Artificial Lift

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Lecture-15 Emulsification and Demulsification

Examples of emulsifying agents include drilling fluid. When you inject fluid for drilling, emulsion is intentionally created to move the drill cuttings up to the surface. This is done for a positive purpose. Without creating an emulsion, the mixture of drill cuttings would not move up efficiently. Wax is ordinarily present in oil or gas and remains in the wellbore, creating a stable emulsion. Corrosion inhibitors are used in wellbores to prevent corrosion caused by gases like H_2S. These inhibitors also act as emulsifying agents. Sometimes, scale inhibitors are used. Scale refers to particles that deposit on the tubing wall over time when the pipe is used for an extended period.

Scale refers to a chemical reaction or the formation of oxides, debris, and other deposits on the tubing's inner surface, gradually reducing the pipe's diameter due to scale deposition. To prevent this, scale inhibitors are added, which can also act as emulsifying agents. Other particles, such as sand or debris, can also function as emulsifying agents. These particles can be deposited in chokes, valves, and throttle points during pumping operations. While they create an emulsion, changes in pressure and temperature during turbulence may allow some of the fluid to settle. During heavy turbulence, particles can come closer and collide. When they collide, they form larger particles, leading to more settling.

The oil will prevent the small particles from settling if you have oil and small particles present. The primary reason is the high viscosity of the fluid, which prevents particles from settling quickly. If the particle size is very small, it will also hinder settling. Density differences influence the settling rate; if the density difference is substantial, settling occurs rapidly, but if it is low, settling is delayed. The formula for this can be described when you have water and oil particles: the oil particles prevent the water particles from settling.

So, we have water in oil and oil in water. Smaller particles will create a more stable emulsion, while bigger particles will create an unstable emulsion or settle quickly, making it a semi-stable or unstable emulsion. When discussing particle settlement, you need to understand the formula governing its behavior. Let's assume there is one particle here, and it's in the fluid flow path. The fluid flows upward from the wellbore to the surface, representing one particle. This particle can be either oil in water or water in oil and will experience buoyancy force pushing it upwards and gravitational force pulling it downwards due to its weight. F_b represents the fluid force due to buoyancy, which pushes it upward. If the fluid force is strong enough, considering all the drag forces, the particle will be lifted upwards. The solid or liquid particle will gradually fall down if the fluid force is insufficient.

The particle has mass (m), and its density is represented by ρ. The fluid density (ρf) is the density of the moving fluid. We have F_g for particle gravitational force, F_b for particle buoyancy force, and Fd for drag force. As the fluid moves upwards, it exerts a drag force on the particle. $F_g - F_d = m\left(\frac{dv}{dt}\right)$

The equation F_g minus F_d equals m(dv/dt) represents the settling velocity (v) over time (t).

$$F_d = \frac{1}{2} C_D \rho_f V_t A$$

V_t stands for terminal velocity. Terminal velocity means the fluid velocity is so high that the fluid is just moving upward without falling. It may be considered static in relation to the fluid flow, resulting in an almost zero relative velocity between the particle and the fluid.

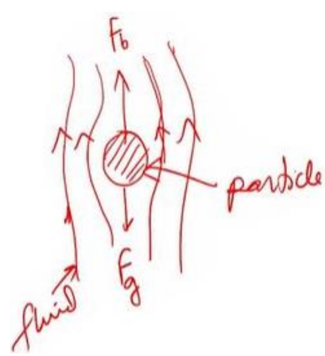

Fig.1. Particle settlement.

Based on Stokes ' law, another formula for drag force,

$$F_d = 6\pi\eta r^2$$

Now, for all these equations, when (dv/dt) equals 0, indicating terminal velocity, the relative velocity is almost zero. The formula gives terminal velocity (Vt),

$$V_t = \frac{2r^2 g(\rho_p - \rho_f)}{9\eta}$$

This is known as terminal velocity. The terminal velocity, which is related to the particle's diameter, determines whether the particle is moving up or down. If the diameter is very high, the terminal velocity will be high, resulting in larger particles settling more quickly. This formula for Vt depends on the radius (r), and whether the particle settles upward or downward it will be determined by the terminal velocity, which is influenced by the density difference (ρ_p - ρ_f).

The density difference is higher, and the terminal velocity will also increase. Furthermore, viscosity (η) plays a role; if viscosity is high, V_t will be low. In a university-related context, V_t or fluid particle settlement depends on whether it moves upward. For example, in the case of oil in water, oil particles move upward quickly due to their lightweight nature, especially if they have a larger particle diameter and a higher density difference. On the other hand, in the case of water in oil, water particles tend to move downward, requiring a lower density difference and lower viscosity. Changing specific parameters, such as the diameter of the particle (r), can influence these factors.

So, how can you change the particle's diameter (r). You can create conditions where particles collide with each other. When tiny particles collide, they can form larger particles, resulting in a quicker terminal velocity. This theory is applicable in situations such as drilling fluid sand settlement, wellbore sand settlement, or surface production separation units where different fluids or solids and liquids need to be separated. In such cases, this formula is commonly used. Remember that settling is influenced by three main factors: the diameter of the particle, the density difference of the particle, and viscosity. To settle particles quickly, you may need to create larger particles from smaller ones and create an environment where particles collide. Additionally, removing the coating on the particles, if possible, can promote faster settling.

In many cases, we don't want to settle. Take hair gel, for example; we don't want the tiny particles in it to settle. The same goes for toothpaste; new types of toothpaste are coming in various colors for kids, and if the particles settle, it won't look good. To prevent settling, they are formulated to maintain stable emulsion.

Now, let's discuss surface tension. Surface tension involves two types of forces on a surface: adhesive force and cohesive force. Cohesive force is an internal force that pulls liquid particles together, causing them to occupy a smaller surface area. For instance, if you take a certain amount of fluid, like water, the cohesive force tends to minimize the surface area, resulting in a spherical shape. This is why raindrops, for example, are nearly spherical.

Regarding adhesive force, it occurs when two dissimilar fluids or a solid surface and a fluid interact. The strength of adhesive force determines whether the fluid wets the surface. If the adhesive force is high, the fluid wets the surface; if it's low, the fluid doesn't adhere well. You can observe this in the case of a lotus leaf, where water forms small droplets, maintaining a spherical shape due to cohesive forces and weak adhesive forces, which prevent it from firmly sticking to the leaf's surface.

When there's an oil particle in water, a specific phenomenon occurs. The oil possesses its cohesive force, causing it to form a circular or spherical shape naturally. Additionally, it has less adhesive strength. When two dissimilar fluids are present with very high surface energy or interfacial tension (IFT), they tend not to mix together. However, if you can reduce this interfacial tension or surface force using specific methods, the two fluids will mix, creating a stable emulsion.

Surface-active agents, such as wax, asphaltene, and other chemicals, are examples of substances that reduce this surface energy. These agents create hydrophobic and hydrophilic ends, which allow water and oil to mix. Although the two fluids retain their distinct identities, they will mix together, making separation difficult. The particles will not move or collide, resulting in a stable emulsion.

Surface-active agents, also known as surfactants, reduce interfacial tension. When discussing relative viscosity, changes occur as you increase the water cut. Visually, you can represent this as a graph ranging from 0 to 100 percent water cut. Initially, with 100 percent oil, viscosity increases steadily as you gradually add small amounts of water with proper mixing to create an emulsion. This increase continues until it reaches around 80 percent, at which point a sudden change in viscosity occurs.

So, it goes like this: There's a point called phase inversion. Initially, you have a large amount of oil and add a small amount of water. This creates a water-in-oil mixture, where the water content is, let's say, 10 percent, and the oil content is 90 percent. Something interesting happens as you continue to increase the water percentage, going from 10 percent to 20 percent, 30 percent, and so on. When the water percentage reaches around 60 to 80 percent or even 70 to 80 percent, there is a sudden change in viscosity.

As you add water, the viscosity steadily increases: add water, measure viscosity, add more water, measure viscosity, and so on, and the viscosity keeps increasing. However, after a certain point, the viscosity suddenly drops. This point where the viscosity drops is known as the phase inversion. At this stage, the oil content decreases, and the water content increases. Now, it becomes an oil-in-water mixture. So, this part was water-in-oil (W/O), and this part is oil-in-water (O/W), like this.

So, a phase change occurs because when the water and oil content are high, this sudden viscosity changes. Now, imagine you have a wellbore with a water cut of, let's say, 50 percent. Suddenly, you start getting more water due to certain changes in reservoir properties, so the viscosity goes up. As you continue to receive more water, something interesting happens: the viscosity suddenly drops, and at that point, it becomes an oil-in-water mixture. So, the viscosity change can significantly impact your reservoir, tubing flow, pressure drop, and other aspects of production when the water cut changes. Monitoring and recording all these changes is crucial when you aim for stable production from the wellbore.

You've already observed the effect of droplet size. Droplet sizes can range from 0.1 micrometers to 1000 micrometers. As indicated in the Vt formula with the r^2 term, smaller droplet sizes result in lower terminal velocities and slower settlement rates. Conversely, larger particles settle more quickly. Water particles in oil tend to create a more stable emulsion, while oil particles in water produce a less stable emulsion. Greater stability implies that you need more time for the emulsion to separate, while less stability means less time. For example, in a water-oil mixture without any asphaltene or resin content, the two fluids will quickly separate, resulting in an unstable emulsion.

Demulsifying agents are especially necessary during techniques or surface production operations when you're separating fluids. It would help if you injected certain demulsifying agents to facilitate the quick separation of water and oil. Demulsifying agents are also chemicals that remove surface coatings, allowing two particles to mix. When they mix, they form larger particles, and as you might recall from the formula, larger particles settle more quickly, whether water particles go down or oil particles go up.

Some solvents, like benzene, toluene, and xylene, are demulsifying agents. When you add them to an emulsion, they remove the surface coating, enabling the two particles to combine and create larger particles.

So, how do these processes work? Imagine you have a proper emulsion with one fluid in the continuous phase and the other in the discrete phase. In the case of lighter oil particles in water, the lighter particles move upward, a phenomenon known as 'creaming.' On the other hand, 'flocculation' occurs when nearby particles come together and form larger particles. This is different from 'sedimentation,' where water particles in oil settle at the bottom, creating a distinct liquid layer. Creaming, however, involves particles moving upward and attempting to join together.

Then, they will come much closer and join like this, ultimately creating larger particles. In this case, my creaming phase will have a continuous layer, while my flocculent phase will consist of much larger particles. The sedimentation phase will involve deposition at the bottom, with more fluid on top. You can separate the two liquids or fluids using a demulsifying agent. However, using only a demulsifying agent may not be enough; you also need to employ mechanical or electrical means to increase agitation so that the particles can come closer together quickly, collide, and form larger particles, thus accelerating the settlement rate.

This was the work of one of my students who completed his Ph.D. a few years ago in 2017. He published a paper on artificial lift systems, such as the Electric Submersible Pump (ESP), which we'll discuss in more detail later. He investigated how emulsions affect the performance of ESPs. To conduct his experiments, he took a sample of crude oil from ONGC's Cricle unit and mixed it with specific chemicals to allow water and oil to settle. He created different mixtures of chemicals, water, and oil at varying percentages to see how long they took to settle. Some mixtures were very unstable, so he manipulated one blend to make a stable emulsion by adding a surface-active agent. He conducted tests for 10 minutes, one day, five hours, six hours, and so on. Finally, he selected a stable solution and pumped it through a centrifugal pump to assess the drop in efficiency or performance due to the emulsion's creation at different water cut levels. He discovered a phase inversion curve like this, and then it suddenly dropped. This is the phase inversion, and this axis represents viscosity (mu over eta), while this axis shows water cut percentages, ranging from 0% to 100%. The specific data can be found in his paper.

From this experiment, he found that his efficiency was dropping. Initially, the efficiency was higher, but later it dropped. This drop in efficiency occurred because the centrifugal pump, when dealing with higher viscosity, faced increased resistance to fluid flow through the pump. Consequently, due to this high resistance, its efficiency decreased, resulting in a reduced head or a lower amount of fluid being delivered.

In situations where emulsion or water cut changes occur, you may consider using other pumping systems, such as jet pumps, gas lift systems, or sucker rod pumps. In certain positive displacement pump systems like sucker rod pumps or PCP systems, the efficiency might not drop significantly. However, it's essential to note that the entire pipeline will experience higher viscosity. This increased viscosity will require the pump to consume more electrical power from the surface, ultimately leading to higher electricity or diesel consumption.

Because of this emulsion, if your water cut changes due to certain reservoir reasons, your entire reservoir and production system will be affected, including changes in electrical consumption. For explanation purposes, I have taken a bottle containing water and oil. I've added a blue color to the water to make it visible on camera. When properly shaken, it creates an emulsion, with tiny oil and water particles mixing together and appearing non-separable.

However, if given enough time, let's say two or three minutes, you can slowly observe that the bottom part becomes bluish, while the top portion turns yellowish, indicating that they are separating. This separation occurs because we don't have any surface-active agent to prevent the particles from settling. The particles collide with each other, with some rising to the top due to the lightweight nature of oil, while others, being heavier water particles, move downward. Over time, you can see this separation occurring.

A similar emulsion can also form in the oil industry. However, the separation may not happen quickly if there is a lot of agitation or turbulence. If wax, asphaltene, or other surface-active agents are present, the separation will be very slow, as the presence of surface-active agents implies the creation of a stable emulsion.