Artificial Lift

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Lecture-58 Surface Pump Units for Jet Pump - Part 2

As I mentioned earlier, a positive displacement pump includes various configurations like simplex, duplex, and many more. Let's begin with the simplex pump and see how it operates. You can liken it to the sucker rod pump in some aspects. A sucker rod pump is generally used in a vertical orientation, whereas a simplex pump and other pumps of its type are usually horizontal. I'm drawing a horizontal piston pump here. This is the piston, and it features two valves. When the piston moves in this direction, it's the plunger or piston. Some people call it a piston, while others call it a plunger. This part is the piston rod; we have two valves, V1 and V2. These ends are known as TDC (top dead center) and BDC (bottom dead center).

If I create a PV diagram, the pump will draw in fluid during the suction stroke, attempt to pressurize it, and then discharge it during the delivery stroke. This diagram represents volume and flow rate. I've left some sections without touching. This is known as an indicator diagram. It's an idealized indicator diagram, assuming no losses occur during 1-2-3-4, which corresponds to the suction stroke from top dead center to bottom dead center. During the suction stroke (1-2), one valve must be closed, while the other must be open. So during the suction stroke, when it is drawing in fluid, suction valve V1 is open, and V2 is closed.

Next, during 2-3, when the pump is pressurizing, the valve opening and closing will occur. The piston moves from 2 to 3, but only the direction of the piston changes. When the piston changes direction, the valve will open and close. During the 3-4 phase, high-pressure fluid is being delivered. So, 3-4 signifies the delivery stroke, where high-pressure fluid is being delivered. At this point, V1 is closed, and V2 is open. As the piston moves in this direction, fluid is expelled, and fluid is drawn in when it moves in the opposite direction. In this manner, the fluid flows in and out, with both valves not open simultaneously. The cycle continues as the piston reaches top dead center once again before moving back, reversing its direction. This is a simple simplex pump.

With a simplex pump, the cycle involves delivering fluid in one stroke and not in the other; instead, it draws in fluid. The cycle repeats in this fashion. If we look at the relationship between time and pressure, we see that suction initially occurs, characterized by low pressure. This is followed by a high-pressure delivery phase, after which suction begins anew, and the process repeats. If this system generates pulsating pressure, it can introduce alternating stress into your piping systems, which is not suitable for pumping fluid to your hydraulic jet pump system. For this reason, people have endeavored to design a double-acting pump. The one described thus far is a single-acting pump. Double-acting pumps work as follows. This is the end of the single-acting description; now let's move on to the double-acting concept.

In a double-acting pump, the piston features two additional valves, creating a total of four valves. The mechanism is almost similar, but it adds complexity.

What is happening when the piston is moving back is that, in a single stroke, you're not just delivering, but in a double stroke, you are delivering. First, moving forward, there are two cavities, C1 and C2. I'm labeling them as C1 and C2. The piston is drawn in the same way. C1 takes in fluid, delivers fluid, and results in a pressure pulse like this.

Now, C2, another cavity, is used by the pump. How does it work? When the piston moves towards TDC (Top Dead Center) and BDC (Bottom Dead Center) from BDC to TDC, it's in the suction stroke. For C2, the piston moves from BDC to TDC. When C2 is open, V3 is open, and V4 is closed. Another thing to note is that just assume V3 is open with V4 closed. So when V3 is open, it indicates the suction stroke from BDC to TDC.

Now, what happens next? The piston moves from TDC to BDC, which is the delivery stroke. During the delivery stroke, V3 closes, and V4 opens. One valve acts as the inlet, and the other serves as the outlet. Thus, during the piston's movement from TDC to BDC, C2 delivers, and when it moves from BDC to TDC, C1 delivers. So, both times you get delivery. Therefore, if you observe the pressure curve over time, it becomes something like this. You see the pressure pulse, no pressure, pressure, no pressure.

In a double-acting system, the pulsations are reduced. Now, let's look at how a duplex pump works.

A duplex pump functions as follows. I'll draw a horizontal piston again since it works well for visualization. I have one piston with a cylinder and another piston with a cylinder. One set of valves, V1 and V2, is associated with one piston and cylinder, while another set of valves, V3 and V4, is connected to the other piston and cylinder. There is a single shaft, and a motor drives it. The shaft looks like this, and when it rotates continuously, it generates the motion. Now, you rotate it, and it generates torque. The motor is here, and there are bearings. There must be bearings here as well, and it results in a shape like this. If you keep rotating, it continuously moves, causing one piston to move at a time. When one piston reaches the bottom dead center, the other piston is at the top dead center. Two pistons move in opposite directions simultaneously.

So, V1, V3, V4 operate accordingly, generating a pulsating pressure curve like this. If C1 delivers this much of a pulse, C2 will provide a similar pulse. This results in an almost smooth pulse when averaged.

Now, let's examine how it operates for the triplet (triple throw) pump. It has three cylinders. Drawing it is a bit challenging, but I'll attempt to sketch it in three dimensions. So, we have one cylinder like this, another cylinder like this, and the third one is oriented differently. Now, there are pistons. This piston is moving up, moving down, and somewhere in between. Another piston is here, moving up, moving down, and it will be in between. A third piston is here, moving down. The pistons are connected to a common shaft, and there's a crank. This crank is connected to a motor. Motor connects like this. There are three pistons in different planes, and the crank helps move them with a 90-degree or 120-degree angle between them. Looking at it from the side, if one piston is here, another will be here, and a third piston will be here.

This is the connecting rod. One piston is moving up, another at a 120-degree angle, not 45, but 120 degrees. The piston is going up, another at another angle. So, here we can see 120 degrees, 120 degrees, 120 degrees, and 120 degrees.

The shaft is here. Again, one is going vertically. Another piston's crank will be 120 degrees from this vertical piston, and another will be a vertical piston on this side. One of the cranks will be like this, and another crank will be like this. Pistons are going up, up, up. So, all pistons will not be delivering simultaneously.

My pressure pulse will look like this: one piston is doing this, another piston is doing this, and another piston is doing this. So I get a smoother pulse. If you have less than five pistons, what can you do? You take 360 degrees and divide it by 5, which gives 72 degrees. One piston will give a pulse like this, another piston will give a pulse like that, and another piston like this. So, you will get almost a smooth pulse. If you increase the number of pistons, your storage tank of fluid will have a smoother pump and smoother pressure. But still, if there is any pulse, you will need to use a pulsation dampener. When the piping system connected to your storage tank gets a pulsed flow, they experience alternating stress. This can reduce their lifespan due to fatigue. To avoid this, you use a pulsation dampener. I'll explain more about what a pulsation dampener does later. However, if you use multiple cylinders, you can reduce the pressure pulses. Like the triplex or quintuplex, this arrangement is similar to multi-cylinder engines in internal combustion engines. They arrange multi-cylinders to reduce pressure pulses.

Now, let's discuss the diaphragm pump. We've seen simplex, duplex, triplex, and diaphragm pump. What is a diaphragm pump? If you're dealing with certain chemicals and leakage is an issue or want to create a leak-free system, you can use a diaphragm pump. How does it work? A diaphragm pump operates like this: there's a piston or cylinder with a piston, and you provide reciprocating motion to the piston. The diaphragm is made of a soft, expandable material that can expand and contract. You have two valves, V1 and V2. In the piston-cylinder arrangement, you had one piston that slid inside the cylinder and two valves, V1 and V2. In a diaphragm pump, you also have two valves, V1 and V2, and you provide continuous vertical motion, like this. The diaphragm will move up, down, up, and down again. Due to this reciprocating motion, your valves open and close, allowing you to deliver fluid. In this case, there's almost no leakage. If diaphragm leakage occurs, that's a different issue. But otherwise, there's no leakage. In a piston pump, the piston slides inside the cylinder, which results in some leakage.

Normally, we achieve about 95% to 98% volumetric efficiency. However, in this diaphragm pump, there is 100% volumetric efficiency. 100%. But in this case, the volumetric efficiency (η volume) will be less than 100% because there will always be a certain amount of leakage. If the pressure is very high, there will be more significant leakage, but the leakage will be lower with lower pressure.

If you remember the formula we discussed for sucker rod pumping applications, q leakage flow rate is proportional to your viscosity increase, which reduces it. If leakage increases, your flow rate (q leakage) will increase. However, there is no such thing as clearance anywhere in a diaphragm pump. You get a 100% flow rate, but the life and the amount of pressure you can develop are limited. In this context, life means that your diaphragm continuously experiences alternating stress, moving up and down. Due to this movement, it will undergo fatigue, and after a certain period, it may develop leakage. So that's one limitation.

In many cases, people use gear or screw pumps. We've already discussed the single screw pump, which is the PCP (progressive cavity pump). But if you have multiple screw pumps, that is also possible. It requires more space because, for example, two shafts will be present, one screw will be here, and another will be there. Two screws matched in a certain way will create a double screw pump, and you can even create a triple screw pump. Multiple screw pumps are also possible. PCP with multiple screws will require a larger amount of space, and that's one limitation when using them for artificial lift.

However, for surface applications, you can use multiple screw pumps. Another type is the gear pump, which involves two gears meshing together to deliver fluids. Both gear pumps and progressive cavity pumps are positive displacement pumps. They can compress air or gas and can be used for pumping fluids. Their speed is also higher than PCP, with several hundred RPMs possible in both cases. Gear pumps come in external and internal varieties. The animation you see here illustrates the external gear pump, but there are also internal gear pumps, with gear teeth inside and a rotating gear delivering fluids. This is called an internal gear pump.

Another example of a single screw pump is the Archimedes screw. People have been using Archimedes screws to deliver fluids for a long time. If you search online, you'll find plenty of pictures and videos showing their use in agricultural applications. However, we do not use them for oil and gas applications; I won't be discussing that. You can use positive displacement pumps or other types, such as piston pumps, for metering and pumping applications. In a piston pump, the total volume delivered per stroke is limited, providing a fixed volume delivery. You can calculate it using the formula pi by 4 times d squared times L times N, delivering that volume per RPM when you know the RPM. If you consider one stroke, then N equals 1. In that case, you are delivering pi times d squared times L, which represents the total volume of the cylinder.

That can be used as a metering pump. Another option is the diaphragm pump, which can also be used to deliver a specific amount of fluid. A peristaltic pump, like this, involves a liquid inside a tube, and one rod squeezes the pipe, delivering a fixed amount of fluid. This is called a peristaltic pump.

You can use a diaphragm pump to avoid leakage, as I mentioned earlier, with piston pumps or reciprocating pumps, there might be a certain amount of leakage. Gear pumps can also be used for metering applications. API 675 provides specified design criteria for metering pumps. It's an API document that offers information related to metering pumps.

As I mentioned, reciprocating pumps, like diaphragm pumps, or anything with reciprocating motion, will have pulsed flow. Pulsed flow means that if you have one pump and one outlet pipe, the pipe will experience pulsations like this—pressure high, pressure high. This is similar to our body; our heart also pumps blood with a pulsing flow. That's why we use thermometers these days. Previously, doctors or rural healthcare providers would check your pulse by pressing and listening to the beeps. An increasing number of pulses could indicate a fever.

Pulsations are normal for our bodies, but in industrial applications, your piping system can become fatigued if you have pulsations. You can't pump the same fluid for subsurface applications like hydraulic jet pumps. In such cases, you need to use a pulsation dampener. This dampener helps reduce these pulsations, providing nearly smooth pressure to downstream systems.

So, how does a pulsation dampener work? It contains a high-pressure area with air or nitrogen. You have an inlet pipe where you receive pulsating flow and an outlet with lower pulsations. When pulsating flow enters the inlet pipe, the high-pressure gas acts as a cushion, absorbing the peak pulsations. When the pressure is low, it expands slightly, and if you supply very high pressure, it compresses the section. However, your outflow pressure remains relatively constant.

In cases where excellent pulsation dampening is needed, you may require a large pulsation dampener to absorb all the pulses and deliver a fixed amount of fluid with a consistent pressure. Small pulses are generally acceptable for regular applications because fluids have some degree of compressibility, and the small pulses tend to dissipate when flowing through long pipelines.

However, very significant pulses will be absorbed by using a pulsation dampener. Pulsation dampeners have other uses, such as surge control or addressing fluid hammering. You may be hearing about fluid hammering for the first time. So, what is fluid hammering?

Imagine you have a long pipe through which you are delivering fluid. You have a valve or a pumping system, and now you suddenly stop it. What happens when you stop abruptly? Due to its momentum, the entire column of fluid delivers a significant jolt to the entire piping system. This sudden jerk can lead to vibration, breakage, and even bursts.

You can implement a fluid hammer-dampening system to mitigate these issues caused by a sudden pulse. This system absorbs any additional pulses that might occur. It serves to protect your system from damage.

Alternatively, if you want to prevent fluid hammering without a dampening system, you can use a pulsation dampener or bypass valve. When a pressure pulse occurs suddenly, the bypass valve opens, reducing the pressure and ensuring the safety of the entire system. This approach prevents bursting, breakage, vibrations, and noise.