Artificial Lift

Prof.Abdus Samad
Department of Ocean Engineering
Indian Institute of Technology Madras, Chennai

Lecture-03 Well Completion

Once drilling is completed, the cementing process is typically part of the completion stage. When you are completing the wellbore, you have a drilled hole. Let's say you've already mentioned that cementing is done. So, these are rocks you've cemented around them, and this is the metal pipe or casing used for drilling. You can also opt for tubing less production, drilling a hole directly into the reservoir, and oil and gas flow up without additional pipes. This is known as tubing less production. However, for safety reasons, government agencies often require tubing. If there is a casing leak, hydrocarbons can potentially enter the aquifer zone, posing a risk to the environment and drinking water sources in areas with trees.

Tubing is often necessary, and you would have to use it. You have the hole and casing in place and insert the tubing. The casing and tubing are shown here, and this is the surface. Between the tubing and casing, you install a packer. When we refer to a packer, it is represented by a symbol like a square with a cross. What happens is that wellbore fluid, if present, may enter the space here, but it will not penetrate the annular area. The annular area remains isolated from hydrocarbons or wellbore fluids. Wellbore fluid can consist of oil, gas, water, and sand; these four components may be present in the reservoir or wellbore. If you do not put packer then fluid will enter into the annular area between tubing and casing that annular area also will be filled by your wellbore fluid. So normally people will be packing or putting some sealing arrangement so fluid will not enter there. So that area will be used for another purpose we will discuss later. Now in some cases there will be two type of sand one called consolidated sand another will be unconsolidated sand.

Compact sand can be either consolidated or unconsolidated. Consolidated sand refers to sand that is tightly packed, unlike unconsolidated sand, which is loose. If you visit a sea beach and pick up sand, it will be loose, demonstrating unconsolidated sand. In contrast, consolidated sand resembles rock; you cannot easily separate the sand particles by hand. Consolidated sand is bound together, while unconsolidated sand lacks sufficient bonding.

If a reservoir contains unconsolidated sand, it can easily move when fluids such as oil, gas, water, and sand flow into the wellbore, eventually reaching the tubing. In such cases, the small sand particles can cause issues, which I will explain later. Following drilling and cementing, the wellbore is prepared for production during the completion stage. When preparing it, consider whether there is consolidated or unconsolidated sand. If there is consolidated sand, then you can go for a barefoot completion. Barefoot completion means you do not need anything just you drill a hole you get a production like only casing is there or maybe you can put one tubing. You put one tubing and tubing will get production so you are not putting any sand control and other equipment. So next is a pre-drilled slotted liner. So you drill a hole and you put one tubing and you put lots of liner pre-drilled liner. Liner means like one pipe is there one enclosed then you put lots of small small holes. So the fluid oil gas will be entering there, but big sand particles may not enter that slotted liner. So it is the easiest option for sand control. If sand is coming this because of small small holes and may not be entering so you will get oil gas.

So, this is called a pre-drilled slotted liner. Fluid enters the wellbore because the higher reservoir pressure creates a natural flow. Sometimes, cementing and perforation are also required. Let's say you have a wellbore with casing in place, and cementing has been performed, but perforation is still needed. Perforation, which I'll discuss later, involves creating holes in the casing. Simply drilling holes in the pipe won't suffice. Instead, it would help if you created longer holes so that the reservoir can connect to the wellbore, enabling production.

Without this connection, production would be limited, especially in cases where the sand is not highly permeable. Permeability refers to the ability of oil or gas to flow through the interconnected pores. If you fail to connect these small pockets within the reservoir, drilling a hole may only yield oil or gas from one pocket while leaving others isolated. To maximize the production, it's crucial to establish connections between these pockets. Cementing and perforation are essential in achieving this goal in some cases. In other situations, open-hole sand control is employed, where only a pipe is used without additional sand control equipment.

So, sand can automatically enter the wellbore in unconsolidated cases, but in consolidated cases, you may have more control over this. There are different types of sand control systems. First, you can drill a hole without considering whether sand will enter, and you proceed with production. Another option is to drill a hole and insert a pipe with small holes, known as a slotted liner. This helps reduce the amount of sand entering the wellbore, allowing for smoother production. In another approach, you cement the casing properly, blocking the flow, and then create numerous perforations or long holes. These perforations connect the reservoir fluid pockets to your wellbore, enabling production.

The reason for implementing sand control techniques is to prevent a significant build-up of sand, which could block the pipes, chokes, or valves within the conduit. This is particularly important in upper completion. The wellhead includes components like the casing hanger, tubing hanger, and tubing hanger, facilitating the flow path. When fluids move from the wellbore to the surface, they pass through the wellhead.

The wellhead facilitates the flow of fluids coming out. It is connected to a choke, which provides control over how the fluids are released. Additionally, there is accessibility for kill fluid. Kill fluid accessibility means that if there is any issue in the wellbore, you can inject a very high-density fluid to stop oil and gas production. This is crucial because uncontrolled oil and gas reaching the surface can be disastrous and dangerous. It's a combustible mixture, and if it comes into contact with the atmosphere, it can lead to explosions or fires. For example, in the event of a failure in the artificial lift system within the wellbore, such as needing to replace a centrifugal pump or an Electric Submersible Pump (ESP), you must halt production first. To do this, you inject kill fluid—a high-density fluid. When the reservoir and hydrostatic pressure in the column become equal, production ceases, and no oil or gas enters the wellbore. The flow is stopped at this point, and you can remove the tubing and the centrifugal pump or ESP.

After the injection and replacement are complete, another fluid is injected to replace the high-density kill fluid. Once the kill fluid is removed from the wellbore, reservoir production can resume. A kill wing or kill flow path is essential for controlling the flow during various operations. Another related term is called a choke.

A choke is essentially a valve used for production control. A choke valve is employed to regulate the flow rate. For instance, if you aim for a production rate of five barrels per day, the choke valve has an adjustable mechanism, typically a wheel, to control the flow rate. Changing the production rate must be done slowly and in consultation with reservoir engineers. This allows for monitoring potential issues, such as sand accumulation or increased water production. For example, when changing the production rate from five barrels to ten barrels, there might be instances where more water is produced than oil or gas. While water is produced, it is not usable and needs disposal. Disposing of water is not easy, mainly if it contains hydrocarbons, as removing those hydrocarbons is an expensive process.

Ideally, you should minimize water production as much as possible throughout the wellbore's lifespan to make it more cost-effective. Disposing of water involves either reinjecting it into the wellbore or treating it to remove hydrocarbon particles, both expensive. In summary, abrupt changes in production rates should be avoided. Gradual adjustments are necessary to prevent sudden shocks to the reservoir, which can lead to altered sand-to-water ratios. Such issues can be economically problematic and pose challenges for maintaining the entire system.

A choke valve controls the flow rate, allowing you to regulate whether you want zero flow or any desired flow rate. This is part of the upper completion. The wellhead contains components such as the casing and tubing hanger, which enable the flow path. When fluids move from the wellbore to the surface, they pass through the wellhead. The wellhead facilitates the flow coming out, connecting it to a choke, and provides accessibility for killing fluid. Kill fluid accessibility is crucial, as it allows you to inject a very high-density fluid into the wellbore in case of issues. This high-density fluid stops oil and gas production. Uncontrolled oil and gas reaching the surface can be disastrous and dangerous, forming a combustible mixture. If something goes wrong, you can inject kill fluid to halt production. For example, if there is a failure in the artificial lift system within the wellbore, such as the need to replace a centrifugal pump or an Electric

Submersible Pump (ESP), you must first stop production. To do this, you inject a high-density kill fluid. When the reservoir and hydrostatic pressure in the column are equal, production ceases, and no oil and gas enter the wellbore. After the injection, you replace the high-density kill fluid with another fluid. Once the kill fluid is removed from the wellbore, reservoir production can resume. This is why a kill wing or kill flow path is necessary to control the flow during various operations. Another related term is called a choke valve. A choke valve is a valve that provides production control. For instance, if you want to produce at a rate of five barrels per day, the choke has an adjustable mechanism, often a wheel, to control the flow rate without causing shocks to the wellbore.

When changing the production rate, proceeding slowly and consulting with reservoir engineers is important. This allows you to assess whether there might be issues such as sand accumulation or water influx. For instance, if you're increasing the production rate from five barrels to ten barrels, there may be instances where water production exceeds that of oil or gas. While you do produce water, it's not usable, and disposal is challenging, especially if it contains hydrocarbons. Removing those hydrocarbons is also an expensive process. Ideally, you should minimize water production as much as possible during a wellbore's lifespan, as it's more cost-effective. Disposing of water is difficult; you may have to reinject it into the wellbore or treat it to remove hydrocarbon particles, both of which are costly. Therefore, sudden changes in production rates should be avoided. Adjustments should be made gradually to prevent sudden shocks to the reservoir, which can result in changes to the sand-to-water ratio. Such issues can be economically problematic and pose challenges for maintaining the entire system. The choke valve plays a crucial role in controlling the flow, allowing you to regulate it from zero discharge to 100 barrels or 2 barrels, providing precise control.

Next is the Christmas tree. During the drilling process, the first thing you install is the wellhead, and within the wellhead, there is a system called a BOP (blowout preventer). The BOP serves a critical role. As I've explained earlier, let's consider a reservoir with gas located beneath a cap rock, and you're drilling a hole up to that point. You drill up to the cap rock, and suddenly, your drill bit reaches the gas zone. When this happens, there's no pressure in the cap rock, but the gas zone has very high pressure.

The gas will attempt to enter your drill pipe and other areas, causing a sudden gas release. If the hydrostatic pressure applied by the drilling mud, which has a high density, as I mentioned earlier, cannot control this release, it will gush uncontrollably. In such a scenario, a piece of equipment is known as a BOP (blowout preventer). The blowout preventer is designed to stop this uncontrolled flow. When the blowout preventer comes into action, the entire operation is halted because it signifies an unsafe situation.

So, once the blowout preventer (BOP) has taken action, drilling engineers will assess the mud density and other factors to regain control over the wellbore. Failing to control it could lead to a major fire incident. A few years ago, in 2010, off the coast of Mexico, there was offshore drilling on the semi-submersible platform known as the Deepwater Horizon. During drilling, gas unexpectedly surged up the wellbore. The BOP activated, but unfortunately, it failed, allowing the gas to escape and triggering a fire. Tragically, this incident resulted in the loss of several engineers' lives, and the entire semi-submersible platform sank, releasing significant amounts of oil and gas into the water.

When oil and gas are released into the water, it poses severe environmental hazards. After several months, British Petroleum (BP), which was conducting drilling operations in American waters in Mexico, regained control of the wellbore and resumed production. The BOP consists of several stages of RAM (blowout preventer rams) or valves. If one stage fails to act, another stage will activate. Unfortunately, the entire BOP system failed in this case, leading to the submersion of the massive semi-submersible platform in the water. During the drilling process, the first step is installing a wellhead and then placing the BOP (blowout preventer) above the wellhead. Once drilling is completed, the Christmas tree is established.

How is the Christmas tree installed? Well, you begin with the wellhead, which includes the casing hanger, tubing hanger, flow loop, flow line, and the Christmas tree. The Christmas tree is equipped with multiple valves designed to control the flow. Why so many valves? It's primarily for safety reasons. There's the primary valve, a secondary valve, and a kill valve, among others. If you look at a picture or search Google Images for a Christmas tree used in the oil and gas industry, you'll see an arrangement of several valves. There's a lower valve, an upper valve, a kill wing valve, a choke wing valve, and more, including pressure gauges.

The Christmas tree is essentially a setup with several valves integrated into it. After drilling, the Christmas tree is installed to enable stable production. Production is obtained through the choke, and the kill wing injects high-viscosity, high-density fluids. The upper and lower completion parts are fixed and then handed over to the production engineer during well completion. The engineer ensures stable production and manages other aspects, which we will discuss later. Imagine you have a solid rock formation and a reservoir, perhaps containing gas, oil, or both, with substantial sand content and very durable rock. In such cases, there may be limited connectivity or permeability, which are important terms to remember when studying oil and gas: permeability and porosity.

In reality, a reservoir consists of numerous pores, which may not always be connected. You won't achieve production when the pores are not connected, and you drill a hole. To enable production, there must be connectivity. If the rock is permeable, it naturally has this connectivity. However, there are cases where there are pores but they are not connected. In such situations, a technique called fracking is employed.

To perform fracking, you start by drilling a hole and then apply very high pressure from the surface using a pump. This high pressure is applied to crack the rock formation. As a result of this high pressure, the rock fractures, creating spaces like jaws. This opens up the small pores that were previously disconnected, providing extended connectivity from the wellbore. However, the challenge is that these cracks tend to close over time.

Proppants, such as sand particles, are injected into the fractures to prevent closure. These sand particles help maintain the openings, ensuring the fractures do not seal shut. This creates gaps through which oil and gas can flow into the wellbore, resulting in increased production. Multiple cracks are created using this process, commonly known as hydraulic fracturing or fracking. Another related term is acid fracturing.

In acid fracturing, the process involves applying higher pressure to create fractures and then injecting hydrochloric acid (HCl). A reaction occurs if the rock contains calcium carbonate: CaCl + H_2O. This reaction creates openings in the rock, enhancing connectivity by generating numerous tiny pores through the acid's reaction with calcium carbonate. Many times, petroleum engineers opt for acid fracturing, where they inject hydrochloric acid into the wellbore. This acid reacts with the calcium carbonate rock, eroding it. When the acid reaction is complete, the rock automatically opens up because of the erosion. Unlike in the previous case of hydraulic fracturing (hydrofracking), where proppants are used to keep the rock fractures open, this step isn't necessary in acid fracturing. Due to erosion, gaps are naturally created, and numerous small pores form, leading to increased production. Acid fracturing is typically performed during the completion stage.

I've already mentioned perforations. So, what are perforations? Perforations come into play when you have a solid rock or consolidated formation that has been cemented. In such cases, you won't get production if the reservoir is behind cemented layers. Perforations are made by creating holes in the cement and casing to overcome this. Here's how it's done: When you have a cemented area, you use a perforation gun. Typically, explosives like TNT and RDX are injected through the gun. The gun is inserted, and when it's in place, the gunpowder detonates, creating these holes known as perforations. These explosives generate extremely high pressure, which fractures the rocks and creates holes. It's important to note that these explosive materials are susceptible, and large oil companies require government permission to transport them between countries due to the potential for misuse.

The government imposes restrictions on using explosive materials like TNT and RDX. Only major companies like ONGC are granted licenses for their use, and even then, they require special permission. Selective perforation involves deciding where to make holes in the well casing. Let's say you have a reservoir with oil, gas, and water in different areas. When drilling, you need to determine which areas to perforate. If you want to extract oil, you only perforate the oil-containing area. Similarly, for gas, you drill in the gas-rich zone. It's crucial to avoid mistakenly perforating the water zone, which would increase water production. Drilling in the oil zone yields oil, while drilling in the gas zone yields gas. When drilling for the first time, if you have gas and oil in the wellbore, it's advisable to extract the oil first. This is because starting with gas may lead to reduced oil pressure, making oil production less economical. Therefore, the sequence matters. Every wellbore contains a mixture of water, oil, and gas. Engineers classify them as gas or oil wells based on the gas-oil ratio (GOR). If the GOR is high, indicating a significant proportion of gas, it's considered a gas well. However, oil may still be present, requiring careful management during artificial lifting.

Once drilling, exploration, hole completion (including casing and cementing), perforation, and fracturing are completed, you fix the wellhead, Christmas tree, kill wing, and choke. With these components in place, the wellbore is ready for production. Production is facilitated through the wellhead, Christmas tree, and choke to regulate the flow. Now, let's talk about artificial lift. During the completion stage, if the reservoir pressure is low, you must apply additional pressure to move the fluid to the surface. If the reservoir pressure is very high, natural flow may occur initially for a few years. However, as you extract fluids from the wellbore over time, the pressure will gradually decrease. Eventually, production may cease. To maintain economical production, you need artificial means or mechanisms to lift the well fluid from the wellbore to the surface. This is where artificial lift techniques come into play.

Several artificial lifting techniques are available, including gas lift, submersible pumps, progressive cavity pumps, sucker rod pumps, jet pumps, and hydraulic jet pumps or hydraulic engine pumps. These techniques are used for pumping and managing wellbore sand control. Regarding sand control, I've previously mentioned that sand can harm production. For instance, excessive sand can block the flow path, erode surfaces, or destabilize the wellbore. So, how do we control sand? Consider a wellbore with perforations in a cemented area, creating a tunnel through the rock. The area comprises sand, cementing, casing, the wellbore, and reservoir.

When you are producing sand from a wellbore with gas, there may be a relatively small amount of sand production initially. Slowly, it will form a small arch. However, this arch can be broken if you suddenly change your production rate. When the arch breaks, sand production will continue until a new arch is formed. This continuous sand production can lead to increased sand output. That's why it's important not to make abrupt changes in your wellbore's productivity rate at the surface. Maintaining a stable production rate over an extended period can minimize sand production, avoid water injection, and achieve greater economic efficiency.

*****Thank you very much*****