Artificial Lift

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Lecture-31 Introduction to Progressive Cavity Pump

In this lecture, we are going to discuss the classification of pumps, progressive cavity pumps, the geometry of progressive cavity pumps, the types of progressive cavity pumps, and then the theoretical discharge and leakage of progressive cavity pumps.

Now, let's start with the classification. Before classifying pumps, it's important to understand the basic definition of pumps. As you all know, pumps are fluid machines that transfer energy to the fluid or move fluid from one place to another. Based on how they transfer energy, pumps can be classified into positive displacement pumps and centrifugal or dynamic pumps.

First, let's look at positive displacement (PD) pumps. In PD pumps, fluid is trapped within a closed volume by the movement of a motor inside the stator. To illustrate this, let's consider the example of a reciprocating pump. In a reciprocating pump, there's a cylinder and a piston arrangement. This cylinder has a piston that moves in a reciprocating motion. As the piston moves from the top dead center to the bottom dead center, it transfers energy to the fluid through mechanical action. Pumps of this type are known as positive displacement pumps. Examples of reciprocating pumps include piston pumps and plunger pumps.

Another classification is rotary pumps. While reciprocating pumps have a reciprocating motion, rotary pumps have a rotary motion of the rotor. These pumps are called rotary pumps, and examples include gear pumps, screw pumps, and progressive cavity pumps. We will delve into the details of progressive cavity pumps in the upcoming slides. However, we will also briefly touch on dynamic pumps. Dynamic pumps, or centrifugal pumps, consist of two key parts.

Two crucial components are present in all types of pumps: the rotor and the stator. When the pump name changes, the names of these components also change. In the case of a dynamic pump or centrifugal pump, the rotor is referred to as the impeller, and the stator is known as the volute casing. Dynamic or centrifugal pumps transfer energy to the fluid through kinetic energy. The rotor rotates, imparting kinetic energy to the fluid. This kinetic energy is then converted into pressure energy by the stator, known as the volute casing. Examples of dynamic pumps include centrifugal pumps and axial pumps. Now, let's delve into the details of the progressive cavity pump. I hope you now understand pump classification and can place the progressive cavity pump within it.

Firstly, progressive cavity pump falls under the classification of rotary positive displacement pumps. Since we've already explained these terms, it should be clear that the progressive cavity pump belongs to the category of rotary positive displacement pumps. It was invented by the French mathematician René Monod in 1930. As mentioned earlier, it comprises two vital components: the rotor and stator. In the case of a progressive cavity pump, these components take on a helical shape. We'll explore their geometry further in the following slides.

Now, let's discuss some advantages of the PCP. It can handle highly viscous fluids, including abrasive slurries. Additionally, it can handle low-viscosity fluids, ranging from 1 cP to highly viscous fluids of up to 10,000 cP. It can also manage solid-fluid mixtures, such as slurry or cement clay. One notable advantage of the PCP is its excellent self-priming capability.

Next, we will delve into the geometry of the progressive cavity pump. When it comes to positive displacement pumps or PCPs, both the rotor and the stator play crucial roles. Both of these components have helical elements. Let's now discuss the geometry of the rotor and the stator in greater detail.

The rotor is a single-lobe helical rotor with a circular cross-section. As you can see, the rotor's cross-section is circular and follows a helical path. However, it doesn't start from the center; instead, it begins at a distance known as eccentricity.

The center of the rotor's circular cross-section is offset from the rotor's axis, a property referred to as eccentricity. The helix starts from this point and extends in this manner, as shown. The cross-section of each part is circular.

Now, let's turn our attention to the stator. The stator has a double lobe, with one lobe here and another lobe here. In contrast, the rotor has only one lobe, and the stator's cross-section is semi-circular, with the two semicircles connected by a line. As the rotor rotates from one end to the other, fluid from one cavity moves to the other. Similarly, fluid moves from the other cavity when the rotor rotates back. This rotation of the rotor facilitates the transfer of fluid between the cavities.

You can observe the cross-sections of both the rotor and the stator here. The rotor has a circular cross-section, as I mentioned earlier. This is the stator's front view and its side view. You can also see an elastomer here, which we'll discuss in the upcoming slide. But before that, we'll cover an essential concept regarding pitch.

This distance is known as the rotor pitch, measuring from one point to another on the circular cross-section as the circle rotates. At this point, it is 90 degrees, and at this point, it is 180 degrees. When the circle rotates 180 degrees, it completes one rotor pitch. However, if it rotates a full 360 degrees, which spans between two points, it constitutes a stator pitch. This means that a full 360-degree rotation of the rotor displaces fluid by a distance equal to one stator pitch. Therefore, a stator pitch is equal to twice the rotor pitch. Each stator pitch is referred to as one stage, which we'll delve into in greater detail when discussing PCP.

Now, let's shift our focus to the classification of PCP. PCPs can be categorized into elastomeric and metallic PCP based on the stator material used. Elastomeric PCPs are constructed using materials like natural rubber, nitrile, hydro, generator, NBR, fluoro, and elastomer for the stator. When the stator employs such elastomeric materials, it falls into the category of elastomeric PCPs. Conversely, if the stator material is metallic, the PCP is classified as metallic PCP. This distinction marks a significant difference between elastomeric and metallic PCPs.

Now, let's discuss the materials used for elastomeric PCP. As mentioned earlier, the materials include natural rubber, nitrile, hydro generator, NBR, fluoro, and elastomer. We will delve into these materials in detail.

Elastomeric PCP has its limitations. It cannot withstand high temperatures, run in dry conditions, or handle highly abrasive slurries. These disadvantages prompted research, leading to the development of metallic PCP. Unlike elastomeric PCP, metallic PCP is constructed from metal instead of elastomers. This design eliminates wear in the stator, prolongs the pump's life, and makes it suitable for high-temperature operations. The materials used for metallic PCP typically include stainless steel, alloy steel, or bronze steel.

In the images provided, you can observe the differences between elastomeric and metallic PCP. Elastomeric PCP features positive clearance, with a tight fit between the rotor and stator, resulting in no clearance. Conversely, metallic PCP exhibits negative clearance, with a noticeable gap between the rotor and stator.

Now, let's delve into the materials used for elastomeric PCP in more detail. Most elastomeric materials used in PCP are conventional nitrile or NBR elastomers. NBR elastomers are produced through emulsion copolymerization of butadiene with acrylonitrile (ACN). The ACN percentage in the mixture can vary from 30% to 50%. It's important to note that higher ACN percentages result in increased costs for the PCP or stator. Increasing ACN levels enhances the elastomer's resistance to non-polar oils and solvents due to increased polarity. However, NBR cannot withstand high temperatures, and it is not recommended for applications with high levels of hydrogen sulfide, exceeding 100 degrees Celsius (212 degrees Fahrenheit).

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Hydrogen sulfide is a harmful gas produced during the underground gas extraction process. Due to this disadvantage, we need to consider using another stator known as hydrogenated NBR. Compared to conventional NBR elastomers, conventional NBR contains unsaturated double or triple carbon bonds that can react with chemicals or gases. To address this, we employ a process called hydrogenation. Hydrogenation involves adding hydrogen to these bonds, forming saturated bonds. Saturated bonds are less susceptible to interactions with other gases and exhibit higher heat resistance. Hydrogenated NBR also boasts improved chemical resistance and better hydrogen sulfide tolerance than NBR or nitrile. However, it is worth noting that HNBR is more expensive than conventional NBR elastomers.

Next, we have fluoroelastomers. Fluoroelastomers contain a high level of fluorine, providing excellent heat and chemical resistance. However, their mechanical properties are inferior to those of NBR and HNBR. Nonetheless, fluoroelastomers have the advantage of withstanding high temperatures, up to 200 degrees Celsius or 400 degrees Fahrenheit. They are a suitable choice for applications involving elevated temperatures, albeit at a higher cost than other elastomers.

These are the various types of elastomeric materials used in PCPs. Now, let's move on to the last topic: the performance of PCPs. The performance of PCPs depends on factors such as discharge and leakage. We will explore how to calculate these parameters.

As discussed in the previous slide, the cross-section of a PCP is shown here. You can calculate the volume flow rate by determining the area and multiplying it by the stator length or one-stage length. To find the volume flow rate (Q), use the formula Q = volume per second, which is equal to the volume (area × length) divided by time (per second).

We can calculate the area to find the theoretical discharge. How do we find the area? We can divide the cross-sectional area into two parts like this. One part is here, and the other part is here. We can split the rotor into two sections as well. One will be here, and the other will be here. The remaining portions will form rectangles. This is the cross-sectional area for the PCP. The length is 4 times the eccentricity, and this length is the diameter.

So, the area can be calculated as 4 times 'e' (4e). This area, multiplied by the diameter, gives us the total area. You'll obtain the volume for one rotation if you multiply this by the pitch, equivalent to one stage (stator pitch 'Ps'). To find the discharge for 'N' rotations, you multiply this by 'N.' Here, 'N' represents the number of rotations, 'Ps' is the stator pitch, and this yields the theoretical flow rate or theoretical discharge.

Now, let's determine the leakage. The leakage ('QL') can be calculated as 'Q theoretical' minus 'Q actual.' 'Q actual' is determined through experimental measurements. The reason for leakage is the reverse flow. In a PCP, there are different cavities with varying pressures. This creates the possibility of flow from high to low pressure in the reverse direction of the normal flow. This reverse flow, known as leakage, opposes the normal flow, ultimately reducing pump efficiency.

Okay, in this class, we have discussed the classification of pumps, PCP, the geometry of PCP, types of PCP, and the use of elastomeric materials. We also covered PCP discharge and leakage. In the next session, we will discuss PCP performance, how to calculate it, and stage calculation.

Hello, everyone. In this lecture, we will delve into PCP performance, the effect of viscosity, and stage calculation.

When it comes to the performance of a PCP, we consider a typical pump experiment setup. In this setup, you can see a recirculating pump experiment configuration. The fluid is stored in this tank, and due to the head difference, it flows into the PCP's inlet. The rotor rotates, imparting energy to the fluid, causing it to move upwards and back into the tank, creating a recirculation loop. There's a valve to regulate the flow rate, a flow meter to measure the discharge, and a pressure transmitter to monitor outlet pressure. Additionally, there's an RPM sensor to measure the rotation per minute (RPM), denoted as 'N,' which is used for speed calculations. The motor is connected to a VFD (Variable Frequency Drive), from which we can determine the inlet power.

Now, let's move on to the calculations. We primarily apply Bernoulli's equation at the inlet and outlet to obtain the total head.

So, to find the total head (H), we use the equation: $H = P / (\rho g) + V^2 / (2g) + Z_{outlet} - (P / (\rho g) + V^2 / (2g) + Z_{inlet})$. This equation is based on Bernoulli's principle. If we want to consider Hf, which represents the friction loss, we can set it to 0 for a small experiment like this.

Now, let's focus on H. We've already determined it. Here, we need to find the velocity. The diameter at the inlet is equal to that at the outlet, which means the areas are also equal. Applying the conservation of mass, we have $\rho A(V_{inlet}) = \rho A(V_{outlet})$. Since the fluid passing through the PCP is incompressible (or we assume it to be incompressible), ρ_{inlet} equals ρ_{outlet}. From this, we find that the velocity at the inlet is equal to that at the outlet. You can substitute this into the H equation, making it $H = P / (\rho g) + Z_{outlet} - (P / (\rho g) + Z_{inlet})$.

So, the pressure is measured using the pressure transducer, and the height (Z) can also be measured. This Z represents the height difference; you can calculate H in meters. Once you have H, you can determine the power. How do you find the power? You can calculate power by multiplying pressure with the discharge or flow rate. Pressure can be obtained from the formula ρgh, and the discharge is derived from the flow meter, representing the flow rate, denoted as Q.

$$H = \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{out} - \left(\frac{P}{\rho g} + \frac{V^2}{2g} + z\right)_{int} + H_f$$

$$D_{in} = D_{out},\ A_{in} = A_{out}$$

$$(\rho A V)_{in} = (\rho A V)_{out}$$

$$V_{in} = V_{out}$$

$$H = (P/\rho g + z)_{out} - (P/\rho g + z)_{in}$$

$$= \_\_\ m$$

$$\text{ower} = \text{Pressure} \times \text{Discharge}$$

$$= (\rho \times g \times H) \times Q$$

So, here, we can obtain the power in watts or, if needed, convert it into kilowatts. This represents the output power, and the input power can be obtained from the VFD, perhaps with the motor. If you multiply it by the motor efficiency, you can get the value in watts or kilowatts. You can calculate the pump's efficiency once you know the inlet and outlet power. How do you determine the pump's efficiency? Pump efficiency is calculated as the power output divided by the power input, and if you multiply it by 100, you'll get the result in percentage. This is how you find the machine's efficiency.

If you were to plot the characteristic curve of a PCP, it would look like this. If you draw it like this, you'll have the discharge on one axis and pressure on the other. So, here we have pressure. For the theoretical discharge, you'll notice a straight line. This is Q, representing discharge, and this is P, representing pressure, with Q versus P being the characteristic curve, where P is on the x-axis and Q is on the y-axis. This represents Q theoretical.

However, in actual conditions, as we discussed earlier, there is leakage, and this leakage increases as the pressure increases. So, when the pressure increases, the actual discharge decreases. You will get a curve like this.

Now, let's consider the effect of viscosity. To do that, I'll assume a fluid with a specific viscosity. Let's consider this as a low-viscosity fluid. So, when viscosity increases, what happens? When viscosity increases, leakage decreases.

When leakage decreases, the actual discharge, Q actual, increases. So, you will get another curve like this. This is for high-viscosity fluid. The leakage is less for high-viscosity fluid, and the Q actual is greater. However, the leakage is more significant for low-viscosity fluid, and the Q actual is less. This is the reason why the efficiency of the pump with high-viscosity fluid is more important than that with low-viscosity fluid. The reason behind this is that with high-viscosity fluid, the reduced leakage leads to less reverse flow. Consequently, the Q leakage is less, resulting in a higher Q actual. That's why the curve is like this for high-viscosity fluid, while this is for low-viscosity fluid.

Now, let's move on to the stage calculation. In the first lecture, we already discussed that one stator pitch is called a stage. This is one stator pitch, which may be the second stator pitch, indicating the second stage, and this is the third stator pitch. When the number of stages increases, the pressure in the pump also increases. For example, if the pressure at one pitch is 10, it may double in the second stage, and if you move to the third stage, it will be 30. If you want to increase the pressure, you need to increase the number of stages in the PCP. Let's do a simple calculation to understand how to calculate the number of stages.

This is a straightforward calculation, for example, and most manufacturers recommend that the delta P, or the pressure difference between stages, should be equal to 80 to 90 kilopascals. In a single stage, the maximum permissible pressure is 80 to 90 kilopascals. Now, let's perform a calculation. For instance, we need to lift a fluid to a height of 100 meters. The density of the fluid is 900 kilograms per cubic meter, and I'll use a discharge value of 2.5 cubic meters per hour for this simple calculation. Please note that discharge is not typically used in this calculation; I'm using it here for illustration purposes.

Here, H is given, and from this H, we can calculate the pressure using the formula: hydrostatic pressure (P) equals H times rho times g, where H is 100 meters, rho is 900 kilograms per cubic meter, and g is 9.81 m/s². When you multiply these values, you get a result of 882 kilopascals. This is the total required pressure, and we want to calculate the number of stages. It's given that the delta P should be a maximum of 80 to 90 kilopascals per stage. To find the number of stages, you can use the formula: Number of stages = P total divided by delta P per stage. So, P total is 882 kilopascals divided by, and I'll use 90 (you can also use 80). When you perform this calculation, you get approximately 9.8. Since you can't have a fraction of a stage, you would round it up to 10 stages. This is how you can calculate the number of stages in a PCP.

→ $\Delta P = 80-90 \text{ Kpa/Stage}$

→ $H = 100 m, \; \rho = 900 \text{ Kg/m}^3, \; Q = 2.5 \text{ m}^3\text{/hr}$

$$P = H \times \rho \times g$$

$$= 100 \times 900 \times 9.81$$

$$P_{total} = 882 \text{ Kpa}$$

$$\text{Number of Stages} = \frac{P_{total}}{\Delta P} = \frac{882 \text{ kpa}}{90 \text{ Kpa}} = 9.8 \simeq 10 \text{ number of stages}$$