Artificial Lift

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Lecture-26 Sucker Rod Pump (SRP)- Part-5

How does the valve work? So, let's say you initially assume this is an insert-type pump. An insert-type pump means you have a barrel here, one traveling valve, and a standing valve. Then you have a barrel here, a traveling valve, and a sucker valve. So, this is SV, this is TV. I will assume different pressures here: P well, wellbore pressure, or tubing pressure is there, and you are anchoring here. This one is cylinder pressure, which may be plunger pressure, P plunger, P cylinder, and P, what will you say, P tubing. When fluid is lifted, the pressure will be P tubing. Let's assume your traveling valve and standing valve position like this initially. The traveling valve is at the lowest position. If you see this beam pump, for instance.

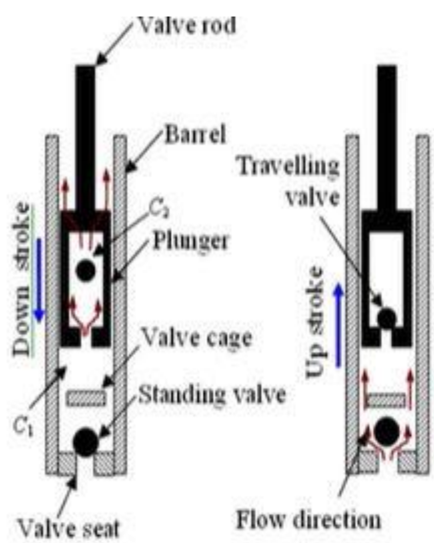

Fig.1. Valve mechanism

So, it is in the lowest position, the most down position, and has stopped. So, what will happen at that time? This valve is closed, and this one is also closed because this is not running. The beam pump the plunger is coming to the bottom of the position, and both valves are closed. Now, this area will be almost sealed; there will be no leakage, we are assuming. So, almost no leakage; there will be some leakage, we are assuming, almost or negligible leakage.

At the bottom position, both valves are closed, TV, SV. Now, after, say, 2 seconds, what will happen? After 2 seconds, this plunger will try to move up. So, initially, this distance was there. I am assuming this is the valve cage distance. Now, this distance has increased a little bit after 2 seconds. So, after 2 seconds, what will happen is the plunger is moving up; this is moving up after 2 seconds.

Initially, both valves are closed, and the plunger is at the bottom. Now, the plunger is trying to move up; it is trying to move up. What will happen is wellbore pressure and cylinder pressure. So, the wellbore pressure must be equal to the cylinder pressure. Below the standing valve, the pressure will be higher than inside the cylinder chamber; if it is not higher, the valve will not open, and the fluid will not enter here. The liquid will enter here once the pressure is higher, filling this area. Then, with the plunger increasing, moving up, up, up, that area will be filled.

After a few seconds, let's say what will happen: the plunger is here, and your standing valve is here the topmost position. The plunger is at the top position; it cannot move further. So, at this moment, what will happen is that the plunger will move up, and then it will try to move down. So, the movement is completed, and momentarily, it will stop. We are assuming both are not moving now. What will happen then: the standing and traveling valves will be closed; what's the pressure? Cylinder pressure and wellbore pressure.

Both are not moving, so you are not creating any lower pressure here. If the plunger is moving up, and there is no leakage in the cylinder, that area you are creating is low pressure. The plunger is moving up, and you are getting low pressure because of the low pressure. Wellbore pressure is higher. Wellbore pressure is pushed into the cylinder area. If the plunger stops there, then fluid will not enter because you are not creating extra vacuum there or extra low pressure here. When you are not creating extra low pressure, what will happen? The standing valve will fall, and it will be closing this inlet path. It will be sitting on the valve seat.

So, there will be no inflow at the top position at that time. Now, the cylinder is filled with liquid. Now, the plunger will try to move down, and both valves are closed. So, at the bottom-most position, the plunger is here, both valves close again, the plunger moved up, stopped, and both valves will be closed. Now, the plunger will try to move down.

Now, when the plunger is trying to move down after 2 seconds, the plunger is here, and the plunger is attempting to move down. So, what will happen is this valve, because of its weight (SV), will be closing the path: P-cylinder, P-wellbore. Wellbore pressure does not matter because the plunger is moving down. So, the plunger is trying to pressurize the cylinder.

So, the P-cylinder will be slightly higher than the wellbore pressure, and the standing valve will close the path because of its weight. There will be no inflow or outflow from the standing valve. Now, what is happening in the traveling valve? This is the traveling valve, right? TV. When it is trying to move down, and the cylinder is filled with liquid, what will happen is that this traveling valve will be trying to open the flow path. The traveling valve will be trying to open the flow path, and whatever fluid is inside the cylinder, there is some fluid already that you have taken from the wellbore. So, that fluid will be passing through the traveling valve, and it will be moving up.

So, what will happen is my traveling valve is here. This is closing, this is almost closed, and there is a gap. So, this fluid will be entering the tube, and it will go above the plunger. This fluid will go above the plunger when the plunger is moving down. Again, the plunger will come down to the bottom, so momentarily, both will stop.

When both get stopped, both valves close again, and the plunger moves up. When the plunger is moving up, the standing and bottom valves open, allowing fluid to fill this gap. When the plunger is moving up, it creates many gaps, and some liquid must fill them. So, the liquid will be coming from the standing valve, filling it. When the plunger moves down, the liquid will not go anywhere; it will pass through this traveling valve, going up. So, this is the sequence.

The sequence is as follows: first, the traveling and standing valves close when both are nearby. The traveling valve moves up; the standing valve opens, filling this gap. When the traveling valve is at the top position, it will try to move down. The fluid will go above the traveling valve when it is moving down. All the fluid above the traveling valve will be delivered to the surface when it moves up. It is like this: let's say I have a standing valve and a traveling valve here; it is fixed and moving like this. So, all this fluid will go to the surface, separating the system. When it is moving down and moving up, when it is moving down, the fluid will not return because of the traveling valve-standing valve arrangement.

Now, coming down, wellbore fluid will be taken above the plunger, moving out, and it will be delivered again. So, one-time delivering, two-time delivering, three-time delivering, four-time delivering, so many times it will be delivered. So, one time and how much volume it will be delivering. So, if we have the plunger area, as I already told, the area of the plunger, and you know the number 'm', the stroke length, bottom to top stroke length if you know 'L,' then this volume will be delivered whenever it is pumping. Let's say you have six strokes per minute; one stroke delivers this one. So, how much is it delivering? Six, let's say 'n' number of strokes per minute.

So, if I have the area of the plunger, A_p, and the stroke length, and I know the number of strokes, then I can determine how much volume it delivers per minute. The volume delivered per minute equals A_p times n, where you must adjust the units. A_p is the plunger area, L represents the stroke length, and n stands for strokes per minute (spm). This way, you can calculate how much volume it delivers, assuming it's an ideal situation with no leakage or other problems. Ideally, you can deliver this much fluid per minute and convert it to barrels per day.

All other pumps, like tubing pump, top-anchored, bottom-mounted, thin-walled pumps, follow the same basic procedure: the traveling valve opens, fluid fills the cylinder, the bottom valve opens, the traveling valve moves up, then down, and fluid goes up. This sequence continues, resulting in a pulsating flow. With every stroke, you deliver a specific volume of fluid; when it's moving down, nothing is delivered, and when it's going up, you deliver again. This is how the whole system works.

There's a formula for pump displacement or the volume of fluid delivered.

$$P_D = 0.1166SNd^2$$

If you have the piston displacement (P_d), piston speed (N), or pumping speed (N), the number of strokes per minute (spm), stroke length (S), and plunger diameter (d), you can use this formula. A constant term comes into play because you're converting units to barrels, and your data is given in inches. For this purpose, you must use this constant.

Now, a question for you: In the above problem, if my stroke length or the number of strokes changes, what will be the displacement, or how much volume will you deliver per day (barrels per day)? Here's a similar problem: The sucker rod pump well has a one-and-a-half-inch plunger operating at 20 spm with an effective plunger stroke of 50.

Problem: A shallow stripper well equipped with a 1-1/2 in insert pump has an pumping unit with a stroke length of 18 inches, and is pumping at 12 strokes per minute.

Sol: PD= 0.1166X12X18X1.5^2=56.67 B/D.

So, many times, our plunger stroke can be changed actually. Later, we will discuss how the plunger stroke is changing, but we assume this is a simple plunger stroke for simplification. The liquid production rate specification is specific gravity, given as 0.85, with a production rate of 210 barrels per day (BPD). The unit is B per D, as I have written here, which is sometimes expressed as BWPD (barrels of water per day) or BOPD (barrels of oil per day). Sometimes, "barrel per day" is abbreviated differently, so you should not consider it an unknown unit. This is a well-known unit in the industry, and you should be familiar with the various terms used by different authors and in different books.

We calculate the total theoretical displacement and the volumetric efficiency of the pump.

PROBLEM: A sucker-rod pump well with a 1.5 in. plunger is operating at a speed of 20 SPM. The effective plunger stroke is 55 in. The liquid production (SG = 0.85) at the surface is 210 BPD. Calculate the total theoretical pump displacement and the volumetric efficiency of the pump.

Sol: Dp=1.5in, N=20spm, Sp=55in, Q=210 B/D
Ap= (pi/4).Dp^2 = 1.767 in^2
PD=0.1484XApXSpXN=288 B/D
Eff=Q/PD=73%

The most straightforward formula in sucker rod pumping is analogous to a positive displacement pump in mechanical engineering. It calculates the cylinder volume per second, representing how much you are delivering. This displacement calculation is essential for the oil industry.

So, you have to convert the units. Normally, in mechanical engineering in India, you learn SI units, but field units are used in the oil and gas industry. You have to convert to field units, and sometimes, you have to remember the conversion factors. You will face difficulties if you do not remember them and mix up the units. For example, if I give the dimension as 1.5 inches, you must convert it to centimeters or vice versa—keeping all units in the same format, either SI or field units.

If you use SI, your results will differ, but the final result, such as BPD (barrels per day), requires everything to be converted into barrels per day format. This is crucial to consider.

Now, let's discuss the indicator diagram for a sucker rod pump and its relevance to positive displacement pumps used in other applications, such as surface applications or machinery in different industries. Imagine this as a sucker rod pump with a plunger representing piston movement, displacement, and pressure development. When designing a sucker rod pump or reciprocating pump, there is typically a gap between the piston or plunger and the cylinder head. This gap is known as the top dead center (TDC) and bottom dead center (BDC). TDC is the maximum point to which the piston can move upwards, while BDC represents the maximum downward movement of the piston or plunger.

Within this range, we have the TDC and BDC positions. However, the maximum part of the rod's dead portion, the piston or plunger on the right-hand side, does not reach TDC. Why? A specific gap prevents it from making continuous contact with TDC. This is due to mechanical reasons; if it were to touch TDC continuously, there would be a higher risk of inevitable failures.

So, engineers or designers keep a small gap; the distance traveled within that gap is called the swept volume. The area traveled is known as the swept area, which gives you the swept volume when multiplied by the distance traveled. The swept volume will be less than the actual total volume. Now, if there is a small amount of gas in that area, the story changes. We're assuming everything is filled with liquid. Initially, when the piston or plunger moves down at the bottommost position, your traveling and standing valves are in a certain mechanical gap. As I mentioned, the piston or plunger will not cross that gap for mechanical reasons; it should not hit your valve cage, or problems will arise. Therefore, a certain gap is necessary. We can't make it zero due to mechanical constraints. If you're fortunate, you might be able to eliminate it, making life easier. However, we must allow for a specific gap because of mechanical reasons.

Both valves are closed when the piston or plunger is very close to your valve cage. Let's consider that the pump operates under atmospheric conditions, ignoring reservoirs and other fluid considerations. The plunger is trying to move up. Initially, the standing valve must open when it's moving up because you need to fill the gap in the cylinder with liquid. So, the standing valve opens, and if you have a pressure gauge in the cylinder, the pressure should ideally be lower than atmospheric pressure when moving up. If the entire pumping system is working under atmospheric conditions, roughly one bar of pressure, then during the suction phase, the pressure in the cylinder must be lower than atmospheric pressure for the valve to open. If the pressures are the same, no fluid will enter.

As the piston moves up, it creates lower pressure than atmospheric pressure. Atmospheric pressure, approximately one bar, pushes the piston and opens the standing valve, allowing air to enter in reservoir or wellbore conditions. When the plunger moves up, wellbore fluid enters when the cylinder pressure is lower than the wellbore pressure. This is why the piston or plunger moves from bottom to top, and the actual pressure is lower than atmospheric pressure or the reference pressure when considering surface conditions, disregarding reservoir conditions. Now, the bottom dead center (BDC) position will be here.

When the piston or plunger reaches the top in atmospheric conditions, the cylinder pressure is very low and lower than atmospheric pressure, and it has taken in all the air. Now, the plunger or piston will start moving down, initiating the opposite direction movement. In this case, the pressure inside the cylinder will increase as the plunger moves down. Pressure will continue to increase as the plunger moves down. Which valve will open in this situation? The upper valve will open, allowing all the air or liquid to pass through.

During this time, your pressure will remain fixed at a certain level and will be delivered steadily. Here's what's happening: TV (traveling valve) opens, then A, B, C, D. Your traveling valve is open, and it delivers. After delivering, your standing valve opens when you suck in the fluid. After sucking, the standing valve closes, and the traveling valve opens again. This cycle continues: the traveling valve opens, delivering is done, and then it tries to move down. TV closes, the standing valve opens, and the same cycle repeats. This represents one ideal cycle; if you have a pressure gauge inside the cylinder, you can draw this figure.

Remember that this is an ideal figure, and the actual figure may differ. Now, let's assume there is some acceleration because when the piston moves up and down, there will be acceleration, and the standing valve will not open immediately; it requires some additional force at the beginning. So, what happens if there is acceleration? In that case, the figure will change like this.

So, the figure will change like this. If there is some acceleration, what will happen when the standing valve attempts to move up is that it will exert a bit more force than the pressure difference, let's say 'x.' However, when the standing valve is trying to open in the initial static condition, you need to apply a bit more force for it to open. So, when it exerts more force, it results in lower pressure. This is the most downward pressure when the standing valve is opening. When the standing valve closes, the pressure increases. Again, when the traveling valve opens, it requires a higher pressure, and your cylinder will show a higher pressure for it to open. This is why the pressure is initially higher and gradually decreases as the piston moves. Due to these modifications, it forms a curve like this: A, B, C, D. The original curve becomes A', B', C,' D.'

Now, you have to account for friction in the pipe. This modifies the curve further. The original curve is shown here, but due to friction, the curve appears like this. You can draw this to illustrate it. Friction is present in the suction pipe, making it more challenging to suck in the fluid. This indicates friction in the delivery pipe.

In this way, the indicator diagram is modified. If you have a liquid, things are better. However, in oil and gas, factors like formation volume factor, gas-liquid ratio, or gas coming out of the fluid when the cylinder pressure is lower than the wellbore pressure can lead to two-phase flow. This can introduce air or natural gas into the cylinder, further distorting the indicator diagram. Such conditions create more difficulties. When pumping liquid at the surface and from the wellbore, the situation is entirely different due to the presence of small dissolved gas, which can cause multiple issues. We will discuss later why gas is a significant problem for sucker rod pump systems.