ESTIMATING BOTTOMHOLE PRESSURE IN IGL, PAGL, GAPL, AND FAGL

Jonathan De La Cerda

Texas Tech University

ABSTRACT

This paper explores current methods to estimate bottomhole pressure for various gas lift applications, and the numerous challenges in each. Gas lift methods such as IGL, PAGL, GAPL, and FAGL are essential for improving lift performance in aging wells. Each method has unique challenges, including pressure fluctuations, liquid fallback, and gas injection dynamics that complicate accurate pressure estimation. For IGL, the weighted average method estimates bottomhole pressure by accounting for pressure variations throughout the gas lift cycle. While estimation methods for PAGL and FAGL provide useful results, additional research is needed to improve accuracy. In GAPL applications, estimating bottomhole pressure becomes more challenging due to shut-in periods. Additional research is needed to understand the pressure effects of the shut-in period and improve bottomhole pressure estimation in this lift application.

INTRODUCTION

Improving artificial lift methods will be essential to maintain oil production while keeping operation costs low. Recently, gas lift has become a popular artificial lift choice for unconventional assets in the Permian Basin. While gas lift has helped maintain oil production for decades, its economic viability in low-volume wells has discouraged operators from utilizing this artificial lift method to its full potential. Late-life applications of IGL, PAGL, GAPL, and FAGL offer a means to extend the life of gas lift operations by reducing liquid holdup, decreasing gas injection, and increasing fluid production. Accurate bottomhole pressure estimation is needed for optimizing these artificial lift methods. However, these methods present challenges in bottomhole pressure estimation due to pressure variations, liquid fallback, and gas injection effects.

INTERMITTENT GAS LIFT

Unlike continuous gas lift, intermittent gas lift introduces transient pressure variations that complicate bottomhole pressure estimation. In IGL, bottomhole pressure is primarily dependent on cycle frequency and the location and size of the liquid slug within the tubing. Additional factors such as fluid inflow into the wellbore and liquid fallback affect the pressure dynamics. To improve bottomhole pressure estimation in IGL systems, Beadle, Harlan, and Brown proposed a weighted average method that incorporates cycle frequency to more accurately represent pressure changes (Beadle et al., 1963). This method considers pressure fluctuations over the gas lift cycle, accounting for maximum pressures when the gas lift valve opens and minimum pressures when the liquid slug is produced. This weighted average method provides a practical approach to estimating bottomhole pressure by averaging over multiple cycles. Additionally, this estimation depends on the presence of a standing valve in the well. A standing valve installation prevents fluid inflow to the wellbore and results in a lower average bottomhole pressure (Figure 2). In contrast, wells without a standing valve experience higher average bottomhole pressure due to continuous inflow from the formation (Figure 3).

One challenge with this average method for estimating bottomhole pressure is needing both the productivity index and static bottomhole pressure. Sandoval developed a mathematical model that estimates bottomhole pressure during the accumulation stage of IGL (Sandoval, et al., 2005). Though this estimation does not provide a pressure estimation for the entire IGL cycle, it provides a refined approach to one part. This model determines liquid holdup and fluid density using the superficial liquid and gas velocities. The model was developed by applying the Buckingham Pi Theorem to the pressure gradient and identifying the dependent variables, leading to those affecting liquid holdup (Figure 3). The study found that liquid holdup was primarily dependent on inertial and buoyancy forces at high $Re_{vs}l$ and viscous forces at low Re_{vsl}. Once this liquid holdup is defined, estimations for mixture density, pressure gradient, and fluid column height are calculated. However, in real applications, using these average properties is insufficient for bottomhole pressure estimation, as fluid density and viscosity vary with pressure and temperature. To account for these property variations, the tubing is divided into segments by pressure or length increments, with liquid holdup and mixture density calculated for each section. After determining these values for the entire tubing length and applying Churchill's correlation for the friction gradient, the average mixture density and pressure gradient is calculated. The accuracy of this estimation increases with an increased number of segments. Sandoval provides a greater explanation of this procedure in his article.

PLUNGER-ASSISTED GAS LIFT

Estimating bottomhole pressure in plunger-assisted gas lift presents several challenges due to the interactions between the plunger, gas injection, and the effect on liquid holdup. PAGL integrates a continuous-run plunger with continuous gas injection and operates with little to no shut-in time. This system uses a bypass or two-piece plunger to fall against fluid flow while gas is injected. The addition of the plunger does not directly affect gas injection, but it serves as a mechanical device to reduce liquid fallback. However, the liquid fallback is not entirely prevented, and the induced pressure change must be accounted for in bottomhole pressure estimation. Because the plunger gathers liquid that would otherwise contribute to liquid loading, the bottomhole pressure of a PAGL application would be lower than that of continuous gas lift. Knowing this, a pressure estimation for continuous gas lift can be applied as a lower limit to pressure estimation for PAGL. Additionally, the Fancher and Brown no-slip holdup correlation can be used, providing a theoretical maximum for vertical lift performance and bottomhole pressure (Farag, et al., 2016). Though there is no direct approach to estimating bottomhole pressure in PAGL, combining these two estimations provides a pressure window, with the probability of the actual pressure value decreasing as it approaches the theoretical maximum.

GAS-ASSISTED PLUNGER LIFT

Despite being used interchangeably, gas-assisted plunger lift and plunger-assisted gas lift are distinct artificial lift methods with significant differences in operation and bottomhole pressure estimation. While both methods integrate plunger lift with gas lift, their mechanics and applications vary. GAPL operates similarly to conventional plunger lift but incorporates intermittent gas injection to provide lift support to the plunger. It requires a shut-in period for fluid accumulation, significantly affecting pressure buildup throughout the lift cycle. One major challenge is that current nodal analysis software does not have a dedicated model for PAGL or GAPL. As a result, pressure estimation is typically simplified based on the applied gas injection, whether intermittent or continuous. However, this simplified modeling ignores the pressure effects and fluid accumulation caused by the shut-in period in GAPL. An additional key distinction is that, unlike PAGL, GAPL does not use a packer, allowing direct access to the fluid level via the annulus. This means casing pressure in GAPL can often be assumed to reflect bottomhole pressure. In the case that this assumption is insufficient, bottomhole pressure estimation methods for IGL could be applied. However, these estimations may result in significant errors due to the complexity of GAPL.

FOAM-ASSISTED GAS LIFT

Foam-assisted gas lift is a combination of continuous gas lift with surfactant injection and works best in wells with a high water cut. This lift method is useful when a well's fluid level drops below the last gas injection valve, as the surfactant helps increase fluid column height, enabling gas injection. The addition of surfactant in gas lift reduces gas slippage, lowers fluid density, and decreases bottomhole pressure. Estimating bottomhole pressure in FAGL can follow a similar approach to PAGL. The Fancher and Brown no-slip holdup correlation is used to determine a theoretical maximum for vertical lift performance and bottomhole pressure, serving as an upper limit (Farag, et al., 2016). While there is no direct method for estimating bottomhole pressure in FAGL, a pressure estimation for continuous gas lift can be used as a lower limit, similar to PAGL. The combination of these two estimations creates a window for predicting bottomhole pressure.

CONCLUSION

Improving gas lift methods will be key to maintaining oil production while reducing operating costs. Late-life applications of IGL, PAGL, GAPL, and FAGL provide practical ways to improve lift performance in depleted oil and gas wells. However, estimating bottomhole pressure remains challenging in these applications due to pressure fluctuations, liquid fallback, and gas injection. While methods for PAGL and FAGL offer practical estimations, refinement of these models is necessary to increase accuracy. Also, a distinction between PAGL and GAPL is to prevent oversight in GAPL's unique challenges. While methods for IGL bottomhole pressure estimation have been established and tested, further research can improve accuracy and allow operators to make calculated decisions.

REFERENCES

1. Beadle, Glenn. "Evaluation of Surface Back - Pressure for Continuous - And Intermittent - Flow Gas Lift." J Pet Technol 15 (1963): 243–251. doi: https://doi.org/10.2118/442-PA

2. Farag, A., Robertson, T., Kerem, M., and J.. Montero. "Foam Assist in a Gas-Lifted Oil Well." Paper presented at the SPE Middle East Artificial Lift Conference and Exhibition, Manama, Kingdom of Bahrain, November 2016. doi: https://doi.org/10.2118/184217-MS

3. Sandoval, S., Solórzano, L. R., and S. Gasbarri. "Transient Two-Phase-Flow Model for Predicting Column Formation in Intermittent Gas Lift Systems." Paper presented at the SPE Latin American and Caribbean Petroleum Engineering Conference, Rio de Janeiro, Brazil, June 2005. doi: https://doi.org/10.2118/94950-MS

<u>TABLES AND FIGURES</u>

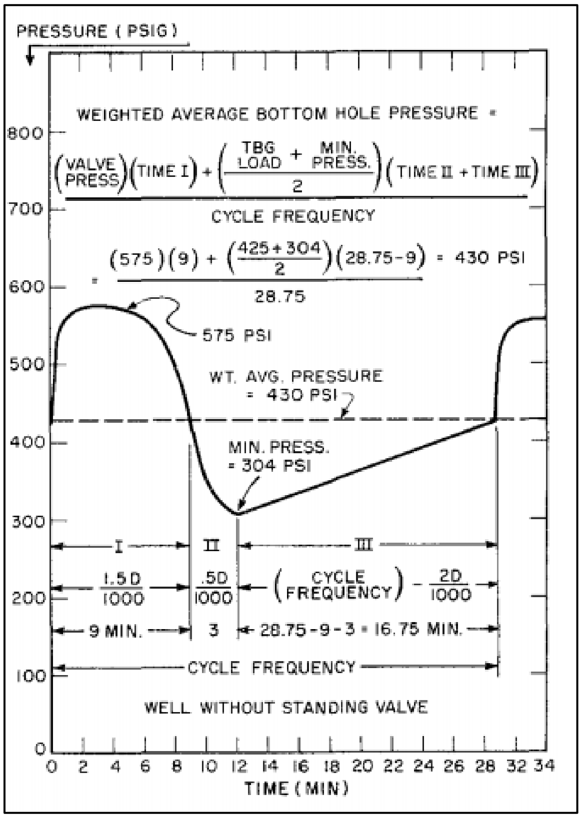

Figure 1 - Weighted average flowing bottomhole pressure without standing valve (Beadle).

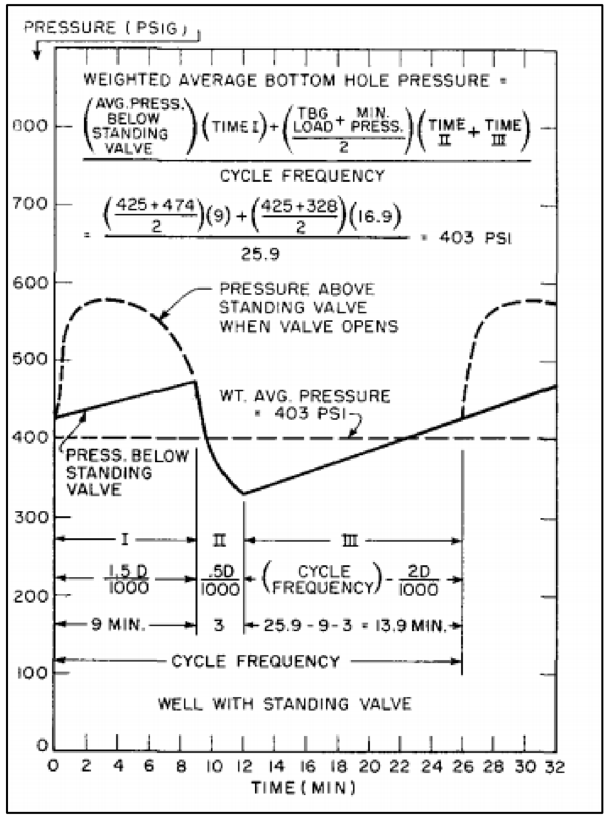

Figure 2 - Weighted average flowing bottomhole pressure with standing valve (Beadle).

$$Hl = f\left(\frac{(\rho_l - \rho_g)\cdot v_{sl}\cdot d}{\mu_l}, \frac{v_{sl}}{v_{sl}+v_{sg}}, \frac{\mu_l}{\mu_g}\right)$$

Figure 3 - Dimensionless group to determine slippage liquid holdup (Sandoval).

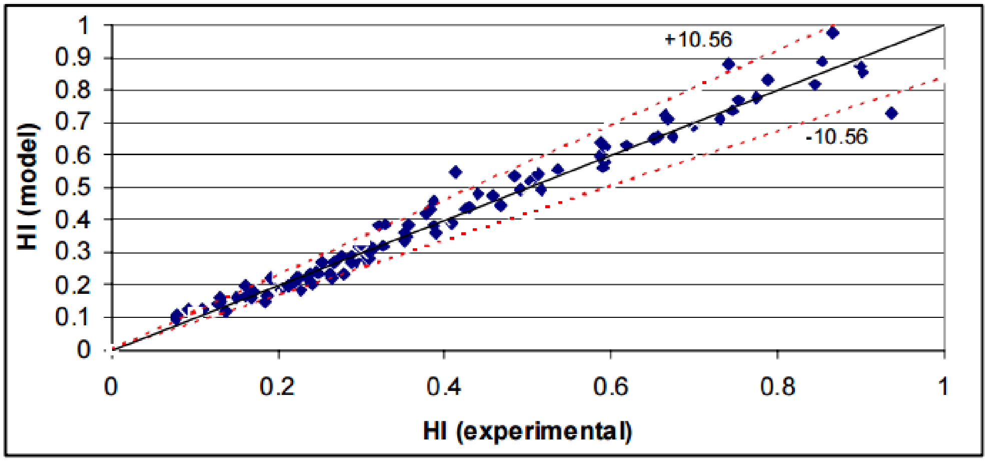

Figure 4 - Liquid holdup measured vs. model calculated (Sandoval).

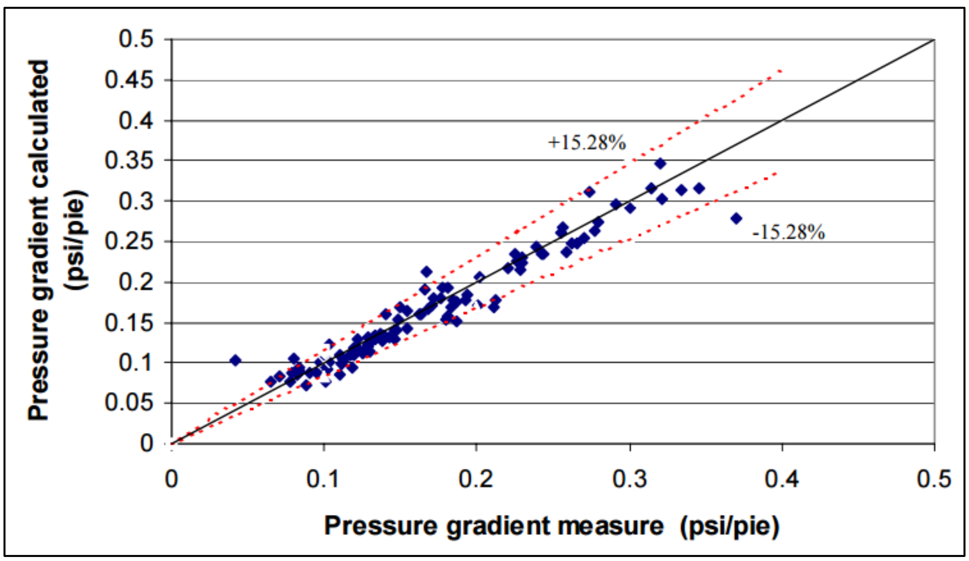

Figure 5 - Pressure gradient measured vs. model calculated (Sandoval).

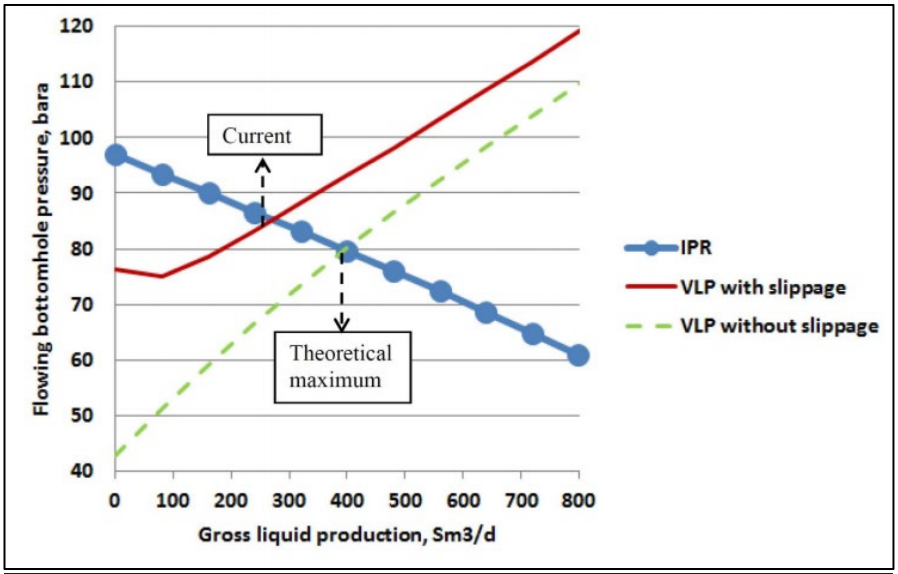

Figure 6 - IPR versus VLP curve. Surfactant assisted gas lift is expected to result in a production rate between the intersections of the two VLPs with the IPR (Farag).