Artificial Lift

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Lecture-39 Electrical Submersible Pump-Part-3

In our laboratory, we conducted experiments to demonstrate the pumping system's behavior. Here's what we did: we had a pump with a delivery and suction pipe. Before starting, we filled the tank and opened all the exit valves on the delivery side to ensure there were no restrictions. This allowed us to measure the flow rate and note the pressure at its lowest point due to the absence of restrictions.

As we gradually closed the delivery valve, the flow rate decreased, and the pressure increased, giving us the HQ curve. We also recorded the shaft speed and motor torque to calculate efficiency and power consumption. It's crucial to follow safety precautions, have at least two people present during handling, insulate all electrical components, and avoid fully closing the exit valve to prevent overloading the motor. When experimenting with a pumping system, caution and safety measures are paramount.

The impeller we used was a closed impeller, which consists of both a front and a back plate. Removing the front plate would turn it into an open impeller.

One plate, either the back plate or front plate, must be present; removing it turns the impeller into an open impeller. This design is preferable when dealing with suspended particles, as they can block small channels in a closed impeller. Closed impellers work well for lighter applications without sand and can develop higher head pressure.

In some cases, semi-open impellers are used, where half of the impeller is open and the other half is closed. Different impeller types have different applications. Closed impellers are common for the oil industry, especially in submersible pumping applications. Open impellers are not used, assuming no large particles will block the system. A sand control system is typically in place to prevent particle blockage.

Open or semi-open impellers can be used for slurry transportation and similar applications. Another type of centrifugal pump is the screw impeller, which is basically an axial type system. It can achieve high flow rates and high efficiency levels.

Centrifugal pumps are rotodynamic or velocity pumps; they generate velocity and convert it into pressure. The energy transfer occurs through a mechanical device, primarily a shaft. The impeller's kinetic energy converts into pressure energy within the casing or diffuser. The main components are the impeller, casing, suction pipe, strainer, foot valve, and delivery pipe.

In subsurface applications, foot valves and strainers are not typically used but may be present in surface applications. The tubing serves as both the delivery and suction pipes. These pumps can be single-stage or multistage, measuring the head in meters or feet. They usually run at speeds of 3600 rpm, and power is measured in horsepower, while flow rate is indicated in gpm and can be converted to BPD (barrels per day).

The image on the right is from our research paper. It illustrates an ESP (electric submersible pump) with multiple stages, showcasing the impellers in each stage. This is a larger impeller, and you can see everything clearly. But here, if you look closely, I hope it's visible on camera. There is the impeller eye, and fluid enters through it, taking a radial direction and exiting through these small holes. These holes might not be clearly visible, but they're there. The fluid enters and exits here, rotating at a very high speed due to the rotating shaft.

When the shaft is rotating, fluid enters through the eye and exits. For its exit, you need a volute or some other mechanism. Here, I have a diffuser mechanism, which is this white portion. The diffuser takes the high-velocity fluid from the impeller and enters from the top. Unfortunately, I cannot remove this diffuser. It enters from the top, goes through an internal path, and exits from the opposite side. It's the opposite of the impeller; the impeller increases speed, while the diffuser decreases speed and adds no energy to the fluid.

There might be some small losses, but the diffuser doesn't add energy; it only reduces velocity and increases pressure. This constitutes the first stage of the impeller-diffuser combination, also known as a stage. If I draw it, you can see the picture on the right. I'll place it here. This is my impeller in the right-side picture. It's not shown radially; it's a rough drawing for explanation. The impeller looks like this, and this is the eye. The eye is placed like this. In the picture, you can match it. The fluid flows from the eye almost radially toward the axis, and this is where my brother, the diffuser, comes into play.

The diffuser takes the high-velocity fluid and reduces its velocity before delivering it here. So the diffuser is located here. Let's assume we have one bar of pressure. After exiting the first stage, let's say it's 5 bar. So, after the first stage, it's 6 bar; after the second stage, it would be 6 plus 5. Assuming the inlet pressure is relatively 0 relative to the atmosphere, then it's 5 bar. In the next stage, it's 10 bar, and then 15 bar, and finally, 20 bar. The entire impeller produces a 20-bar pressure. I'm assuming the first stage here. The pressure it develops depends on the impeller's design diameter and many other factors. But if I have one stage, let's say 5 bar or 10 bar, then it's 5 bar, 5 bar, 5 bar, 5 bar, summing up to 20 bars. If I want to reach 100 bars, I need to add 1, 2, 3, 4, 5 more stages.

One impeller and one diffuser create one stage, and multiple stages create a multi-stage centrifugal pump or an electric submersible pump. The shaft, where is your shaft? It's here, and fluid flows through this path. It's going again, it's turning again, going impeller, turning again, impeller, turning again, exiting. Although it's shown like it's going like this, actually, it will be turning three-dimensionally. So showing it in a 3D form is challenging, which is why this picture is drawn in a simplified form. When you see this impeller, when fluid enters, it doesn't go like this, but it's turning; it's turning again, going again, turning again, so every time there will be turning. Fluid will be turning like this, turning, rotating, turning, rotating. But actually, it will be going like this again, so complex flow. If you ask any turbomachinery experts, they'll say the fluid flow situation in the turbomachinery system is the most complex among all flow phenomena, whether it's atmospheric flow, human body flow, blood flow, or anything else. Turbomachine flow is the most complex because the blades are rotating. You don't see it, but, for example, in air compressor design optimization or turbines, you don't see fluid flow but calculate it. The most complex flow situation is in turbomachine flow. This is called turbomachinery. Turbomachinery is rotating machinery. And, oh, two terms I forgot to explain: one is the pump, and one is the turbine. You should remember these. So a pump actually takes electrical energy and gives fluid energy, electric or any other form of mechanical energy to fluid. A turbine takes energy from fluid, so fluid to power generation, power to fluid. Like a ship's propeller, a pump delivers fluid, while a turbine takes energy from the fluid. Gas turbines, steam turbines, and wind turbines are turbines. Turbines take energy from the fluid and produce rotation, torque, and power, electricity. But when you talk about a fan, a fan delivers fluid. Fans are categorized as pumps, but together, they're referred to as turbomachines.

Now, how is fluid pressure developed? It's also taken from the same paper. You can see this: 12,000 pressure to 20,000, 23,000, and no 235,000. Pressure is increasing. This is the impeller, and this is the diffuser. So from the impeller, pressure is going up, up, up. The diffuser shows very high pressure in this picture. This means the diffuser increases pressure, so the diffuser's function isn't to give any extra energy; it just takes energy from the fluid and converts velocity to pressure. The impeller is the only component giving energy to the fluid.

Some commonly used laws include the affinity law. If you want to change the impeller diameter or speed, the formula is that flow rate (q) or diameter (d) and speed (n) will be proportional to power (bhp).

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad \text{OR} \quad \frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \quad \text{OR} \quad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{BHP_1}{BHP_2} = \left(\frac{D_1}{D_2}\right)^3 \quad \text{OR} \quad \frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3$$

It's proportional, so q is proportional to d and n. So if you change the speed, the flow rate will also change. What about head? Head is proportional to d^2 or n^2, so if you change the speed, the head will be squared. BHP also changes with d, but BHP is cubic power, not d squared, but d cubed. So you should remember that n cubed and d. When you apply the affinity laws, when you change the diameter or anything, some experts say that you can change a maximum of 20 percent. If you go for more than this, the equation may not be valid.

The term "NPSH" stands for "Net Positive Suction Head." Whenever you have a pump, let's say we have a pump here. This is the prime mover, and it will be delivering. This is the pump, the impeller eye. The pump delivers fluid, and you get fluid from here. What's happening is your pump is at a lower level than your tank's water level. So that means your tank is helping to fill your pump, and if you're using normal water with atmospheric pressure, this pump will probably work okay. But if you have a lot of bends, sharp corners, or a narrow suction pipe, say friction loss will be there. If you have a very narrow suction pipe or the pipe has very high friction, or the fluid has very high viscosity, in that case, friction loss will be very high, and the pressure drop will be very high. There will be bend loss, fittings, and so on. So in that case, your pressure drop will be high. In that case, the required suction pressure may be 3 meters, but you're only providing 10 meters. Due to friction, the actual available head will be less than 10 meters. If your pump requires 3 meters and, in the end, the pressure drops below 3 meters, then the pump will not work because it will start cavitating. Your net positive suction head will not help you pump.

So there are two types of NPSH: NPSH A and NPSH R. NPSH A stands for available NPSH, while NPSH R stands for required NPSH. The pump company determines the required NPSH. When a pump company designs a pump, they test how much NPSH (Net Positive Suction Head) is needed for the pump to operate properly. They will specify the required NPSH. Your task as an engineer is to read that document and ensure that the net positive suction head does not fall below the required NPSH. NPSH A, which is the NPSH available, is your responsibility as an implementation engineer. You should make sure that there is enough NPSH available, and if you don't maintain it, your pump will fail.

Now, what is this picture? This picture is taken from my own paper. Some time back, I published some popular articles, and from there, total inlet head, NPSH available, let's say this one. If there are no losses, then the total head is represented by Z. The left-side picture shows Z. Z represents the total head available, but because of losses, which can be due to friction or other factors, the total head will be reduced. Friction losses, bends, fittings, and other losses contribute to this reduction in head.

So after accounting for these losses, the pressure available at the inlet is determined. Putting a pressure gauge at the inlet should show the pressure available for the pump to operate correctly. You have to decide whether the pump can operate at this pressure. NPSH available should be greater than or equal to NPSH required for the pump to work smoothly. To ensure this, you need to make more NPSH available than you spend. In certain situations, the NPSH available may be lower than the required NPSH. To run a pump properly, NPSH available must match or exceed NPSH required.

Just like in life, you must earn more than you spend to survive. Therefore, you should provide a safety margin when designing pumping systems and calculating NPSH available. For instance, if the company specifies a required NPSH of 3 meters, it's better to ensure that you have 5 meters of NPSH available. This additional margin can account for unexpected changes in conditions, like inlet blockage, preventing the NPSH from dropping to the critical 3 meters where cavitation and other issues may occur.

In some cases, the entry pipe will be connected to a tank at a higher location, while in other cases, the entry or suction pipe may be located at a lower level, as seen in agricultural applications where the water source is in a pond at a lower elevation, and the pump is located at a higher point. In the latter scenario, cavitation can become a concern if the height difference exceeds 10 meters. However, cavitation issues are less likely if the pump and water source are at similar elevations. For centrifugal pumps, the NPSH requirement can sometimes be high, like 75 psi (5 bar). In such cases, an inducer pump may be added to the system, assisting in achieving the necessary NPSHA without providing extra head to the main impeller. The inducer acts as a helper pump and is typically connected to the same shaft as the ESP but helps to meet the high suction pressure requirements.