Artificial Lift

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Lecture-61 Surface Compressor for Gas Lift - Part 2

For centrifugal pumps, several advantages come into play. Positive displacement pumps, such as reciprocating pumps, possess noteworthy qualities. They can generate the high pressure levels often required for gas lifting applications. Centrifugal pumps have their own merits, which include high flow rates and the ability to create high pressure through multiple staging.

Moreover, maintenance for centrifugal pumps is minimal due to the limited number of moving parts. When designing an engineering system, it's essential to consider that systems with many moving elements typically have a shorter lifespan. In the context of a centrifugal pumping system, just one rotating shaft connects the motor to the impeller. Compared to reciprocating pumping systems, this streamlined design minimizes wear and tear, which feature numerous valves continually opening and closing, causing back-and-forth motions that decrease system longevity. Centrifugal systems require no cooling water due to their high volume flow rates, and their compression ratios are not exceedingly high, making cooling water less critical.

Additionally, centrifugal pumps offer continuous flow, unlike reciprocating systems with pulsating flows, where accumulators are often needed to mitigate the stress caused by alternating flow patterns.

In contrast, reciprocating systems provide the advantage of achieving very high pressure ratios and accommodating substantial volume flow rates through the use of multiple stages. Flow rates can be significantly increased by employing piston-driven configurations, such as duplex or triplex designs.

The following formulas are employed to calculate various parameters for a centrifugal pump or centrifugal compressor: P V power n equals constant, assuming a polytrophic heat process. Here, "n" signifies the polytrophic exponent, and "k" represents the specific heat constant (or specific heat ratio). These values are interconnected, with the relationship described by the equation n minus 1 divided by n equals k minus 1 divided by k into 1 divided by η_p (or e_p), where η_p denotes polytrophic efficiency. The formula for e p is provided as 0.61 plus 0.03 times the logarithm of q1 (inlet flow rate), where q1 is measured in cubic feet per minute (CFM). Additionally, the compressor ratio (compressor r) is determined by p2 divided by p1, and q1 is calculated from pb (base pressure), t1 (inlet temperature), and q under standard conditions.

Centrifugal

$PV^n = C$, n denotes polytropic exponent, $\frac{n-1}{n} = \frac{k-1}{k} \cdot \frac{1}{\eta_p}$ or E_p, η_p = polytropic eff. $= 0.61 + 0.03 \log(q_1)$

k → sp. heat ratio, q_1 → inlet flow rate cfm

compression ratio, $r = P_2/P_1$

$q_1 = \frac{P_b}{P_1} \cdot \frac{T_1}{T_b} \cdot q$ | q → under standard condition, q_1 → inlet condition

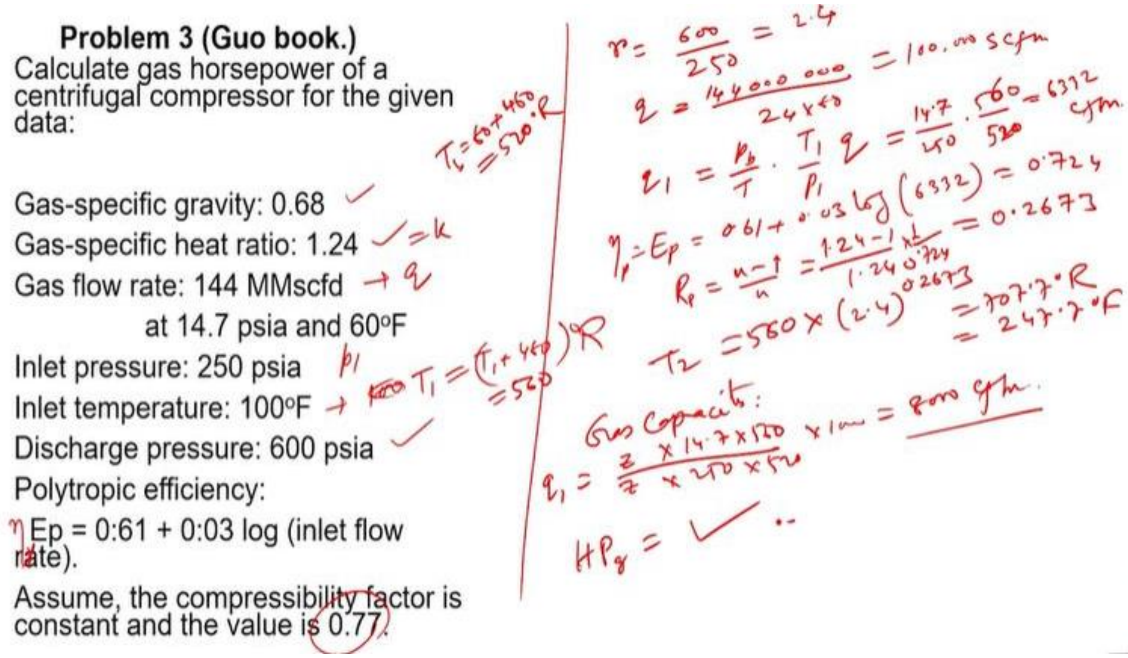
polytropic ratio, $R_p = \frac{n-1}{n} \cdot \frac{k-1}{k} \cdot \frac{1}{\eta_p}$

$T_2 = T_1 (r)^{R_p}$

$q_1 = \frac{z_1 P_b T_1}{z_2 P_1 T_b} q$

To illustrate, let's consider a specific problem. Given values such as gas specific gravity (0.68), specific heat ratio (k), gas flow rate (q), inlet pressure (p1), and inlet temperature (t1, which needs to be converted to Rankine by adding 460), polytrophic efficiency (e p or eta p), and matching z values, you can work through the calculations. The first step involves finding the value of r (the pressure ratio), which equals 600 divided by 250, resulting in a value of 2.4. Converting the flow rate (q) to standard conditions yields 6,332 CFM. Substituting this value into the formula for e p results in e p equaling 0.724. The polytrophic ratio (r p) is then calculated as 0.2673. Using r p, t2 can be determined to be 707.7 degrees Rankine. Finally, the gas capacity (q1) can be found, resulting in a value of 8,000 CFM. The text concludes by hinting at further calculations for h p, leaving it to the reader to compute.

Please note that there might be some specific technical terms or notations in the text that I couldn't fully interpret, and some adjustments may be required for precise calculations.



The formula for these types of compressors can be found in the book. Rotary compressors come in various forms, such as gear-type or scroll-type compressors. In a scroll-type compressor, for instance, one component rotates, compressing and squeezing a pipe. This design effectively draws fluid in and delivers it. While these rotary compressor types exist, centrifugal and reciprocating compressors are the most commonly used for gas lift applications.

If you wish to explore this topic further, I've provided a link for your reference. The operation of reciprocating compressors is based on a similar principle to reciprocating pumps. In this case, a piston moves back and forth within a cylinder, alternately operating valves V1 and V2. This action results in pressure development. These compressors intake gas or air and deliver it into a designated chamber or storage area. The essential principle of reciprocating compressors involves understanding the indicator diagram and its appearance.

Consider a piston-cylinder arrangement, similar to what was discussed for pumps in a previous lecture. In this context, we'll focus on the PV diagram (pressure vs. volume) in the piston-cylinder system, with TDC (Top Dead Center) and BDC (Bottom Dead Center) labeled. Valves V1 and V2 alternate their function. The process begins with the cylinder completely filled with air. As you commence compressing, it reaches a point where air begins to be delivered. This typically happens after a certain level of compression.

To illustrate, consider the analogy of inflating a bicycle tire at a roadside cycle shop using a hand pump. Initially, air doesn't enter the tube as you apply pressure. It's only after a specific level of compression that the air begins to flow into the tube. This occurs because the pressure inside the piston-cylinder arrangement exceeds the pressure in the tubing. Initially, if the tube already has 2 bars of pressure and you're compressing with less pressure, no air will enter the tube. When you apply a pressure higher than the existing pressure in the tube, air flows in.

The process is as follows: 1 to 2 depicts the initial compression, followed by the delivery process. The piston begins at bottom dead center (BDC) and moves toward top dead center (TDC). Just before reaching TDC, it delivers air, marking the completion of one delivery phase. The piston then reverses direction, transitioning from 3 to 4 and 4 to 1.

The cycle operates as follows: 1 to 2 illustrates the movement of the piston from BDC to TDC, characterized by polytrophic compression, typically represented as PV^n = constant. It's important to note that this process is not completely adiabatic or isothermal.

Please keep in mind that the technical nature of the text may contain specific terms and notations that could require further elaboration or clarification for precise interpretation.

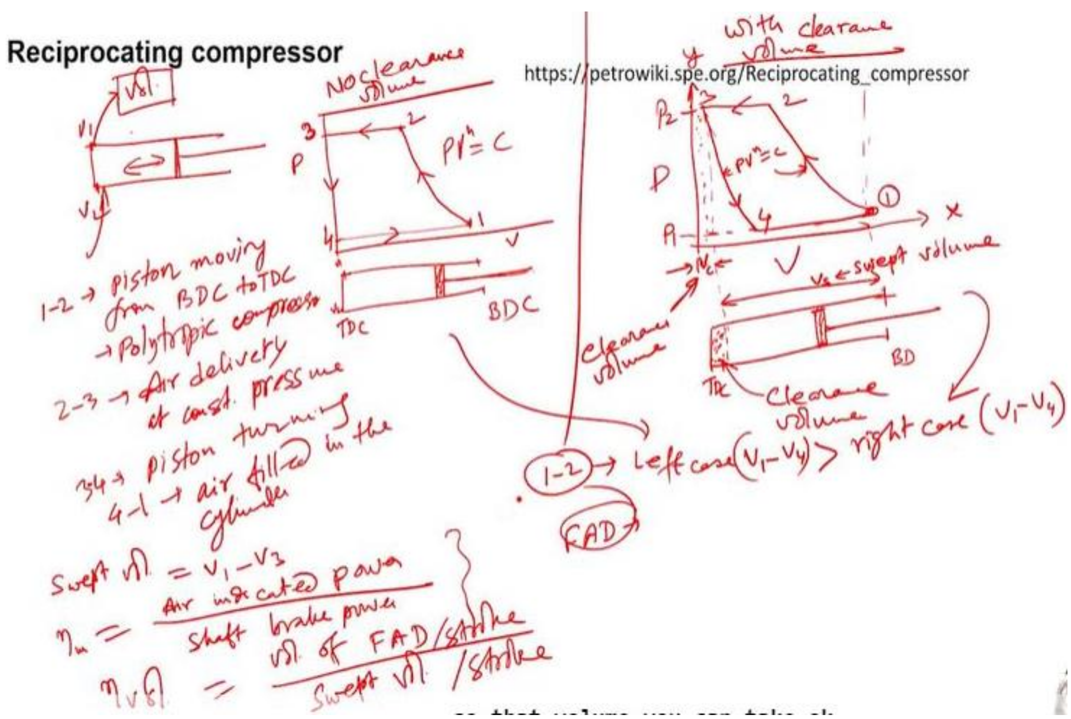
So, now when it reaches 2, the next phase is 2 to 3 where air or natural gas delivery occurs. During this phase, the delivery happens at a constant pressure.

As the piston moves from Bottom Dead Center (BDC) to Top Dead Center (TDC), the pressure increases when it reaches 2. Afterward, you deliver the air or gas at constant pressure, constituting an isobaric process during the transition from 2 to 3. Then, from 3 to 4, the piston merely turns, and no active process occurs. In this phase, the pressure decreases. The piston is turning in the opposite direction.

In the last stage, from 4 to 1, the piston is taking in air, filling the cylinder. I'm assuming there is no clearance in this explanation. I will explain what clearance is.

I'm demonstrating how the pressure is developed in this simple piston-cylinder arrangement. However, in practical situations, there will be a clearance between Top Dead Center (TDC) and the piston. The piston's maximum distance does not allow it to touch TDC, the top dead center. To illustrate, consider the cylinder, where the piston moves but doesn't touch the end. Due to mechanical limitations, this gap ensures that the piston maintains a certain distance from TDC.

In your sucker rod pump, you also had to provide a gap to prevent gas lock issues, as you may recall. In this case, you create a specific gap, known as the clearance volume. This area corresponds to the clearance volume. The piston moves through a distance, denoted as V_s (swept volume), from 1 to 3. The location marked as 3 is the maximum distance the piston can travel. Beyond this point, there is a gap where the piston cannot travel. This gap is then filled with air or the compressed gas used. If you're compressing air, this gap will be filled with air. Alternatively, natural gas will fill the gap if you use natural gas.



Clearance volume in the PV diagram is indicated as V_c (clearance volume). The piston's travel distance, from 1 to 3, is represented as V_s (swept volume). This arrangement accounts for the clearance volume.

So, after 2, the piston moves from 1 to 2, then 2 to 3, and 3 to 4. Where is 4? 4 will be here. No, sorry, 4 will not be here. 4 will be here. I will draw a different figure. 4 will be connected like this. Why is 4 curved? Previously, I drew a vertical line from 3 to 4 and a horizontal line from 4 to 1. Now, I am not doing that. I am drawing 3 to 4 as a curve. Again, this adheres to the principle that PV power n equals constant, which actually represents a polytrophic process. When the piston moves up and down, we can also assume it to be adiabatic without any issue.

So, there is some small amount of air inside the cylinder. If you have one cylinder, you compress, compress, compress it until there's a small gap. When the piston is at this point, the pressure in this gap is very high. When the piston tries to move backward, the pressure will expand, and only after a certain expansion will fluid intake occur from outside. So, from 3 to 4, the pressure inside the remaining air is expanding. Once it reaches 4, it reaches normal intake pressure, and fluid will enter the cylinder again. From 1 to 2, we are delivering that fluid, and from 2 to 3, we are compressing it, and from 3 to 4, the clearance gap allows that much air to expand up to 4 before the intake happens.

What's the difference now? On the left side, there's no clearance volume. On the right side, there's clearance volume. This is the left case, and this is the right case. The intake part length is reduced in the right case. In both cases, from 1 to 4, the volume difference, V1 minus V4, is more significant in the right case. Practically, reaching the left side figure is not possible, but you can try to reduce clearance as much as possible. This way, V1 minus V4 will increase, and you can approach the left side figure. Creating isothermal compression takes a lot of time, which is usually not feasible, so you can opt for polytrophic processes.

Moving on to volume definitions: A volume is defined as V1 minus V3. Mechanical efficiency is calculated as air indicated power divided by shaft brake power. Shaft brake power is the power where the pistons are moving, and the motor is running, which results in some losses. The shaft power is lower than the power indicated on the machine. Therefore, mechanical efficiency is defined as the lower power divided by the higher power.

Volumetric efficiency is the volume of free air delivery (FAD) per stroke divided by shaft volume per stroke. Free air delivery means that you assume the air is delivered at atmospheric conditions after delivery. If you change the pressure, the resulting volume is the one considered for calculations.