Artificial Lift

Prof.Abdus Samad

Department of Ocean Engineering

Indian Institute of Technology Madras, Chennai

Lecture-02 Drilling and Completion

This lecture contains a basic description of upstream, midstream, and downstream oil and gas operations, focusing on the upstream side. Upstream oil and gas activities encompass exploration, drilling, completion, and production. You must undergo these phases before obtaining oil, gas, petroleum, or crude oil. Once you produce the fluid, whether gas or oil, it undergoes separation during production. After this, you move to the midstream phase, which involves pipeline, truck, or shipping to transport the resources from one location to another. The ultimate destination for these resources is typically the refineries.

It's important to note that this course primarily concentrates on the upstream sector, including artificial lifting techniques. At each stage of upstream operations, various challenges arise. For instance, during the exploration phase, you need various instruments and technologies to determine the presence and quantity of oil and gas in specific locations, fields, or reservoirs. Once you confirm a sufficient amount of oil and gas, you proceed to drill in the reservoir area to extract these resources.

When drilling, several issues can arise. For example, an uncontrolled flow may occur due to extremely high reservoir pressure. If oil and gas gushing out uncontrollably, it can lead to disasters and dangers. Therefore, it's crucial to maintain control during drilling operations. Once drilling is complete, the wellbore must be prepared for production. During the completion stage, various issues are addressed, and the wellbore is readied for production. Completion activities include cementing, proper installation of pipes, fixing Christmas trees, operating valve systems, connecting piping systems, and installing artificial lifting systems, among others. Once all these tasks are completed, production engineers ensure stable production over an extended period. Oil and gas engineers aim to optimize production, not necessarily maximize it.

For example, if you aim to maximize production today, let's say you're getting 100 barrels per day, you may not achieve the same production rate tomorrow. This variation occurs because high production rates today could result in water instead of oil or an increase in sand content tomorrow. That's why production engineers focus on optimizing production rather than maximizing it. The next step is to transport the produced fluids, such as oil and gas, downstream through the midstream to refineries. Refineries separate products, including diesel, petrol, naphtha, kerosene, aviation fuel, plastics, and various medicinal compounds. So, petroleum products have applications beyond just being fuels. This is why exploration, gas, and production will likely continue for several decades. When discussing upstream oil and gas, there are two types of wellbores: offshore and onshore. We've already talked about offshore wellbores related to the ocean.

For instance, imagine you have the ocean seabed on one side and land on the other. There's a vast expanse of water in between. Sometimes, you may find an oil reservoir beneath the seabed, while others might be on land. When drilling in an offshore area with a reservoir, you must install a platform, perhaps a semi-submersible, or a drilling ship. This platform comes equipped with a mast or derrick, allowing you to drill a hole down to the reservoir from the semi-submersible platform. This platform is a drilling rig with a pipe extending to the seabed. As you drill the hole, you must pass through a large body of water, which can be quite turbulent due to wave motion, currents, and wind loads affecting the semi-submersible platform. When the wind blows, the semi-submersible platform begins to float and can move in various directions—left, right, forward, backward, and even vertically. This means that the drilling rig experiences a wide range of motions.

In such cases, you must have a satellite positioning system. Satellites send signals that help accurately control your drilling ship or vessel's position. The drilling pipe could break or deviate from the intended reservoir location without precise positioning. Sometimes, the drilling platform may be moored, while others may not. You don't encounter the same water-related motion issues when dealing with land-based wells. You can drill directly into the reservoir to begin production. So, now you understand the difference between offshore and onshore wellbores. Offshore drilling requires a ship, floating platform, or some form of platform to send the drill pipe through the water and into the reservoir. This is the technique used for offshore drilling. On the other hand, with onshore drilling, you can directly insert your drill pipe into the reservoir.

Once drilling is complete, it's essential to complete the wellbore before you can start production properly. There are various types of platforms available for offshore drilling. I've drawn one here, which is a semi-submersible platform. Other options include jack-up rigs, gravity-based structures, drill ships of various shapes, movable drill ships, and what they call MODUs (movable offshore drilling units). With MODUs, you can drill one wellbore and then move the drill ship to another location to drill another hole. However, for onshore applications, you don't typically use large semi-submersible platforms or jack-up rigs—these options are unnecessary.

When moving your drilling equipment, you can use trucks. However, helicopters can transport the rigs to the desired location when the location is inaccessible by road. For instance, helicopters can transport the drilling equipment and rigs, clear the area, and commence drilling to extract production if you're drilling in a forested area with no road access. Now, regarding drilling, I previously mentioned the exploration phase. During this phase, you evaluate the quantity of oil and gas available at the depth of the reservoir and make predictions of this sort.

The subsequent phase is drilling itself. When preparing for drilling, several considerations come into play. It would help if you determined whether a platform is necessary, whether you'll require a derrick and mast, need drill pipes for transport, or need clearance from government agencies. Numerous activities must be undertaken before drilling. Once you're ready to drill, you'll have a platform in place and employ a mud system, which I'll explain later. The mud system functions like when you observe metal-cutting machines or wall-drilling machines. Often, a liquid is used to lubricate and facilitate faster and safer movement of the drill cutter.

Next, a derrick and mast will be in place for the drilling operation. The derrick or mast typically looks like this. All drilling activities are conducted from this mast, and there's usually a small platform connected to it. Over the platform, you'll have a pipe. This pipe is the drill pipe, which plays a crucial role. When you embark on drilling, there's a connection to the drill pipe, which carries the drilling fluid. This drilling fluid flows through the drill pipe connected to the derrick. A drill cutter is employed in the drilling process, and as it cuts, the drilling mud passes through the tube. Subsequently, the drilling mud circulates back to a pond, where it is pumped again. This is a simplified representation, and I'll provide a more detailed depiction shortly.

Before drilling begins, the rig site must be prepared. Sometimes, after exploration, you may find the drilling area inaccessible. Inaccessibility could be due to dense forests or numerous trees obstructing access. In such scenarios, the question arises: how can drilling be performed there? Options include building a road or planning for helicopter transport. If a road is feasible, then trucks are the means of transportation. However, there are instances where a nearby road exists, but there is no direct connection from the road to your drilling site. In such cases, road construction becomes necessary. Before road construction, you must obtain permission from the landowners who own the land providing access to this reservoir or area. So, then, you have to obtain permission from the landowners. You need to construct a road to clear the area, and if it's a forest, you may need to remove a few trees to ensure the land is clean and smooth. Sometimes, you'll also need to create pits, including mud pits. A mud pit is where the drilling fluid, as I mentioned earlier, will circulate and be stored—similar to a small pond. You must prepare these elements beforehand.

Additionally, you'll need to set up small houses for accommodating engineers and technicians. There should be provisions for food, including a small restaurant system for people to eat, as well as toilet facilities. A power connection system is essential for running various equipment. All these preparations must be completed before actual drilling begins, including obtaining land and local environmental permissions, government approvals, road construction, and the acquisition of pipes, drilling equipment, and trucks. This phase is referred to as preparing the rig site.

Next is the drilling stage. Once you've prepared the drilling site, everything, including the drilling rig system with the derrick, comes together. You'll also bring in all the necessary pipes, including drill pipes, casings, and the mud handling system. Furthermore, you'll require a cementing and cement handling system. When it comes to power sources, you can use electricity directly if you have access to electrical connections. However, in many cases, there won't be access to electricity. In such situations, you'll need to bring in internal combustion engines, often called IC engines. I'll discuss IC engines in more detail later. These IC engines provide power, which needs to be converted into electricity. This electricity will run various items, including geysers, water systems, and other necessities such as bathing and cooking. Essentially, a diesel engine will be used as the primary power source.

Now, when you are going for drilling, you need to carry drill pipes. Drill pipes are like metal pipes, typically several feet long, maybe 30 to 40 feet long. These pipes will have drilling fluid. Let me draw the drilling process again. First, you drill a hole, and then the drill pipe, which looks like this vertically, connects to the drill collar and bit. This is the drill collar, this is the drill bit, and these are the drill pipes. There's a pipe connection that goes to the mud pit.

This pipe connection sends the drilling fluid to the mud pit during drilling. Let me also draw a derrick, which is a structural element. It looks like this from a distance. This is the derrick, these are the drill pipes, this is the drill collar, and this is called the mud pump. The fluid flows like this from the mud pump. Before the mud pump, there's a shell shaker, which I'll draw like this. During drilling, the fluid is pumped through the system. The drilling fluid or mud passes through small holes in the drill bit, which cuts the rocks. As the drill bit cuts the rocks, significant friction generates heat. The mud serves two purposes: it reduces heat and provides lubrication. This lowers the heat generation due to friction. If heat is generated, the mud removes it because the fluid circulates constantly. How does it circulate? The fluid exits, moves up after cutting, and goes like this. This continuous loop is the mud flow. So, what about the mud you prepare? Mud typically contains bentonite; you mix bentonite with water to create drilling mud. Sometimes you also add other types of chemicals, like caustic soda, to modify the drilling fluid's properties. You may need to increase or decrease viscosity or density based on the specific requirements. I'll explain why drilling fluid properties are important for this application shortly.

First, let's understand the drilling fluid circulation. The loop consists of a drill pipe coming vertically from top to bottom. At the bottom, a rotating drill bit continuously cuts into the rock. Simultaneously, a mechanical arrangement at the top keeps the drill pipe spinning continuously, allowing you to cut the rock while applying pressure. As the rock breaks apart, many small particles chip off. If these rock particles were to stay in place, they could block the pipe. You need to lift the rock particles to the surface to prevent this. How do you do this? By using drilling fluid with high viscosity and density. The high viscosity of the drilling fluid helps the rock particles move upward with the fluid flow. You inject the drilling fluid into the system, which doesn't have rock particles initially. As it mixes with the rock particles, they get carried along with the fluid and move upward.

The mixture first passes through a shale shaker when it reaches the surface. The shale shaker contains a mesh that continuously shakes. As the mixture flows over the mesh, the fluid passes through while the solid rocks remain above it. This process separates the larger, discarded rocks from the liquid. The separated liquid is directed into a mud pit. Additionally, there may be a centrifuge or centrifugal separator, which uses centrifugal force to further separate smaller mud particles and rock particles from the mud.

So, once you've separated the bigger particles from the smaller ones, you store the same fluid in a mud pit for a certain time. This allows any remaining smaller particles to settle down within the mud pit. Afterward, you can mix it with the desired fluid or chemicals. Otherwise, you pump the same fluid using a mud pump. The fluid From the mud pump goes through the Kelly, the section before the drill pipe. Through the Kelly, the fluid flows into the drill pipe and the drill bit, maintaining the circulation loop throughout the drilling process. Sometimes, you need to adjust the drilling fluid's properties. The purpose of drilling fluid is to provide sufficient viscosity to transport the drill cuttings from the wellbore to the surface. It also reduces temperature by acting as a coolant for the drill bit.

Additionally, it helps create hydrostatic pressure. The need for hydrostatic pressure arises because oil and gas are typically stored within a specific rock formation when drilling into a wellbore. This formation has a cap rock. As I discussed in another lecture, maintaining hydrostatic pressure is crucial when drilling vertically into it.

So, there will be a cap rock. When the cap rock is drilled, you suddenly enter the formation or a high-pressure zone. The high-pressure fluid will push everything from the wellbore to the surface if you don't control the pressure. This can be disastrous, as uncontrollable gas and oil can come out, and if there's any small ignition source, it can lead to a significant burst. To prevent such incidents, drilling mud is pressurized to a certain extent. When you encounter high-pressure areas after cutting through solid rock, the fluid will attempt to enter through the drilled hole. To counter this, you inject drilling fluid with very high pressure and density, creating (h. ρ. g) pressure, where increasing rho results in higher pressure within the drilled hole. This higher pressure in the drilling fluid ensures reservoir fluids do not enter the wellbore. However, in cases where the pressure remains very high and cannot be controlled, an additional safety mechanism known as a blowout preventer is employed, which I will discuss later.

Now, with the mud system in place, you understand its purpose: to cool the drill bit, lubricate, and maintain hydrostatic pressure. Now, once everything is set, you start drilling a hole. Initially, you might drill a vertical hole. Another possibility is drilling a hole vertically and then going horizontally or choosing a slanting path. Different types of wellbores are available. A vertical well is relatively easy to drill, but there are issues. For instance, a vertical wellbore provides a limited connection area if you have a thin reservoir and want to maximize production. As a result, fluid enters through these small openings, resulting in a low flow rate. In such cases, you might perforate the reservoir to create more extended connectivity areas.

In this case, you only get this one, so in case 2, 'longer' means you are getting more production. Your flow rate will be higher. However, in some cases, you might create a horizontal wellbore based on your reservoir size or conditions. In other cases, you might create shapes like 'S' shapes. Many different shapes are also possible, depending on reservoir conditions. Another condition can be remote areas. For example, what can you do if you want to drill a hole inside an IIT campus but IIT or the government won't allow it? You drill a hole outside the IIT campus where land is available. This is your IIT campus, and the available land is here. You drill a hole here and go horizontally to access that area. IIT will not be aware that the oil is coming from IIT. Similarly, instead of going directly into the ocean in offshore areas, you can drill a hole here and reach a reservoir.

In cases where there's geological isolation, and you can't drill directly into the reservoir, you may need to drill horizontally or in different shapes instead of vertically. If there are accessibility issues, such as forests, cities, ponds, or other obstacles, you may opt for horizontal drilling or different types of holes instead of vertical ones to increase production. Ultimately, the goal is to maximize production, which benefits both the company's and the country's economy. Engineers worldwide, including those in India's Mumbai High, have explored various wellbore types. Initially, they drilled vertical holes, but later, they drilled horizontal wellbores to achieve higher production rates. Another option is multilateral drilling. In multilateral wellbores, you start with a vertical hole and create branches like this. For example, you have oil or gas sources in different locations. You can access all the oil and gas from a single surface location using a multilateral wellbore. Consider offshore drilling, where you have a large platform equipped with all the drilling mechanisms, including mud handling. You need to access multiple areas several kilometers away to maximize production.

So, one costly platform is costly mainly because it requires satellite communication, radar systems, and thrusters and typically resembles a mini-town for oil and gas operations. Engineers reside there, and it includes amenities such as swimming pools, sports facilities, and even a helipad for accessibility. If you search on Google, these platforms are among the largest artificial structures. They are typically semi-submersible or floating platforms with a single access point. However, when they reach the reservoir, they have multiple branches, each leading to a different reservoir. Sometimes, selective perforations or drilling are necessary. In this case, you may have multiple layers of reservoirs, one for gas, one for oil, and one for other substances. You drill a hole and insert pipes for each type, and these holes can be made horizontally, vertically, or even as multilateral branches in various directions. Many types of people are attempting to harness the ever-advancing technology to increase wellbore complexity and achieve higher production with minimal investment. This is the primary goal behind exploring various drilling options. Now, during drilling, I haven't discussed casing and cementing yet. When drilling, you prepare the area and then drill a hole, typically starting with a 36-inch hole. Afterward, you insert a metal casing pipe.

I'll use different colors to illustrate. Once the casing is in place, you proceed with cementing. Cementing is depicted in a different color. The casing and cementing have distinct colors. This is the cementing phase. Normally, the initial hole is 36 inches in diameter. After inserting the casing, you fill the space between the rock or mud and the metal pipe with cement, usually regular cement like Portland cement or other varieties used in construction. You insert the pipe and ensure a proper cement seal to prevent mud from entering or any movement. After securing the larger casing, conductor casing, or surface casing a few feet into the well, you repeat the process with additional casing and drilling.

Gradually, the top portion of the wellbore becomes wider. Then, you cement it, followed by inserting a narrower drilling pipe. You continue to drill, cement, insert another narrow pipe, drill again, and then cement again. This process results in a progressively widening wellbore, with alternating pipes and cementing. There are different types of casings involved: surface casing, conductor casing, intermediate casing, and finally, production casing. Each time, you need to apply cementing to secure the casing. When you reach the production casing phase, it may have perforations with many holes used for production purposes. The production casing extends up to the surface, and these sections are already sealed with cement. The production casing is responsible for extracting oil and gas. Cementing is essential at every stage to ensure the stability of the wellbore. Without cementing, the pipe may shift, causing mud to leak, and the wellbore becomes unstable.

So, how do you apply cementing with high pressure? You start by drilling a hole and inserting a metal pipe. Then, you inject a high-pressure cement slurry that you create and mix, pumping it into the wellbore. The cement fills all the gaps between the mud and the pipe at very high pressure. Once the gaps are filled, you allow some time for settling. After settling, you insert another pipe, called a "casing" pipe, and resume drilling further, perhaps another 100 to 1000 feet. Then, you repeat the process, adding mud and cement as needed. The surface area, roughly 100 to 1000 feet deep, needs special attention because it is a safe zone. Trees grow there, drinking water sources are present, and various surface ecosystems thrive. Thus, no hydrocarbon leaks or wellbore fluid escapes into this area. Such leaks could damage the environment and harm the trees. Multiple layers of cementing are applied to ensure the surface area remains safe.

However, different drilling methods may be used as you drill deeper, reaching depths of 500 to 1000 feet or more. Sometimes, open-hole drilling is chosen, where no cementing is required. In other cases, you may employ wellbore completion techniques, sand control systems, or other methods depending on the specific conditions. The purpose of these cementing systems is to stabilize the wellbore and make it safer. They ensure that reservoir fluids do not enter the piping and that the wellbore fluids do not contaminate the reservoir. To achieve this, multiple layers of metal pipes and cementing are employed. Cementing is done from the surface, where a cementing pump delivers a high-pressure mixture, typically using Portland cement. Various agents are added to the cement mixture to control parameters like settling time and viscosity. Based on these parameters, engineers decide the type of chemicals to add during the cementing process. Once the cement is adequately resolved, drilling resumes.

Drilling holes can extend from 100 meters to several kilometers, with standard depths reaching 5,000 or even 10,000 feet. Horizontal wellbores, spanning 10 to 20 kilometers, are also common depending on the project's requirements. Oil and gas experts make decisions regarding whether to create a horizontal, vertical, or multilateral wellbore based on feedback from reservoir engineers, exploration engineers, and initial information gathered during drilling. Other factors, such as accessibility, play a role; drilling may need to be redirected horizontally to access the reservoir if an area is inaccessible. Additionally, permissions are required before drilling can commence.