Artificial Lift

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Lecture-14 Single-Phase, Multi-Phase-Emulsion

Good morning, everybody. Today, I will start the class on multi-phase flow. However, I should clarify that it's not exactly multi-phase but emulsion flow. In the previous lecture, we covered single-phase flow through tubing. Now, we have two more topics to discuss: emulsion transport through tubing and the transportation of gas, oil, or water mixtures through tubing. Today's lecture will focus on emulsion flow and how emulsions work.

First, consider the wellbore, which looks like this with tubing. The previous lecture discussed the casing, tubing, wellhead, choke, separation process, and product delivery to customers, refineries, or transport lines. When oil and gas enter the wellbore, they may contain oil, water, gas, and sand. Therefore, it is not a single-phase flow; it involves multiple phases and components.

We define phases in thermodynamics as gas, solid, and liquid. However, when two liquids are mixed, such as oil and water, it's considered a multi-component flow or sometimes a multi-phase flow. When we add gas to the mix, it becomes an accurate multi-phase flow.

When we have emulsion flow, it's essential to understand how viscosity changes and why viscosity is relevant to artificial lifting systems. This course is related explicitly to artificial lift techniques. Viscosity represents a fluid's resistance to flow, and the inverse of viscosity is called fluidity.

If viscosity changes, it means your resistance changes; if resistance changes, it implies that the pressure drop is changing. In such cases, your pump will need to work harder to lift the fluid. For example, if you alter the water cut or the percentage of water in the oil or suddenly have more water due to changes in reservoir properties, this increased water content will result in higher viscosity. More viscosity leads to more excellent resistance to flow and, consequently, increased pressure drop. If you already have an Electric

Submersible Pump (ESP), sucker rod pump, jet pump, or gas lift system installed, the energy supplied by your pump may no longer be sufficient. In some cases, the pump may not work at all due to the change in viscosity.

Therefore, it's crucial to understand the properties of emulsions, how they affect viscosity, and how this ultimately impacts the artificial lifting system and the entire production process. To comprehend emulsions fully, we need to understand the flow physics, reservoir properties, and how to correlate and formulate these aspects, which I will discuss in this lecture.

Definition of an emulsion is a mixture of two immiscible fluids. For instance, immiscible fluids could be oil and water, similar to the fluids in this bottle, where one part contains water and the other contains oil. When oil and water are mixed, they form an emulsion. However, in most cases, oil and water tend to separate relatively quickly, with very little settling time.

In most cases, oil and water tend to separate relatively quickly, but if we introduce certain chemicals that prevent separation, the oil and water will not separate easily, creating a stable emulsion. This stability is similar to what you might observe in various products, such as hair gels or certain medicines, where suspended particles remain in one fluid without settling quickly. The critical parameter to consider when dealing with emulsions is the water cut, which represents the percentage of water added to the oil. Water cuts can range from 0 percent to 10 percent, 20 percent, 30 percent, 80 percent, or even 90 percent. However, when the water cut exceeds 95 percent, producing oil and gas alongside so much water may not be economically viable.

In such cases, there might be a need to abandon the wellbore or implement strategies to alter reservoir properties to extract more oil and reduce water production. One approach involves chemical injection, which alters viscosity. By changing the viscosity, the oil and water layers within the reservoir can separate more effectively, potentially increasing oil production while minimizing water production.

In the life of a wellbore, if water production exceeds oil or gas production and water is not economically viable, it can significantly reduce the well's profitability. Properly disposing of excess water and managing sand production can incur additional costs. Ultimately, producing excess water can lead to financial losses.

To maximize the economic benefits for your company or country, you must carefully manage wellbores and reservoir properties to control oil, gas, and water production. Emulsions, as mentioned earlier, typically occur when you combine oil and water. Water, denser or with higher gravity, tends to settle below the lighter oil. Generally, when you mix substances like petrol, diesel, or grease with water, they do not readily blend together due to particle size and polarity differences. However, with proper agitation or shaking, as in the case of shaking a bottle, the two substances may briefly mix, but they will usually separate within a short time, sometimes within seconds. When the two fluids separate quickly, this indicates an unstable emulsion.

An unstable emulsion, during pumping, causes water to slide down while oil rises. It becomes relatively easy to separate oil and water in such a separate system. However, the goal is to create a stable solution. A stable solution, where oil and water are mixed and remain stable, typically requires the addition of specific chemicals or surface-active agents known as surfactants. These surfactants prevent the rapid separation of oil and water and contribute to forming a stable emulsion.

To disrupt this stability, you must introduce another chemical type, apply heat, or modify specific mechanical and chemical properties. These actions will cause the small particles to combine into larger ones, promoting quicker settling. Emulsions typically form under intense agitation when oil and gas are present. For instance, if you take one layer of oil and one layer of water and agitate them vigorously, it will create tiny oil and water particles. When these particles mix with certain chemicals, they resist settling and form a stable emulsion. An unstable emulsion will form if you lack these surface-active chemicals or surfactants.

Two types of emulsions commonly found in wellbores are oil-in-water (O/W) and water-in-oil (W/O). In an oil-in-water emulsion, a significant amount of oil coexists with a smaller amount of water as discrete particles. Water serves as the continuous phase in this scenario. Conversely, in a water-in-oil emulsion, a larger amount of water and a smaller amount of oil are present. In this case, we refer to it as oil in water.

Water-in-oil emulsions are typically more stable, and their settling rate is quicker. Smaller particles lead to a more stable emulsion. For example, tiny dust particles remain suspended in the air and don't settle quickly. This also creates an emulsion effect. However, if you take larger sand particles and place them in water, they will settle quickly. But if you grind the sand into very fine particles, it will remain suspended for longer, creating a more stable emulsion or suspension. Sometimes, this is referred to as a colloid. Although colloids and emulsions are distinct, they can share similarities.

When discussing emulsion viscosity, mentioning apparent viscosity (μ_A) is important. The apparent viscosity is the viscosity that is measured and appears to be the highest when the water cut is around 60 to 80 percent. Water cut refers to the gradual increase in the water content when you add a small portion of water to a certain volume of oil.

The percentage of water increases as they refer to it as the water cut. For example, a water cut of 10 percent means a small amount of water, while a water cut of 95 percent indicates that water dominates and the amount of oil is very small. This may still be economical for production. However, if the water cut changes, perhaps due to alterations in reservoir properties or depletion, and water content rises to more than 50 percent, especially in the 60 to 80 percent range, the viscosity becomes significantly higher.

High viscosity increases resistance and pressure drop, potentially causing your pump to malfunction. It's crucial to understand this. The relative viscosity (μ_r) is calculated as the ratio of the apparent viscosity (μ_a) to the continuous phase viscosity (μ_c), where the continuous phase refers to the dominant phase, such as 95 percent oil. Therefore, in this case, the continuous phase viscosity (μco) dominates.

$$\mu_r = \frac{\mu_a}{\mu_c}$$

Now, let's discuss emulsifiers or emulsifying agents, which are sometimes referred to as surfactants. Surfactants have one hydrophilic end and another hydrophobic end. The surfactant molecule appears like this: it has a hydrophilic head (or end) and a hydrophobic tail (or end). Imagine you have an oil particle in water, where the two substances typically do not mix due to their different properties. However, something interesting happens if you introduce some surfactants, such as wax or asphaltene, which have polarity, with one end being hydrophilic (water-loving) and the other being hydrophobic (water-fearing or water-hating).

The hydrophobic end of the surfactant molecule enters the oil particle, while the hydrophilic end interacts with water, which it 'loves.' As a result, the hydrophilic part becomes associated with water, while the hydrophobic part seeks to hide within the oil. This means that one end of the surfactant molecule will be in the water phase, and the other will be in the oil phase.

Now, think of it like this: you have many such molecules protruding, with one end like a hydrophilic head and the other like a hydrophobic tail. You can draw them in any shape; it doesn't matter; the point is to explain the concept.

Now, what will happen? These hydrophilic and hydrophobic molecules will work to reduce their surface energy. When they reduce surface energy, the oil and water won't separate quickly; they'll mix instead. But if there's a significant polarity difference (with water having high polarity and oil having low polarity), the surface energy is very high, and the two fluids won't mix. However, the presence of a surfactant reduces the power by forming a coating around the oil particles.

Due to this coating, the oil particles won't try to move closer to each other, even if you have multiple oil particles, such as oil particle 1 and oil particle 2, each coated with surfactant. They will not approach each other or try to move. This stability creates a stable emulsion. However, breaking that surface coating is not easy, and neither is causing the particles to collide.

So, you have to make some other arrangements as well. For example, you can create artificial mechanical means to increase collisions artificially. This will result in more collisions, leading to the formation of larger particles and quicker separation. An emulsifier, emulsifying agent, or surfactant has polarity – hydrophilic (water-loving) and hydrophobic (water-hating). Like a nail, the hydrophilic end will enter the water, while a portion of it will enter the oil. This creates a coating all around the particle.

In this context, the volume of oil is very high, making it a continuous phase. Conversely, if the volume of water is very high, water becomes the continuous phase, and the dispersed particles are referred to as the discrete phase. In my case, water is the continuous phase, and oil is the discrete phase. The oil particles are separated, like so, and this is the discrete phase.

In the case of oil in water emulsion, you add wax or asphaltene, certain chemicals, to coat the surface of the oil particles. This prevents the oil particles from moving or colliding with each other. When they do collide, they form larger particles that separate more quickly. However, this doesn't happen naturally due to surfactants; they work against breaking the emulsion. We often create emulsions, for example, in the hair gel or oil industries.

So, the oil and water will mix and move up. You need to separate them on the surface because refineries only want oil, not water. They won't buy if you try to sell a mixture of oil and water. Therefore, you must separate them at the surface. However, if you have a stable emulsion, the difficulty and cost of separation increase. You can often not do anything about it because the wellbore contains chemicals like asphaltene, wax, and others that inherently mix with water and oil, creating a stable emulsion. A stable emulsion results in higher viscosity, which means more pumping power and increased energy loss.

One example of a surfactant is sodium dodecyl sulfate (SDS). In this case, you have carbon atoms in a chain. The chain is connected to oxygen, and oxygen is connected to sulfur. Sulfur is connected to sodium, and sulfur has a valency similar to oxygen. This end has H3C, H3, H, H, H, H, H, H, H, which is a hydrophobic tail. On the other end, you have a hydrophilic tail. The oxygen with a negative ion (O-) and water with a positive ion (H+) create a bonding interaction. This interaction makes one end hydrophilic, water-loving, and the other hydrophobic, which prefers to stay away from water.

So, what will they do? They will enter the oil, thinking they are safe and no water is attacking them. This creates a bonding, coating the surface of the oil particle, and results in a stable emulsion.

Now, for Newtonian and non-Newtonian fluids in emulsion, Whenever you talk about emulsion, it will exhibit non-Newtonian properties. In contrast, a single-phase water will have Newtonian properties. In a non-Newtonian fluid, viscosity changes with time. In such cases, the figure depicting shear rate and shear stress looks like this: Newtonian fluid follows the tau equals mu du by dy formula. Non-Newtonian fluids show shear-thinning, shear-thickening, and even Bingham plastic behavior. As you increase the water cut, the fluid transitions from Newtonian to shear-thinning, and its shear stress changes with pressure. Emulsions typically exhibit shear-thinning properties.