Artificial Lift

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Lecture-43 ESP Numerical Problems-Part 1

Good morning. Today, we will start with some calculations related to ESP (Electric Submersible Pumping) systems. We discussed the electrical system in our previous class and performed some calculations. Today, we will delve deeper into the pumping systems, understanding how intake occurs, fluid flow, and heat generation. Before we proceed with the calculations, it's important to have a solid grasp of the basics of pumps. Some of this might be a recap of our previous lectures.

Let's begin by examining the pump. I've shown this image previously. This is the flow passage, and this part is the impeller eye. The impeller has curved blades, typically around 5 to 7 blades within this range.

Now, there's a shaft hole through which fluid enters. This section is called the impeller eye, and these are the blades. Impellers consist of blades that rotate in a specific direction. The direction of rotation is as shown. When the impeller rotates, the blades have a suction and pressure surfaces. The suction surface is the side where fluid enters the blade, and the pressure surface is where higher pressure is generated due to the rotation.

Now, let's understand the concept of the suction and pressure surfaces. The blades are rotating, and fluid flows through the channels. This channel, where fluid flows, has two surfaces. One surface is the pressure surface, and the other is the suction surface. The pressure surface receives higher pressure from the fluid as the blade rotates, while the suction surface experiences lower pressure. The channel flows from the impeller eye to the impeller exit.

This is the impeller exit, marked as IE, and this is the exit area. The number of blades determines the design if the impeller has 5, 6, 7, or 8. For example, if there are 5 blades, you will have 5 blades arranged helically. It's important to note that this is a radial flow impeller because the fluid enters perpendicularly to the axis. It has a shaft with a keyhole. The shaft goes vertically, perpendicular to the shaft.

You can see a big shaft here, indicated by the red line connected to the impellers. The impellers are arranged as shown. The purpose of the impeller is to provide energy to the fluid. It's connected to a diffuser, and the fluid flows back and forth between impellers and diffusers. The fluid moves away from the shaft, back towards the shaft, away again, and so on. This radial movement characterizes radial flow impellers. In contrast, mixed flow impellers are inclined at a 45-degree angle, producing a different flow pattern.

In this picture, you can see a mixed flow impeller eye, inclined at a 45-degree angle.

What's happening here is that fluid enters the impeller eye, flows through the impeller, and exits from the impeller exit. From there, it enters the next diffuser, and this process continues - entering the diffuser, exiting, and so on. The purpose of the diffuser is to increase the pressure head, while the impeller imparts velocity head to the fluid. The impeller is responsible for providing a significant amount of kinetic energy to the fluid. It gives velocity head, and the diffuser aids in developing static pressure head, which is a measure of the amount of liquid column it can sustain.

This is a multi-stage centrifugal pump, or you can call it an Electric Submersible Pump (ESP). Multiple stages are involved in this setup. If you recall from our previous lecture, the entire system is connected to a hexagonal-shaped shaft that allows the impeller to rotate. The shaft connects to the motor, providing the necessary rotational motion for the entire system.

Now, let's examine a single impeller. I have a thin plastic impeller here. Fluid enters through the impeller eye, travels through the channel, and exits the impeller. The flow path is from impeller entry to exit. With a radial flow impeller, the fluid follows a path like this. A diffuser is connected, which has an entry, and the impeller entry is aligned with this.

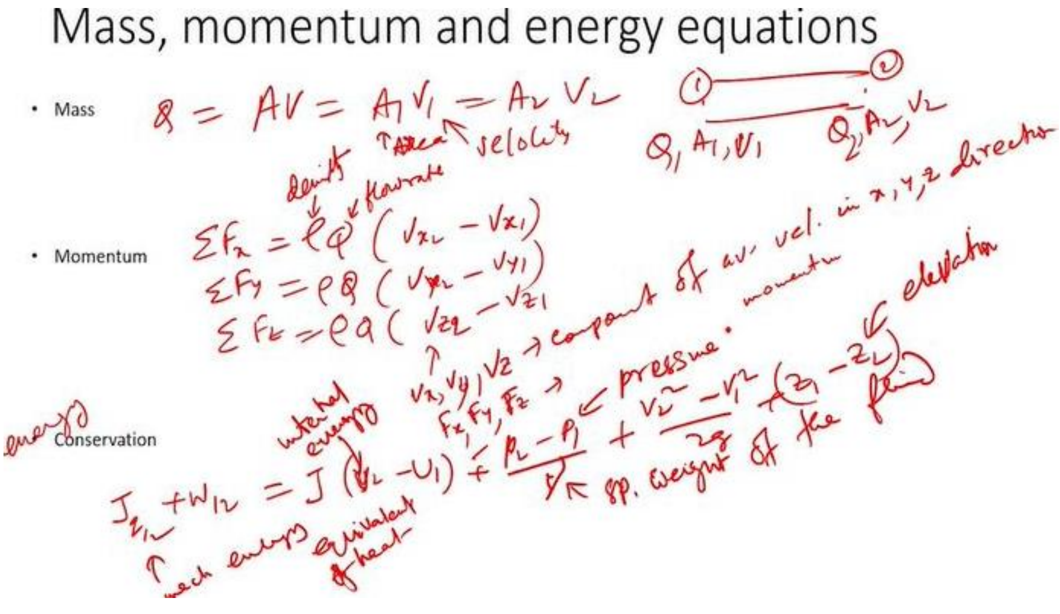
The fluid moves in this pattern - entry, exit, entry, exit - and it's not just two-dimensional. While I've depicted it as two-dimensional for representational purposes, in reality, the impellers are curved and the system operates in three dimensions. Each impeller and diffuser pair constitutes one stage.

Here's an example: Impeller entry, diffuser exit - that's stage 1. Impeller entry, diffuser exit - that's stage 2. This assembly continues for multiple stages. The fluid enters, moves vertically, enters the diffuser, and then travels axially again.

Now, let's proceed to the next stage. I will add another stage. So, fluid moves in a three-dimensional manner. What's happening is that fluid enters axially, then vertically, and again vertically (meaning perpendicular to the axis). It then enters the next stage with another impeller, goes through the process, and keeps turning, turning, and turning. This turning is not just two-dimensional, it's three-dimensional; the fluid moves in a rotational pattern. The shape of both the impeller and the diffuser has curvature.

So, suppose one stage is generating a pressure of 5 bar, and you have 7 stages. In this case, you would have a total pressure of 7 times 5 bar, which is 35 bar.

Now, let's delve into some formulas. You've got the basics down; let's explore the formulas related to mass conservation, momentum conservation, and energy conservation. These three equations are universally applicable when analyzing pumping systems or fluid systems. Mass cannot be destroyed, momentum is conserved, and energy is transformed in various ways.

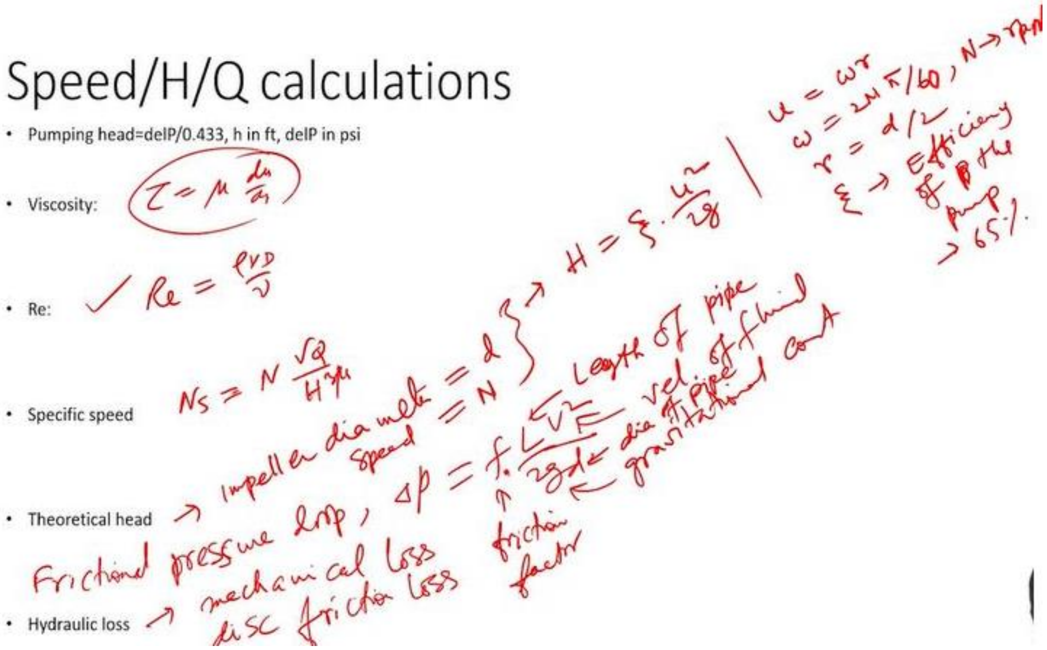


Mass, momentum and energy equations

- Mass $Q = AV = A_1 V_1 = A_2 V_2$
- Momentum
  $\Sigma F_x = \rho Q (V_{x2} - V_{x1})$
  $\Sigma F_y = \rho Q (V_{y2} - V_{y1})$
  $\Sigma F_z = \rho Q (V_{z2} - V_{z1})$
- energy Conservation $J_{Q12} + W_{12} = J (U_2 - U_1) + \frac{P_2 - P_1}{\gamma} + \frac{V_2^2 - V_1^2}{2g} + (z_1 - z_2)$

For mass conservation, the equation is Q equals A v, which is equivalent to A1 v1 equals A2 v2. Here, A represents the cross-sectional area, and v represents velocity. If you have point 1 with flow rate Q1 and area A1, you'll get velocity v1. The same holds for point 2 with Q2, A2, and v2. The relationship is A1 v1 equals A2 v2, ensuring mass is conserved. The equation may include the density term if you're dealing with compressible fluids where density changes. However, density is considered constant for incompressible fluids like water or oil under relatively low pressure differences, and there is no variation.

Now, moving to momentum conservation - if an object is in motion at a certain velocity, it has momentum, a product of mass and velocity. The formula for this is the summation of forces in the x, y, and z directions. In the x direction, it's rho (density) times Q times v x (the component of average velocity in the x direction). Similar terms apply for the y and z directions. These equations consider the conservation of momentum.



Speed/H/Q calculations

- Pumping head=delP/0.433, h in ft, delP in psi
- Viscosity: $\tau = \mu \frac{du}{dy}$
- Re: ✓ $Re = \frac{\rho v D}{\nu}$
- Specific speed $N_s = N \frac{\sqrt{Q}}{H^{3/4}}$
- Theoretical head → impeller diameter $= d$, speed $= N$ → $H = \xi \cdot \frac{u^2}{2g}$
- Hydraulic loss → mechanical loss, disc friction loss

$u = \omega r$

$\omega = 2N\pi/60$, N → rpm

$r = d/2$

ξ → Efficiency of the pump > 65%

Frictional pressure drop, $\Delta p = f \cdot \frac{L V^2}{2 g d}$

Length of pipe

vel. of fluid

dia of pipe

gravitational const

friction factor

Finally, let's talk about the conservation of energy. The equation looks like this: J (mechanical energy equivalent of heat) times Q1^2 plus W1^2 equals J times Q2 minus Q1 plus P2 minus P1 divided by gamma plus v2^2 minus v1^2 divided by 2 times v plus z1 minus z2. Here, J represents the mechanical energy equivalent of heat, u is the internal energy, z represents elevation, gamma is the specific weight of the fluid, and P is the pressure - terms that you're already familiar with.

This formula is similar to the one you've encountered in Bernoulli's equation. In Bernoulli's equation, we assume no energy transfer; the equation would look like this if there were energy transfer. However, we're considering cases with no heat energy transfer, which is similar to Bernoulli's equation. You might recall using this formula for calculations, such as Venturi meter calculations.

Next, let's discuss some more parameters. We've previously covered viscosity; you're already familiar with the formula,

$\tau = \mu(du/dy)$.

We discussed viscosity in earlier lectures, covering topics like Newtonian and non-Newtonian fluids. For more details, please refer to those previous lectures.

You're probably familiar with the Reynolds number formula: Re equals (μ into V into d) divided by ν. We've also discussed the specific speed formula applicable to pump specific speed, $N = \sqrt{(Q)} / H^{3/4}$.

This formula was explained in previous lectures when discussing theoretical head.

Speaking of theoretical head, when calculating it, you'll consider the pump impeller's diameter and speed, N. In this case, the theoretical head is calculated using the formula:

Head = $\zeta * (u^2)$ divided by $(2 * g)$.

Here, u is equal to $\omega * R$,

where $\omega = 2 * \pi * N / 60$, and R equals d / 2.

We assume the impeller eye diameter is small compared to the outer diameter, and this formula is an approximation. ζ represents the efficiency or coefficient of the pump or impeller. For calculation purposes, a typical range for pump efficiency is around 65% to 70%. Using very low or very high efficiency values is generally not recommended. In ESP systems, the efficiency is typically around 65% (plus or minus), and N should be in RPM. The resulting head will be in meters if the RPM is provided in meters. This calculated head is theoretical.

Moving on to the volumetric ratio, it's the ratio of practical head to theoretical head. You need to gather data from experiments and then compare it to the theoretical head for practical head. Any difference you find can help you calculate hydraulic losses. There are several types of losses in ESP systems, including mechanical and disk friction losses.

For friction calculations, you might recall that we've discussed frictional pressure drops or head in previous lectures. The formula for calculating frictional pressure drops or head is as follows: $f * (L * V^2) /(2 * g * d)$.

In this formula, L represents the length of the pipe, f is the friction factor (you can refer to charts or use specific formulas depending on the flow regime), V is the fluid velocity, g is the gravitational constant, and d is the diameter of the pipe. Be sure to check the units of the variables in the formula.

Please refer to the previous lectures for a more detailed analysis and comprehensive formulas.

Every time you select a pump, the company designs and tests it. In this case, I've taken information from the Schlumberger website. The company offers various pump models, including the M series. Each series corresponds to different pump sizes designed for specific conditions. The data is presented as characteristic curves for the M675A pump restriction. These curves illustrate the pump's performance.

You can see a curve for head, another one for power, and an efficiency curve. The head curve shows that the head gradually decreases. The efficiency curve reaches a maximum before declining. Power, on the other hand, increases steadily.

As indicated on the efficiency curve, the best efficiency point is the Best Efficiency Point (BEP). However, you don't typically operate the pump exactly at the BEP. You'll usually run it slightly below or above that point, within a certain range. This range is your operating range, depicted in yellow shading. The head at the BEP is around 115, and power varies accordingly as you move up or down along the curve.

Now, draw a line and follow it on the power curve. You'll find that the power is around 25. At the Best Efficiency Point (BEP), the power is approximately 25. If you operate the pump to the left or right of the BEP, you'll experience more cavitation, vibration, and a higher risk of failure. Additionally, energy consumption will increase.

You can observe that energy consumption increases if you move to the right side of the curve. Therefore, the goal should be to run the pump at the Best Efficiency Point (BEP). In terms of specifications for ESP systems, you can see the details here. The flow rate is given as 25,000 barrels per day at 60 hertz frequency. It's specified in barrels per day (BBL per D). A different unit is provided if you prefer using cubic meters per day.

The head per stage is given as 112 feet at 60 hertz. It indicates that the outer diameter of the impeller is quite large. However, the RPM (revolutions per minute) isn't mentioned, but it's typically assumed to be 3,500 RPM due to the 60-hertz frequency.

The pump efficiency is notably high, around 74%. The required horsepower for this system is approximately 30 horsepower. It utilizes a mixed flow impeller for stage geometry. The present ESP system is equipped with a radial flow impeller, while the one shown here uses a mixed flow impeller.

Mixed flow impellers have a specific advantage. They offer higher flow rates, although the head may be somewhat lower compared to radial flow impellers. To achieve this, the mixed flow impeller has a longer impeller length, as it doesn't turn the fluid at a 90-degree angle but at a 45-degree angle.

The total stage length increases due to the fluid's path in a mixed flow impeller, making it beneficial for applications requiring higher flow rates.

In terms of stage metallurgy, they use a specific type of alloy called nickel resist 5530 alloy, specified by a unique code. You can refer to the relevant materials for more information.

The shaft diameter is 1.37 inches, which is larger than the typical shaft diameter of 1 inch or less, in this case, it's almost 1.5 inches. The shaft material is inconel, a high-strength material. Additionally, there are shaft radials and shaft protection in place.

The pump's construction features an enhanced compression design and is factory-shimmed. They've provided information about the pump's manufacturing method.

Now, when you refer to a specification chart from any company, you should be able to understand most of the details provided.