Artificial Lift

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Lecture-37 Electrical Submersible Pump-Part-1

Good morning, everybody. We have already finished discussing the Sucker Rod Pumping System, which is a positive displacement type pump. Today, we will start discussing the Electric Submersible Pump or ESP. ESP is basically a centrifugal pump, and when centrifugal pumps are connected in a series, they create a multi-stage centrifugal pump. When this pump is submerged in liquid, it is referred to as a submersible pump. An electric motor powers it, hence it is called an electric submersible pump.

Three key terms to note are 'electric,' which means it is powered by an electric motor; 'submersible,' indicating that it must be submerged in liquid; and 'pump.' If it is not submerged, priming issues may arise, and NPSH (Net Positive Suction Head) considerations also come into play. Submerging it in liquid before pumping is essential for efficient operation in your wellbore.

Let's take a look at how an electric submersible pump appears within the tubing. This represents your casing, which is cemented. Then, you have perforations and the reservoir. Various components, including fluids such as liquid, gas, water, and sand, may enter the wellbore. Proper sand control mechanisms can minimize sand ingress, and a well completion procedure can help reduce water ingress. However, sudden changes in production rates might introduce water or sand into your wellbore, which should be avoided because they can increase costs without generating revenue.

When using ESP, the primary goal is to produce oil and gas. Although these fluids have lower densities and naturally rise to the surface, gas interference with ESP can pose problems.

Now, let's examine the ESP within the tubing. This represents the tubing with a packer installed. A cable runs down to the pump, which is the heart of the pumping system. The pumping system includes a motor, and there is also a protector section. This section is crucial for safeguarding the motor. Since the motor is an electrical component, any wellbore fluids or water entry could lead to motor coil damage. In normal applications, you want to avoid motor damage, as replacing the entire system can be costly.

So, you must avoid the inadvertent introduction of water inside the motor. Inside the motor is transformer oil or motor oil, creating an environment where the coil and magnet do not make contact, preventing burning or the generation of sparks. Any water entry acting as a dielectric fluid could lead to issues. So, you must prevent water from entering through seal leakage or any other means.

To achieve this, we have a protector. This protector is not a small component; it's quite lengthy and incorporates multiple seals to ensure that neither water nor motor oil nor transformer oil from inside the motor can escape.

Next, there is a pumping unit. The pump intake is situated here; the fluid enters through the pump intake, and there's a pumping area. This pumping area houses a multi-stage centrifugal pump that lifts the fluid to the surface. A cable is also present, which connects directly to your motor. It's not a coil but rather an electric cable. This cable is controlled from the surface, determining how much power is supplied and at what frequency.

Once the fluid reaches the wellhead at the surface, you extract it, and the cable proceeds to a junction box. From there, it goes to a switchboard, and from the switchboard to a transformer. The transformer then supplies the high voltage line.

The purpose of the transformer is to step down the voltage. For instance, if you have very high voltage, like 11,000 volts, but you require only 440 volts for your pumping operations, you need to reduce the voltage. Providing 10,000 volts to your motor would result in motor failure due to the excessively high voltage.

In the transformer system, you lower the voltage using a step-down transformer and direct it to the motor. The motor runs, and its shaft transfers power through the protector and intake section. The protector does not provide energy but incurs some energy loss due to friction.

The pump intake features numerous holes through which fluid can enter the wellbore. It then travels through the pump to the surface. At the surface, you have components like the wellhead, Christmas tree, MAS tree, and several valves, including master control valves like primary and secondary valves.

If you encounter gas, you need a gas separator to separate gas and liquid. The gas must be extracted from the wellbore through another line, possibly the annular area. Various issues may arise when dealing with ESP and gas, and we will discuss these in detail.

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We will discuss the three-phase, induction, and the seal chamber section. As I mentioned, the seal chamber is part of the protector section, and there is a power cable and a surface control unit.

These are the basic components of ESP systems, and the choice of ESP for your wellbore depends on specific speed formula. In a previous lecture, I mentioned that specific speed is denoted as NS, divided by N to the power of Q times H to the 3/4. Here, NS represents the specific speed, N is the RPM of the impeller (I'll explain the impeller shortly), Q is the flow rate, and H represents the developed head – how much head you're creating. This formula tells you how much fluid it can handle, the head it can develop, and the flow rate it can accommodate. In this context, N is the impeller speed, which is not necessarily the same as the motor speed. Motor speed may be higher, but the impeller speed may be lower due to slippage and other potential losses, and this speed can also vary.

It's important to note that specific speed is not a dimensionless number; it has units. Therefore, when you mention specific speed, you must include its units. As you can see, N has RPM units, Q has cubic meters per second divided by 2, and H has meters. These units are not canceled out, so they must be included.

When you represent specific speed on a curve, typically on the x-axis, you input N values; on the y-axis, you have efficiency values.

If we consider lower specific speed, we are moving towards a radial-type impeller. I'll explain radial-type impellers later; I might have explained them in a previous lecture, but I'll clarify that again shortly. On the other hand, if we aim for a higher flow rate, denoted as Q, we are heading towards an axial-type system. Further below the specific speed range, we can opt for a positive displacement-type pump. Examples of positive displacement pumps include sucker rod pumps and PCPs. These pumps have a very low specific speed, even lower than radial impellers.

Now, let's discuss radial flow impellers. I have an impeller system with me. This is an impeller, as you can see. The impeller has a flow path, where fluid enters and exits. There's a shaft hole; this is the shaft that imparts rotation to the impeller. The shaft is connected to the motor, so when the motor rotates, it also spins the impeller. The impeller is quite thin, and it's designed for radial flow. In radial flow impellers, the fluid enters parallel to the axis and then makes a turn inside the impeller blade, ultimately moving vertically. It makes a 90-degree turn, which is why it's referred to as radial flow, as it turns radially, not axially. Axial flow impellers, on the other hand, allow fluid to enter and move directly. For example, think of a wind turbine; it typically employs an axial flow turbine. In this case, the turbine is situated here, and the fluid flows in and out. A similar principle applies to ceiling fans. During the scorching summer months in India, you often run ceiling fans. Ceiling fans are axial flow fans, characterized by their ability to handle large volumes of air while developing relatively low pressure. If you were to measure the pressure above and below the fan, you'd likely find minimal pressure difference.

If we consider a ceiling fan or a wind turbine, rotating the turbine results in a pressure difference of less than 1 bar. However, the pressure difference can be as high as 5 bars when using a centrifugal pump. The inlet pressure may be 1 bar, while the exit pressure can reach 5 bars or even more. This pump type generates a significant amount of head, providing high-pressure capabilities. In contrast, axial flow systems like ceiling fans and wind turbines have lower pressure differences but handle very high volume flow rates.

In some cases, such as ceiling fans, a high volume flow rate is desirable without an excessively high pressure or velocity, as high velocity can create a noisy airflow. In such scenarios, the goal is to circulate air throughout the room evenly, rather than generating a concentrated jet of air. On the other hand, wind turbines handle a massive volume of air passing through them to generate energy. When you need to develop a significant amount of head, such as pumping fluid to the Burj Khalifa or a tall building with multiple floors, you typically require a certain level of head pressure to overcome resistance and lift the fluid effectively. In such cases, centrifugal pumps are commonly used.

Conversely, sucker rod pumps (SRPs) are used when low volume flow rates are needed, but high pressure is essential. For instance, some fuel injectors in engines employ sucker rod pumps, or positive displacement pumps like beam pumps or SRPs, as positive displacement pumps excel at providing high head and low flow rates.

Regarding pump curves, I mentioned that centrifugal pumps provide high head and low flow rates, while reciprocating pumps, such as positive displacement pumps, offer low head and high flow rates. Here, I've included a picture taken from the thesis of Mr. Bellary et al., completed at IIT Madras in 2015. In his experiments using an impeller, a component of a centrifugal pump, Mr. Bellary developed a curve representing head (H) and flow rate. Please note that the units in this graph are in the SI system since it originated from his thesis work. The curve displays head, efficiency, and power.

The power consumed by the pump is known as the pump system curve. The system curve represents how much power the pump consumes and how much friction it encounters, which collectively determine the total energy consumption of the pump. This curve illustrates the relationship between head and flow rate. The head curve typically starts at a certain point and gradually decreases, eventually reaching zero flow rate. At this point, it represents an open flow condition, where there are no restrictions on the exit valve, resulting in maximum flow. During open flow, the pressure measured on the pressure gauge will be at its lowest.

However, the HQ curve will appear completely vertical when using a positive displacement pump like a Sucker Rod Pump (SRP). The SRP HQ curve is vertical because it can develop a high head, almost infinitely, under ideal conditions, as long as there is no leakage. SRPs have a limited flow rate based on the number of strokes per minute (SPM), and they can theoretically produce infinite head in the absence of leakage. Leakage in SRPs is related to factors like plunger and barrel clearances.

In contrast, centrifugal pumps have limitations and cannot produce infinite head. To overcome these limitations, multiple stages of centrifugal pumps are used to achieve higher head levels. Single-stage centrifugal pumps have a Best Efficiency Point (BEP), which is the point of highest efficiency. Achieving and maintaining BEP can be challenging due to various factors like restrictions and friction.

To operate a centrifugal pump efficiently, running it within a certain range, typically within plus or minus 10 percent of BEP is recommended. This range is known as the operating range, and staying within it ensures the pump runs efficiently, consuming less energy. Deviating from this range can result in reduced efficiency, cavitation, noise, vibration, and even pump failure.

The primary goal is to operate the pump at BEP, but adjusting the pump speed may be an option if flow rates or other parameters change. Changing the pump speed can affect flow rate, head, and other parameters, allowing you to maintain efficient operation within the pump's specified operating range.

At the same time, SRP does not have a specific operating range. You simply move and run the plunger, and it will deliver. However, if you provide a very high stroke rate, such as 20-30 strokes per minute, and use a very large rod, the entire rod's momentum and the motor's power can cause the rod pump or sucker rod pump to fail. In deep wellbores, especially those with very long rods like three-way cup rods, running at very high speeds due to the added load of the rod's weight, the momentum of the walking beam, gearbox, and V-belt system can lead to system failure. Ideally, the speed should be around 6 to 10 strokes per minute, but slower speeds are acceptable. However, going higher, especially above 20 strokes per minute, in very deep wellbores can lead to system failure.

In contrast, depth is not a limiting factor in an ESP system because there is no such issue. Even if you have a very deep wellbore or need to develop high head, you can simply increase the number of stages, although this may pose some challenges. Ideally, you can generate any amount of head by increasing the number of stages.

When discussing ESP, certain parameters need to be defined. One of them is the total power required, often expressed as brake horsepower (BHP). Brake horsepower is a measure of the power required to stop the impeller or machine, typically by applying a brake to the shaft connected to the motor. It quantifies how much energy is consumed by the motor. Normally, the motor's power output exceeds its consumption to ensure continuous operation. If energy consumption exceeds the motor's capacity, the motor may fail. A dynamometer is often used to measure brake horsepower by forcing the motor to stop and measuring the energy consumed in the process.

The formula for calculating brake horsepower is $\mathrm{BHP} = (Q \times H \times \gamma) / (3960 \times \eta)$, where Q is the flow rate, H is the head, γ is the specific gravity of the fluid being pumped (e.g., water or oil), and η represents efficiency. This formula accounts for the conversion of units from HP feet to pounds per minute to US gallons. It's important to remember and use the correct units when working with these calculations to avoid difficulties in problem-solving.