Artificial Lift

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Lecture-28 SRP- Pump Performance Analysis-Part-1

Good morning, everybody. We have already discussed surface and subsurface units; these two topics are nearly covered. Now, we have two more topics to address: performance analysis, how to draw a dynamic dynamometer or pump curve, and how to understand them. The next topic is the sucker rod, which connects the surface unit and the bottom hole assembly. In between, there will be a big, long rod. We'll discuss these long rods' physics and stress analysis in a moment. Before I go into details, let me explain a bit. I have an air pump unit; it's not for water since I don't want to spill water in the studio. So, I've taken this air pump, and here's a hole.

As you can see, air will blow out when I pump it. When I'm pumping, this red part is being pushed. You can assume this is a sucker rod pump. The sucker rod will be on top, and this rod goes to the plunger. There's one standing valve and one traveling valve. When I move it down, it will take in liquid. If it's a liquid pump, it will fill up here. When it moves up, this liquid will flow through a hole, and the whole system is placed inside a tubing.

This pump must be securely anchored, or some nipple must be used to ensure the entire assembly doesn't move up and down. These nipples can be bottom-anchored or top-anchored, as we discussed in a previous lecture. Bottom-anchored means holding it here and moving the plunger up and down, while top-anchoring is done at the top. Now, let's open this plunger assembly. This isn't an actual sucker rod pumping system. Here, they're using a simple elastomeric rubber system. This is a small plunger for air pumping, essentially for blowing up a balloon. Now, when you pump this plunger, you probably won't see it, but the plunger is right here. You can observe the distances between these points as it moves directly to this position; the plunger almost touches here.

In actual practice, the plunger will not touch the bottom; it will maintain a certain gap. This position is the top dead center, and the plunger cannot move beyond this point. Similarly, it cannot move more than this point either. The plunger moves from here to here, representing the stroke length, which is the actual stroke length of the plunger. Due to mechanical reasons, the plunger must not contact the ends, as any contact due to stretching or other issues can lead to system failure. Therefore, there must be some gap, and the piston or plunger must not touch; there should be some clearance. The portion of the piston's travel is the swept volume, and some portions must remain clear, which will be filled with air in the case of an air pump or liquid in the case of a liquid pump. The entire system can fail if the piston continuously hits the bottom valve cage or valve. Hence, there needs to be a small distance where the piston does not travel, known as the swept volume.

There is no clearance volume if the piston travels all the way and hits this point. Understanding clearance volume and its benefits will be discussed later. In mechanical terms, some clearance needs to be provided. In performance analysis, we will examine the dynamometer and pump curves. The dynamometer curve provides a force profile. Imagine this is the sucker rod; when the horse head is pulling it up, it applies force or pressure to this rod. To illustrate, think of the system used to measure the weight of airplane luggage, where you check if it's 20 kg or more. When you put the bags on it, it shows a certain importance. When you pull up, it registers a weight; when you move down, it shows another weight. Pulling up implies a higher load, including the weight of the liquid and the rod, friction, and other loads. Thus, the load should ideally follow this curve: stroke length, stroke, stroke, stroke length, and load. When the piston is at the bottom, and you're trying to move it up, you exert a higher force, resulting in a higher load. This higher force translates into a horizontal load, represented by this horizontal line. When you're moving down, you're applying lower pressure or load, and it will appear like this.

So, you have vertical higher force, lower force, higher force, lower force. Why the higher force? Higher force indicates that you're lifting the entire fluid column, along with the weight of the rod, which includes fluid friction. As it goes down, the fluid load decreases, and due to the rod's weight, it naturally tries to descend. Consequently, the needle on the weighing machine will show a lower amount of force or load. That's why you get this curve. This is the bottom of the plunger, and you're lifting it up to the top. This is the top of the plunger. Again, the pressure and force change when it's at the top, and you're moving it down immediately. It's still at the top, but it's moving down. This process repeats, and when it's at the bottom, the force differs from when you pull it up. This force variation is represented by points A, B, C, and D. At the bottom, the measuring needle will show a downward movement, indicating a lower load. But when you're trying to move it up again, the force changes abruptly, as seen at point B. When it's continuously moving up, it maintains a constant force, staying at the top. And once it reaches the top, and you're moving it down, the force becomes relatively constant again. So, the force changes as it moves up or down. This graph is plotted using the dynamometer curve or pump curve mechanism, which we will discuss later.

This dynamometer curve, also known as the dynamograph, may use a piezoelectric or a mechanical type system to provide the force profile of the polish rod. The measuring instrument is placed on the polish rod because measuring at any other point inside the wellbore would be challenging. You can recall that the polish rod has a section passing through the stuffing box and connects to the sucker rod. In this polish rod section, there's the force or pressure measurement equipment to determine the force or pressure it experiences. I mention pressure sometimes because pressure can be calculated as force divided by rod area. This represents the stroke length, and this graph illustrates the load on the polish rod.

Many times, we write 'polish rod load.' Now, let's consider what happens when the plunger moves down. When the plunger moves down, the traveling valve is in action. The plunger has a traveling valve, and there's also a standing valve in the barrel. Here, we have the barrel, the plunger, the traveling valve (TV), and the standing valve (SV). The TV is open during the downstroke while the SV is closed. At the bottommost position, the traveling valve (TVc) is the first valve to close. The standing valve (SVo) opens as it begins to move up. Let me clarify the abbreviations: TVc stands for traveling valve closing, while SVo stands for standing valve open.

As the plunger continues its downward movement, it will eventually stop at the bottommost position. At this point, the traveling valve will close instantaneously. When you attempt to move the plunger back up, after a brief moment (let's say, 1 second), the traveling valve will close (TVc), and the standing valve will open (SVo). So, at position B, the standing valve is open while the traveling valve is closed. As you lift it, all the fluid will flow into the tubing, ultimately reaching the surface. When you reach the top position, denoted as position C, what happens is that as soon as you begin moving it down again, the standing valve (SV) will close.

First, the standing valve will close. This valve will be closed. Then, as you press down further after 1 second, the traveling valve will open. There is a sequence of events when you are at the bottom and trying to move up. When you attempt to reach the bottom and stop instantaneously, the traveling valve is closed briefly as you start moving up. At that time, the cylinder pressure will be lower than the pressure in the tubing, causing the traveling valve to open.

Now, let's understand the sequence of events. I'll draw a picture like this: there's a barrel with a standing valve, and there's a plunger with labels A, B, and C (there's a gap here, so this is also labeled as C). This is the traveling valve (TV) and the standing valve (SV). When you are trying to move up, initially, the pressure is P (previously referred to as P well) in the well, P cylinder in the cylinder, and P tubing in this area. So, P tubing and P well are higher when you are moving up.

As you move up, the cylinder pressure must decrease. When the cylinder pressure decreases and becomes lower than the wellbore pressure (P wellbore), the standing valve (SV) opens. When you are attempting to move up, the piston or plunger moves upward, reducing pressure in this area. Consequently, the cylinder pressure decreases. When the cylinder pressure reaches a level lower than the wellbore pressure, the higher the wellbore pressure causes the standing valve to open. Thus, the valve is now open.

First, let's discuss what happens when you are trying to move up. The traveling valve is closed initially, as shown in the top picture. I'm using 'one' as a placeholder name. The full view shows that the traveling valve (TV) closes at position A, and then your standing valve (SV) opens. As you continue moving up, there is no change. When you reach the top and your velocity is reduced, please note that this velocity is sinusoidal. Initially, it's a low velocity, followed by a very high velocity, and then it slows down again because of the sinusoidal pattern. The velocity in the middle of the plunger will be very high due to this sinusoidal motion. As the velocity decreases, the standing valve will eventually close the path. So, at position C, your standing valve closes near the top.

As you attempt to move down with the standing valve closed, the cylinder pressure increases because you are pushing down. When the standing valve is closed and the pressure is high (P cylinder more than P tubing), the traveling valve (TV) opens. That's why you see in the top picture that the TV opens at position D, even though both plungers are at the top. The sequence follows: the traveling valve closes, then the standing valve begins as you move up. Moving up further, the standing valve closes, and the traveling valve opens. Any fluid in the system moves up and eventually reaches the surface, where it goes to a separator.

In actual practice, tubing and extension rods come into play. I'll explain how tubing and extension rods come into play. Imagine this is your plunger assembly, and let's say it's filled with liquid. This plunger assembly is inside a barrel or cylinder, moving up and down like this. There are traveling and standing valves, and the plunger has its weight and a rod. They all contribute to the functioning of the system.

So, when you move it up, the rod, although it's metallic, will still stretch because it's a very long rod with a high weight, causing it to elongate. They use the term 'stretching' to describe this. That's why I've added this elastic component for demonstration. I'm assuming the rod is elastic, hence the elastic representation.

The plunger is here, and when the piston or plunger is at the bottom, and you try to move it up, let's assume this is a walking beam. My hand represents the walking beam, and this is the horse's head. The horse head is trying to move up. When it's attempting to move up, you'll notice that the rod undergoes stretching first, and then it begins to lift. When it's going down, the rod experiences compression. So, the rod will continuously go through compression and decompression cycles. If it's at a slow speed, the rod will stretch gradually without any noticeable wavy motion. However, at very high speeds, for instance, if I'm moving up rapidly like this, the rod will exhibit more noticeable elongation because it's elastic. If the rod is short in length, you won't observe much elongation, but with longer rods, such as 1 kilometer, 2 kilometers, or 3 kilometers (or 3,000 feet, 4,000 feet, or 5,000 feet), the elongation becomes significantly noticeable. Due to this substantial elongation, when your beam pump or polished rod moves, let's say, 2 meters or 6 feet, the actual plunger in the pumping system doesn't deliver the same amount of fluid because the rod is elongating. You can observe this from the difference between the hand positions from the bottom position.

Now, your horse head is trying to move it up. When it's attempting to move up, you can see that it's stretching, stretching, and then it starts to lift. So, even though it might move only 2 feet, the actual displacement of the horse head could be 4 or 5 feet. This means that the stroke length on the surface will be different from the actual stroke length in the wellbore due to this rod stretch.

Another thing to consider is when you have tubing that is not anchored. You've seen that tubing can be either anchored or non-anchored. What is tubing anchoring? Tubing anchoring is as follows: you have a casing, tubing, and a bottom hole assembly or pumping system. The pump is attached here and properly secured with a nipple, which we use to hold the pump, either bottom or top anchored.

Bottom anchored means you hold it there, while top anchored means you hold it somewhere else. Let's assume this is the cylinder, which must be anchored here; otherwise, moving it up and down will move like this. So, it's better to anchor it either at the top or the bottom.

Now, the tubing will be fixed to the cylinder, which must also be secured to the casing, shown here as the casing. The tubing needs support here; otherwise, it will just hang loosely, like this. If it's not anchored, the tubing will elongate because it's a long steel tube, and long steel tubes tend to exhibit elastic properties, as this diagram shows.

Now, you add your bottom hole assembly and secure the tubing. You hold it and apply a very high force when you move it up. Due to this high force, the tubing will experience some motion. Again, the tubing will elongate a bit when it's moving down. Because of its own weight, the tubing is already elongated, and when you move it up, the plunger pulls up, causing fluid friction and reducing the load on the tubing due to the entire fluid column. This results in the tubing being shortened slightly. When you move it down again, the tubing elongates a bit. This elongation and contraction of the tubing occur repeatedly. However, if you have anchored tubing securely fixed to the casing, this movement will not happen.

So, you now understand the difference between anchored tubing and non-anchored tubing. There will be no tubing motion or elongation if you have anchored tubing. However, with non-anchored tubing, there will be some movement. This difference can impact the dynamograph curve or figure.

Another scenario is when you encounter sticking tubing, such as tubing sticking in the barrel or the rod sticking. In such cases, you need to apply very high force when you attempt to lift it up. If it's freely moving, you can calculate the required force. However, the tubing may get stuck due to issues like bends or other problems. In this situation, the needle weight meter reading on the surface or a piezoelectric measuring device will show a higher reading because it's encountering an obstruction.

In some cases, there may be leakage in the plunger or barrel. If the barrel has a leak, fluid will leak out when you lift it up, and you'll need less force.

Sometimes, the traveling valve may leak, or the standing valve may leak. There could be friction caused by the fluid or tubing rubbing against the sucker rod, especially in crooked wellbores. Crooked wellbores deviate from the vertical, as customarily assumed. In such cases, the rod may sometimes rub against the wellbore wall. Additionally, there could be areas filled with gas.

If the wellbore is gas-filled, when you compress it or move it down, it will get compressed according to the ideal gas law:

$PV = nRT$

When it's going down and filled with gas, the standing valve will be closed, and the traveling valve will open when the cylinder pressure exceeds the delivery or tubing pressure. So, when you attempt to move it down, the gas gets compressed. Proper pressure development becomes challenging because of this compression, compression,

compression. The traveling valve will only open when the pressure exceeds the delivery or tubing pressure, so that gas compression can create issues.

Another possibility is that the intake pressure is shallow, and due to this low pressure, it doesn't fail. The cylinder pressure is also shallow because of the low inlet pressure. To maintain a fluid column, some entry pressure must be at the positive suction head. It will attempt to suck something without sufficient entry pressure, but there's nothing there. As a result, it can create very low-pressure conditions, and even water vapor can form.

When the piston moves down under such low-pressure conditions, it moves rapidly. If filled with liquid, the traveling valve opens smoothly, and the liquid goes up. However, when there's no liquid and the pressure is very low, there's no resistance from the liquid to open the traveling valve. Consequently, it moves at a faster rate, and in the middle of the stroke, as I mentioned earlier, the speed is very high due to the sinusoidal motion. At this point, if it encounters water or a liquid surface, it can create sudden jolts that may cause joints to break or result in wavy motion. This wavy motion can lead to rubbing against the tubing, potentially causing failure.

So, how can you sense this? From the surface dynamograph curve or graph, you can understand it. Let's explore the different types of dynamograph curves. Several idealized dynamograph curves have been designed or understood, and a proper understanding of these curves requires much experience. Experienced engineers have devised specific mechanisms to understand various properties of these curves.

For an ideal curve, it will appear completely rectangular. This axis represents the stroke length, and this one represents PRL (Pumping Rod Load). Here, we have the counterbalance mass. As you already know, the counterbalance stores and provides energy. The curve represents the average force required by the counterbalance mass. During the downstroke, the energy will be lower, and during the upstroke, the energy will be higher. That's why some portions of the curve will be below the counterbalance line and some will be above it. You're already familiar with the downstroke and upstroke. In the case of an ideal pump, it's complete, and there are no issues.

Now, regarding the dynamograph curve, there are two aspects to consider. If you're measuring it at this point, the instrument won't show you information about rod stretch, tubing issues, or similar concerns. It will primarily provide pump-related information. However, if you place the same machine on the surface where your polished rod is, the polished rod will reveal all the details about the rod, pump, tubing, and fluid. But using the same machine here won't capture information about rod or tubing stretch, tubing leakage, or fluid friction.

So, all this part will be removed, making it more idealized. This curve will be more on the pump side. That will be more complex if you want to understand the surface side. First, understand the simpler one, then move on to the complex one. In the case of an ideal pump, it's complete, and there are no issues, making your life beautiful.

Now, in some cases, you have a flowing wellbore. You aren't applying any pressure in a flowing wellbore, so the pressure will be lower than required. This results in a flowing wellbore, and the flowing rod won't experience any fluid load. Putting a dynamometer on the polished rod in this scenario will display a negative reading.

Next, let's consider a bend or parallel sticking pump. An ideal pump curve looks like this. However, if you encounter sticking, for instance, when the plunger is moving up and gets stuck, it introduces the need for significantly more energy at certain moments during the movement. This alters the curve and will look different with spikes at the end.

Moving on, we have gas interference. As I mentioned before, if there's gas present, this is closed, only half-filled with liquid or oil, with the rest being gas. The curve will change as a result. It compresses following the PV per gamma equals constant formula. Gas interference causes the gas to compress, and liquid will enter this area once that's done. When you move it up, there will still be some remaining gas, causing it to expand. This expansion is reflected in curves A, B, C, and D. Notice the smoother area at B due to gas expansion; from C to D, there's compression. It roughly follows the PV per gamma formula, resulting in a curved shape. During this time, you get production, but it's not a pump-off condition, which means you aren't getting any pump delivery or flow because it's gas-filled.

There is no liquid, so it is not pumping. This is called a pump-off condition. In this case, you must stop the pump for a specific time, or if you anticipate much gas coming in, you can slow down the pumping speed. When you slow down, you allow for leakage and other adjustments, reducing the likelihood of a gas lock. Perhaps your intake pressure is shallow, and liquid inflow into the wellbore is minimal. In such cases, slowing down or temporarily stopping the pump allows the fluid column to build up before resuming pumping.

Next is the tubing extension. When you lift the tubing, it also moves upward. In this situation, the beam pump's horse head's energy is reduced because the tubing's spring constantly assists in lifting. This results in slower movement, contributing to tubing contraction and expansion, represented as A to B and C to D. K represents the tubing spring constant, and this is tubing elongation.

If tubing elongation occurs, the curve can look like this. Another possibility is fluid friction. If you have very narrow tubing, lifting the fluid can result in high fluid friction, as per the formula:

$\Delta P = FLV^2 / (2gD)$.

The pressure drop will significantly alter the curve's shape in such cases. First, you draw the ideal part, and then it will change like this due to fluid friction. Why is the center part higher? As I mentioned, it follows a sinusoidal curve, and the fluid velocity is very high when the plunger is in the middle position. With higher velocity (V), the pressure drop (ΔP) is also higher, leading to the expanded and bulged curve. Therefore, you need to design tubing properly to minimize fluid friction.

Next is a crooked well. If you have a crooked or bent well, the curve will change because the bending tubing or rod can lead to rubbing, requiring additional energy when moving up and down. This is a crooked or bent well. Additionally, there's the concept of a split barrel, which looks like this.

The curve will appear like this. Why does it look like this? When it moves up, there will be leakage here after some time due to high pressure. As a result of this leakage, the pressure drops suddenly, leading to what we call barrel leakage. The pressure might initially be too low for the leakage to be noticeable, but after some time, the split becomes visible, causing the fluid pressure to drop in another area. This phenomenon is referred to as barrel leakage.

Next is fluid pound. Fluid pound is characterized by a curve that goes like this and then suddenly drops. What happens in the liquid pound? As I mentioned earlier, when the piston at the top moves down and there's very low intake pressure, the pressure inside the chamber is also low. Due to the low chamber pressure, as it moves down initially, the low-pressure increases, causing even small amounts of gas to compress. Then, when it's in the middle of the stroke, and the plunger's velocity is very high, it will strike it if it encounters a liquid surface, resulting in vibration. That's why this curve follows this pattern, with sudden pressure changes. This phenomenon is referred to as the fluid pound curve.

Next is a worn standing valve. If the standing valve is worn out, what happens? The standing valve, the lower valve, starts to leak when moving down, failing to close completely. As you move down, it leaks, causing continuous pressure loss. When you reach a certain point, the pressure increases again. So, it's a cycle of moving down with leakage and then up with more leakage.

So, it's not correctly filling this system, and you're losing energy. This is a worn-out standing valve. The figure will look like this if I consider a worn-out traveling valve. Now, in any wellbore, you can't isolate these scenarios. There will be a mixture of things. For example, you may have a bent barrel with a sticking pump, gas interference, or tubing elongation with a crooked well, barrel leakage, and maybe a worn standing valve.

So, it will be a combination of these figures. There are several hundreds of varieties, actually. To understand them, you need good experience, and then you can recognize that these combinations may be possible. Otherwise, just looking at these pictures won't provide much insight. But you have to grasp the basic concepts.

Factors affecting the dynamometer curve. You can see high blisters, and there are several factors. One factor is the speed of pumping and the depth. As I mentioned earlier, there will be no waves if you have a slow speed. If the speed is high, then this motion will occur. Fluid conditions, such as different bubble points, two-phase flow, single-phase flow, or corrosiveness, also affect the curve. You need to understand how these properties affect the dynamometer curve.

Abnormal conditions, the pump friction factor, fluid friction factor, pumping unit geometry, gas law conditions, loading conditions, and whether there's a crooked wellbore or not – all these parameters will impact your dynamometer curve. First, you need to understand the basic shapes, and then you can combine them to create more complex shapes.