Artificial Lift

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Lecture-60 Surface Compressor for Gas Lift - Part 1

In previous lectures, we discussed compressors. Compressors and pumps have similar features because both impart energy to the fluid. One operates through reciprocating motion or positive displacement, while the other is based on centrifugal action. There are various types of compressors, each suited to different applications in gas handling, surface production operations, gas lifting, reinjection, booster applications, vapor recovery, flash gas recovery, and flare gas recovery.

Beyond oil and gas energy production, compressors find applications in various fields. For instance, household refrigeration and freezers use compressors in different types such as reciprocating, rotary (positive displacement), and dynamic or kinetic compressors like centrifugal compressors, mixed flow compressors, and axial flow compressors. While pumping typically involves incompressible fluids, compressors deal with compressible fluids.

Reciprocating compressors are ideal for high-pressure applications, while rotary compressors are also suited for high-pressure tasks. Rotary compressors are commonly found in household refrigerators. These compressors are hermetically sealed systems, meaning all components are enclosed within a single unit.

Centrifugal compressors are dynamic compressors that we'll explore further. Likewise, mixed-flow compressors share similarities with centrifugal compressors. Axial compressors, such as aircraft engines, are best suited for applications with high flow rates and low head pressure. These compressors are used in aircraft engines, situated within the wings, and have multiple stages. Each stage operates at a specific compression ratio, allowing them to manage varying volume and pressure levels. Unlike reciprocating compressors, axial and centrifugal compressors tend to operate with lower compression ratios, typically requiring multiple stages to achieve the desired compression.

I note that you mentioned axial compressors and their application in gas turbine systems, often used in aircraft engines. These gas turbines utilize multiple stages of axial compressors to achieve their specific compression ratios. This aligns with my PhD thesis, which I completed in 2008, focusing on axial compressors used in gas turbine applications. These compressors are optimized for lower compression ratios, which are well-suited to the requirements of gas turbine systems used in aviation.

The relationships between volume, pressure, and temperature will be discussed later. Most of this information is derived from Guo and Petro Wiki, which is a useful website. You can explore these resources for more details.

Now, let's delve into the types of compressors. Similar to pumps, compressors are categorized as intermittent flow or continuous flow systems. We have positive displacement compressors, such as reciprocating pumps for intermittent flow. On the other hand, continuous flow systems include dynamic and ejector compressors. We previously discussed ejectors in our earlier lectures. Ejectors feature a nozzle that draws in another fluid, resulting in high pressure after mixing. While you can't achieve very high compression ratios with ejectors, they're suitable for moderate compression.

In dynamic systems, we have radial flow, mixed flow (which is centrifugal), and axial flow. You'll find reciprocating and rotary compressors in the positive displacement compressor category. Rotary compressors offer smoother flow, whereas reciprocating compressors result in more pulsating flow, leading to higher pressure fluctuations at the outlet. Reciprocating compressors typically employ mechanical pistons, while rotary compressors use sliding vanes, helical lobes, and various other designs. Many of the pump types you're familiar with are also applied in compressor applications.

In contrast to raising fluids in a liquid pump, compressors do not lift fluids vertically. Instead, they compress air or gas for transportation or various other purposes.

When compressing air or gas, specific laws, such as Boyle's, Charles's, and Gay-Lussac's law, come into play. Boyle's law is represented as,

$$P V = C,$$

Charles's law as,

$V / T = C$,

Gay-Lussac's law as,

$P / T = C$.

The equation $P V / T = C$ pertains to isothermal processes, particularly those involving low-pressure conditions. You can think of isothermal processes as those where compression occurs gradually at lower pressures. During these slower compressions, heat dissipates. This heat dissipation is how Boyle first formulated his law, stating that the product of pressure and volume remains constant.

These laws are Boyle's law, Charles's law, and Gay-Lussac's law.

Boyle's law is represented as $P V = C$,

Charles's law as $V / T = C$,

and Gay-Lussac's law as $P / T = C$.

When we combine all these laws, we get the ideal gas law, which is expressed as,

$P V = nRT$.

If we modify Boyle's law to account for adiabatic conditions, such as high pressure and rapid piston movement, we get

$P V^{\Upsilon} = C$.

In this scenario, we assume that there's no heat transfer. In contrast, the term "isothermal" implies maintaining an equal temperature, allowing heat to dissipate. However, in adiabatic processes, we trap all the energy inside the system, resulting in the formula,

$P V^{\Upsilon} = C$.

In practical cases, some heat dissipation occurs, so we use the polytropic process equation: $PV^n = C$.

The value of gamma, which is specific heat at constant pressure (Cp) divided by specific heat at constant volume (Cv), is typically around 1.4 for air.

$$\frac{C_p}{C_v} = 1.4 \; or \; 1.2 \; to \; 1.3$$

This process is known as the polytrophic process, and there's no term called "isotropic" in this context.

Another term to consider is compressibility, where the formula,

P V = ZRT is used,

and Z represents the compressibility factor.

Some gases can be compressed easily, while others, like hydrogen, have high compressibility factors, making compression more difficult. Typically, natural gas has a compressibility factor in the range of 0.5 to 0.7, while hydrogen and helium have higher compressibility factors.

The compression ratio is defined as the ratio between the inlet pressure and the outlet pressure from a compressor. We've previously seen the relationship,

$PV^{\Upsilon} = C$

The process occurs from one point to another, such as from points one to two. If we consider,

$PV^{\Upsilon} = C$,

we assume an adiabatic process with no heat transfer. On the other hand, using

P V = C,

implies an isothermal process with heat transfer.

In practical applications, achieving an isothermal situation can be slow, so machines need to operate faster.

As mentioned before, polytrophic processes are described by,

$P V^n = C$,

with n being lower than the gamma value and not necessarily equal to one or adiabatic. When represented graphically,

$PV = C$, appears as a horizontal line,

adiabatic follows an inclined curve $PV^{\gamma} = C$,

and polytrophic takes on a different shape with the equation $P V^n = C$.

In compression systems, such as reciprocating compressors, achieving an isothermal situation is ideal, as it reduces energy consumption. This can be accomplished by implementing cooling arrangements to maintain constant temperature and enhance system efficiency.

No. of stages:

$$\frac{T_2}{T_1} = \frac{\left(\frac{k-1}{k}\right) \ln\left(P_2/P_1\right)}{\eta_p}$$

Here, eta_P represents polytrophic efficiency, typically ranging from 0.72 to 0.85, and equals 1 for reciprocating compressors.

For centrifugal compressors, the term "compression ratio per stage (R)" is defined as R = P2 / P1 ^ (1 / N), where "N" represents the pressure ratio. The compression ratio indicates the extent of compression that occurs in a single stage. To better understand how this works, consider the scenario where the initial inlet pressure is P1, and you need to compress the gas to a higher pressure P2. During this process, the temperature increases significantly. A common strategy to manage this temperature increase is to divide the compression into multiple stages. In each stage, you compress the gas from one pressure level to another and then cool it down before the next compression. This cooling process helps reduce the temperature rise associated with compression.

In such a multi-stage system, the pressure increases from P1 to P2 in the first stage, from P2 to P3 in the second stage, and so on. The cooling arrangements between stages ensure the pressure does not drop as the gas passes through the components. Each of these compression and cooling cycles is referred to as a "stage." A multi-stage compressor can consist of several such stages, especially in cases where high compression ratios are required.

The choice of compressor type depends on the flow rate and the desired pressure ratio. In your diagram showing flow rate on the x-axis and pressure ratio on the y-axis, you have different compressor types categorized as follows:

1. Single-Stage Reciprocating Compressor
2. Multi-Stage Reciprocating Compressor
3. Single-Stage Rotary Compressor
4. Axial Flow Compressor

A multi-stage reciprocating compressor is suitable for applications where a high-pressure ratio is needed but with relatively lower flow rates. This type of compressor can achieve pressure ratios up to 200 or even higher, such as 200 bar after compression.

On the other hand, a single-stage reciprocating compressor is better suited for high-flow rate applications, providing moderate pressure ratios.

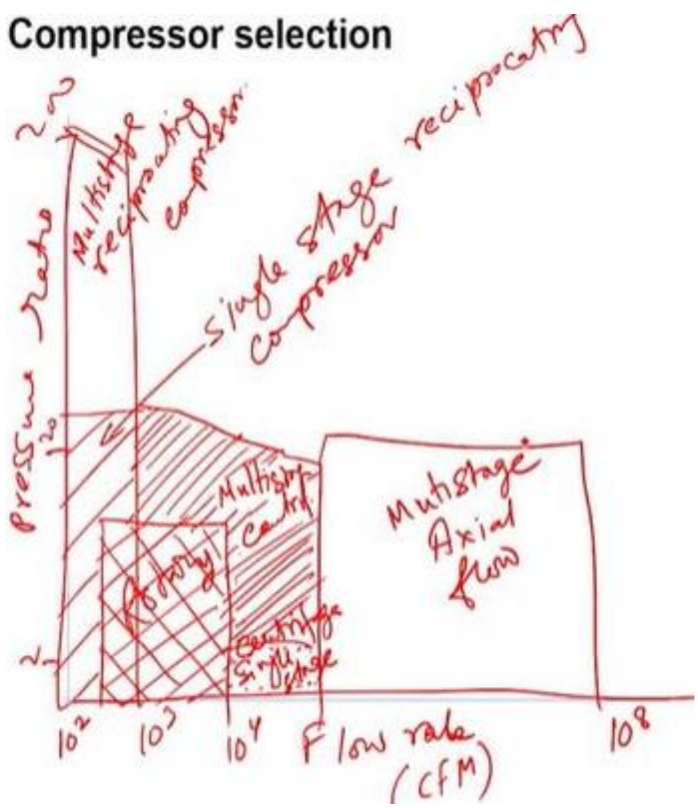
Axial flow compressors used in aircraft engines are designed for high-flow scenarios where very high-pressure ratios are not a primary concern.

The choice of compressor type should align with the application's specific requirements, considering factors like flow rate and desired pressure ratios.

In the context of compressor types, axial flow compressors are commonly used for applications requiring high flow rates. You'll often find centrifugal compressors between the low flow rates, suited for single-stage reciprocating or multi-stage reciprocating compressors, and the high flow rates, suitable for axial flow systems.

Centrifugal compressors come in various forms:

1. Single-stage centrifugal: As the name suggests, this is a single-stage centrifugal compressor.
2. Multi-stage centrifugal: Multi-stage centrifugal compressors consist of multiple stages. These stages are designed to incrementally increase the pressure, allowing the compressor to achieve high-pressure ratios.
3. Rotary-type compressors: This category includes rotary-type compressors.



Single-stage reciprocating or multi-stage reciprocating compressors are appropriate for applications with very low flow rates. In contrast, for applications with high volume flow rates, axial flow systems are employed. Axial flow systems can handle high volume flow rates and are often used in scenarios like fans, where high flow and low pressure are needed. Blowers, on the other hand, generate high-velocity and low-pressure airflows.

Multi-stage reciprocating compressors or multi-stage centrifugal compressors are typically used for gas lift applications. Centrifugal compressors are particularly well-suited for high-volume flow rates, operating at speeds of around 3000 rpm, and can range from 500 horsepower to 50,000 horsepower, accommodating both smaller and large-scale applications.

A centrifugal compressor can comprise up to 10 stages, each contributing to increased pressure. This multi-stage approach results in very high-pressure outputs. While in electric submersible pump (ESP) applications for pumping purposes, it's not uncommon to employ up to 100 stages, on the surface, using radial compressors up to 10 stages is typically sufficient to meet pressure requirements.

One can plot a curve illustrating discharge pressure (head pressure ratio) and volume flow rate versus inlet volume flow rate to understand the compressor's performance characteristics. On this curve, various sections are labeled to indicate different operating conditions:

1. Constant speed curve: This represents the performance of the compressor at a constant speed.
2. Stone wall (choke): Below this point, achieving a higher flow rate is not feasible.
3. Surge limit: Above this point, backflow can occur, leading to compressor instability, pressure fluctuations, and noise.

The compressor typically operates at the design point, but it can also function under off-design conditions. Stonewall and surge states limit flow and pressure that must be observed. The stone wall marks a vertical limit beyond which you cannot achieve higher flow rates, and the surge condition pertains to the region where compressor instability occurs. In these situations, you should avoid operating below the stone wall or above the surge limit, as it can negatively affect the compressor's performance.