ratio (GLR), pressure gradient of the mixed fluids (injection gas and production fluid), pressure gradient of mixed fluid density  $\rho_{mix}$  and bottomhole flowing pressure (pwf) using Equation 1. Using Equations 4 and 5, the depth and pressure corresponding to each flow rate can be estimated. This serves as the basis for constructing the equilibrium curve. Table 2 presents the parameters result used to develop the equilibrium curve.

Table 2 The equilibrium curve's calculation result

Q (b/d)	GLR (scf/b)	$\rho_{mix}$ (psi/ft)	$P_{wf}$ (psi)	$D_t$ (ft)	$P_t$ (psi)
200	2,250	0.07	3056	2468	273
400	1,125	0.08	2611	3823	406
600	750	0.11	2167	5593	715
800	563	0.19	1722	9372	1881
1000	450	0.22	1278	12894	2937

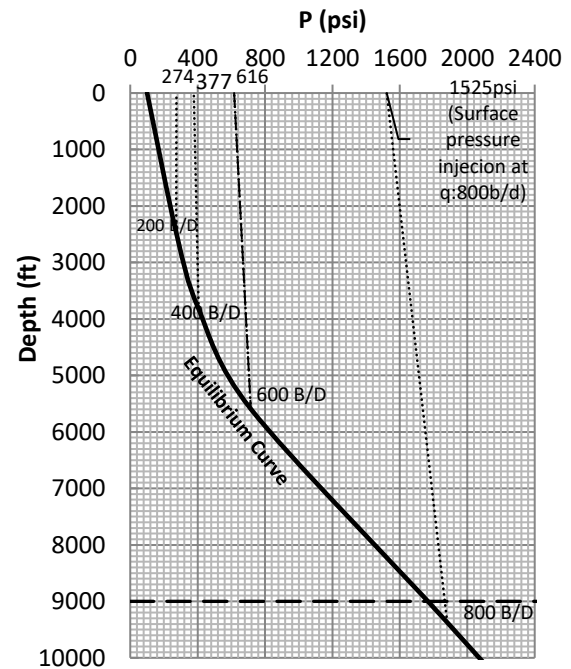


Figure 3 Pressure-depth Profile of the Equilibrium Curve

As shown in Figure 3, the four plotted points are connected by a line forming an equilibrium curve. This curve represents the production flow rate that can be achieved when injection gas is introduced at a specific depth.

**Determination unloading valve depths**

A graphical method can be employed to determine the depth and operating pressure of unloading valves (Pertamina, 2003). The average pressure and temperature within the well influence the gradient of the gas injection pressure. Therefore, to accurately calculate the average gas pressure gradient, temperature correction must first be applied. The injection gas used in the well has a specific gravity of 0.6 and an operating pressure of 1,300 psi at the surface. Based on graphical analysis, Brown (1980, Appendix 3) reports a gas pressure gradient of 0.033 psi/ft.

By plotting both the equilibrium curve and the gas injection pressure gradient on the same graph, the point of intersection represents the theoretical depth at which the operational gas lift valve should be installed. Once this point is identified, the depths of

the unloading valves can then be determined. Figure 4 illustrates the unloading valve locations and other relevant details.

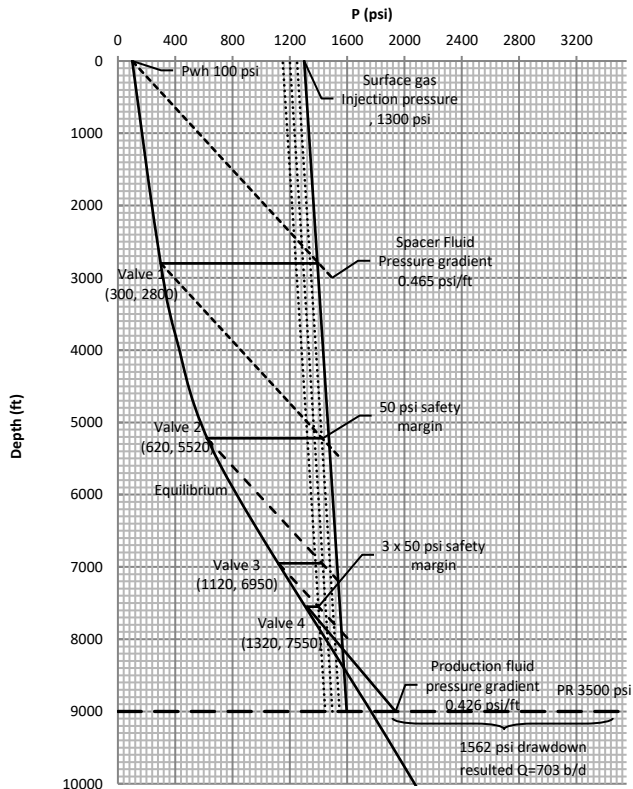


Figure 4. Spacer unloading valve depth.

Since this study adopts a worst-case scenario approach, a 50-psi pressure reduction from initial gas injection pressure gradient is applied in each depth during the unloading operation. This is to ensure operational reliability. As illustrated in Figure 4, three unloading valves require a pressure reduction of 50 psi each to ensure reliable operation, resulting in a cumulative safety margin of 150 psi. In contrast, the fourth valve is positioned in close proximity to the equilibrium line, thereby eliminating the necessity for an additional 50 psi pressure allowance.

**Bracketing valve Determination**

In field practice, valve bracketing is essential to mitigate potential design flaws, determine the operational depth of the gas lift valve, and accommodate changes in well conditions throughout the production

process. According to Davies (2016), the minimum feasible spacing between valves is 500 feet (approximately 150 meters). In compliance with this guideline, Valves 3 and 4 are placed at depths of 6,950 and 7,550 feet, respectively—both within acceptable limits of practical application. An additional bracketing valve can be installed 500 feet below the operating valve, at a depth of 8,050 feet. Accordingly, the bracketing envelope zone can be defined as extending from Valve 3 (6,950 ft) to the bracketing valve (8,050 ft).

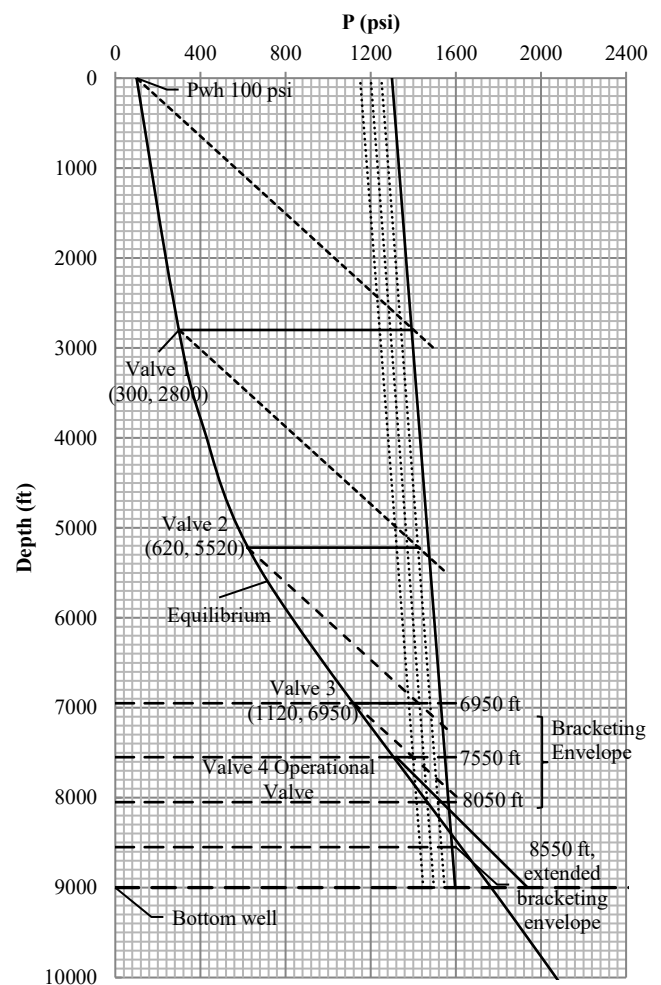


Figure 5. Final Gas Lift Design

Typically, an extended bracketing envelope can be positioned several feet above the top of the production zone. In this well, which has a total depth of 9,000 feet, an extended bracketing valve (dummy valve) can be placed at a depth of 8,550 feet.

Figure 5 and Table 3 present a comparison between the original design and the revised configuration after the bracketing envelope was implemented.

Table 3 Result: Unloading, operational & bracketing valves

Initial design		Final Design	
Valve no.	Depth (ft)	Valve no.	Depth (ft)
1	2800	1	2800
2	5220	2	5220
3	6950	3	6950 (B)
4	7550	4	7550 (O)
		5	8050 (B)
		6	8550 (B)

Where:

B : Bracketing or extended Valve

O : Operational Valve

## CONCLUSION

The equilibrium curve developed for the well can be used to predict flow rate behaviour within the tubing under certain depth. It also serves as a reference for identifying the valve unloading point, where fluctuations in flow rate typically occur during the unloading process. Based on this analysis, four unloading valves are identified at depths of 2,800 ft, 5,220 ft, 5,950 ft, and 7,550 ft.

To account for potential adjustments or calculation uncertainties, bracketing valves must be included. These additional valves referred to as extended bracketing valves are placed at depths of 8,050 ft and 8,550 ft. By modifying the valve operation at this depth, the flow rate can be increased or decreased as needed

The primary operating valve is located at a depth of 7,550 ft, where the corresponding production flow rate is estimated at 703 B/D. An increase in production fluid by 703 B/D will undoubtedly provide additional positive impacts on both company revenue and government income through the profit-sharing scheme.

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