Artificial Lift

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Lecture-22 Sucker rod pump (SRP) - Part 1

Good morning, everybody. Today, I will discuss SRP, which stands for Sucker Rod Pump or Pump Jack. It goes by various names, including Pump Jack, Sucker Rod Pump, Beam Pump, Rod Pump, Nodding Donkey, and Horsehead. It's essential to be aware of these different terms when searching for information on Google or when using ChatGPT, as different sources may use different names for the same equipment.

As a quick recap from our previous lecture on pumps, pumps can be categorized into two main types: positive displacement pumps and kinetic pumps. When discussing positive displacement pumps, you can see in the picture on the right that a hand pump is commonly used in households or rural settings. Another example of a positive displacement pump is the human heart. The term 'positive displacement' implies that these pumps deliver a fixed volume of fluid regardless of the pressure or head requirements.

But the flow rate will be limited, just like the human heart pumps constantly, ensuring a consistent blood flow throughout the body. However, when you engage in physical activity, your body requires more energy and oxygen. Consequently, your body demands increased blood flow. This results in an elevated heart rate, which leads to higher fluid flow, not necessarily increased pressure. So, the flow rate increases when you're using a hand pump, such as the one shown, and you start pumping faster. Similarly, tabletop devices increase their flow rate when you increase the rate at which you operate them. In these cases, you boost the flow rate while maintaining constant pressure.

As discussed in a previous lecture, remember the variables H and Q, where Q represents the flow rate. Flow rate can be measured in various units like gallons per minute (gpm), cubic meters per second, or other units depending on the industry. In the oil and gas industry, gallons per minute are commonly used, but some companies may use cubic meters per second. When working on calculations or drawing curves for different applications, paying attention to the units is crucial. Mismatched units can lead to incorrect results.

As for H, it's typically expressed in meters. Why meters? We often measure pressure in pounds per square inch (psi) or pascals (Pa), but when we refer to head, we're talking about the equivalent height of a liquid column. This is known as the 'head of liquid,' typically measured in meters, equivalent to some 14.57 psi. So, for SRP, the curve will look like this. You may recall the picture I explained last time, where I had a pump drawing water from this tank, and there's a valve that you gradually close. As you slowly turn the valve, your pressure sensor and flow meter will show an increase in flow rate, but the pressure (or head) will also increase. While the head is increasing, you can draw this vertical curve.

This vertical curve or line doesn't touch the H-curve or the y-axis. This indicates that you can achieve infinite heads with this type of pump. However, considering a centrifugal pump, the curve will look different. The maximum head is limited for a centrifugal pump, unlike positive displacement pumps like the Sucker Rod Pump, hand pump, or the two pictures you see here: the heart and the tabletop water pumping device. Additionally, there are progressive cavity pumps, diaphragm pumps, scroll pumps, volumetric pumps, gear pumps, and several other types of pumps. These pumps are designed for low flow rates but can generate very high head or pressure when needed, even though their flow rates are limited or very low.

So, in this case, you can use a positive displacement pump. You can also have higher-volume pumps for positive displacement, which we will discuss later. You can generate a very high flow rate for centrifugal pumps, but the head will be limited. In such cases, there are mechanisms like multi-staging, enlarging the pump, or increasing its speed. We will discuss these options later.

A positive displacement pump is defined by its ability to trap a fixed amount of fluid. If you examine a hand pump, you'll find a cylinder with a flap-type valve at one end and a rod connected to a plunger or piston. Water is drawn in and pushed out when you operate a hand pump by moving it up and down. In the hand pump, there is a lower valve and an upper valve. When you press the handle down, the upper valve closes, and the lower valve opens, allowing fluid to be delivered. The opposite happens when you move the handle up, and no fluid is delivered.

The same principle applies to other positive displacement pumps like the Sucker Rod Pump (which we'll discuss later) and ESP, PCP, or diaphragm pumps. These are constant flow rate pumps, where the head can change, and typically, the flow rate is lower while the head or pressure is very high. Ideally, they can develop any head.

Now, if we consider the Sucker Rod Pump in a wellbore system, it operates on a similar mechanism as a hand pump. It consists of a wellbore with a rod that connects to the reservoir where the fluid is located. There is a plunger or piston in this reservoir area, and a surface mechanism is used to provide the relative motion of the rod.

So this is the mechanism of the sucker rod pump. The mechanism of the sucker rod pump, hand pump, and all these devices is the same. In a hand pump, you'll find a cylinder and a valve. When the piston of the hand pump moves up, it seals this area tightly. Sealing means there will be very little clearance or leakage, so when the piston moves up and down, the fluid should not flow back into the area ABC.

When you lift this rod due to this action, the fluid in the area I'm calling F, the area F, will move upward. You can assume this initial height as h. So, what is the pressure at location B? At location B, the pressure will be P,

$$P = h\rho g$$

Here, ρ represents the density of water or any liquid you are pumping. Normally, water has a density of 1000 kg per cubic meter. The constant g has a value of 9.81 for SI units. If you use FES units or field units, it will be 32.17 pounds mass per cubic foot.

As the rod is lifted, h decreases, and the fluid is delivered at that time. When you move the piston down again, h increases, and h changes. When h changes, the pressure at location B also changes. This is how the sucker rod pump or pump jack operates. I've shown you a picture in a previous lecture from our laboratory setup. In this laboratory setup, there is a pump labeled P and a water tank next to it.

So, this is the tank, and this pipe is connected to the tank. This picture has been cut, so something got cut. This is the inlet or suction pipe, and one pipe is going like this from the pump. Here, this is called the delivery pipe. So, on the suction and delivery sides, you can see that I have one flow meter and one pressure sensor. You can see the pressure sensor for pressure measurement here. Also, there is another pressure measurement being done here. I will have a tachometer. I think there will be a closing valve somewhere and an exhaust valve somewhere here. Somewhere here, there will be a closing valve.

To draw this HQ curve, the head and flow rate curve, you start by switching on the pump. Initially, you switch off the pump, and the exhaust valve is open. Then, slowly, you close it. If it's a positive displacement pump, your flow meter will show the same flow rate, but your pressure gauge or pressure sensor here will show higher pressure. This way, you draw the HQ curve, and your hydraulic efficiency curve will also be almost horizontal. Actually, for a positive displacement pump, you can draw the same thing for a PCP diaphragm pump or other types of pumps. But if you are using a sucker rod pump, the case will be a little different because the sucker rod pump has pulsating flow. If you want to reduce pulsating flow, you may need to use an accumulator. We can discuss what an accumulator is. Before you dive into the details of the pump or sucker rod pump, or any pumping system, you need to understand specific definitions.

So, as for density, you already know it's in cubic pounds per cubic foot or meter cube per kilogram per meter cube. One foot of water equals 62.4 divided by 1.433 pounds per square inch. Ten feet of water will be 4.33 pounds per square inch in terms of the head height of a fluid column. One psi is equivalent to 2.31 feet of water head.

$$\Psi = \frac{p}{\gamma}$$

$$\Psi = \frac{p}{\rho g}$$

Here, rho represents density, g represents acceleration due to gravity, and p is the pressure. If you use SI units, life is easier, and you can get the meter head of water directly. Normally, we compare pressure with an equivalent column of water height. Absolute pressure is the term commonly used. It differs from actual pressure or pressure gauge and atmospheric pressure. Absolute pressure is always greater than 0, and gauge pressure equals absolute pressure minus atmospheric pressure.

$$p_{gauge} = p_{abs} - p_{atm}$$

Now, when we talk about pressure and flow rate, another term that comes into play is temperature. You should know the conversion units, such as degrees Celsius, degrees Fahrenheit, Rankine, and Kelvin. In the oil industry, Rankine or degrees Fahrenheit temperatures are typically used. Although degrees Celsius and Kelvin can also be used, people usually specify temperatures in degrees Fahrenheit or Rankine. The conversion formula is Fahrenheit temperature plus 460 equals Rankine temperature. It would help if you also understood the differences between temperature and heat. Heat refers to the amount of energy, while temperature pertains to whether that heat is high or low. This can be sensed using specific measuring instruments for temperature. Now, let's move on to pressure measurement and flow rate measurement.

Several instruments developed over time for pressure measurement include Bourdon tube pressure measurement, transducers, Pitot tube, orifice plate, and Venturi meter. Each pressure-measuring instrument has its strengths and weaknesses. So, based on the application, we can choose the most suitable one. Normally, manometers are used in laboratories at universities or colleges because they are very simple, with just one pipe to measure pressure. Bourdon pressure gauges are also cost-effective and readily available in the local market. They are even present in our experimental setup on the right side, where you can see a pressure sensor and a Bourdon pressure gauge.

A Bourdon tube pressure gauge works like this: it has a C-shaped tube. When pressure is applied to this metal pipe, the C shape changes because of the pressure. Small pressure causes a smaller radius, and it attempts to straighten out as pressure increases. If you apply too much pressure, it may become completely straight, but typically, it does not. Many children play with similar rolling pipes, blowing air to make them straight and letting them roll up when not blowing air. The same technique is used in Bourdon tube pressure gauges.

When very high pressure is applied, the tube straightens out, and a gear mechanism and a needle are used to measure the pressure.

So, what do the needle and gear mechanism do? They are connected to a dial. When the C-shaped tube moves due to pressure, it is linked to a gear. As the gear turns, it is connected to a needle that moves left or right. When there is high pressure or low pressure, the needle slowly moves left or right. Based on the position of the needle on the dial with measurements like 0, 1, 2, 3, and 4, you can directly read the pressure. This is called a Bourdon tube pressure gauge, and it is commonly used in fluid laboratories because it allows you to see how much the pressure changes visually.

Now, there are also pressure gauges based on transducers. These pressure gauges utilize piezoelectric materials, which means that when you apply pressure to such a material, its electrical properties change. You can sense these changes in electrical properties using electronic devices. You can determine the amount of pressure applied to the system by measuring the electrical signal. So, when you change the properties or increase the pressure on a piezoelectric material like this, the electrical properties change in the system. You can determine the corresponding pressure level by detecting these changes in electrical properties.

For example, these days, devices like touchpads use this mechanism. When you change pressure or try to bend some piezoelectric material, it changes its electrical properties, and based on that, you can measure pressure.

Now, let's talk about the pitot tube. The pitot tube consists of a small pipe with a tiny hole. Due to this small hole, there will be a pressure stagnation point. When fluid flows through the pitot tube, some of the fluid gets impacted by this area, leading to pressure stagnation. As a result, the pressure inside the fluid column increases, causing the column height to rise. By measuring this column height, which may be represented by a different color (e.g., red fluid), we can determine the pressure generated and use it to calculate flow rates.

In some cases, an orifice plate is used. An orifice plate is created by introducing a restriction into the pipe. This restriction results in the formation of a vena contracta. By using an orifice plate with a manometer or similar device, we can detect flow changes that create pressure variations. As flow rates change, pressure also fluctuates, allowing us to measure pressure in such cases.

In a similar way, you can also use a venturi meter. There are several options for pressure measurement, and based on your application, you can choose the most suitable one. Nowadays, automation is becoming prevalent, and in many cases, electronic-based pressure measurement systems are employed. These systems often have electronic connections that enable full automation, especially in the context of SCADA systems. When using SCADA systems, all sensors, including pressure, temperature, and flow, are integrated into a master computer system. Operators can monitor the entire process from this central control unit.

Now, let's discuss flow meters. Flow meters create obstructions that cause changes in pressure and flow rates. Turbine flow meters, for instance, use a turbine to measure flow rates. Turbines are similar to the fans or wind turbines you may be familiar with, but in this case, they are much smaller and placed within pipes. As the flow rate changes, the turbine's rotational speed changes accordingly. By measuring this speed, you can calculate the flow rate. Typically, when designing a turbine flow meter, you first assume a certain flow rate and then calculate the expected speed. In this case, it works the other way around: you measure the speed and extrapolate to determine the flow rate. Turbine flow meters are readily available in the market due to their simple construction.

Another type of flow meter is the electromagnetic flow meter. Electromagnetic flow meters rely on changes in electromagnetic properties as flow rates vary. These changes in properties allow you to measure different flow rates.

Positive displacement systems, like piston-based systems or progressive cavity pumps (PCP), deliver fixed volumes of fluid. For instance, the human heart pumps a certain fixed volume of fluid with each beat: one stroke delivers one fixed volume, two strokes another fixed volume, and so on. Similarly, a sucker rod pump, as it moves up and down, delivers fixed volumes of fluid with each stroke. PCPs operate on the same principle: they deliver fixed volumes with each rotation. When you need to measure fixed volume flow rates, positive displacement pumps are suitable.

Anemometers and electromagnetic air flow meters are commonly used for airflow measurement. Additionally, ultrasonic flow meters and mass flow meters are available. While we won't delve into the details of these devices here, it's essential to know the various flow meter options available for measuring flow in piping or pumping systems. Selecting the right flow meter for your specific application is a crucial consideration.

Now, if you observe any picture of an oil field, you'll likely see a familiar sight: the sucker rod pump, also known as the beam pump. This is because approximately eighty percent of all oil wells employ some form of artificial lift, and about seventy percent use sucker rod pumps. Its widespread application is due to its simplicity in both use and handling.

Let's discuss the various components of this setup. The sucker rod pump, or beam pump, consists of a working beam connected to a Samson post. The Samson post is linked to a horse head, and the horse head, in turn, connects to a structure known as a bridle. The polished rod passes through a sealing section called a stuffing box. Near the stuffing box, you'll find a T-junction. This T-shaped junction connects to a pin or bearing called a saddle bearing. This part is known as the tail pin; you have the pitman's arm adjacent to it. In the terminology of internal combustion engines, it's called a connecting rod, but in the oil and gas industry, it's referred to as the pitman arm. The pitman's arm connects to a crank, and this component is called the crank pin.

The crank is connected to a gearbox, further linked to a sheave or pulley. You'll find this sheave or pulley attached to a V belt. There are two types of sheaves: the engine sheave and the unit side sheave. The engine sheave connects to a motor, which, in turn, is linked to an electrical unit or switch. This setup should be connected to your primary power grid.

Additionally, there are heavy counterbalance masses present in the system. These counterbalance masses help stabilize the operation. When the motor runs, it provides power to the smaller sheave or pulley. This pulley is connected to a V belt or a chain mechanism and transfers power to the gearbox. The gearbox then reduces the speed and connects to the crank.

The crank is connected to the pitman arm, which, in turn, connects to the walking beam. The walking beam connects to the horse head, the horse head to the bridle to the polish rod, and the polish rod to the seal section. The seal section prevents fluid leakage. The polish rod continues through the stuffing box and connects to the sucker rod, which extends down the well.

In this entire system, the walking beam, Samson post, and bridle work together to create a see-saw-like motion. When one side of the walking beam moves up and down, the other side does the same, much like a see-saw in a children's playground.

The entire system is set in motion when the walking beam moves up and down. This system connects the walking beam to the horse head, which, in turn, is linked to the bridle. The bridle connects to the polished rod, and the polished rod connects to the sucker rod. This transfer of power continues down to the plunger assembly. As the plunger assembly moves, it lifts the fluid.

The design of the horse head is significant in this process. If we look at the horse head design, we can imagine it as a circle with a radius. The bridle, polished, and sucker rod must all align vertically in a single line. To achieve this vertical alignment, the horse head and bridle must be tangent to each other when the horse head moves up or down. They can introduce additional forces into the system, causing extra pressure on the sealing arrangement if they are not perfectly tangent. To prevent this, the horse head is designed in an arched shape.

Okay, because there is an arc, and the bridle is tangent to the arc. So, due to this tangential connection, it always remains completely vertical. The horse head's design, radius, and curvature are also essential. Sometimes, people refer to it as a horse head, and at other times, they call it a nodding donkey because it continuously nods up and down. The oil industry often uses unique and sometimes quirky terms, like monkey board, mud house, dog house, rat hole, mouse hole, and more. Although these terms are not part of this course, if you are studying petroleum engineering, you will become familiar with these specific terms. On the other hand, the Pitman arm is known as a connecting rod in IC engines. The walking beam resembles a simple beam, and it's often compared to a see-saw.

Okay, so they use different terms, and you have to remember them because if you are thinking about working in the oil industry, they will use their technical terms instead of the mechanical engineering terms you are familiar with. For example, in mechanical engineering, you might use the term 'piston,' whereas in the oil industry, they use 'plunger.' The function is the same, so you must know these terms. If you have a background in mechanical engineering, you can link your words with the oil industry terms to understand more easily.

Now, let's discuss why this counterbalance mass is used. When the walking beam moves up and down, here's what happens: when it is lifting, for example, let's say this is my Samson post, and this is the walking beam. On this side, there is a motor that is moving like this. The sucker rod pump is here, and when it moves up and down, the sucker rod pump also moves up and down. When it moves up, it's like operating a hand pump where you are pushing down to lift fluid. But in this case, when you push down, it moves up, and you lift fluid. This means you need more energy in this type of operation.

When a hand pump is moving up, you do not need energy, but you need energy one time, and you do not. In either case, when you need energy, you need a very high amount of energy in a sucker rod pumping system. However, when pushing it downward, you do not need as much energy because the rod moves down due to its weight. They use a heavy counterbalance mass to average out these two extreme energy requirements. When the system moves up, this counterbalance mass helps by providing the necessary force. When it is moving down, the counterbalance mass does not help; instead, it absorbs energy. This averaging of energy requirements reduces the power required from the motor and the power needed for the bearing, double reduction gearbox, triple reduction gearbox, or any wellhead system. This results in significantly lower power requirements for transferring energy to the crank, pitman arm, working beam, horse head, and all other components on this side.