Artificial Lift

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Lecture-40 ESP Basics Electrical Systems-Part-1

Good morning. Today, we will discuss the electrical systems used in submersible pumps. But before diving into the electrical systems, let's review the equipment used in an Electric Submersible Pump (ESP) setup, starting from the surface and working our way down to the reservoir.

Assuming we have a reservoir, there will be perforations for fluid flow. The sides are cemented, forming a wellbore. Now, let's introduce tubing, which runs down the wellbore. The tubing passes through a tubing hanger, and then we have what's known as a Christmas tree assembly.

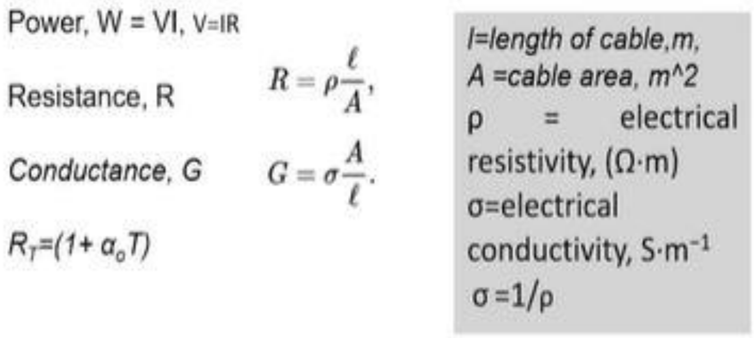
Inside the wellbore, we also have casing, and if we're using an electric submersible pump (ESP), a cable runs from the surface down to the motor, which is submerged. The motor is followed by a protector section, ensuring that no liquid enters the motor. The protector contains a dielectric fluid to safeguard the motor.

The motor shaft extends through the protector and connects to the pump. The pump contains multiple impellers for enhancing fluid flow. The fluid travels from the pump into the wellbore. Within this path, there's a gas separator. The electric cable exits the wellbore and goes to a junction box. From there, it continues to a switchboard (TCH switchboard), and then to a transformer. The transformer connects to a three-phase high-tension power line.

This summarizes the basic equipment. I'm not detailing the wellhead or Christmas tree components, as we've covered those in previous discussions. Now, let's focus on the electrical components, which include the transformer, switchboard, junction box, and the cable running down to the motor.

The motor draws electricity from the surface and utilizes it to rotate the shaft. The shaft passes through the protector section, the gas separator, and eventually connects to the impellers within the pump. The pump derives power in the form of torque from the motor, and this torque is transmitted through the shaft. The impellers within the pump rotate, imparting energy to the fluid. The fluid changes velocity and pressure as it moves through the system, providing the fundamental functionality of the submersible pump.

Now, let's delve into the electrical aspect. We'll start with a fundamental formula: VIP



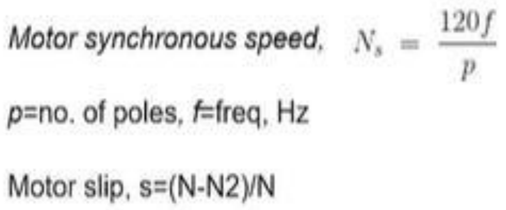
Power, $W = VI$, $V=IR$

Resistance, R $R = \rho\frac{\ell}{A}$,

Conductance, G $G = \sigma\frac{A}{\ell}$.

$R_T=(1+\alpha_o T)$

l=length of cable,m,
A =cable area, m^2
ρ = electrical resistivity, (Ω·m)
σ=electrical conductivity, $S\cdot m^{-1}$
σ =1/ρ



Motor synchronous speed, $N_s = \frac{120f}{p}$

p=no. of poles, *f*=freq, Hz

Motor slip, s=(N-N2)/N

In this equation, V represents voltage, I represents amperes or current, and P signifies power. So, V equals IR, where R is resistance. R denotes resistance, and P equals VI. The standard unit for power is typically watts, and if you divide by 1000, you get kilowatts. H is for heat generation, represented as I squared RT, where T signifies time. This heat generation is significant because when a motor receives electricity, not all of it can be transformed into mechanical energy. There are inevitable energy losses, and the lost energy is converted into heat. Continuously generated heat can increase temperature in a closed system like a wellbore. If the motor's temperature surpasses a certain threshold, issues can arise with insulation and elastomer seals, leading to seal failures.

Insulation and seals are vital components, and if there are problems with these, the motor may come into contact with wellbore fluid. There is dielectric fluid inside the motor, which serves as an insulator. We'll discuss this dielectric fluid further later. If the dielectric fluid is displaced by wellbore fluid, the properties will no longer be the same. The original purpose of the dielectric fluid will be lost, and internal sparks may occur within the motor, risking the entire electrical system. Therefore, it is crucial to maintain proper seals, ensure the presence of dielectric fluid, and maintain the correct pressure so that wellbore fluid, whether it's oil, gas, or water, does not enter the motor system. If there is excessive heat generation, the entire system can overheat. To dissipate this heat, flowing fluid, whether water or oil, is essential. However, heat can accumulate if the motor is running while the pump is not operating and fluid delivery isn't happening. The temperature can spike from 100 degrees Celsius to 300 degrees Celsius, eventually causing the system to fail.

So, if you notice the motor is running without fluid flow when it should be, it's crucial to investigate the issue and take corrective action, whether it's shutting down the system or addressing the problem. If left unresolved, the motor may burn out, resulting in costly system replacement, as I've mentioned in previous lectures regarding the expense of replacing artificial lifting systems that fail.

You must avoid these sorts of problems to ensure your system enjoys a longer, more stable production life. You can't change the production rate; the goal is to achieve stable, consistent production for an extended period, making it more economically viable. Frequent servicing is necessary in problematic wellbores, which can become more expensive. It's crucial to minimize heat generation within the wellbore.

We'll discuss series and parallel connections for motor cables, the pot head, and the pot hole. Pot head refers to the point where electric cables enter the wellbore and submerge in the liquid. A secure connection is vital to prevent any water or outside fluids from entering the system, which could lead to sparking or insulation issues.

As I mentioned before, the protector safeguards your motor, containing bearings and seals. The protector is an important component. Junction boxes are located on the surface, connected to the switchboard and variable frequency drive, which is used to change the motor's speed. We'll show the heat generation calculation at the end.

Next, we'll explore voltage-current analogy, analyzing fluid flow compared to electricity. We can liken a fluid flow loop to an electricity circuit. For instance, we have a pressure difference from P1 to P2 in the fluid flow loop, akin to a voltage difference. Then there's resistance, equivalent to resistance in electricity. If electrons encounter resistance when flowing through a wire, it's known as electrical resistance. In fluid flow, we can create resistance by narrowing a section of a pipe or using a valve, causing pressure loss or drop.

To make a comparison, we also have switches and controlling valves, allowing us to relate flow rate (akin to current in electricity) and voltage (similar to a pressure difference). This concept means that if you understand fluid flow, you can grasp electricity and vice versa.

You can relate different aspects between the two systems: volume in fluid flow corresponds to charge in electricity, mechanical momentum to flux, volume flow rate (Q) to current (I), and stress (sigma) to the potential difference (del P), which I've already mentioned as voltage. Moreover, we have force (F) as another parallel between the two systems.

Comparing these two systems makes it easier to remember. As I mentioned earlier, power (W or P) is equal to VI,

where $V = IR$,

and resistance (R) is determined by the resistivity (ρ) of the material, the length of the conductor (L), and the cross-sectional area (A). For instance, copper, with a low resistivity, serves as a conductor, while materials like wood or plastic with very high resistivity are used as insulators. Conductance is the inverse of resistance, denoted as G, and it's equal to 1/R, which translates to

$G = \sigma L/A$,

Where, σ represents electrical conductivity.

Resistance can be temperature-dependent; as temperature increases, resistance typically increases as well. This is because higher temperatures cause electrons to collide with one another, impeding their flow compared to lower temperatures. The formula R_T represents this relationship between resistance and temperature, which involves a multiplying factor R_T = (1 + alpha * (T - T_0)),

where alpha is determined at 0 degrees Celsius.

For electric motors, especially induction motors, the synchronous speed (n_s) is given by 120f divided by the number of poles, with "f" representing the frequency. Motor speed is affected by load; when you connect additional loads, such as an Electric Submersible Pump (ESP) system, the motor speed may decrease. This speed reduction is referred to as motor slip and is typically expressed as a percentage. So, you can calculate slip by taking the difference between synchronous speed and loaded speed, dividing by synchronous speed, and multiplying by 100.

The types of conductors used for ESP cables will vary. ESP cables are quite long, as ESP motors are often installed at depths of 2000 to 3000 feet, resulting in cables stretching over one to three kilometers.

Electric losses are a common concern with a long cable due to resistance. You've probably noticed the formula R equals rho times L divided by A, which expresses the relationship between resistance (R), resistivity (ρ), conductor length (L), and cross-sectional area (A). As cable length (L) increases, the total resistance also increases. You can consider a few strategies to reduce this resistance and avoid voltage drops.

One approach is to increase the conductor's cross-sectional area (A). However, the options for changing the area are limited because the tubing and casing sizes are specific, and the cable enters through the annular space between the tubing and casing, which also has a fixed area.

So, you have limited flexibility to change the conductor size as you see fit. In some cases, you might use flat-type conductors when the available area is minimal, while circular conductors are suitable when the area is larger.

The most effective way to reduce resistance is by changing the material (ρ) of the conductor. This involves selecting a material with lower resistivity and, consequently, lower resistance. When it comes to material options, copper and aluminum are commonly used for conductors.

Copper is preferred due to its high number of free electrons available on its surface. Free electrons move easily in response to even a small potential difference, carrying electrical current. When applying a slight potential difference, these free electrons readily conduct electricity. In some cases, copper conductors are used in a single solid configuration, while multiple smaller conductors are employed in other situations.

The single solid configuration uses slightly thicker wires, ensuring efficient electrical conduction. When considering conductors for your ESP cable, you have the choice between a single solid configuration and multiple strands. The single solid configuration utilizes slightly thicker wires and is efficient for electrical conduction. On the other hand, multiple strands are more flexible, making them preferable for electrical conductance. However, managing multiple strands can be challenging, and if one wire gets cut, it can lead to issues. Nevertheless, multiple strands offer great flexibility. They may have small gaps between them, which could allow gas to migrate in the cable if present in the wellbore, making gas vent junction boxes necessary on the surface.

Stranded cables are mechanically flexible, but the voids between the strands make it easier for gases to migrate along the cable. They are coated and insulated to prevent copper conductors from oxidizing and to extend their lifespan. Insulation is crucial for preventing electron flow between adjacent wires. ESP cables that are rubber-insulated use bare copper conductors.

In this context, a braided wire is a term describing multiple strands of flexible wire wound in a spool or circular pattern around a core. Braided wires are used in various applications.

When calculating motor power, the formula to remember is.

$P = T\,\omega$.

For instance, if a motor consumes 100 kilowatts of power, you can calculate its RPM based on the torque it produces. The formula for calculating angular speed (ω) from RPM is 2N pi by 60. Torque (T) and RPM (N) are the key parameters for calculating power. Knowing either torque and RPM or power and RPM allows you to determine the remaining parameter.

If two parameters are given, you can calculate the third parameter. I already mentioned that conduction implies low resistance. An insulator, on the other hand, means there are almost no free electrons. When almost no free electrons are present, if the material covers a copper, silver, or aluminum wire, electrons won't flow through it. An insulator prevents electrons from passing through the material and from passing from one wire to another. This is why all electrical wires are usually insulated for safety reasons and to prevent the cables from touching each other and creating sparks.

Conductor refers to a material with free electrons, allowing electron flow. In contrast, non-conductor or insulator means no free electrons are present, resulting in no electricity conductivity. Another term you're probably familiar with is a semiconductor. This material, found between metals and insulators, often contains doping materials that modify its electrical properties. Semiconductor behavior is also temperature-dependent. For example, in a computer, elevated temperatures can affect performance; cooling mechanisms like fans are employed to counteract this. Overheating can lead to insulation issues, where softer materials like rubber or polypropylene may melt, causing leaks and burnt odors.

Electricity and magnetism are fundamental concepts. Electricity can generate magnetism, and conversely, a magnet can produce electricity. This phenomenon is harnessed in generators, motors, induction heaters, and applications like wave energy devices, as demonstrated in a laboratory setting. The basic principle involves moving a magnet within a coil (solenoid), generating an electromotive force (EMF) or electricity. For instance, in a wave energy device, a coil is connected to a vertical buoy, and as the coil moves up and down with the motion of the waves, it induces an EMF, producing electricity that can be measured using a digital meter.

If a magnetic flux surrounds a coil, the coil will generate EMF. You can detect this EMF when it is produced. When only a coil is present, passing electricity through it creates a magnetic field. However, when both magnetic fields are intersecting, EMF, or electromotive force, is generated.

The simple system shown here produces electricity, and similar systems are available in the market. This concept is based on linear generators and linear motors.

The inductance, denoted as L, is calculated using the formula,

$L = \Phi / A$,

where Φ represents the magnetic flux and A is the cross-sectional area.

Magnetic field intensity, symbolized as H, is given by the equation

$T = h * F / M$,

where F represents the force and M is the length per meter.

As seen before, magnetic fields are involved in this process. If a coil conducts electricity, it generates a rotating magnetic flux. When both components are correctly connected, EMF is produced. In the case of a generator, you provide mechanical energy to obtain electrical energy. A motor, on the other hand, converts electrical energy into reciprocating or rotary motion. So, the difference between a motor and a generator lies in the direction of energy conversion: a generator converts mechanical energy into electrical energy, while a motor converts electrical energy into mechanical motion.