Artificial Lift

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Lecture-32 Progressive Cavity Pump- Part 1

Good morning, everybody. Today's lecture is based on the progressive cavity pump as an artificial lift. We know that PCP is a high-viscosity pump used for heavy oil, such as toothpaste and grease, and in industries such as food processing, like pulp pumping for filling tubes. Dr. Mirnal has already provided some basic background information about PCP and pumps in a previous lecture. In this lecture, I will further elaborate on PCP.

PCP is typically not used for thin fluids, but if you have thick fluids, such as pulp, toothpaste, or grease, you can use a PCP. Another application is metering. In metering applications, PCPs have a rotating rotor. Each rotation delivers a fixed amount of fluid. By controlling the rotation, you can use it as a metering pump to deliver a precise amount of fluid based on the number of rotations.

I also hold a patent related to human blood flow applications. This patent is relevant for designing left ventricular assistive devices (LVADs), where it's crucial to prevent damage to blood cells like red blood cells, white blood cells, and platelets. For instance, centrifugal pumps subject these cells to turbulent environments that can cause damage. PCP, on the other hand, transfers fluid progressively within its cavity, minimizing the risk of cell damage.

So, in this setup, one cavity rotates and progresses. It doesn't cause any shearing action on the cells. Therefore, it can be used for human blood applications, specifically for blood flow. There are many other applications as well, but PCPs are typically utilized for thick fluids and high-viscosity metering pumps.

As an artificial lift, PCP is relatively newer in usage. If you look back 50 to 60 years, people started using it. Moynau developed the original PCP, and there is still a company named Moynau Pump Company. Moynau stumbled upon this pump while working on his

PhD thesis. Sometimes, innovation can arise from mistakes, and in this case, his mistake led to this pump's development.

Now, I have an example of a PCP here. You can see the stator and rotor. As Mirnal explained earlier, the rotor has a helical shape. In this case, it's a single-screw PCP with a single lobe. This conventional PCP is entirely made of metal and features a helical shape, as you can see in red. The pitch is the distance between these two red lines. Each complete turn corresponds to one pitch.

The rotor rotates continuously. On the other hand, the stator doesn't rotate; that's why it's called the stator. It remains fixed in place, and you rotate the rotor. As you rotate it, the fluid enters here. The stator also has a helical cavity. If you look closely, you'll see the helices, as I'm drawing them here. I hope this is visible from your perspective.

Here, I am drawing a helical shape. Then, in this red-marked area, there's another helix. This one is coming like this, and this one is coming like this. There will be two helices in this part. Now, one pitch is here, one in the upper portion, and another in the upper portion forms a ridge and valley. So, the distance between ridges is one pitch. The stator also has this from the outside; you can probably see some red color here. It goes like this, and the rotor is also helical. The stator also has helical shapes. You can see these two lines coming here because the stator also has helical shapes.

If I put these together, you can assume it's like a nut and bolt. This is the bolt, the nut, and you give it rotation. But with a nut and bolt, the pitch of the nut and bolt is the same. If we don't keep the same pitch, then the nut will not enter the bolt cavity. In this case, we intentionally use different pitches because having different pitches creates a cavity. You see, I've put my rotor here with this circular cross-section.

Now, I have the stator, which has a cavity, but the cavity is not circular; you can see it's not exactly circular. It has an oval shape, more or less. I'm approximating it here. Now, if I rotate it, let's say I rotate it, and you see this rotor end moving. Let's assume this is one end of the stator and the other end of the stator. Now, if I rotate it, you can observe the rotor moving up and down. If you look at the screen, the rotor moves to the other end as I rotate it in one direction.

So the rotor will be moving from the top; there's a gap now. If I rotate it here, you can see that the gap has changed. This cavity is moving from here to here like this. The broken side looks better. If I rotate it like this: one cavity, rotor cavity, stator cavity, this rotor has a circular cross-section. Now, if I rotate it, you can see the rotor moving up, and if you look closely, there's one gap. This is one gap my finger is going through now. You see, my finger is going here. Now, if I rotate it, this gap is moving. This is a cavity. So, again, I carry this rotor like there's no gap now.

Furthermore, if I rotate, a gap is created. Slowly, my finger is not going, but if I move further, my finger is going. That means this gap is created, and the gap is going like this, ending here; again, another gap will be there. Small gaps are moving, moving, moving; the gap of this cavity, as you see, this cavity. So, the cavity is moving. That is why this is a progressive cavity. The cavity is progressing. Now, you take any fluid, water; you take any grease, toothpaste, your heavy oil, Canadian sand oil, anything you put there, and you move it; this cavity will be moving. The cavity will be rotating like this and moving. I have one figure I will show.

Here, you see one picture I have taken; these are cavities. If you see this blue color, this cavity is moving. This is taken from Wikipedia. The cavity is moving; how is the cavity moving? When the rotor is rotating, the cavity is moving and moving and moving and moving, or moving. So here also, if I rotate it, you see, my model. So how did I get this model? Actually, we prepared this one; one of my master's students was trying to do some design and optimization work. So we were trying to design using CAD models, but then we found that the CAD software had a helix option that didn't work. So we created lots of planes; we created small, small planes. Then, the planes were connected with a lofting option, and then we manufactured them using 3D rapid prototyping. This is called rapid prototyping. Within 24 hours, they manufactured it. These days, industries use rapid prototyping machines, and even academic institutions use lots of rapid prototyping using one machine. So quickly, they can manufacture.

Now, this is the PCP, and I will explain again regarding leakage. Dr.Mirnal has already demonstrated the leakage so that you can see my cavity here. I said, like one finger is going, a small finger is going here, the index finger is going here. Now the finger is going, but the finger has two sealing lines. So one cavity is there, but the cavity is sealed like this, one line is there, one line is there, so it is creating a proper cavity. It's not just a hole; it's a cavity. So a small cavity is here, another cavity is here, one cavity here, so one cavity means two seal lines will be there so that you are blocking this and creating a small cavity. If the seal line is not sealing properly between the rotor and stator, then there will be leakage. Let's say this is the low-pressure end. Your PCP is like this; your fluid is sucked from here, and you are rotating continuously; fluid is getting delivered. That means low pressure here, high pressure here. So what will happen is you are trying to create high pressure, but the fluid will try to leak back towards this intake area. It will come through the sealing leakage when it is trying to come back to integrate. So how this sealing is occurring, I will explain later.

So I will show it again. Let's see this one first. Whenever you are thinking about PCP as an artificial lift, you will have one downhole or subsurface unit, and one will be an upper unit or surface unit. In the surface unit, what you have is one prime mover. This is a prime mover or a motor, normally. Or it can have some other type of drive system as well. Normally, it will have one electric motor, so one will be a wellhead drive unit. There will be one polish rod; a polish rod will be there. One will be a stuffing box, not a packer, but this is called a stuffing box. A stuffing box will be there. So before the stuffing box, you will have a flow line. Okay, a T-joint will be there, and then this is the wellhead. Through the wellhead, you can access your wellbore. Then, your prime mover, which is giving power, will come through your gear and a belt drive. Why is gear or belt drive required? Actually, PCP speed, normally, PCP speed is 300 rpm. This is a thumb rule you have; if no information is given, you can assume 300 rpm PCP speed. So 100 rpm and 500 rpm are also possible, but more than 500 normally will not be available. But people are trying to design your type of PCP that will have more than 500 rpm. However, normally, 300 will be optimal.

Now, when you have PCP speed at 300 and the motor speed, let's say 1400, 3000 rpm, or 3600 rpm, that means you have to reduce the speed. How to reduce it? One option is to use a VFD (Variable Frequency Drive) and change the electrical frequency to reduce the motor speed. However, this can create lots of issues. Another way is through a mechanical arrangement, which I have already explained during sucker rod pumping applications. You have a belt drive mechanism or gear drive mechanism to reduce the speed. Here also, a similar sort of mechanism will be used to reduce the speed to make it 100 or 200 rpm. Once you achieve a lower rpm, the torque will be transferred to your polished rod. In this case, your sucker rod (this is called a sucker rod again) will not have any tension force; normally, it will not experience tension force. Instead, it will be transferring torque. From here, you are rotating, and it will transfer torque to your pump, which is at the bottom. On the surface, you have all the drive mechanisms, a stuffing box, and the polished rod. Near the perforation area at the bottom, you have the pump.

So, how do you transfer power? You use a sucker rod. This sucker rod experiences torque, and shearing action will occur. But in SRPs (SRP or beam pump), they use a sucker rod that has tensile force. However, in PCP applications, the only rod used is metallic and bent. It transfers torque. Therefore, this sucker rod should be metallic. It will be very difficult to handle if you want to use non-metallic materials because they cannot withstand the shear force. However, in sucker pump applications, you can use non-metallic materials if they have high tensile strength. You can use anything for SRP or beam pumping applications. But in PCP applications, only metallic rods will be used, and they will have torque. When they transfer torque, they experience shearing action. Torque results in shear force.

When the rod goes from the surface to the tubing and down to the pump, centralizers will be required. Why are centralizers needed? Look at the picture on the left side of the wellbore.

Okay, you have tubing, and you put lots of centralizers. What will they do? If the rod gets bent due to any reason, centralizers will prevent the rod from touching the tubing. This way, the tubing will not experience any friction. These centralizers allow space at the center. The pump will have its rotor and stator mechanism.

Another pump I have taken from the PCM website. This pump illustrates how the systems are arranged from top to bottom. First, there's an electric motor, followed by a gear reducer. They are using a gear reducer directly. I have explained this during your

SRP (Sucker Rod Pump) course, so please refer to those SRP lectures to understand how a gear reducer or gearbox works in detail.

The whole shaft will move to this pumping area. You can see the rotor; normally, it will be shaped like this. However, it's three-dimensional; we cannot draw it in two dimensions on your screen. But if you close one eye and look closely, it will appear somewhat like this.

Okay, like the helical shape. Now, next is the experiment. This picture I have shown you several times; this is our PCP setup, actually a progressive cavity pump setup. So, we have one motor here, horizontally placed. Instead of placing it vertically, we have one motor guard and bearing arrangement, along with a gear, to reduce the speed to 300 rpm. This is the gearing arrangement to reduce the speed. Then we have a guard. Why have we put a guard? Because this is high-speed rotating machinery, we have this metallic frame just to protect people walking nearby.

Actually, there will be one connecting rod or coupling; I'll explain later what a coupling is. Then we have the pump. The pump will be delivering fluid, and the suction is here; this is the suction, and this is the delivery.

Now, what happens if you want to draw a characteristic curve? First, I have to plot H (head) and Q (flow rate). You can remember that I have explained this before in centrifugal pumps and SRP; it's about flow rate and pressure development. So, the curve will be vertical, okay? We are assuming no leakage. If no leakage is present, then this curve will be completely vertical.

But if there's some leakage because of high-pressure creation, let's say, the exit valve or gate valve is nearly closed. So, very high pressure will develop during the pumping operation. When you create that high pressure, the fluid will leak back toward the inlet. At that time, your actual flow rate will be lower, and your flow rate will decrease with pressure.

Ideally, metallic PCPs or elastomeric PCPs, like conventional PCPs, will have no leakage. Why is that? No leakage occurs because inside the stator, there is an elastomeric layer. The stator contains this elastomeric layer, which is a softer material.

Okay, elastomeric materials are used, so you cannot use plastic; you have to use elastomers, which are high-strength materials. When elastomers get depressed, the rotor diameter will be a little larger, and this diameter will be slightly smaller. So, if this is 'd,' then this will be 'd' minus delta, a smaller diameter. When you are inserting it, the elastomer will get slightly depressed. When it gets depressed, what happens is this: here's my rotor, and this is the elastomer. It will be depressed with high pressure on one side and low pressure on the other. One side has high pressure, and the other has low pressure. So, when the high-pressure fluid touches the elastomer, it won't be able to pass through this gap. There is no gap, actually, because this is already depressed. This is a softer material, right? It's already depressed. The fluid is trying to pass, but it won't be able to cross. So, ideally, it will have zero leakage.

But if you have very high pressure, let's say you have elastomer like this: this is metal, and this is my elastomer, and this is my rotor. Okay, this is my rotor, and this is the elastomer, and the rotor is making a zero clearance. The rotor and elastomer are just touching, with no diameter change. Okay, now this is 'P' high, and this is 'P' low. High pressure will try to depress the elastomer a bit and cause it to leak out. However, if you have an interference fit, let's say initially your elastomer is like this, and you apply very high pressure, in this case also, the same thing will happen. A small gap will be created, and then leakage will occur.

So, normally, elastomeric PCPs should not have any leakage for lower pressure applications. So, ideally, the HQ curve will be completely vertical. A PCP is a positive displacement pump; ideally, there is no leakage, so you get 100% volumetric efficiency. However, if you increase the pressure, the elastomer will get depressed, and because of this depression, leakage will start. That's when you'll get some leakage flow. As Menel mentioned, your theoretical flow may be different from your actual flow, and your volumetric efficiency will be lower, around 70-99%.

But very low volumetric efficiency may not be possible. Again, each stage, so normally one pitch of the stator is called one stage of PCP. Okay, so one stage of PCP will have how much pressure you can give. So, this will be depending on how much clearance you are giving, whatever material you are using for the elastomer, and if you create very high pressure, then leakage will start. So, the normal thumb rule will be there, like 75 psi per stage. Okay, you can use this thumb rule if no data is given. So, 75 psi per stage will be created per same is one pitch.

Now, you want to increase the pressure to, let's say, 100 bar (1000 psi). So, what will you do? How many stages, how long will the PCP be? So, this is, let's say, 4 inches, for example. So, one stage is 4 inches, so you want 1000 stages. Okay, 1000 stages per 75. So, 75, if we divide, approximately 12 stages will be required. And whatever the length of the PCP, like, say, if it is 4 inches, so 12 multiplied by 4, so 50 inches. Okay, so about 50 inches of PCP length will be there. So, in that way, you can calculate the length of the PCP, and you can calculate how many stages will be required.

As I already told, ideally, there is no leakage. Then actually, a single stage can develop infinite pressure. But practically, because of this depression of the elastomer, the pressure will be limited by, let's say, 75 psi or something. There is some rule; this will be depending on the material and other different properties, but normally we assume this one. This whole experimental description I have given in previous lectures. Please follow those lectures.

Now, when you are using PCP as an artificial lift, how does it affect? Okay, so you can see this flowing pressure, Pwf (wellbore flowing pressure). Okay, wellbore flowing pressure, you can remember this one, Pwf, Pr (reservoir pressure). Okay, now you have inflow performance relationship. This is IPR. We are assuming this is curved. And if I have very low pressure, a fluid Pwf is unable to produce any fluid. Let's say the initial condition is this one, Pwf high. So, Pwf high means it will not give enough flow rate. Why? Or it will not give any production. Why? Because this drawdown, drawdown equals Pr minus Pwf. Okay, so if drawdown is very, very low, if it is low, then no flow, right? If it is very high, that means higher production rate.

Now, Pr, in Pr, normally, reservoir pressure is fixed. If you reduce the flowing pressure, your drawdown will increase. Okay, drawdown increasing means more fluid will be entering into the wellbore. Okay, now how to reduce Pwf? So, to reduce Pwf, what will happen is, initially, you have a fluid column here. Okay, using PCP, you remove that fluid. Okay, PCP or any artificial lift method removes the fluid. So when you remove the fluid, what happens is that Pwf, actually h ρ g h reduced. When h is reduced, Pwf reduces, so more fluid will be entering into your wellbore. So, what you do using PCP is reduce this one. Okay, ΔP (pressure difference) - the pump is here, it is written. Okay, so this pump, this energy pump, is supplying; this pump is removing the fluid. Okay, because of fluid removal, your Pwf reduces, drawdown increases, more fluid will enter, and you will get more production. Okay, so this IPR curve is related to your artificial lifting systems.

Now, sizing - I already said, PCP speed will be around 500; here, they have given 600 also, but normally, you will not find PCP with more than 600. Okay, and I have taken this data from MOINEAU pump. Okay, from their website, I have taken this data. And if you see, they have different models, and you see the maximum flow rate, okay, for 0 bar. So, 0 bar means when there is no pressure, your flow rate is increasing. Okay, now, differential pressure in the pump is 24 bar, and rpm is 600. Okay, now, many other models are there, just to show how this pressure and your speed are linked.

Okay, next thing is that RPM, if you increase, they say increase RPM 5 to 300 to 600, so your flow rate will get doubled, actually. RPM becomes two times Q or flow rate becomes double. Okay, because the number of cavities, because the number of cavities is increasing. Okay, one cavity, two cavities, and three cavities increase the number of RPM, so your cavity transfer will also increase. So flow rate also will get doubled. So, you are assuming there's no leakage, so if leakage is there, the same amount of leakage is there, so approximately it will be double.

Now, viscosity effect for PCP - it is designed for higher viscosity. But, if you have lower viscosity, the story will differ. I'll explain later.

Okay, so Dr. Mirnal, I have taken this from Dr. Mirnal. I'll bring this model to show you. We have this rotor, okay, helical rotor, and this is actually the stator, stator means like this. Inside, a cavity is there, but he is not showing the cavity. There is one joint, pin joint; this is called a coupling. Why should a coupling be there? A coupling should be there because, you see this one, rotate it, okay? You rotate it, what is happening is that your rotor, the central axis, is moving, rotating, and moving. Also, if you see, it is moving, okay? You see the rotor's central axis also moving; if you see this one, it is moving, right? It is moving like this. The central axis, when the central axis is moving, and you have a motor, let's say I have one fixed motor here, okay, a motor. The motor is fixed here. Now, I have one pump; the pump has my helical rotor. Okay, so the rotor end must be connected to the motor shaft. Okay, now, I have a fixed motor shaft; the motor shaft is rotating but is not moving like this. Okay, but my shaft is moving when it is rotating. It's rotating plus it's moving like this by motor, but the motor shaft is not moving. So, that means what is happening is that this end will be... if I have one connecting shaft in between the motor and this rotor. Rotor means PCP rotor. The motor also will have one rotor, so I am not talking about this motor rotor; I am saying this PCP rotor. So, PCP rotor is rotating and moving like this; the motor's other end is rotating only, okay? It is not moving like this. Okay, it is not moving like this; that means you have to give some flexibility here, some flexibility here so that when it is rotating, it is moving like this. Okay, it will move like this. Okay, so for that, we have different options. For example, this one I have taken from Wikipedia. This is called a Cardan joint. So, how does it look like? It is like this, okay? If I fix these two, okay, and my hand is one hand here, and another hand is here, okay, these two are fixed, okay, the red one and the black one, okay, and if one is rotating, okay, it will make a certain angle, but both can rotate. Okay, so now, I have two such systems. I'll draw one picture here, and another, okay, so, okay, so see this one, okay? This is also a Cardan joint. Now, I will have another, okay, so, okay, so both can be rotating, but one can make an angle, okay, rotating, but both can make an angle. Okay, so this way, you can give flexibility to the shaft so that one end is fixed, and another is moving, although rotating and giving sliding motion also, so then this will not create extra force on your rotor. Okay, so there are ES-PCP and other PCPs using this sort of joint; otherwise, it will fail. There are some gear sort of mechanisms also, but this is the most commonly used universal joint. So, one end, there will be a pin, and another will have a pin. When you're rotating, it just moves smoothly, and there will be no extra force going into your motor or extra force going into your PCP.