

# BHP & Nodal Analysis

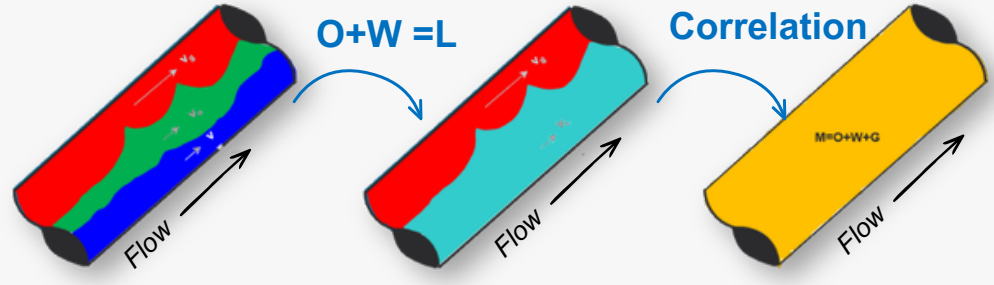
## A Production Engineering Reference Guide



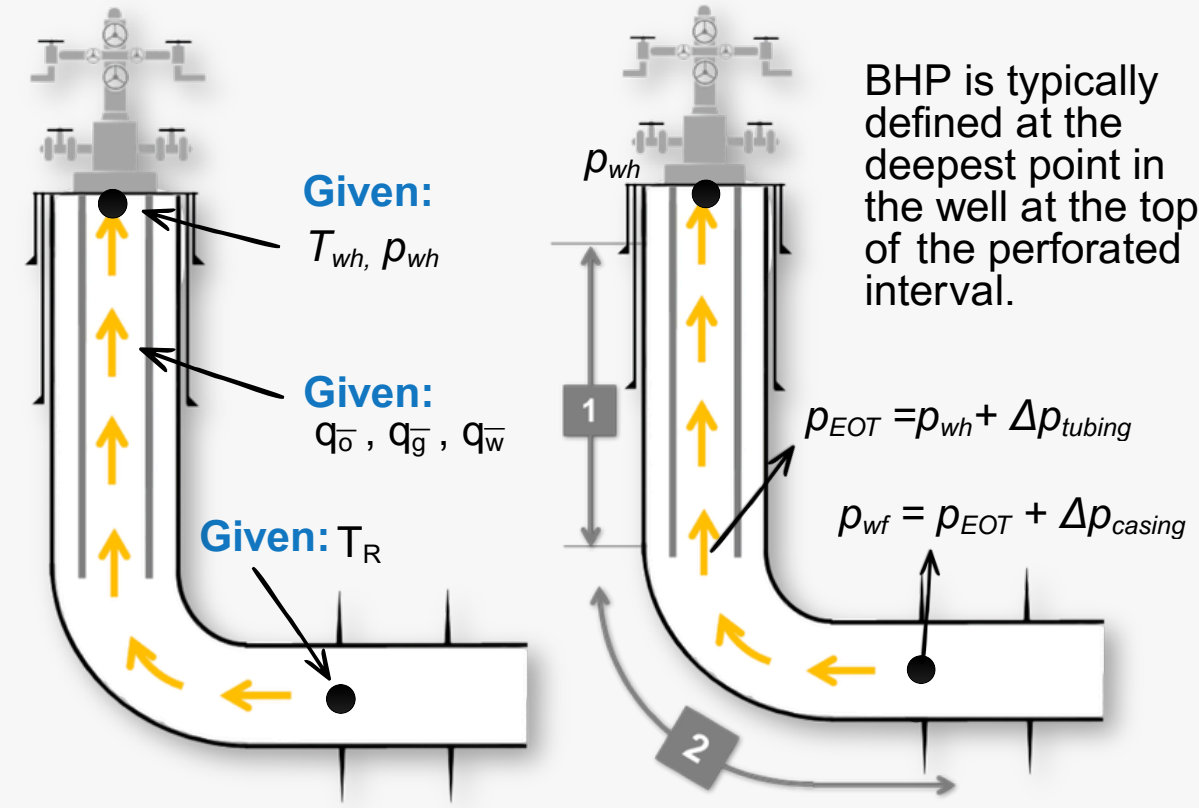
### Bottomhole Pressure (BHP) Calculations

Why do we need to calculate BHPs? Because we don't have a gauge to measure it (or the gauge is far from the top perf!)

BHP calculations rely on using **single-phase flow** equations to model multiphase flow.  
 → Oil and water are lumped into a liquid phase  
 → Liquid and gas are averaged into a single-phase mixture



For a naturally flowing well, calculate from top to bottom:



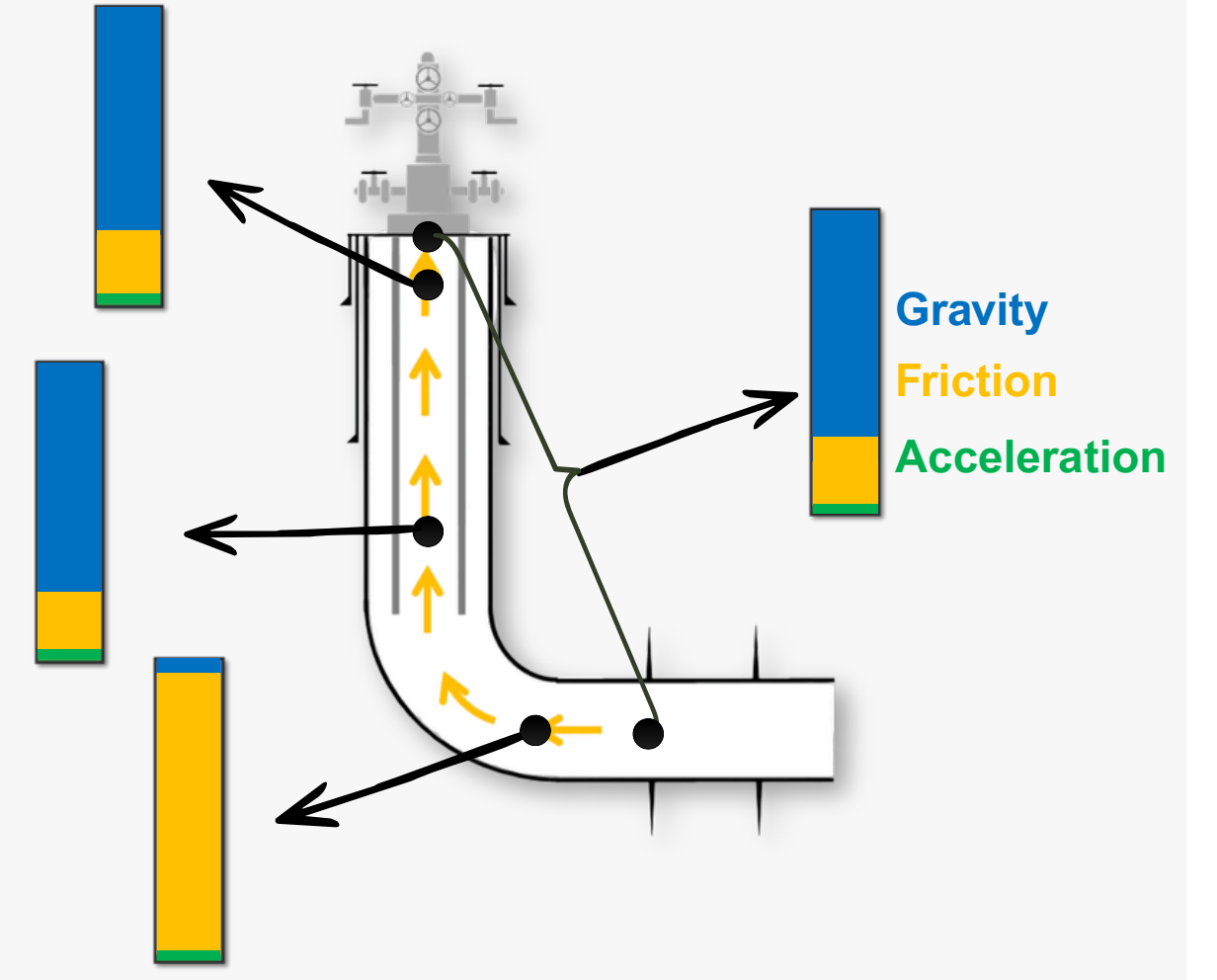
Fun fact With plunger lift, whitson\* lets you define open/shut-in times and plunger travel time to better estimate BHP.

### BHP Pressure Gradients

$$\frac{dp}{ds} = \rho \frac{g}{g_c} \cos(\theta) + \frac{f_D \rho V^2}{2d_h g_c} + \frac{dV}{g_c} \frac{dV}{ds}$$

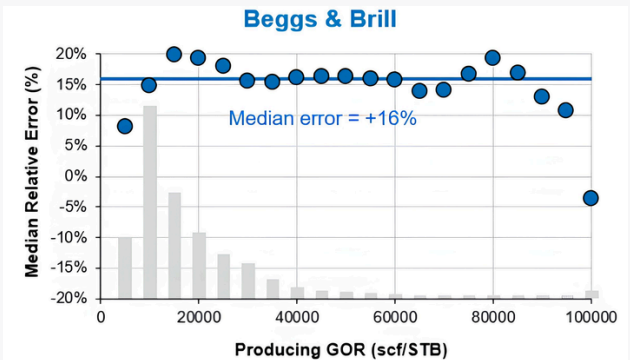
Gravity                      Friction                      Acceleration

**Gravity:** Caused by the weight of the fluids. Acts in the direction of gravity.  
**Friction:** Caused by the pipe wall.  
**Acceleration:** Caused by a rapid expansion of the fluids. Only relevant for gaseous wells near the wellhead for low wellhead pressures ( $p_{wh}$ ).

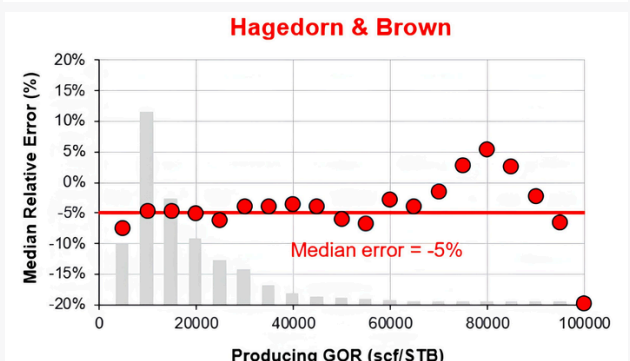


### BHP Correlations

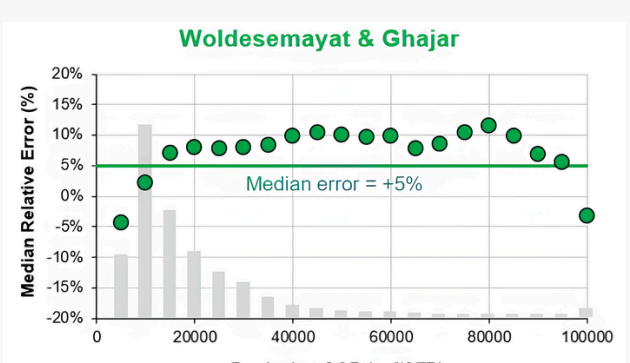
Whitson\* supports multiple drift-flux correlations for multiphase flow, modeling phase slip through empirical mixture relationships. They are preferred for their simplicity and computational efficiency compared with fully mechanistic models that solve separate phase equations.



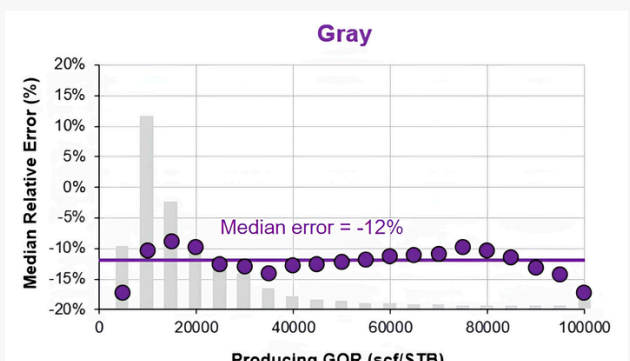
**Beggs and Brill (1973)** General-purpose correlation applicable across all pipe inclinations and flow regimes



**Hagedorn and Brown (1965)** Best suited for vertical oil-gas flow, based on classic experimental tubing data.



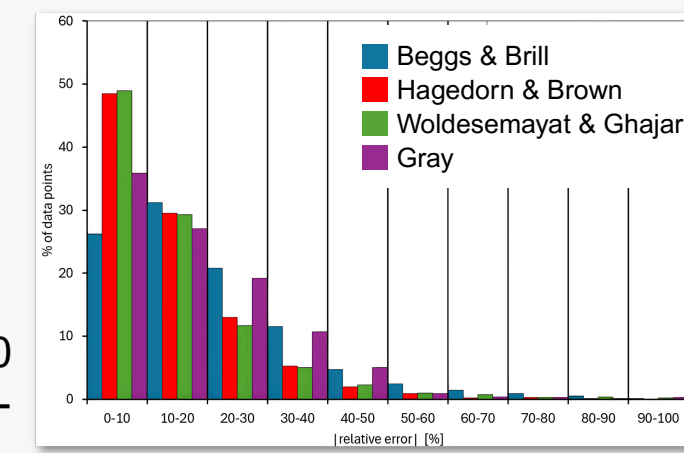
**Woldesemayat and Ghajar (2006)** A modern drift-flux formulation with improved accuracy across fluids, diameters, and inclinations.



**Gray (1978)** Optimized for gas-dominant and gas-condensate wells with high gas-liquid ratios.

Which is the most accurate?

Based on URTEc 4045619, which evaluated 300k data points across 420 wells, accuracy is well- and basin-dependent.



- **When gauge data is available:** compare BHP calculations to measured data and use the best-performing correlation for wells in the same basin.
- **When gauge data is not available:** Woldesemayat & Ghajar (2006) is recommended as the most reliable default.

$$\frac{dp}{ds} = \frac{\rho_g \frac{g}{g_c} \cos(\theta) + \frac{f_{Ds} \rho_l V_m^2}{2d_h g_c}}{1 - \frac{\rho_a V_m V_{sg}}{g_c P}}$$

Where  $\rho_g$  is Gravity Density  
 $f_{Ds}$  is Multiphase Friction Factor  
 $\rho_l$  is Friction Density  
 $\rho_a$  is Acceleration Density

If BHP correlation output does not match gauge data, the pressure drop correlation can be tuned by adding alpha and beta multipliers and running an algorithm to minimize measured vs. predicted error.

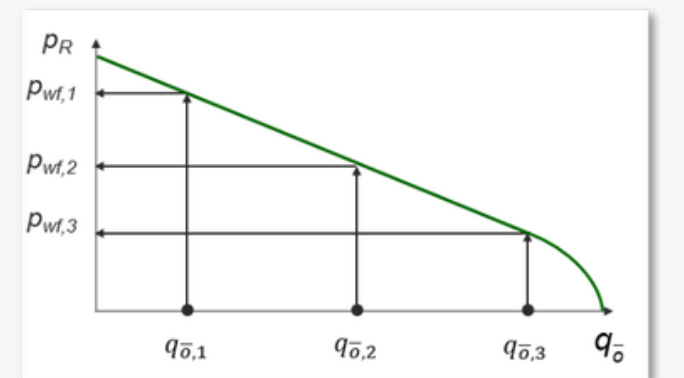
⚠ Be aware: tuning for one well or time period may not apply to other wells, or the same well later, especially after completion or operating changes. Always check against gauge data when available.

### Nodal Analysis

Nodal Analysis provides a simple way of evaluating whether the current well configuration produces the reservoir fluids efficiently, or if a different well configuration would increase the well performance. Nodal analysis is usually performed at specific location, often BHP.

#### Inflow Performance Relation (IPR)

Reflects how a well's oil and/or gas production rate changes at different bottom-hole flowing pressures (BHP), illustrating how the reservoir responds to drawdown and how much fluid it can deliver to the wellbore under varying pressure conditions. Will be **linear** if the BHP is above saturation pressure, and fluids are oil or water; **curved** if the fluids are gas or if oil and bhp below saturation pressure

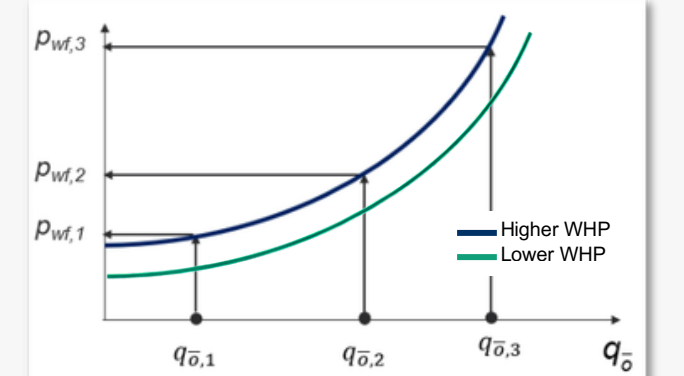


**Gas**                      **Oil**

$$q_g = C(p_{PR} - p_{wf})^n \quad q_o = \begin{cases} J(p_{PR} - p_{wf}), & p_b < p_{wf} \leq p_R \\ J(p_{PR} - p_b) + \frac{J}{1.8} \left[ 1 - 0.2 \left( \frac{p_{wf}}{p_b} \right) - 0.8 \left( \frac{p_{wf}}{p_b} \right)^2 \right], & 0 \leq p_{wf} \leq p_b \end{cases}$$

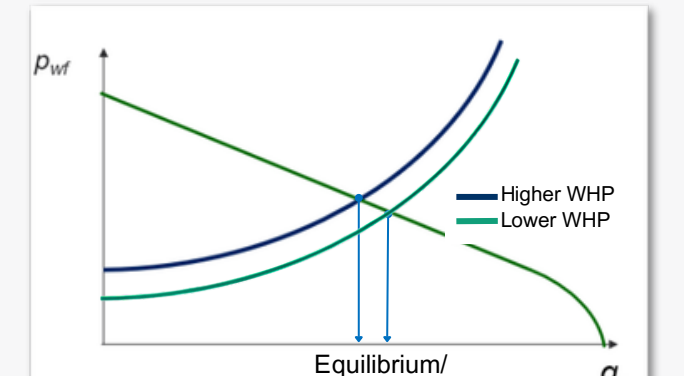
#### Vertical Lift Profile (VLP)

Describes the BHP required to flow against surface pressure and overcome the pressure losses through casing, tubing, annulus. Usually when it points upwards, there is significant pressure drop in the wellbore due to friction. When it points downwards pressure drop is for the most part due to gravity. There could be discontinuities in the curve due to discontinuities in the correlations employed.



#### Combined IPR and VLP

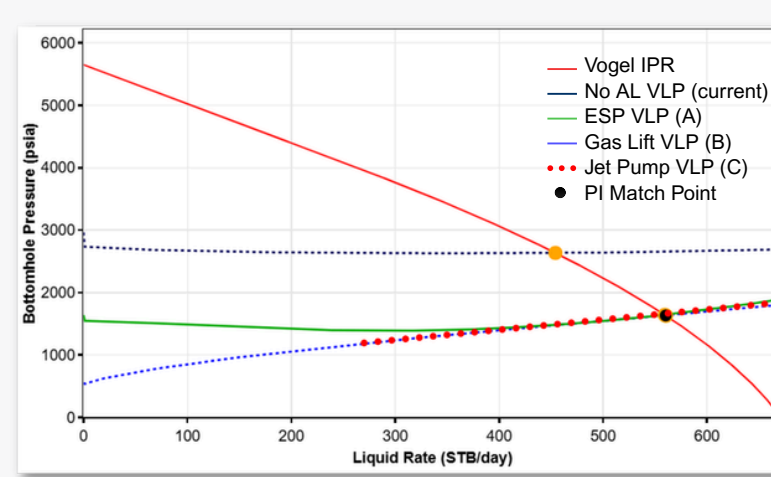
The well's flow rate occurs where the IPR and VLP curves intersect on a nodal analysis plot, defining the operating point where reservoir inflow equals wellbore outflow; if no intersection exists, the well cannot naturally lift fluids to surface under those conditions.



### Artificial Lift Planning

**Current Conditions:** Consider this situation: You want to increase the rate of your oil production with artificial lift, either by adding an ESP or gas lift.

This graph shows a Nodal plot with the new VLP estimated with a gas lift installation, jet pump and ESP installation. All provide the same rate increase, but the shape of the VLP is different.

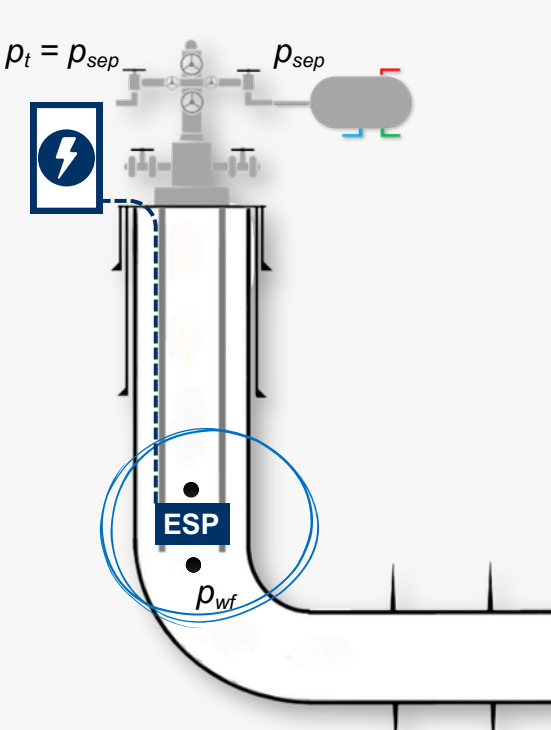


#### Which one to choose?

- ESP: Used for high production rate and deep wells; efficient; sensitive to gas, solids, transients
- Gas Lift: the most versatile option, but less effective for high GOR wells.
- Jet Pump: Similar to ESP but for somewhat lower rates, and less efficient, but very tolerant to sand, high temperature and gas. It has great durability if operated properly.
- Plunger Lift: Used mainly in gas wells with low liquid rates to const-effectively remove liquid loading using the well's own gas pressure.

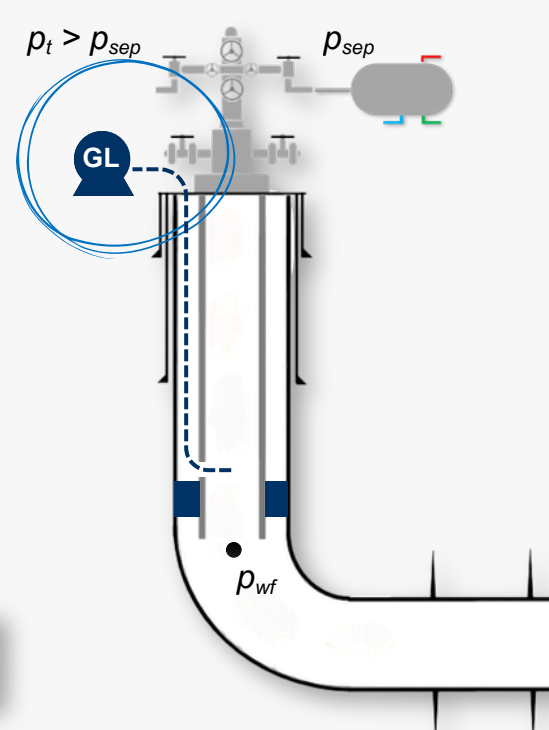
#### Option A: Install an ESP

Electric Submersible Pump (ESP) consists of a downhole pump, driven by an electric motor, that gives a pressure boost to reservoir fluids such that they can flow to surface.



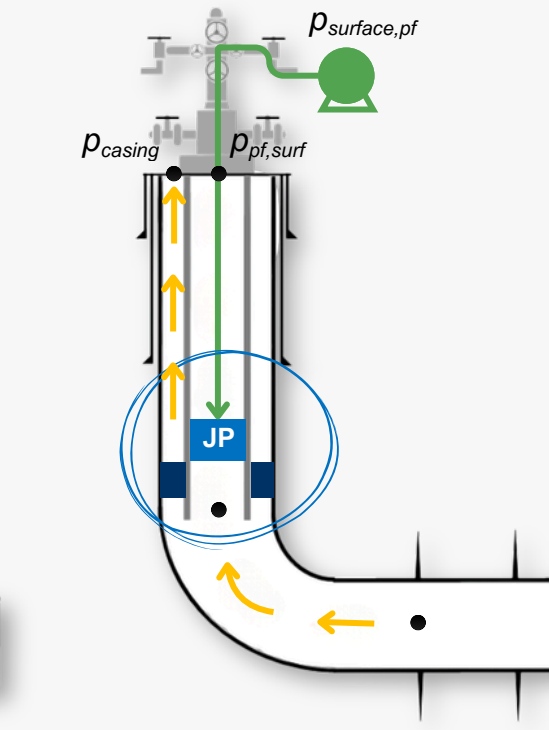
#### Option B: Add Gas Lift

Gas is injected into the tubing at a given depth, which reduces the density of the reservoir fluids, therefore reducing the pressure drop.



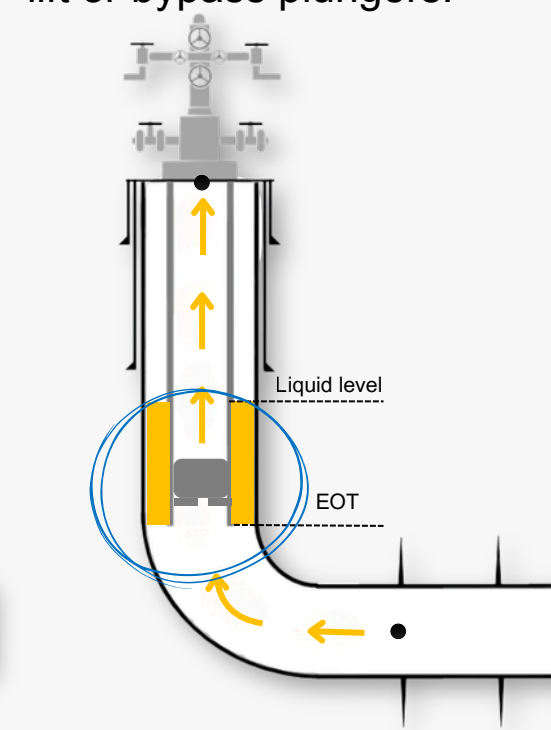
#### Option C: Install Jet Pump

Jet pump is similar to ESP, but is driven by injected dead oil or water from surface, which then flows with reservoir fluids from pump depth to surface and can increase pressure drop.



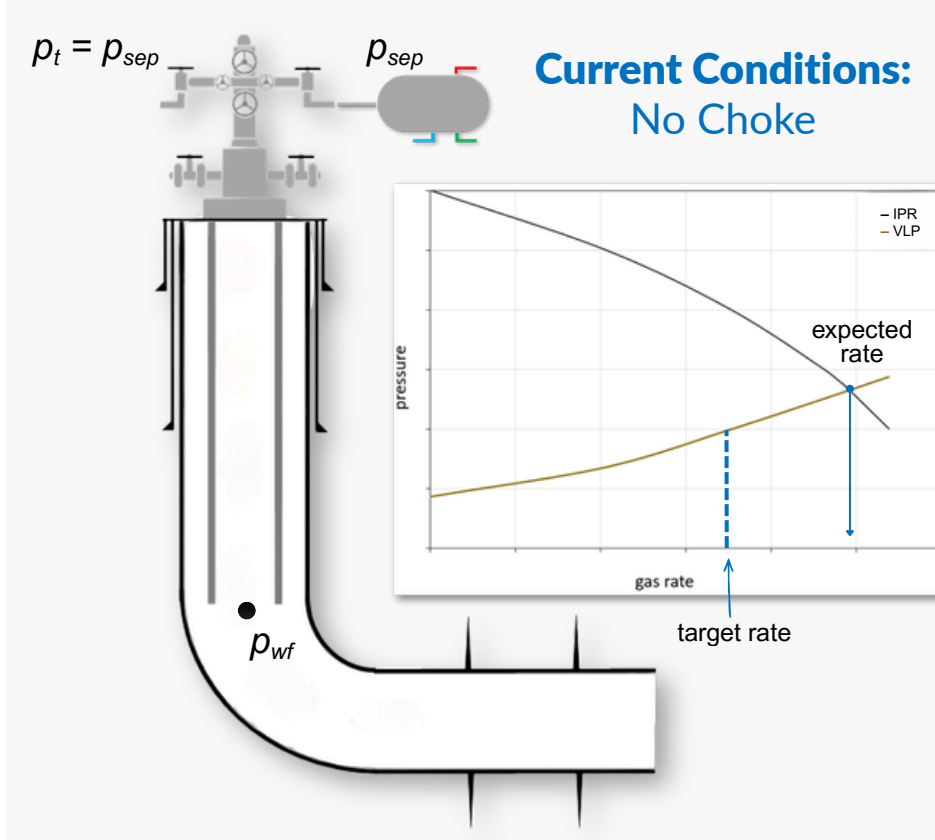
#### Option D: Install Plunger Lift

Plunger lift uses a plunger in the tubing to remove liquids as it rises. It rests at bottom during shut-in, travels to the wellhead when flowing. Variations include PAGL and GAPL, which combine gas lift or bypass plungers.



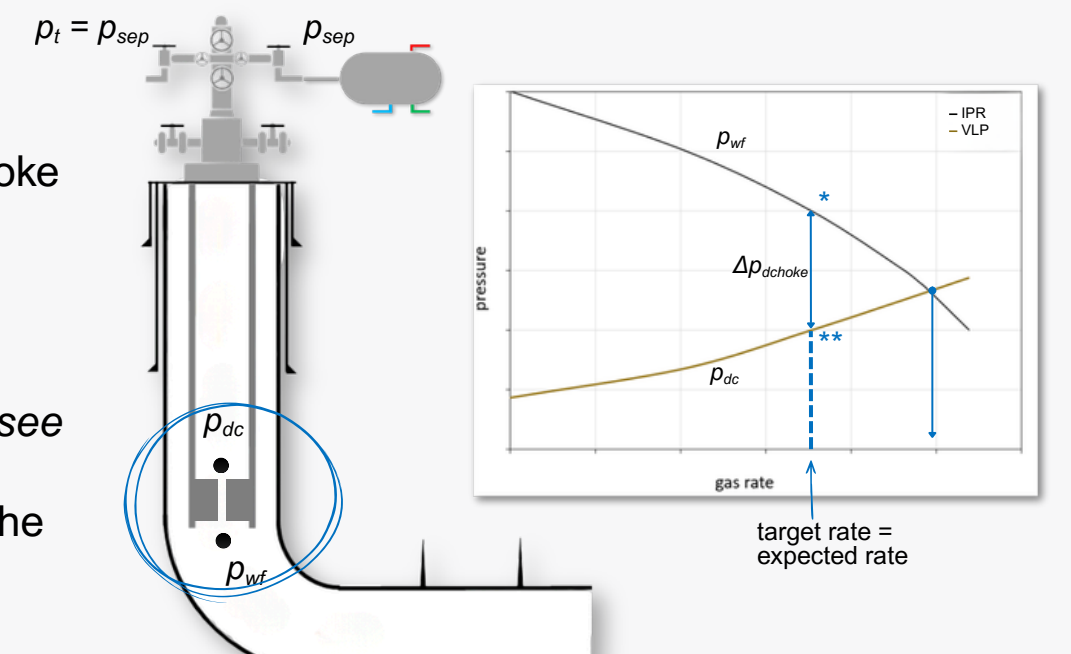
### Choke Planning

Consider this situation: A nodal analysis is performed on a well with no wellhead choke. The **expected rate is higher than the target rate**; therefore, choking is required.



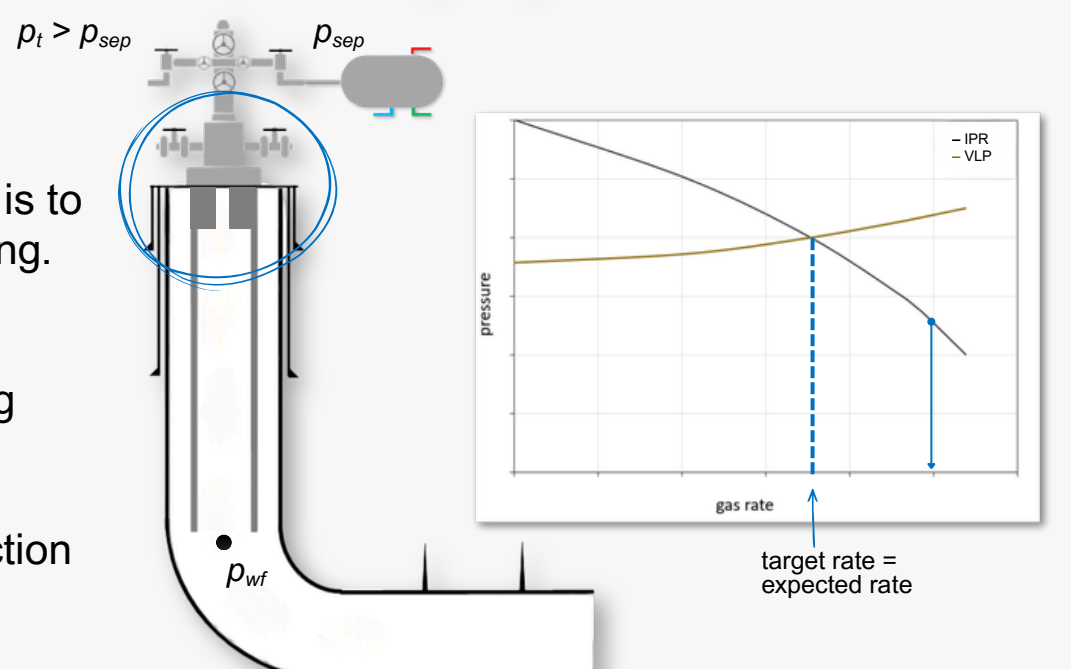
#### Option A: Downhole Choking

If a bottom-hole choke is used, the choke must drop the pressure from the pressure available from the reservoir (see \*) to the pressure required to flow to the surface through the tubing (see \*\*).



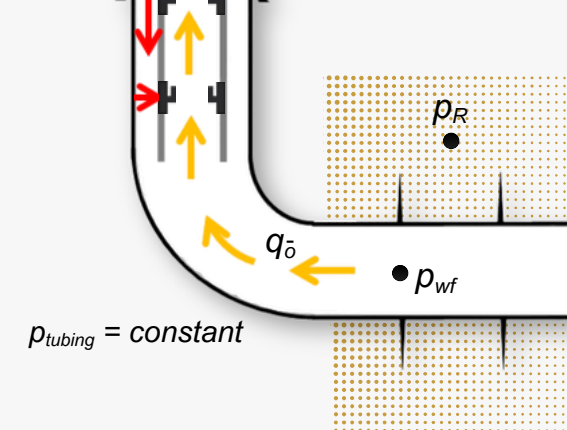
#### Option B: Wellhead Choking

Another alternative is to use wellhead choking. In this approach, wellhead choking increases the tubing head pressure and "shifts" the VLP up, moving the intersection to the left.

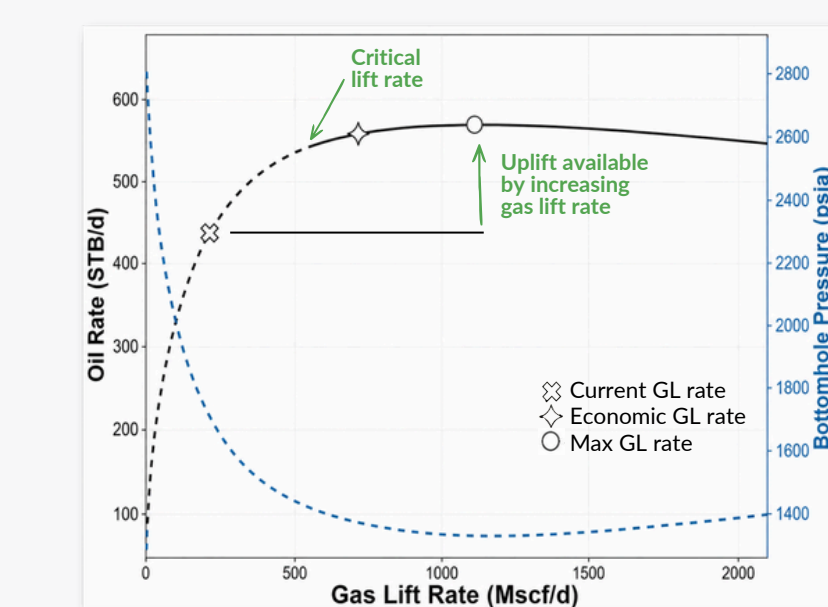


### Gas Lift Planning

Finding the best gas lift rate is challenging, the gas lift curve (plot) represents the reservoir rate at all gas lift rates allowing you to more easily identify the best gas lift rate for your operations.



#### Economic Max Rate



**GL ↑ = BHP ↓ = Rate ↑**  
 By injecting gas into the tubing, this artificial lift method reduces flowing density and pressure losses, lowering bottom-hole flowing pressure and increasing production rates.

When evaluating gas lift performance, it is important to assess the **economic max rate** rather than the peak rate, by accounting for gas lift costs, as producing at max rate may reduce overall profitability.

$$\text{Profit} = \text{hydrocarbon rate} \times \text{hydrocarbon price} - \text{gas lift rate} \times \text{lift gas cost}$$

### Liquid Loading

Liquid loading occurs in gas wells producing associated liquids (such as water or condensate) when gas velocity is no longer sufficient to carry liquids to surface, leading to liquid accumulation in the wellbore, declining rates, and eventually unstable or ceased flow. As loading develops, flow regimes shift from gas-dominated (mist, annular) to liquid-dominated (slug, churn, bubble), reducing effective deliverability.

Common liquid loading criteria used to estimate critical gas rate include the following.

- **Turner** – Based on droplet entrainment/critical gas theory; widely used and robust across many field conditions.
- **Belfroid** – Incorporates pressure effects and high-pressure behavior; often slightly more accurate than Turner.
- **Coleman** – Empirical, field-data-based correlation; tends to be optimistic and underpredict lower critical rates
- **Nagoo** – Focuses on flow regime transition concepts; tends to be optimistic and underpredict critical rates

Read more in SPE 209745-MS

Learn more with whitson!



Upcoming Courses



Manual on Nodal Analysis



YouTube Channel

### Multi-Well Gas Lift Optimization

When optimizing gas lift across multiple wells, the goal is to allocate limited injection gas where it delivers the greatest production and economic response. Rather than splitting gas evenly, some wells may achieve strong gains with less gas while others may provide little return, so optimizing distribution maximizes overall field value and "bang for the buck."

The relationship between gas lift injection and liquid production is shown across wells, highlighting how each responds to incremental gas. A smart allocation approach in whitson\* automatically distributes gas lift to maximize total liquid response, ensuring each unit of injected gas is used where it delivers the greatest impact.

