Artificial Lift

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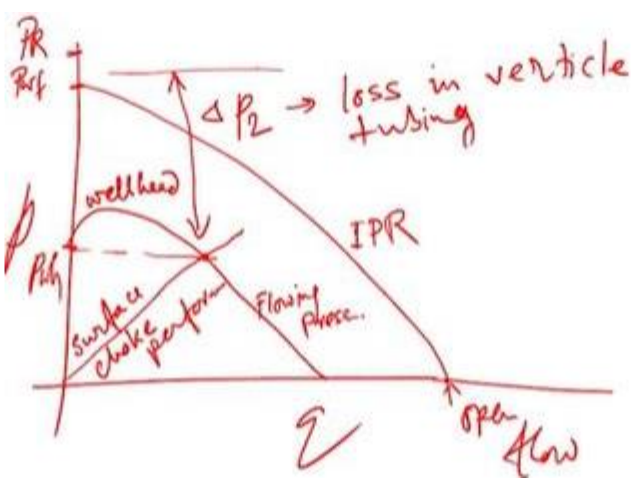
Lecture-18 Choke Performance

Our previous lectures discussed how fluid travels from the reservoir to the wellbore and up to the surface, encountering various pressure losses along the way. We've already calculated pressures for the reservoir to the wellbore and from the wellbore to the wellhead.

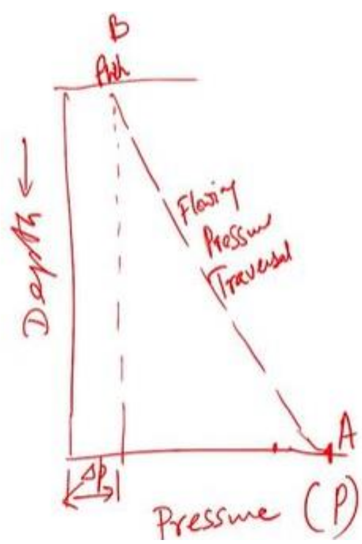
Now, we will focus on the wellhead to the separator, where a crucial piece of equipment called the choke comes into play. The choke is an essential component of wellhead and surface production systems as it allows the control of flow. It ensures that the pressure in the wellbore is not directly delivered to the separator system. When installing a choke, certain relationships need to be considered between the reservoir, wellbore, and the surface.



To illustrate this, let's draw a figure. We have Q (flow rate) and P (pressure). Initially, the reservoir pressure (PR) is here. After surface completion, the reservoir pressure drops, and we reach Pwf (flowing pressure). You have an Inflow Performance Relationship (IPR) curve when you have flowing pressure. It's essential to understand that this IPR curve may not be linear, especially for two-phase flow. The point where you have no flowing pressure, and the reservoir pressure is high, indicates a high flow rate, known as the open flow in the tubing, reaching Pwh (wellhead pressure).

The curve for the wellhead and flowing pressure will differ as you reach the wellhead. Now, let's consider the performance of the surface choke. It will show how pressure drop results in a reduced flow rate. Higher pressure drop leads to lower flow rates. The performance of the surface choke influences flow rates in response to pressure changes.

The installation of a choke is necessary because you shouldn't direct all the pressure to the separator. Instead, you must control the pressure and then deliver it to the separator. Failure to do so would affect separation performance and other aspects. It can also impact pumping performance. Therefore, you should maintain stability in production for extended periods.



In this context, chokes come in two primary types: variable chokes and fixed chokes. A pressure versus flow rate diagram illustrates the pressure change from the reservoir to the surface. This figure depicts how wellhead pressure affects depth, pressure, flow rate, and pressure drop (del P1). As the flowing pressure changes, it follows a specific pattern.

This illustrates the change in flowing pressure concerning depth. When increasing the depth from the surface to the wellbore, you can observe how the pressure changes. Initially, the pressure is very high at point A, gradually decreasing, reaching point B at the wellhead. Due to various restrictions, such as those in the reservoir, sand phase completion, piping, wellhead connections, and choke restrictions, you eventually reach the surface separator system. The surface separator system has several pressure drops before you finally reach the stock tank or balance tank.

The entire system is primarily driven by reservoir pressure. Adding extra pressure through artificial lift mechanisms or other means means investing extra energy, which may come from electricity or other energy sources, resulting in additional costs. To reduce these costs, you must design and operate the system synchronized. You should avoid making sudden changes to choke parameters or other system variables because the goal is to maintain stable production over an extended period. Sudden production fluctuations can be costly and reduce your overall benefits, whether due to issues like sand injection, gas coning, water coning, artificial lift system failures, or surface production system problems.

$$\left(\frac{p_{outlet}}{p_{up}}\right)_c = \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

Therefore, your primary objective should be achieving stable production over a prolonged period.

Now, let's draw a representation of a choke. People typically depict a choke as a restriction, with the piping diameter initially set at D. This diameter reduces to D1, leading to the wellhead. Here, you have cementing, the wellhead, and the choke. Choke restrictions are drawn like this to indicate the reduction in piping diameter. Initially, it's D, but it narrows down to D1 and then to D2. This is the inlet (upstream) and the outlet (downstream). Sometimes, the specification refers to downstream pressure or upstream pressure.

Now, when fluid flows through the choke, you need to understand how the pressure at P2 relates to the pressure at P1. Since the wellhead pressure is fixed, you control the downstream pressure using the choke, and it can be adjusted by adding a substantial restriction after the choke. However, you don't have control over the upstream control pressure because your reservoir system determines that.

Let's consider a scenario where the downstream pressure from the reservoir becomes very low initially, denoted as P2. The flow rate will be very high when P2 is very low and P1 is very high. Now, introduce a certain restriction, gradually increasing the value of P2. As you increase P2, you'll notice that the flow rate becomes somewhat lower. Continue reducing the value of P2, and the flow rate gradually decreases even further. After some time, if you keep reducing the value of P2, you'll find that the flow rate remains relatively constant. This point, where the flow rate becomes nearly constant, is known as the critical flow rate or critical value. This area is the critical region, and the area where the flow rate changes is the subcritical area.

$$q = C_D A \sqrt{\frac{2g_c \Delta P}{\rho}}$$

$$q = 8074 C_D d_2^2 \sqrt{\frac{\Delta p}{\rho}}$$

The ratio of pressure is referred to as the critical pressure ratio. Once a choke operates under critical conditions, any change in P2 pressure won't significantly impact the flow rate. If the upstream or wellhead, wellbore, and reservoir are affected, numerous issues can arise, such as gas coning, water coning, sand influx, debris accumulation, artificial lifting system failures, or valve malfunctions. In the case of wellbore operations, accessing inaccessible wellbores can be quite expensive, particularly in remote areas like oceans, forests, or deserts, where road accessibility is limited. In such cases, helicopter operations for equipment transport, pipe and tubing reconnection, and wellbore recompletion can be prohibitively expensive. Therefore, changing the downstream pressure or flow rate instead of the wellbore tubing pressure makes the system more synchronized and easier to manage. Surface-based operations are more convenient, as there is no need for drilling rigs or wellbore re-completions.

Calculating the critical pressure involves a formula, and we can represent it as follows. Once again, let's consider a choke with P2 as outlet pressure, P1 as upstream pressure, k as a constant term, and this power function. If the ratio of these pressures equals 0.528, it's considered a critical pressure. This ratio is termed the critical pressure, and k has a typical value of 1.28 for natural gas. However, if k varies, the critical pressure ratio will be different, and you'll need to recalculate based on the specific value of k. The value of k depends on the fluid's specific heat ratio, denoted as Cp/Cv.

The formula for single-phase liquid flow through the choke is Q equals Cd into A into 2 into Gc into ΔP divided by ρ. The parameters include Q (flow rate in cubic feet per second), Cd (coefficient of discharge), A (choke area in square feet), Gc (a constant), ΔP (pressure drop in pounds per square foot), and ρ (fluid density in pounds per cubic foot).

For single-phase gas flow, there are two parameters to consider: subsonic flow and sonic flow. Let's first look at the subsonic flow formula. The equation for subsonic gas flow rate (QSC) is in MSCF per day, with Pup as the upstream pressure in psi, A2 as the choke's cross-sectional area in square inches, K as the specific heat ratio, G as the specific gravity of gas, and Tup as the upstream temperature in degrees Rankine.

$$q_{sc} = 1{,}248 C_D A_2 p_{up} \times \sqrt{\frac{k}{(k-1)\gamma_g T_{up}}\left[\left(\frac{p_{dn}}{p_{up}}\right)^{\frac{2}{k}} - \left(\frac{p_{dn}}{p_{up}}\right)^{\frac{k+1}{k}}\right]}$$

$$N_{Re} = \frac{20 q_{sc}\gamma_g}{\mu d_2}$$

$$v = \sqrt{v_{up}^2 + 2g_c C_p T_{up}\left[1 - \frac{z_{up}}{z_{dn}}\left(\frac{p_{down}}{p_{up}}\right)^{\frac{k-1}{k}}\right]}$$

Remember, the temperature should be in degrees Rankine (460 plus Fahrenheit), and the downstream pressure is in psi and the upstream pressure in psi. The given K value is 1.28. To determine the coefficient of discharge (Cd) for calculating Reynolds number, use the formula where QSC is in MSCF per day (gas flow rate), gamma G represents the specific gravity of gas (which is 1 for air), mu is the viscosity term, Cp, and d2 represent the choke area or choke diameter.

In subsonic gas flow, where the velocity is less than the sound velocity, the upstream velocity (V) squared can be calculated using specific heat (Cp = 187.7 lbf feet/lbm R) and the gas constant. Various parameters are almost known, such as the Gc value of 32.12. Now, let's move to sonic gas flow, where the coefficient of discharge (Cd), area of the choke, upstream pressure, K value, and upstream temperature are considered. When gas expands due to the reduction in pressure, the temperature decreases. Using the PV equals nRT formula, you can calculate how much the temperature drops. By determining this temperature change, you can assess whether frost formation will occur after the choke.

$$Q_{sc} = 879 C_D A p_{up} \sqrt{\left(\frac{k}{\gamma_g T_{up}}\right)\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

$$v = \sqrt{v_{up}^2 + 2 g_c C_p T_{up}\left[1 - \frac{z_{up}}{z_{outlet}}\left(\frac{2}{k+1}\right)\right]}$$

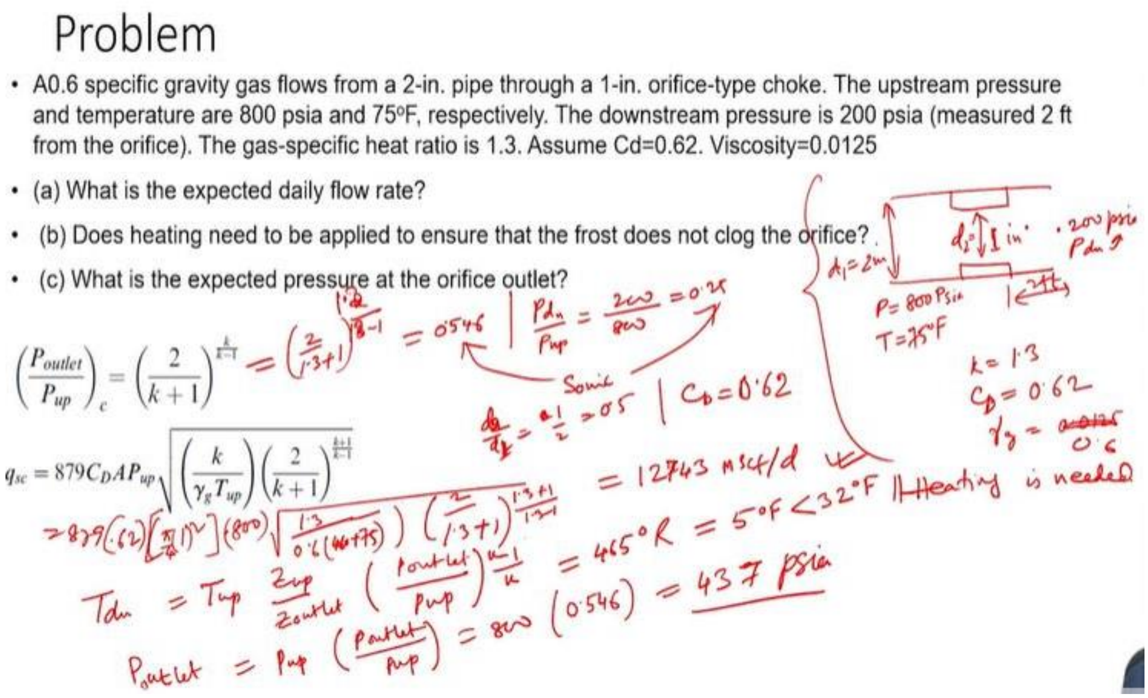
$$v \approx 44.76\sqrt{T_{up}}$$

To calculate the downstream pressure, use the equation: downstream pressure equals T upstream pressure times Z outlet (compressibility factor) times T factor, where the known values are K (1.28) and T factor. By solving these equations, you can answer specific questions about gas flow, such as expected daily flow rate, the need for heating, and the outlet pressure at the orifice.

Calculate the upstream temperature (T upstream) and downstream temperature (T downstream) to determine if heating is needed. T downstream equals T upstream times (Z upstream divided by Z outlet) divided by (P outlet divided by P up) times (K minus 1) divided by K. When I calculate this, it comes out to be 465 degrees Rankine, which means 5 degrees Fahrenheit less than 32 degrees Fahrenheit. Ice will form if the temperature falls below 0 degrees Celsius, so heating is required. Place a heating coil around the choke to prevent ice formation and blockage.

$$T_{dn} = T_{up} \frac{z_{up}}{z_{outlet}}\left(\frac{p_{outlet}}{p_{up}}\right)^{\frac{k-1}{k}}$$

So, heating is indeed needed. Now, let's calculate the outlet pressure (P outlet). P outlet can be found using the equation: P outlet divided by P up equals 800 times 0.546, which equals 437 psia. This is the answer.



Pumps are used everywhere, and our lives depend on them. One pump, our heart, works tirelessly. In some parts of the world, people live for over 100 years, with their hearts pumping for a long time. For instance, in Japan's Okinawa island, people have a longer life expectancy. Scientists and engineers are trying to develop pumps that can work for extended periods. They even consider replacing the heart with artificial mechanisms like centrifugal pumps. Pumps play a crucial role in our modern lives. In buildings, pumps supply water, and pumps are indispensable in various machinery like IC engines.

There are different types of pumps, from hand pumps to cycle syringe pumps, and even the heart can be seen as a pump. Pumps are utilized in agriculture, household applications, and surface production operations. In the oil industry, artificial lift systems are essentially pumps. They are used to lift fluids from wellbores to the surface. There are various applications, from small pumps like injection needles to large industrial pumps. Pumps have wide-ranging uses and are essential in numerous aspects of our lives.