Artificial Lift

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Lecture-04 Oil and Gas Production Systems

This lecture will cover some basics of production engineering, including the completion and production stages. First, let's understand what exploration entails. During this phase, you calculate the estimated oil and gas reserves and determine their locations. Then, in the drilling stage, you install the necessary drilling and completion equipment, ultimately preparing the wellbore for production. Once you have production at the surface, the next step is to transport the fluid to the refineries. Refineries typically cannot process a fluid that contains a mixture of oil, gas, sand, and water, so separation is necessary. I will explain the process in more detail. As I've mentioned, you're essentially evaluating potential resources during the exploration phase. Then, you proceed to the drilling stage, installing various equipment and continuing drilling. In the completion stage, your primary objective is to prepare the wellbore for production. Once the wellbore is ready for production, you still can't begin production because you need to connect it to the surface production systems. Imagine the wellbore here, with tubing and casing already in place and properly cemented. Now, your tubing is ready for production.

Now, the tubing is passing the fluid to the wellhead, and there might also be a Christmas tree. A Christmas tree is essentially a valve arrangement and flow conduit where the fluid from the wellbore passes through the wellhead to the Christmas tree, which has several valve arrangements. Some valves allow fluid to exit the wellbore, while others permit fluid to enter it. I've already explained the various valve mechanisms in previous lectures, so you can refer back for more details.

From the Christmas tree, the fluid continues to a choke, and then there's a separator system. After the separators, a downstream pipeline mechanism can involve pipelines, tanker transportation, or other means to transport the fluid to refineries. The oil is further processed and distilled at the refinery into various products like petroleum, diesel, grease, and naphtha, which are then sent to customers. When we say 'customers,' we mean individuals like you who may have a bike or car or use Indane gas cylinders. Ultimately, you are the end consumer of the oil or gas products. This course primarily focuses on the completion stage and the production stage. Now, let's dive into the production stage. In the production stage, you need to install separators. Imagine you have a wellhead, and you receive the fluid from the choke, which then enters a separator.

Why is a separator required? A separator is necessary because you receive high-pressure fluid from the wellbore containing oil, gas, water, and sand. All four phases are combined when coming from the wellbore. In the first stage of the separator, typically a two-phase separator, you begin by removing the free gas or any dissolved gas that might be present. It's essentially a pressure vessel, where you input oil and gas through an inlet pipe, and there's an exit pipe for oil. On top of the vessel, there's a hole with a mixed extractor, allowing the lighter gas to escape from the top hole, while you get liquid, including oil, water, and possibly sand, from the bottom or near the bottom hole. This setup represents a two-phase separator.

In this separator, you obtain a mixture of oil, water, and possibly sand, while the gas line may contain water vapor, gas, H_2S, carbon dioxide, and other components. I will explain later how to separate the gas. When you have a mixture of oil, water, and possibly sand, you pass it through a three-phase separator. In the three-phase separator, you extract natural gas from a separate gas extraction line.

This structure is called a mist extractor, spelled M-I-S-T, extractor, E-X-T-R-A-C-T-O-R. A mist extractor is designed to capture any water or liquid particles passing through its channels or mesh. When these particles collide within the mist extractor, they coalesce into larger particles and fall. Meanwhile, the lighter gas continues through the gas line. Additionally, there are two layers here, with oil being a low-density fluid, meaning oil will float on top of water. During the separation stage, you separate water and oil. It's important to note that maintaining the oil and water level is crucial. If the oil level drops below the entry point of the exit valve, gas may start to escape through the oil channel. Conversely, if the water level becomes very low or almost zero, the water pipe might contain a significant amount of oil or gas. To maintain proper oil and water levels, a level controller is used.

Here, water will also have a level controller. If you've seen a toilet flush chamber, a level controller works similarly. When you press a button to flush, water flows through this chamber, circulating continuously. Once the upper chamber's water is completely drained, it closes a valve. It then allows fluid to rise again. When the fluid reaches a certain level, it closes the entry valve again. If it doesn't close the water entry valve, there could be an overflow in your bathroom or toilet area. So, there's a mechanism where the valve only operates within a certain range. If it's completely closed, it opens the valve, allowing water to flow into the chamber. As the valve moves up, it eventually closes the path. The level controller in this context operates similarly, working within specific levels of water or oil.

This is called the inlet. From the wellbore, you receive a very high-pressure fluid, let's say 100 bar, for example. In the first stage, if possible, you perform two-phase separation, removing all free or dissolved light gases, including condensate. There will also be a mist extractor to prevent liquid from entering the gas line. There will be some pressure drop once you've separated the gas and liquid. If you don't reduce the pressure, the two phases will remain mixed, making separation difficult. You reduce the pressure to separate the oil and gas at each stage. In the first stage, you reduce the pressure, allowing any gas forcefully dissolved in the liquid or free gas to exit into the gas line. You are left with liquid at a higher pressure, which still contains some gas and sand. Next, you pass it through the three-phase separator. As pressure decreases, the separator separates the gas from the liquid, releasing the required gas into the gas line. The remaining liquid consists of two phases: water and oil. These two phases separate naturally over time due to their density difference. Oil tends to float over water. However, oil may not separate well in some cases due to certain chemicals like wax and asphaltenes. In such cases, additional chemicals may be added to aid separation. Normally, gravity helps in the separation process.

Because of gravity, water has higher density and gravity, while oil has lower density and gravity. Oil will float over water. To ensure proper separation, you need to provide sufficient time. If you don't allow enough time, water may contain oil particles or vice versa. The duration required for this separation process is known as retention time. How much time should be given? It's referred to as retention time. For instance, if you allow a 15-minute retention time, it means that within 15 minutes, most oil particles in water and water particles in oil will be separated. You can then remove the separated oil and water. It's essential to monitor and control the level continuously. Failing to do so can lead to difficulties.

I mentioned the importance of sand control earlier. If you don't manage sand properly, it can accumulate in your separator system. This can block your flow path and erode the system's surfaces. The separator system may not function as intended because it contains small bulbs, nozzles, bends, and turns. Furthermore, if you have H_2S gas, you must carefully select the material properties. When H_2S reacts with iron, it can create hydrogen sulfide, which can further react with oxygen to form H_2SO_4 (sulfuric acid) or H_2SO_3. These are salts of iron, and they are softer than iron itself. So, any force applied to these more delicate parts can remove them. Gradually, the iron surface will wear down due to this chemical reaction with sulfur. This can be harmful, especially in pressure vessels and piping systems that operate under high pressure. Corrosion resulting from sulfuric acid can pose significant safety risks. Therefore, selecting the right material properties is crucial when dealing with hydrogen sulfide.

You can install the entire system once you've chosen the appropriate material properties. If you anticipate sanding issues, you must determine how to manage the sand. Failing to address sand-related concerns can lead to deposition and increased erosion rates. In the presence of sand and H_2S, erosion and corrosion can coincide. Erosion and corrosion coincide. Erosion happens when the softer material, created as a result of the H_2S and Fe reaction, is impacted by sand. The softer material gets removed from the affected area, exposing fresh metal surfaces, which react with H_2S, sulfur (S), or hydrogen sulfide, forming more delicate materials like ferric or ferrous sulfate. This cycle repeats, leading to both corrosion and erosion. As a result, your pipes can rupture quickly, and the salt can block equipment, causing disastrous consequences.

Therefore, when dealing with H_2S or sand, proper handling and equipment design are crucial to ensure the system's safety and long-term functionality.

Now, you've seen the wellhead regarding separators for oil, gas, water, and sand. Fluid flows from the wellbore to the wellhead or Christmas tree. From the wellhead, you encounter a choke valve. After the choke valve, you have a separator. Initially, it may be a two-phase separator followed by a three-phase separator. Depending on your requirements, these separators can come in vertical or horizontal configurations. Generally, the first stage uses a horizontal separator, while the second stage, involving three-phase separation, may employ a vertical separator. As I mentioned earlier, there's also a mist extractor. The flow sequence is as follows: gas, oil, water. You obtain oil, which still contains water particles and some gas due to the high pressure. For instance, let's say the pressure is initially at 100 bar, then drops to around 50 or 40 bar in the first stage and decreases to about 20 bar. The pressure remains higher than atmospheric or normal pressure. In the oil industry, normal temperature and pressure are typically 14.7 psi.

At 60 degrees Fahrenheit and 14.7 psi (pounds per square inch), these conditions are considered standard pressure and temperature in the oil and gas industry. Under these conditions, all parameters are measured, serving as a baseline or surface condition. If conditions deviate from this standard, they must be specified as reservoir conditions or at certain pressure and temperature levels. Failure to specify these conditions can lead to ambiguity and errors. Once you obtain oil, you'll need a separate system due to the continuing pressure, which might still be around 14.7 psi or one bar. Certain units are commonly used in oil and gas, and it's important to familiarize yourself with them. For example, the standard pressure is often expressed in psi, not in units like Newton meters or square meters.

Similarly, temperature is given in Fahrenheit. Other field units include gallons, barrels, and more. I'll provide further explanations later, but it's essential to remember that these are field units. ONGC typically employs both SI and field units, depending on the context. Generally, SI units are used, but field units are the norm in the United States. The United States has historically dominated the oil industry, with many major companies headquartered there. When these companies conduct business in other countries, they often bring their field units. Field units are prevalent in the oil industry, even though converting between these units can be challenging. Conversions such as gallons to barrels or barrels to cubic feet can be complex, so anyone aspiring to work in the oil industry must handle these conversions.

I recall working in the UK's oil industry, specifically in Aberdeen. While I received data in field units, I preferred converting all measurements to the International System of Units (SI) for my calculations. After completing the math, I would reverse the results to field units for delivery to the company. This approach made my work more manageable, as it involved numerous calculation stages and required the preparation of several spreadsheets. Using SI units for my calculations simplified this process.

I received data in field units, and when delivering results, I had to use field units because they would not understand SI units. For instance, if there was a pressure of 5 bar or 72 PSI, I might employ an additional separator with a mist extractor to remove any remaining dissolved gas from the oil. Now, with oil separated, the challenge becomes separating the water. You might need to add chemicals or use a heater treater to achieve this. A heater treater involves increasing the temperature to alter the viscosity. Viscosity is crucial in separation processes because it affects particle settling. Higher viscosity hinders particle movement, preventing them from settling effectively. To reduce viscosity, increasing the temperature is an option. The oil's viscosity changes significantly with higher temperatures, allowing water particles to fall more rapidly. The increase in temperature has a more significant impact on oil viscosity than on water viscosity. As a result, raising the temperature accelerates the settling of water particles, ensuring efficient separation. Water particles will separate from the oil, allowing oil to flow, and gas will exit the system. This process involves the transfer of energy.

If you have higher viscosity, you need to reduce it. By reducing viscosity, the settlement rate becomes quicker. This means that a certain amount of oil or gas inside a separator will stay for a shorter period of time, resulting in higher productivity and fluid flow rates. However, in some cases, particles may take a very long time, say two or three days, to settle at the bottom. This indicates that water is mixed in with the oil, and the ideal condition where water quickly separates from oil is not met. Sometimes, certain chemicals, like asphaltenes and paraffin, act on the surface, preventing water particles from colliding and forming larger particles. You can reduce viscosity, increase particle size, and enhance collision rates to improve settling rates. Increasing particle size and collision rates helps particles settle more quickly, ultimately increasing flow rates and productivity.

Conversely, if the settlement rate or the time required to settle particles is high, you must lower the flow rate to allow particles to remain in the separator longer. In such cases, you should create laminar flow, not turbulent flow. Turbulent flow causes particles to move randomly, with some attempting to move up due to its random nature. Creating a smooth laminar flow ensures that particles settle slowly and efficiently. Now, let's discuss gas separation. I mentioned earlier that you obtain gas like this from the separator system. When referring to gas, it typically contains fewer carbon atoms, resulting in smaller carbon chains. Conversely, if you think of paraffin wax or heavy oil, more carbon atoms join together, forming longer-chain hydrocarbons.

So, volatility will be lower due to long carbon chains. These long chains reduce the tendency of particles to move. On the other hand, when you have tiny particles like methane, ethane, or other short-chain hydrocarbons with just two, three, or four carbon atoms, their volatility is very high. In such cases, even at lower temperatures and pressures, they remain in a gaseous state. Now, let's consider long-chain hydrocarbons. They can result in the formation of substances like paraffin, wax, or heavy oil. So, obtaining natural gas may contain your adversaries: H_2S (hydrogen sulfide) and CO_2 (carbon dioxide). If these components are present in natural gas, it's called sour gas. However, when you successfully remove H_2S and carbon dioxide, the gas becomes sweet. The term 'sweet' here doesn't mean sugary; rather, it indicates the absence of sour or bitter elements.

Now, natural gas may also contain water. When separating natural gas, you must remove both the sour components and the water content. The reason for removing water is that gas suppliers, such as Indian gas companies, aim to provide gas without any water content. This is important because burning gas can cause the water to evaporate, turning it into steam. The process of creating steam absorbs latent heat. As you might recall from your schoolbooks, water boils and creates steam at 100 degrees Celsius. When it does so, it absorbs heat from its surroundings. If you burn, for example, Indane gas, it generates a lot of heat, and this heat can also heat the water, causing it to produce steam. When steam is created, it removes latent heat that cannot be recovered.

Consequently, some of the energy, or calorific value, in the gas is lost. This is why gas companies like Bharat Gas or Indane Gas ensure that their supplied gas is free from water content. The water in the gas would otherwise reduce the total energy value delivered to consumers. They remove the water content to obtain pure gas with a higher heating value. In a gas processing unit, they ensure that all impurities are removed from the gas. If this isn't done, Indian Oil will not purchase the gas, and won't be sent to customers. During the production and processing phases, a contactor column is utilized. This column is known as a contactor column. In the contactor column, gas is injected from the bottom, which resembles a column like this. These are referred to as contactor columns.

Initially, a contactor column is used, and gas flows in from the bottom, while amine solution is introduced from the top. This lean amine solution interacts with the incoming gas, which may contain sour components such as H_2S, CO_2, and H_2O (not O_2). All these components are present when the gas enters the column. As the gas passes through the amine contactor column, lean amine is initially introduced, and as it exits, it becomes rich amine. Rich amine indicates a higher concentration of acidic components like H_2S and carbon dioxide due to the chemical reactions. The rich amine is further processed to make it lean again, and this cycle continues.

The gas injected into the first contactor column contains water because it has been in contact with the amine solution mixture. The gas is passed through the next contactor column to remove this water content, where lean glycol solution is injected. In this second contactor column, the gas loses its water content and becomes dry gas, also known as sweet gas. So, the acidic components are removed in the first stage, and in the next stage, the water content is removed. Both acidic and water components have been removed, and now you have gas that can be sent to the customer. Normally, companies like Indian Oil purchase this gas and deliver it to customers like you and me.

Regarding oil separation, as I mentioned earlier, oil often contains water components that need to be separated. When separating oil, you encounter challenges related to multiphase situations. In cases with multiple phases, it may take longer or require injecting certain chemicals to achieve separation.

Now, let's discuss water and sand handling and disposal. Water separation is essential because you cannot simply dispose of water when producing oil and gas from a wellbore. In fact, throughout the wellbore's lifespan, you will likely produce more water than oil or gas. Water is more abundant in the reservoir than oil, oil, and gas combined. However, the water produced is unnecessary, so it must be disposed of properly. Environmental agencies oversee this disposal process and set criteria. The key criterion is that water must not contain any oil components. Therefore, you must remove oil from the water before disposing of it. To achieve this, separators are used. These separators create distinct layers, typically water, oil, and gas. When extracting gas, you also extract some water. This water is passed through a skimmer, often in a pond or dike.

In a dike, you store the oil for an extended period, allowing the oil and water to separate over time. You can then remove the oil using a particular technique while the water is collected separately. If an oil component is still present, you might consider passing it through another type of mechanism, such as a hydrocyclone, to remove any remaining oil particles from the water. When it comes to disposal, you have several options. If you have a wellbore, you can re-inject the water into the reservoir or another suitable location. Alternatively, you can drill a hole and re-inject the water, eliminating the need for surface disposal. Disposing of water on the surface can lead to environmental hazards due to soil particles, which is undesirable. Therefore, re-injection is often preferred.

For sand handling, let's consider a scenario where you're separating gas, oil, and water. At the bottom of the separator, you may find sand accumulating. Many separation engineers periodically open a bottom valve to remove the sand or thick mud-like deposits. However, it's crucial not to dispose of the sand randomly, as environmental agencies oversee such activities. To address this, you must remove all the hydrocarbons from the sand. You can achieve this by allowing sufficient settlement time, causing the sand to settle at the bottom, with water and liquid oil layers on top. Another method involves using a hydrocyclone.

What is a hydrocyclone? It's like a funnel-shaped structure, similar to a funnel you might have seen. It has an inlet channel from the side where fluid enters tangentially. If I draw a side view, the entry is here, and fluid enters like this, creating a tangential rotation. It touches the wall and rotates due to gravity. The fluid tries to move downward while turning, akin to the swirling motion in a toilet flush chamber, going from a larger diameter to a smaller one. Due to centrifugal forces, high-density particles attempt to touch the walls of the hydrocyclone, whereas low-density particles lack the energy to displace high-density ones. Instead, they rotate along with the flow, creating a rotational motion. High-density particles move outward in the hydrocyclone with their tremendous energy, while the inner core contains low-density particles.

In the case of sand separation, high-density sand particles rotate at larger radii and move downward. This results in sand accumulating at the bottom alongside the fluid component. Lighter components also attempt to move downward but don't find sufficient space, leading to their accumulation in the inner core. A long pipe is used to extract the low-pressure, low-density fluid to separate these low-density components. This process occurs within the hydrocyclone.

Hydrocyclones are used in various applications, including particle settlement in environmental contexts and many other situations. They are highly effective for separation processes because they lack any moving parts. When considering mechanical elements, having many moving parts can reduce reliability and lifespan. To increase the longevity of a mechanical component, you need to minimize the number of moving parts. In the case of hydrocyclones, there are no moving elements; you can observe only fluid particles rotating.

Comparatively, in other recent uses, such as in the medical industry, the lifespan may decrease if you introduce mechanical rotation, and energy consumption becomes necessary. However, in hydrocyclones, you utilize wellbore fluid's existing energy. This fluid is provided at high pressure and velocity, continuously driving the separation of two particles. This approach leads to a longer lifespan and is more straightforward and cost-effective. In practice, hydrocyclones are commonly employed by environmental agencies for particle separation processes. Many industries, including the oil sector, use hydrocyclones or sand separators. The term 'hydro' in hydrocyclone signifies water. Regarding disposal, once all the oil or hydrocarbon particles have been removed, you can dispose of the materials anywhere.