Artificial Lift

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Lecture-33 Progressive Cavity Pump-Part-2

Regarding PCP flow, I've already shown you how this cavity is moving. When you increase the RPM to double, your flow rate will also double because the number of cavities will be increasing to double, and each fixed cavity will deliver only a fixed amount of fluid. So, the rate of moving cavities can be increased, resulting in a change in flow rate.

Dr. Mirnal has already shown this as 4 times the eccentricity, with the rotor center and rotor center; this is represented as 4e, and this is the diameter D.

Now, let's discuss how the leakage is happening. If you observe, I've created this animation using PowerPoint. The rotor is rotating, and one thing you can notice is when it is rotating in the top direction, as it moves in this direction, it is rolling in the A area. When it is moving in this direction, it is rolling, meaning it is rolling on one side, as shown. But you can see sliding happening when it moves in the opposite direction. One side is rolling, and the other is sliding. You can see this sliding, rotating, and moving. So, when it rotates again in this direction, it's walking on the upper side, but sliding on the bottom side. In essence, one surface is sliding, while the other is rubbing. You can observe this in the animation: the rotor is rolling and moving simultaneously. When it's moving in one direction (A to B), it's rolling; when moving in the opposite direction, it's sliding. The roles of A and B reverse accordingly.

In fluid mechanics and fluid dynamics, when one surface is fixed and another is moving, we can approximate it like this: one surface is fixed, and the other is sliding over it. When sliding occurs in fluid dynamics, or leakage properties change, it can be approximated as a flat plate. If I enlarge the top portion, you can see one surface is fixed here, while the other is sliding over it. When sliding occurs, leakage properties in fluid dynamics change. Many researchers, including Gambuoa and others, have formulated equations to explain how this leakage occurs. Mirnal also presented this in his thesis; he didn't develop it but presented it. The leakage formula looks like this:

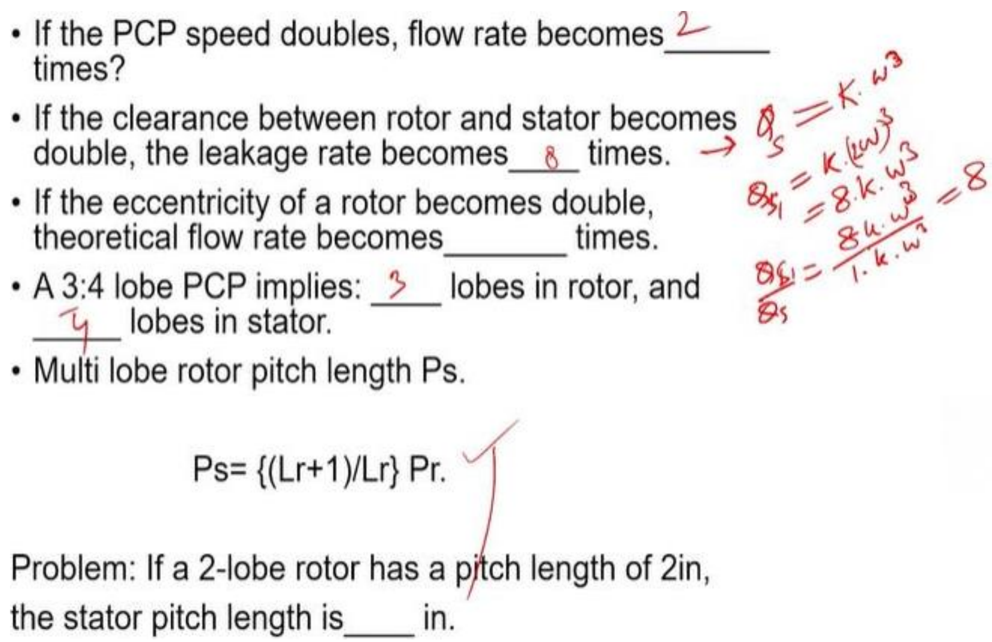
Leakage= $(8bw^3\Delta p)/(c\mu l)$,

where 'b' represents width, 'w' is the height, 'l' stands for length, and 'Δp' denotes the pressure difference. This formula helps explain the leakage occurring between the rotor and stator, considering the sealing areas.

So, if I enlarge it, it will be almost flat actually. If I take a very small area, I can approximate this as a flat area. So, I can assume this is a flat surface, this is a flat area, and this area I am doing like this – this is a flat area. What is the gap? The gap is 'w'; gap means this rotor and stator, and the gap is 'w' in between. What is 'l'? 'l' means this is my leakage length. This is length – length is going like this, it's going like this, and this is the leakage length. So, the leakage length is 'l', and what is 'w'? 'w' is how much clearance is there between the rotor and stator. This is 'w'. This is 'w', actually, this is this big, so I have cut only this one to show that a small portion can be approximated as flat. And what is 'l'? 'l', actually, this one – 'b' is leakage length, so you should remember that 'w' implies how much clearance you are giving between the rotor and stator, and 'l' means in the clearance how much distance you are taking to make a flat plate, and 'b' is the total length of the leakage.

Many terms are unknown here. 'c' is unknown; 'c' is the frictional constant. So, normally, we will not have a value, but we can give an example. And 'Δp' is the pressure difference – how much pressure you are giving. Let's say 'p high' – high pressure on one side, 'p low' – low pressure on the other side. So, this gap will have high pressure and low pressure, so the difference 'p high – p low'. And 'μ' is viscosity. 'μ' is viscosity. Now, 'qs' is your leakage flow rate, and 'qa' is the actual flow rate. So, 'q theoretical – qs', 'qa' is the actual flow rate, 'qs' is the leakage flow rate. Okay, this is the leakage flow rate.

So, using this, we can calculate, for example, how this leakage 'w' can affect your leakage. If clearance size 'w' is increased from 0.0012 to 0.002, or we are making 'w' actually double – 'w2' equals 2 times 'w1'. Okay, so if you are making 'w' or the leakage double, your flow rate will be increased by 8 times because it is a cubic term. 'w' cube is there. Okay, so 'qs' is actually proportional to 'w' cube, so if 'w' is double, that means it will be 8 times. Okay, and percentage-wise, it will be the percentage of flow – 'qs2 – qs1' over 'qs1', so it will give '8 – 1' divided by '1', so '7' times '100' – you know, '700%' increase will be there in your leakage flow rate. So, a small change in leakage flow rate will affect it significantly in your flow rate. If you change a small amount in the leakage area, you already know this – rotor diameter 'D', pitch length 'Pr' for rotor and for stator 'Ps'. Okay, so the relationship is that 'Pr' equals 'Ps' or 'Ps' plus 1. Okay, so for a 1:2 pump or a 1:2 pump or 1:2 pump, it will be double in that case. So in my case, whatever I am showing here, so that will be rotor pitch and stator pitch, rotor pitch will be stator pitch, and stator pitch will be 2 times rotor pitch. So I did some mistake here; I think it will be '2Pr' equals 'Ps'.



For a multi-lobe system, Ps equals Lr plus 1 divided by Lr and Pr. This formula will be there for multi-lobe systems, such as 3:4 or 4:5. In such cases, one pitch will be higher in the stator, and the rotor pitch will be lower. So, depending on the number of lobes, here it is a single lobe. A single lobe means it is completely circular. It can also be a two-lobe rotor where the stator can be like this, and the rotor can be like this. Okay, it will be 3-lobe, 4-lobe, 5-lobe, etc. In this case, the stator lobe will be higher than the rotor lobe.

The length of the cavity will have a formula like this: the number of cavities (C) equals Lr times hs times Pr minus 1. Here, C is the number of cavities, Lr is, as you already know, the number of rotor lobes, hs is the length of the stator, and Pr is the length of the rotor pitch. So, this is the relationship: the length of the cavity is equal to the pitch length of the stator. Mirnal has already given information regarding pump displacement, so pump displacement is also given by V equals 4EDPs, where V is the pump displacement, E is eccentricity, D is the diameter of the rotor, and Ps is the stator pitch.

The theoretical torque has a formula like this: theoretical torque (tau) equals tau o times del P times D times e times Pr. Here, tau is the torque corresponding to the rotor pitch length, del P is the head rating, the specific torque of the pump, specific to the rotor pitch length, D is the reference diameter of the pump, and E is the eccentricity, as you already know. Pr is the rotor pitch length.

The load on the thrust bearing, because the whole system has a long rod, is given by thrust bearing load,

$$F_b = \frac{(\pi \Delta P(2E + D))}{4}$$

The stator can be identified using this code: vvv/hh/Lr/eee. Here, vvv represents the displacement in m^3/day at 100 rpm, hh is the maximum head rating of the pump, Lr is the number of lobes in the rotor, and eee is the manufacturer's code for the elastomer.

Similarly, we will have a rotor code like this: vvv/hh/yyy. Here, vvv represents the displacement in m^3/day at 100 rpm, hh is the head rating of the pump in MPa, and yyy is the length of the rotor protruding below the bottom of the elastomer when the rotor head is at the top of the elastomer.

Like ESP systems, if a PCP also has gas, you must handle that properly. One way is to install the PCP below the perforations. Perforations are here, but your pump should be below—pump should be here, okay. So, when the reservoir is producing, gas will go up, and liquid will fall down due to high density. Below the pump intake, gas will go up. This is called a natural gas separator. You install the pump below the perforations. This is the simplest, easiest way. Normally, you use this method in cases of sucker rod pumps and ESPs. Another case is that you use some gas separator or artificial mechanism so that gas will move up. You create a certain mechanism when fluid will be falling here, gas pump is here, and gas will go up. Okay. So, fluid will be here, perforations are here, liquid is going here, and gas is going up. This way, you can also separate gas. If you have gas, PCP can handle a maximum of 30% gas. PCP can handle this. But if you are using high temperature and there's gas, then there will be an issue with sand. Certain amounts of sand PCP can handle because the sand will be filling the cavity and moving up. But the wear rate will be high. Normally, PCP life will be like, let's say, 4 to 6 months. Why 4 to 6 months? Because the elastomer wears out. Elastomer wears out. PCP's life is very low due to continuous rubbing. One surface will be working, and another surface will be rubbing. I have already explained this. Because of this, PCP's life will be very low.

But many wellbores are there where no other pump is working. I was reading one document where the author wrote that PCP is a progressive-thinking pump. If no pump is working, put a PCP and see whether things are working. If PCP is not working, no pump can deliver fluid. So, that is why the author wrote it's like a progressive thinking pump. Although its name is a progressive cavity pump, just to create attention, he used the term 'progressive thinking pump.' Okay.

Now, let's see some problems. Simple problems you can prepare for this sort of problem for your exam. If the PCP speed doubles, the flow rate becomes two times. Right? If the clearance between the rotor and stator becomes double, the leakage rate becomes—okay, it will be clearance peak rate doubles; then one-eighth—sorry, clearance becomes double; then it will be 8 times. Leakage rate becomes 8 times. If the centrifugal—you can see flow rate leakage Qs term was there, I think. Okay, so s is equal to (constant * W^3), right? So, if W is doubled, now Qs_1, K, the same constant I am using, W becomes 2W doubles; that means 8K W^3. Now, Qs_1/Qs equals 8/1, okay.

$$Q_s = \frac{8\, bw^3\, \Delta P}{C \mu L}$$

$$Q_a = Q_{th} - Q_s$$

Where,

C Friction constant

μ Viscosity of the fluid

A 3:4 lobe PCP implies 3 lobes, actually. You can see this PCP. One lobe means this one circle, and 2 lobes mean this 2 ends. Two ends are there—one end is here, another end is here. If you have 3 lobes, then 3 ends will be there in the stator. Okay. 4 lobes. So, 3:4 means 3 lobes will be there on the rotor, and 4 lobes will be in the stators. Multilobe rotor pitch length formula. Okay, this formula is already given. Now, the problem: if a 2-lobe rotor has a pitch length of 2 inches, the restator pitch length will be—use the formula. Okay. Now, metallic PCP. I said, like elastomeric PCP, it has an issue like continuous rubbing. And if you are using it for a very high-temperature application, elastomer has a temperature limitation. You are thinking of applying high-temperature, high-pressure wellbores, but then, in that case, elastomer may face difficulty. So, to avoid this, some companies develop metallic PCP. Metallic PCP means all-metal PCP or metallic PCP. Metallic PCP means metal will be there, but elastomer will not be there. Here, no elastomer inside the stator. Okay. But in elastomer PCP or conventional PCP, an elastomeric layer was there. In my case, just simple software material—I did not have any elastomer here, but normally, elastomer will be there inside. Here, one layer will be there. Okay. But in metallic PCP, no layer. Direct metal rod, metal rotor, metal stator rotating inside. Okay.

So, whenever there's a metal-to-metal connection, if you have elastomer, elastomer can depress; you can push it, pull it, or rotate it, and things are okay. But if it's metal-to-metal, and you make it an interference fit, a tight fit, things will not work. For example, if I have a rotor like this, and I have a stator, okay, and it's very tightly fit, the rotor will not rotate or move, so things will not work.

So what metallic PCP manufacturers have done is they kept some clearance, some gap between the rotor and stator so that the rotor can rotate. This is a compulsory gap, a necessary clearance. You can make it zero or have a certain positive value, but not negative. Negative clearance means the rotor diameter is larger than your stator cavity. So, clearance is a must. The stator has no elastomer; the rotor is metal, as usual. We are changing only the elastomeric part; we are removing the elastomer. So, the rotor is completely metal, and clearance between the rotor and stator is required.

Now, as you give clearance, what happens? The flow rate is calculated, okay, $K * W^3$. So, W you intentionally provide, so the leakage rate will be high. How to avoid this? You can observe the formula W^3, and mu (μ) is also present. By increasing viscosity, the formula is like mu (μ) * L * ΔP. This type of formula exists, right? Q equals K. I'm treating all the unknown or unnecessary terms as constants. So, if I can change mu (μ), the flow rate can be altered again. So, if I make mu (μ) higher than Q leakage, QS leakage will be lower. This can be used for very high viscosity fluids. For thin fluids, if you are using it, the leakage rate will be very high.

Next, let's consider high viscosity and high temperature applications. There's a limit for higher-temperature elastomers, but in the case of metallic PCP, there is no such limit. Pumping thin fluids results in larger leakage, making it suitable for high-temperature environments. In this PCP design, there's no elastomer, so wear and tear failure, typically associated with elastomers, is not an issue. However, high precision is required. For instance, if the rotor has a slight bend and touches the stator, it can lead to rapid rubbing, requiring high pressure and force, which can lead to failure.

To prevent such issues, precision engineering is crucial. Some companies manufacture PCPs with non-elastomeric or all-metallic components, often referred to as metallic PCPs. While the term 'PCP' is used for elastomeric versions, the 'metallic PCP' term is reserved for those using metallic rotors and stators without elastomers.

As for leakage in metallic PCPs, it tends to be higher. How does this happen? This information is derived from a research paper. The graph illustrates pressure and flow rate at different RPMs—100 RPM, 150 RPM, and 200 RPM. As RPM increases, flow rate naturally increases, as I mentioned earlier. For example, going from 100 to 200 RPM nearly doubles the flow rate.

However, as pressure increases, leakage also increases, causing the flow rate to drop. This negative correlation between pressure and flow rate occurs because a fixed amount of fluid leaks continuously, resulting in a lower flow rate. Next, let's discuss the effect of clearance. Clearance is a cubic power term, as indicated by the W^3Q term. As clearance increases, the flow rate drops quickly. It's important to note that at 0 MPa pressure, there's no leakage. But as the pressure increases to 4 MPa, 8 MPa, and 12 MPa, the flow rate changes. This change in pressure affects the flow rate because, according to the formula

$Qs = K * \Delta P$

(or, proportionally to ΔP), increasing pressure leads to increased leakage, subsequently reducing the actual flow rate.

Let's discuss the stage effect. One stage produces a certain amount of fluid. If you increase the number of stages, you get less leakage because the total pressure drop is divided. Each leakage area and each cavity experience lower pressure – let's say 5 bar, 5 bar, 5 bar, 5 bar – but if you have only one stage, then all of the 100 bar pressure you provide will act on a single leakage area. In this case, you'll have more leakage. So, as the number of stages increases, you achieve a better flow rate. You can see in the graph, with 0 mega Pascal, 4, 8, and 12, lower pressure results in higher flow rates due to less leakage. This graph shows the leakage flow rate, not the actual flow rate. The actual flow rate, Q actual, equals the theoretical flow rate, Q theoretical, minus the leakage flow rate, Q leakage.