Effect of Density and Resistivity Measurement for Foam Flooding Propagation in Static Condition

S Irawan [1], **K A Permatasari** [1(*)] **and R Bayuaji** [2]

[1]Department of Petroleum Engineering
Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia
[2]Department of Civil Engineering
Institut Teknologi Sepuluh Nopember, Surabaya, East Java, Indonesia

E-mail: karina_g03560@utp.edu.my

Abstract. Foam flooding is one of the method that is currently used to optimize the amount of oil in sub surface. Foam flooding is used to overcome the weakness of water injection, gas injection, and water alternating gas injection. Foam is the mixture of gas, water and surfactant. Foam propagation plays an important part in porous medium, foam propagation is related to intrinsic properties of the fluids such as density and viscosity. Resistivity of the fluids should be taken also because in the end of the experiment, method that is used to track foam propagation in porous medium is resistivity measurement. The objectives of this experiment are to obtain fluid characterization and to understand the phenomena that is possibly occurred during foam injection in porous medium, specifically, to obtain the correlation between density and resistivity measurement. Foam is generated with several concentration of solutions which are various concentration of brine, various concentration of MFOMAX, oil, and distilled water. Several tests should be taken to observe the intrinsic properties of the fluids such as density test, viscosity test, resistivity and conductivity test. Based on the experiment, correlation between density of brine and brine concentration towards resistivity is inversely proportional. Correlation between density of fluid mix with MFOMAX and MFOMAX concentration towards resistivity is proportional.

1. Introduction

Enhanced Oil Recovery (EOR) is one of the method for optimizing oil in sub surface. The most recent method for producing large amount of oil is foam flooding injection. Foam Flooding is introduced to overcome water injection, gas injection and water alternating gas injection. Foam is used to increase oil production in sub surface by reducing the mobility of gas that is injected, increase sweep efficiency and is able to travel in both high and low permeability due to higher viscosity of foam compared to gas. [1] However, foam also has negative side which are easily rupture and the velocity of foam is slower than viscosity of gas.

Foam flooding propagation is influenced by properties of each fluid that is mix with other fluids. Based on the negative side of foam, properties of each fluid should be known to determine foam behaviour, velocity and flow rate of foam when foam is injected in porous medium (core sample). Properties of foam that is related to velocity and flow rate of foam are density and viscosity of foam. Another properties of foam are resistivity and conductivity; these properties are related to the method of tracking foam propagation inside the porous medium (core sample). The method that is chosen for tracking foam propagation is resistivity measurement.

2. Theory and Literature Review

2.1.1 Concept of Foam

Foam is made by the mixture of gas and liquid. Foam is formed in a liquid if bubbles of gas are injected faster than liquid. Gas is dispersed in a continuous liquid phase as expressed in Figure 1. Foam disintegrate when the bubbles coalesce as soon as the liquid between the bubbles has drained away [2].
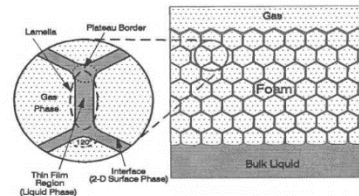

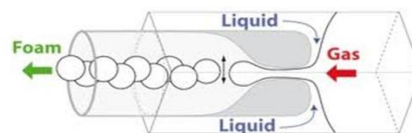**Figure 1.** Foam Structure. [2]

Figure 2. Foam Generated. [3]

Based on figure 2, lamellae is defined as the region that encompasses the thin film, the connection of lamellae (120°) and contains two gas-liquid interfaces separated by a layer of fluid thin film.[2]

Foam has electrical properties; surface potential is a charged interface influences the distribution of nearby ions in a polar medium. Surface potential is related to electrical forces which are repulsive forces and attractive forces. Attractive forces which are the opposite of ion charge (counter ions) are attracted to the surface, while those charge (co-ions) which are repelled are called repulsive forces. The Electric Double Layer (EDL) consists of the charged surface and a neutralizing excess of counter ions over co-ions, distributed near the surface. The EDL can be viewed as being composed of two layers, an inner layer that may include adsorbed ions and a diffuse layer where ions are distributed according to the influence of electrical forces and thermal motions. [4]

An inner layer exists because ions are not really point charges, and an ion can approach a surface only to the extent allowed by its hydration sphere. The Stern model incorporates a layer of specifically adsorbed ions bounded by a plane, the Stern plane. [2]
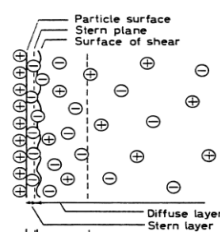

Figure 3. A simplified illustration of the Electrical Double Layer [2].

2.1.2 Density and Viscosity.

Foam propagation in porous medium (core sample) plays an important part and it is related to velocity and flow rate of foam. Velocity and flow rate of foam is related to intrinsic properties in each solution that will be mixed together in one solution. Properties that is influenced by how foam propagate inside the porous medium (core sample) are density and viscosity. In this chapter, density and viscosity will be explained further.

- Density

The mass density or density of a material is defined as its mass per unit volume. The symbol which mostly used for density is ρ (rho). [6] The Mathematical formulation of density can be expressed as below.

$$\rho = \frac{m}{v} \tag{1}$$

Where m is mass, v is volume. From this equation, density should have units of a unit of mass per unit of volume. Density unit in this experiment is g/cm^3.

- Viscosity

Viscosity is a measurement of the resistance of a fluid which is being deformed by either shear stress or tensile stress. In general terms, viscosity is related with the thickness and internal friction. The fluids which have thicker solution make viscosity higher and lower its ease of movement (fluidity). [7] Viscosity of the fluid that is used is related with Newton's Law and stated that the shear stress between adjacent fluid layers is proportional to the negative value of the velocity gradient between them as shown as equation (2) and (3) below. [7]

$$Shear\ stress = \tau = \frac{Force}{Area} \tag{2}$$

Based on the equation (2) shear stress is the ration of force divide by surface area of the plate.

$$Shear\ stress = \tau_{y,x} = -\mu \frac{d\mu_x}{dy} \tag{3}$$

Where $\tau_{y,x}$ is the shear stress in y axis at distance y from the origin and x is the direction of the velocity, μ is the viscosity, negative sign expresses the shear stress that is applied from higher velocity to a lower velocity.

- Resistivity

Resistivity is an electrical resistance measured between opposite faces of a unit cube of a substance at a specified temperature. Conductivity is the reciprocal of resistivity. Ohm's Law is the basic theory to predict foam propagation along the porous medium. Ohm's Law can be expressed as equation (1) and (2).[8]

$$r = \frac{V}{I} \tag{4}$$

$$R = \frac{V}{I} \cdot \frac{A}{L} = \frac{r \cdot A}{L} \tag{5}$$

$$C = \frac{1}{R} \tag{6}$$

Where r is the resistance in ohms (Ω), V is the potential difference in volts (V), and I is the current in amperes (A), R is the resistivity in ohm meter (Ωcm), A is the cross sectional area of core plug (cm^2) and L is the length of the particular zone in meters (cm), C is conductivity in S/cm.

3. Research Methodology

This experiment used several concentration of solutions. As mentioned earlier foam is the mixture of water, surfactant and gas. Each fluid has number variation of concentration, the fluids that is used is mentioned below.

- Distilled Water
- Brine (1 wt%, 2 wt%, 3wt%)
- MFOMAX (0.05 wt%, 0.1 wt%, 0.5 wt%, 1 wt%)
- Oil (7.5 ml)

All of the solutions will be mixed together after characterize has been done for each solution. The solutions will be placed in 250 ml of beaker. After all the solutions is ready, several test will be applied on each solutions in ambient condition (25°). Several test are density test, viscosity test and resistivity test.

3.2 Density Test

1. Each solution is placed on the bottle solution.

2. Bottle solution is placed inside the density meter.

Figure 4. Density Meter.

3. Equipment is ready to operate. First, choose "Methods/products" on the screen then choose "Methods".
4. Choose "Measure 25°" due to ambient condition measurement then click "Start".
5. Sample ID should be added to name for each solution then click "Start" for starting the measurement.
6. The needle starts to move inside the bottle solution and suck the solution into the "U" tube.
7. When equipment starts to measure the solution, there are several process while running equipment. First stage is filling the solution in "U" tube in 90 s, measuring the solution in 74 s, draining the solution from "U" tube in 5 s, rinsing using solvent in 6 s, rinsing using acetone in 8 s, drying the "U" tube in 116 s, calculating the result and reporting the result.
8. Density and specific gravity result is obtained by choosing "Result" on the screen, choosing sample ID that has been measured, and choosing "Calculated Results".
9. After all the process has been done, take out the bottle solution from density meter.

3.3 Viscocity Test
1. Each solution is placed on the small tank.
2. Small tank and spindle is placed on the rheometer until the status in the screen is "Ready".

Figure 5. Rheometer.

3. Small tank and spindle is placed on the rheometer until the status in the screen is "Ready".
4. Open rheometer software in PC then click "Rheometer" in setup measuring profile, set lift position of spindle in 140 mm and measuring position of the spindle in 1 mm, set temperature is 25°, click "Measurement Position" to shift the spindle into measurement position then click "OK".
5. Click "Edit Shear Rate" in setup measuring profile, set measurement points: 20, time unit: s, interval: 120 s, profile : ramp, initial: 1 and final 1000 then click "OK".

6. Click "Start The Test" in setup measuring profile, name the sample ID then click "Start The Test Now".
7. The graph and the data will be shown in the diagram 1: time test single point frame.
8. After data and graph has been obtained, click "Rheometer" and click "Lift Position" to pull out the spindle then take out and clean the small tank.

3.4 Resistivity and Conductivity Test

1. Solution which is placed in the small container is provided to proceed resistivity and conductivity test using conductivity meter.

Figure 6. Conductivity Meter.

2. The electrodes are immersed into solution and press "Read".
3. Conductivity meter is start to measuring the solution and wait in few seconds until the reading is stable.
4. The measurement is taken five times and average the result.
5. Parameter conductivity and resistivity can be obtained at the same time. Parameter result is possibly changed by pressing "Mode" in the conductivity meter.

3.   Result and Dicussion

There are several results that had been obtained from experiment such as correlation between density of brine and brine concentration towards resistivity, correlation between density of the mixture of MFOMAX and distilled water towards resistivity, correlation between density of the mixture of various MFOMAX concentration and various brine concentration towards resistivity, correlation between density of the mixture of various MFOMAX concentration, various brine concentration, and oil towards resistivity.
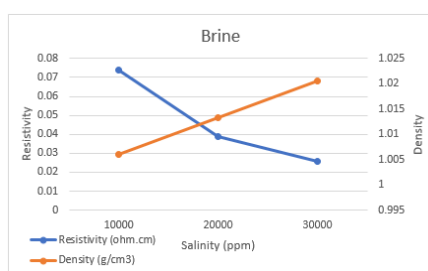

Figure 7. Correlation between Density of Brine and Brine Concentration towards Resistivity.

Normally, higher concentration of fluid, density will be higher. It occurred because of smaller size of molecules that was dissolved in water which was higher based on the equation (1). Theory of density and equation (1) is only applicable for density in various brine concentration. Density and resistivity of brine 1 wt% is 1.006 g/cm^3 and 0.074 Ωcm, brine 2 wt% is 1.0132 g/cm^3 and 0.0388 Ωcm, brine 3 wt%

is 1.0206 g/cm^3 and 0.0255 Ωcm. Based on the figure 7, correlation between density of brine and resistivity of brine is inversely proportional. As can be seen, NaCl has positive (+) and (-) negative charge. The higher concentration of NaCl that is dissolved in water, mass of the NaCl increase and positive (+) (-) negative charge which is carried out by NaCl is also increasing. However, when and positive (+) and (-) negative increase means conductive, in other words lower resistivity.
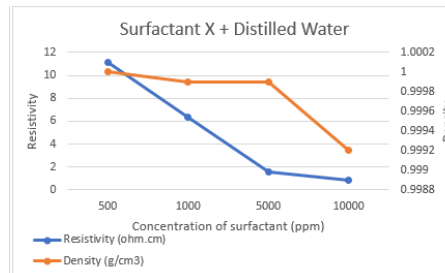

Figure 8. Correlation between Density of the mixture of MFOMAX and Distilled Water towards Resistivity.
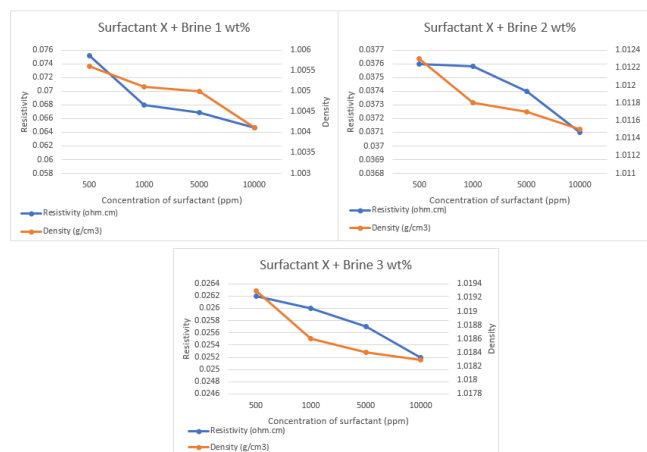

Figure 9. Correlation between Density of the mixture of Various MFOMAX Concentration and Various Brine Concentration towards Resistivity.
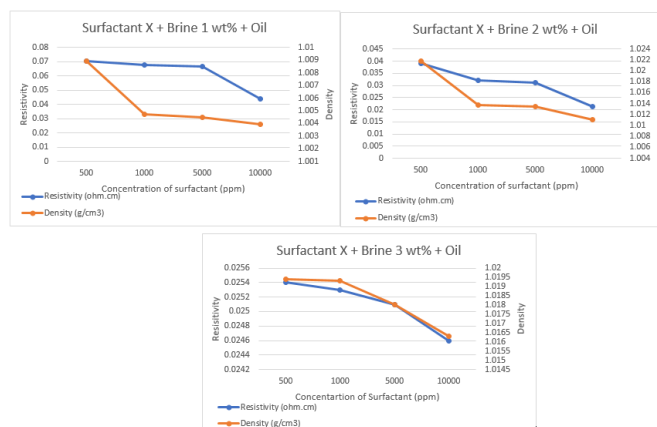
Figure 10. Correlation between Density of the mixture of Various MFOMAX Concentration, Various Brine Concentration, and Oil towards Resistivity.

When MFOMAX is added to the solution, theory of density and equation (1) is not applicable. Density tend to reduce while concentration of MFOMAX is increasing. It occurs because MFOMAX has bigger molecule in the same volume. Bigger molecules in solution will affect the density because bigger molecules will not be able to occupy the empty spaces between other molecules which derive from another fluid.

Based on the EDL theory, conductivity result occurs when positive (+) charge of the fluid and negative (-) charge of the ion of the electrodes is attracted each other or vice versa. Resistivity result occurs when positive (+) charge of the fluid and positive (+) charge of the ion of the electrodes is repelled each other or vice versa. All figures are expressed correlation between resistivity and fluid concentration. Generally, resistivity for all the solution is decreased. It means, all the liquid is conductive. In other words, all the solutions are capable to transmit the current and voltage. Resistivity between the mixture of MFOMAX with various brine concentration and the mixture of various MFOMAX concentration, various brine concentration, and oil is not much different. This issue occurs because when concentration increased, the amount of brine and MFOMAX also increased but the amount of brine that is added into solution is more dominant than the amount of MFOMAX and oil. Conductivity of solution depends on the concentration of all the ions present in the fluid, the greater concentrations, the greater conductivity. MFOMAX is the surfactant that has (+) and (-) charge, in other word MFOMAX can transmit current by itself without any conductive fluid added because MFOMAX is made from the mixture of anionic (-) and zuitorionic (+) and (-). Based on the mixture, MFOMAX has high conductivity.

Theoretically, there is no direct correlation between density and resistivity because density is related with atomic packing, mass and volume of the molecules inside the fluid and resistivity is related with positive (+) and negative (-) charge inside the fluid (electronic structure). Based on the result, the higher concentration of the fluid, density and resistivity will be reduced. It is possibly occurred because when density decrease, means it has bigger molecules that is not fully dissolved in water and reducing the resistivity due to the increasing positive (+) negative (-) charge that is carried out from the solution.
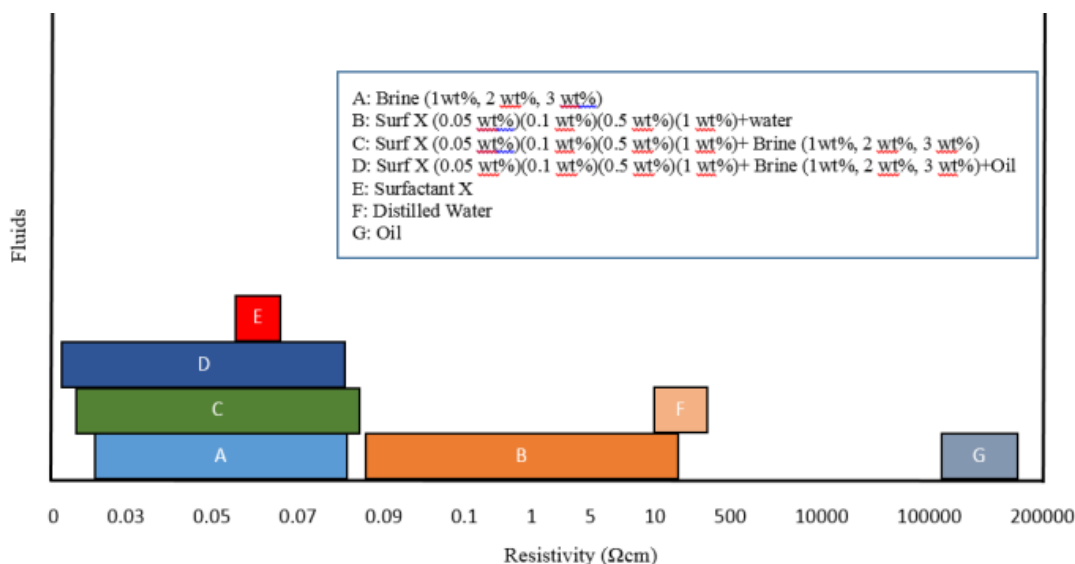

Figure 11. Range of Fluid Resistivity.

As can be seen in figure 11, the smallest resistivity is MFOMAX mix with brine and oil with various concentration. The highest resistivity is oil. Based on figure 11, range of resistivity is quite similar and the resistivity tend to lower. It occurs because the amount volume of brine is more dominant than the amount volume of MFOMAX and oil added in the solution.
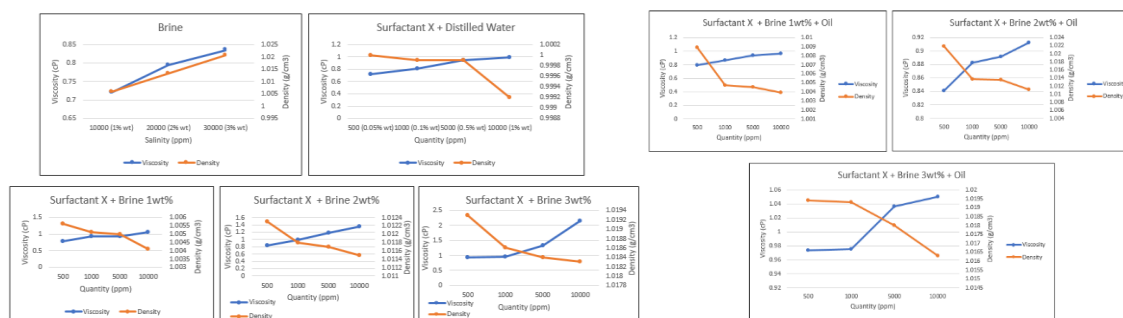
Figure 12. Correlation between Density and Viscosity.

Theoretically, greater number of fluid concentration, density and viscosity will be higher. This theory is only applicable for brine with various concentration. Correlation between density and viscosity towards brine concentration was proportional. Density and viscosity of brine 1 wt% was 1.006 g/cm^3 and 0.7213 cP, brine 2 wt% was 1.0132 g/cm^3 and 0.7954 cP, brine 3 wt% was 1.0206 g/cm^3 and 0.835 cP. For another solution, specifically solution which has MFOMAX, correlation between density and viscosity towards fluid concentration was inversely proportional.

4.   Conclusion

In this experiment, several conclusions can be obtained based on the phenomena that occurred during the experiment. All the results can be concluded as stated below:

1. Correlation between density of brine and brine concentration towards resistivity was inversely proportional.
2. Correlation between density of fluid mix with MFOMAX and MFOMAX concentration towards resistivity was proportional.

Acknowledgment

5. References

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