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Review Paper: The Study of Flow Behavior and Performance of Polymer Injection at Pore Scale Using Micromodel

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Abstract

Polymer injection is one of the Chemical EOR methods to get higher oil recovery by increasing the viscosity of displacing fluid (water), which makes the oil mobility become higher than the mobility of polymer solution. It will result in better oil sweep efficiency due to the front stability and reduction of viscous fingering effect. Therefore, polymers are used to overcome the problem of viscous fingering that occurs in water flooding. However, the implementation of polymer injection on a field scale needs a previous experimental study to analyze the performance and flow behavior of polymer injection in obtaining polymer and its parameters that can give optimum oil recovery. In the experimental study, a micromodel is used in order to visualize the flow behavior of polymer injection clearly. If within the experimental study, we already got the optimum polymer and its parameters, then a pilot test can be conducted. In this case, a pilot test is a trial test of a project that is conducted on a particular well or reservoir to find out whether the project is profitable or not, where if the project is successful, polymer injection can be implemented on a field scale. This review paper will deeply discuss the factors that can affect the performance of polymer injection in oil recovery at the pore scale by using micromodel.

Keywords: Micromodel; Oil Recovery; Polymer Injection

I. INTRODUCTION

An experimental study is a very important step in investigating the performance of polymer injection. In planning the implementation of polymer injection project, an experimental study must first be carried out to test the performance of polymer injection on a laboratory scale so that the optimum polymer with certain parameters is obtained, and afterward continued to the pilot test. If this step is considered profitable, it can be implemented on a field scale. Core flooding is a method that is often used in an experimental study, in which the core can represent the real condition of the reservoir. Nevertheless, to get the original core is not easy and needs high cost. In addition, the core flooding can't visualize the flow behavior of the injected polymer to observe its displacing mechanism, whereas in this experimental study of polymer injection requires clear, and detail visualization of the polymer injection performance on porous media, so transparent media is needed to make it easier in handling observation. Thus, to overcome this problem, micromodel is used as a porous medium that can represent the actual condition of the reservoir. Due to the transparency of micromodel, the entire process of oil displacement mechanism can be directly observed and recorded using Digital Image Analysis (DIA). Accordingly, it can be further analyzed for the mechanism of polymer injection at the pore scale and used to determine oil recovery Generally, there are two types of micromodels used in an experimental study, namely homogeneous and heterogeneous micromodels.

II. LITERATURE REVIEW

II.1. Polymer

Polymers are large molecules (macromolecules) shaped like a chain that is formed from small repeating units called monomers . In general, there are two types of polymers commonly used in the Enhanced Oil Recovery (EOR) process, namely synthetic polymers such as hydrolyzed polyacrylamide (HPAM) and biopolymer such as xanthan gum. The different characteristics of each type of polymer provide the advantages and disadvantages of each. Synthetic polymers have advantages such as; affordable price; the viscosity remains appropriate when used in freshwater, the adsorption that occurs on the rock surface is still acceptable (low adsorption). However, this type of polymer is sensitive toward flow rate and shear degradation. It also has low efficiency in high-salinity water. Meanwhile, the type of biopolymer shows good performance against the water with high salinity and shear degradation, but this type of polymer is sensitive to degradation caused by bacteria (bacterial degradation) at low reservoir temperature.

II.2. Polymer Degradation

Many researchers had conducted an experimental study to investigate various parameters that are affecting the stability of polymer under different conditions. Factors that caused polymer instability are chemical degradation, mechanical degradation, and biological degradation. Oxidation and ferric ions are factors that can affect chemical degradation. The reduction of the amount of oxygen in contact with polymer will prevent the creation of Fe^{3+} ion, Fe^{2+} ion, and free radicals of O^{2-} ion, of which it will make the polymer solution more stable and prevent chemical degradation. Mechanical degradation occurs when polymer molecules break down, caused by shear stress. In this case, the flow rate has a very important role in preventing mechanical degradation, so that it should be optimized. Meanwhile, biological degradation is more common in biopolymers, but in certain cases, synthetic polymers can also be degraded biologically (biological degradation). Using particular additives may be a solution to overcome these problems.

II.3. Micromodel

Micromodel is an artificial tool used to visualize the oil displacement mechanism at the pore scale. Micromodel provides visualization of the flow behavior of injected fluid with the aim of studying and analyzing the fluid injection profile, which cannot be done in the core flooding method In this case, the injected fluid is a polymer. A micromodel often used for polymer injection research is the micromodel with a two-dimensional design (2D Micromodel) having both homogeneous characteristics (homogenous micromodel) and heterogeneous characteristics (heterogeneous micromodel).

Previous researchers had made micromodels using different materials and techniques. Micromodels often used recently are made by photo-etching techniques on materials made of glass, silicon, or polymer. The choice of material used to make a micromodel depends on the objectives of the study, where each material used has its own advantages and disadvantages

The difficulty in using a micromodel lies in the manufacturing process, where it is not easy to make a micromodel with the characteristics that can represent the real reservoir conditions. Many micromodels had been made with different pore patterns, where each micromodel has its own advantages and disadvantages. Figure 1 shows several types of micromodels made by researchers.

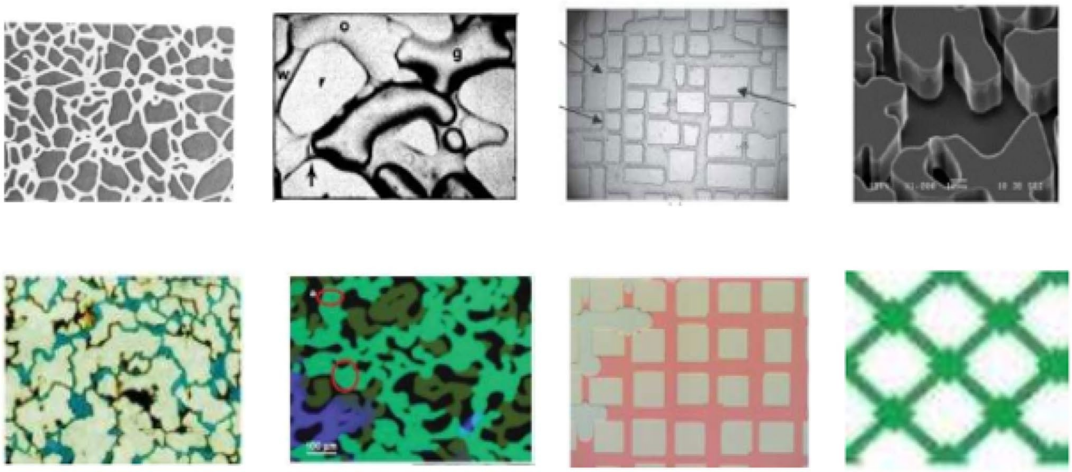
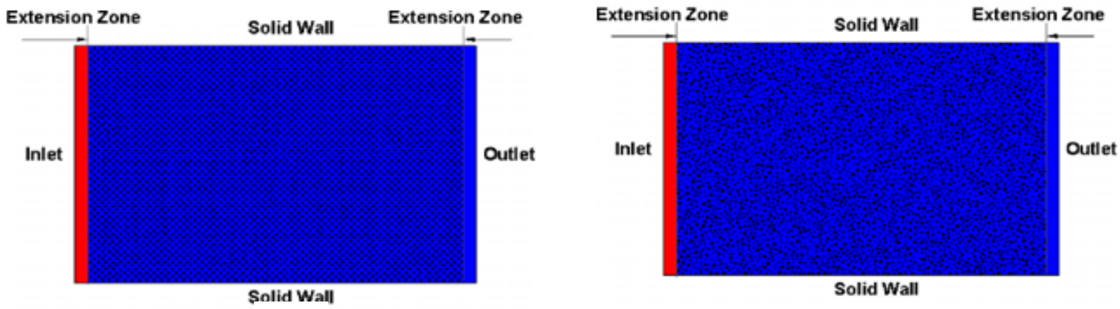


Figure 1. Micromodel Pore Patterns



(a) (b)

Figure 2. Scheme of (a) Homogenous and (b) Heterogenous Micromodel

II.4. Previous Micromodel Studies

Many researchers have conducted experiments using micromodel in order to study and analyze the performance or flow behavior of polymer injection at the pore scale.

- **Hosseini et al. (2018)**

Hosseini et al. (2018) conducted an experimental study of polymer injection on homogeneous and heterogeneous porous media using a glass-type micromodel. The experiment was carried out using a micro model with a horizontal position saturated by heavy oil, namely Iranian crude oil. The experimental result reveals that at higher concentrations and lower injection rates, the polymer could give better sweep efficiency. The visualization of polymer injection on the micromodel showed that the flood front is more stable compared to only injecting water. Heterogeneity, another parameter learned in this study, also has an effect on oil recovery. Micromodel with heterogeneous characteristics is also used in this research to represent the actual heterogeneous reservoir conditions. The result of the experiment indicates that the swept area is strongly influenced by the heterogeneity of the micromodel as long as these characteristics affect the movement of the flood front. Therefore, macroscopic heterogeneities such as layered reservoirs or the existence of fractures and differences in permeability (high- or low-permeable zones) must be considered and taken into account before carrying out a polymer injection project in order to obtain the optimum performance.

- **Wonjin Yun (2014)**

Wonjin Yun (2014) used a two-dimensional micromodel to visually study polymer retention and test quantitatively. In this research, several scenarios were carried out, namely scenario 1 (base case), scenario 2 (high salinity), scenario 3 (mechanical degradation with 7 µm filter and 3 µm filter), scenario 4 (wettability-crude oil), and scenario 5 (wettability-cetyl trimethylammonium bromide, CTAB). After doing these scenarios, the results showed that scenario 2, high salinity (5% NaCl), gave lower polymer retention results (6.34%) compared to scenario 1 (base case) without NaCl and filtration (7.47%). The wettability of micromodel was changed by saturation of Haradh Saudi Arabia crude oil (scenario 4) and CTAB (scenario 5). The polymer retention for scenario 4 is 15.04% and 5.04% for scenario 5. In scenario 3, the polymer retention for a 3 µm filter is 7.75% and 4.26% for a 7 µm filter. Based on the result of the experiment, it can be concluded that mechanical degradation by seven µm filters has the most significant effect on reducing polymer retention in which the polymer retention is only 4.26%.

- **Emami et al. (2008)**

Emami et al. (2008) used a micromodel with a five-spot injection pattern to examine the effect of local and global heterogeneities on oil recovery. The result of the experiment indicates that oil recovery will be obtained maximally when the lie angle is perpendicular to the flow direction. The inclination of micromodel also greatly affects the efficiency of the polymer injection process.

- **Hematpour et al. (2011)**

Hematpour et al. (2011) studied the effect of polymer injection on low-viscosity oil by using a micro model. The result of the study indicates that the usage of hydrolyzed polyacrylamide (HPAM) provides the best performance under test conditions.

- **Al-Dousary S (2012)**

Al-Dousary S (2012) conducted a study on the mechanism of alkaline-surfactant-polymer (ASP) injection at the pore scale using a micro model. Based on the implementation of experiment 5, the result shows that polymer has a very important role in the success of the Enhanced Oil Recovery (EOR) process because polymer can make front displacement more stable so that oil recovery increases.

III. METHODOLOGY

The primary objective of this research study was to investigate the effect of various parameters such as the concentration of polymer solution, injection rate, and heterogeneity on the performance of polymer injection to sweep oil in micromodel. Therefore, several experiments about micromodel studies that were conducted by previous researchers are needed to analyze the effect of those parameters on oil recovery; the general scheme of micromodel set up can be seen in figure 3.

A number of micromodel setups with homogeneous and heterogeneous flow patterns were built and used for the experimental study of polymer injection. The next step was to saturate the micromodel setup with the crude oil without having any connate water saturation. After the flow pattern is saturated, the experiment was started. A pump was used in this study to inject the polymer solution into the micromodel. Emami et al. (2008) conducted an experiment about the effect of reservoir heterogeneity on polymer injection using micromodel. Emami et al. (2008) made layered micromodel with different inclination angles to determine the effect of layer orientation on the performance of polymer injection to sweep oil. Figure4 shows a micromodel scheme that will be used in his experiment. Figure 5 shows layered micromodel with different inclination angles that are 0 ° (parallel to flow direction), 45 °, and 90 ° (perpendicular to the flow direction).

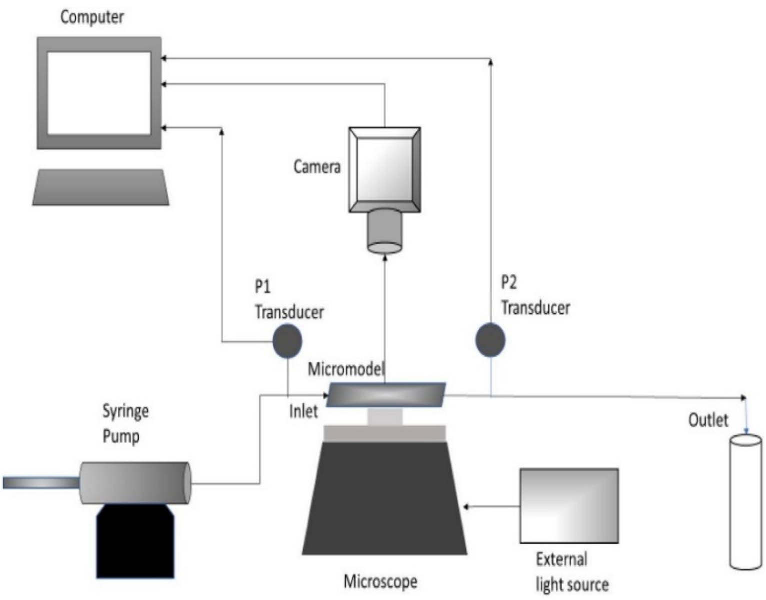


Figure 3. General Scheme of Micromodel Set

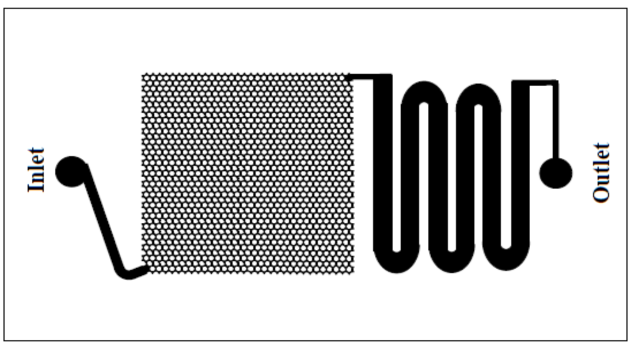


Figure 4. Micromodel Scheme

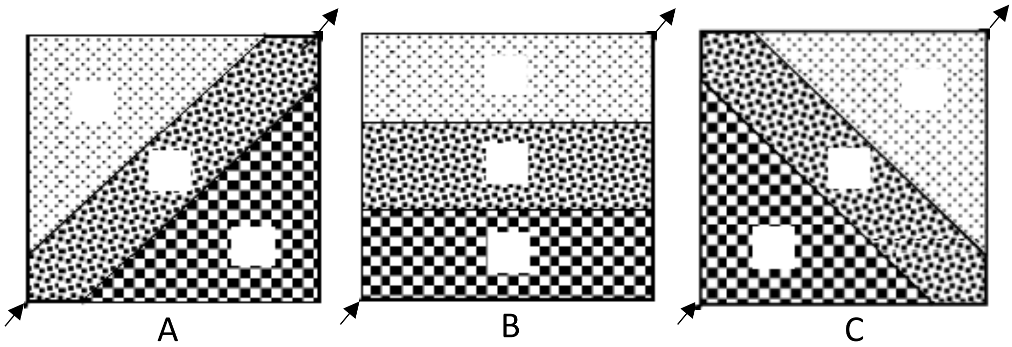


Figure 5. Layered Micromodel Pore Pattern
with Different Angle of Inclination (A= 0°, B= 45°, dan
C= 90°)

IV. RESULT AND DISCUSSION

IV.1. Polymer Concentration

Based on the theory, the increase of polymer concentration will result in obtaining higher oil recovery. An experiment conducted by Hosseini et al. (2019) resulted in a graph shown in Figure 6, which shows the effect of polymer concentration on oil recovery.

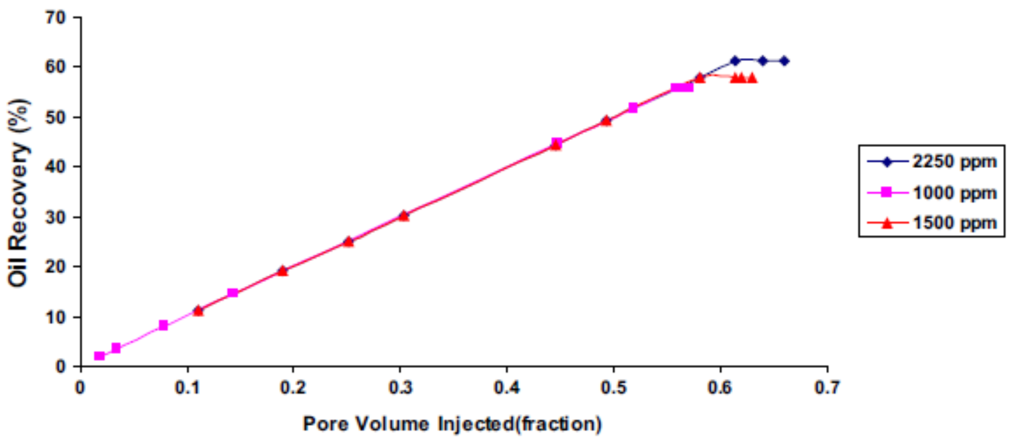


FIGURE 6. Comparison of Oil Recovery Produced by Polymers with Different Concentrations (injection rate = 0.0002 ml/min) [18]

Based on Figure 6, it can be seen that with the addition of polymer concentration with 150% (1500-2250 ppm), the oil recovery increases by 7%. It shows that by increasing the concentration of polymer will also increase the viscosity of polymer solution so that the flood front becomes more stable. It will reduce the effect of viscous fingering and increase oil recovery. It may also be observed in Figure 6 that polymer with the lowest concentration (1000 ppm) sustains the fastest breakthrough at 0.54 pore volume (PV), while for polymers with 1500 and 2250 ppm, the breakthrough will occur at 0.58 and 0.62 PV, respectively. It can be interpreted that polymer with lower concentration will have lower viscosity as well, in which it will affect the mobility of polymer solution. Polymer solution having higher mobility than the mobility of oil will cause both unstable flood front and viscous fingering, and consequently resulting in low sweep efficiency.

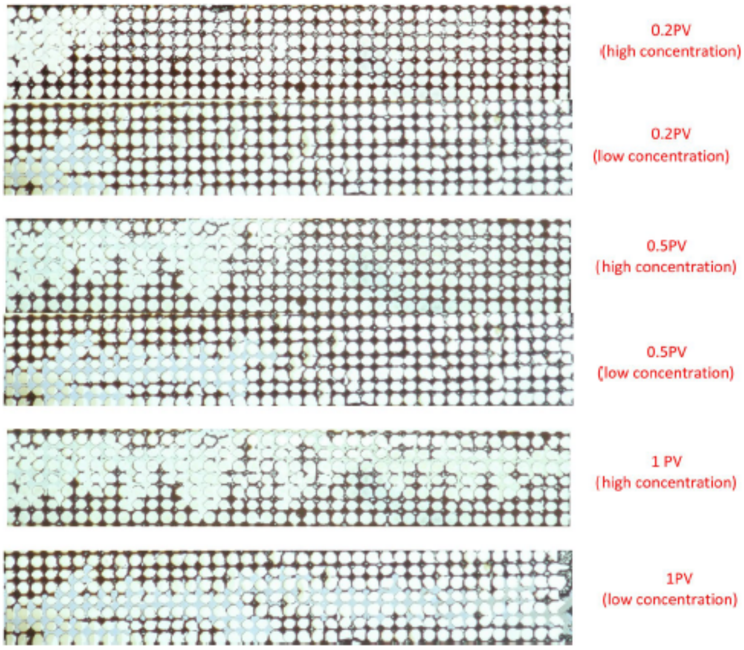


Figure 7. Front stability for a polymer with a low concentration (1000 ppm) and high concentrations (2250 ppm) at 0.2, 0.5, and 1 PV with an injection rate of 0.0002 ml/minute, the injection point is on the left (brown: oil, blue-whitish: polymer)

Figure 7 shows the profile of polymer injection in a micromodel of low and high concentrations with different pore volumes. Polymers with a high concentration (2250 ppm) will have better front stability than polymers with a low concentration (1000 ppm).

Injection Rate

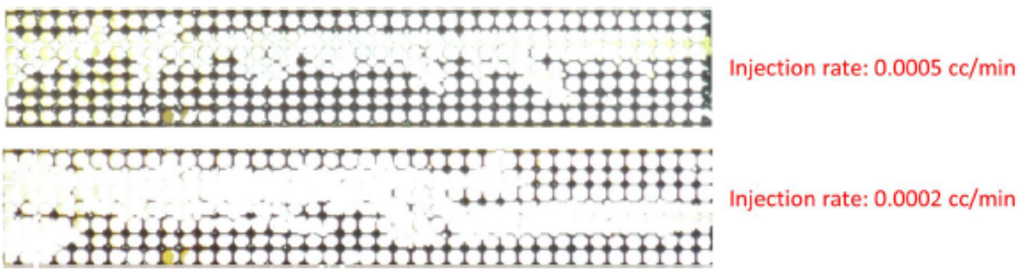


Figure 8. Comparison of Front Stability for Injection of Polymers with different injection rates (0.0002 ml/minute and 0.0005 ml/minute) at a concentration of 1500 ppm, (brown: oil, white: polymer)

In this experiment, Hosseini et al. (2019) used 1500 ppm polymer that was injected at different rates (0.0002 and 0.0005 ml/minute). Figure 8 shows the effect of the injection rate on the front stability of polymer injection. Polymer with a lower injection rate (0.0002 ml/min) will have better front stability and well-distributed compared with a higher injection rate (0.0005 ml/min), which results in an unstable flood front. It may occur because, at a lower injection rate, the polymer solution has a longer time to distribute. Therefore, injection rate sensitivity needs to be considered in order to obtain optimum oil recovery.

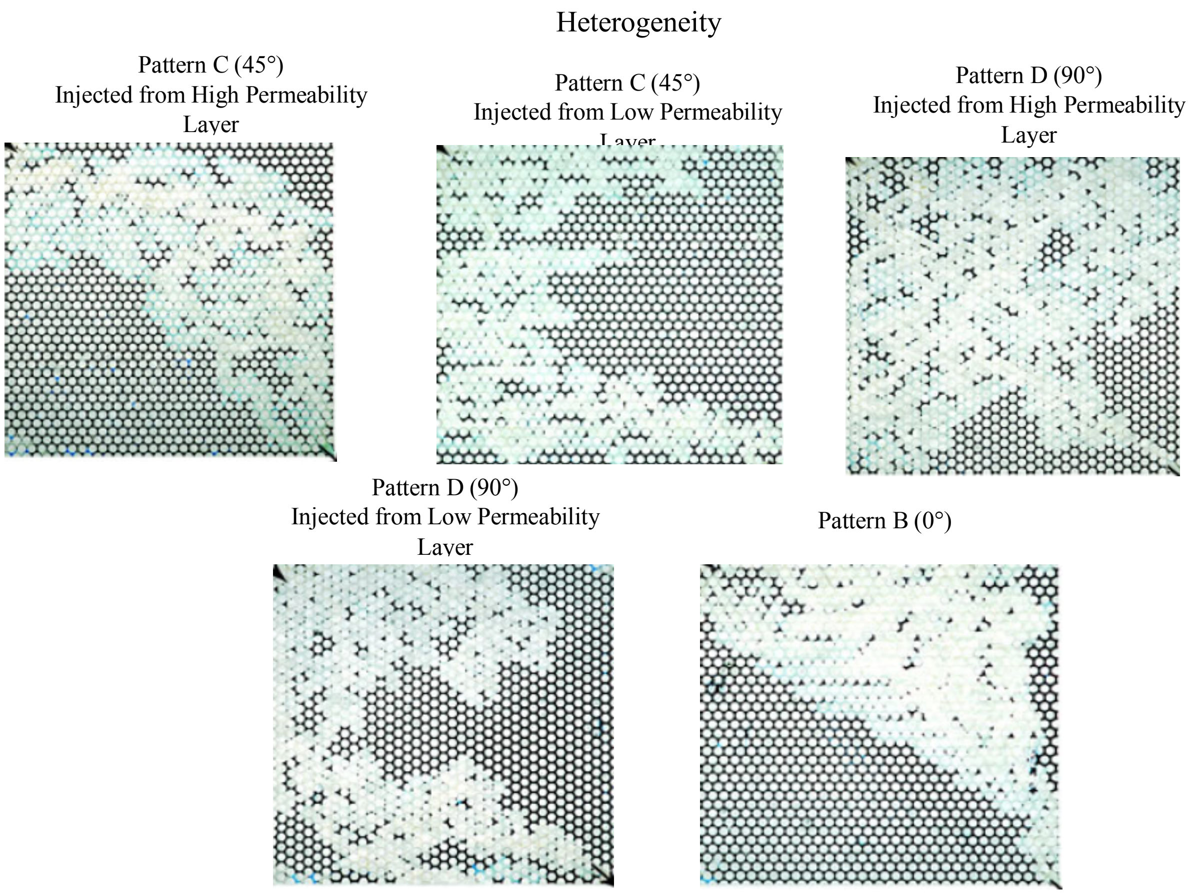


Figure 9. Polymer Injection Profile at Layered Micromodel with Pattern B (0°), C (45°), dan D (90°), injected from top left corner to bottom right corner

Figure 9 shows the result of an experiment conducted on a layered micromodel with different inclination angles. Based on the result of an experiment conducted by Emami et al. (2008) can be analyzed that when the polymer solution is injected from a layer having high permeability into a layer with low permeability, the oil recovery will be directly proportional to the increase in the inclination angle of the layer in micromodel, where it can be seen that the layer with an inclination angle of 90° (perpendicular to the flow direction) will produce the highest oil recovery, while the layer with an angle of 0° (parallel to the flow direction) has the lowest oil recovery. However, when the polymer solution is injected from a zone with low permeability to a high permeability zone, the layer with a slope angle of 0° (parallel to the direction of flow) provides the most optimal oil recovery, and the layer with an angle of inclination of 45° produces the lowest oil recovery. It can also be seen in Figure 9 that at the beginning of the polymer injection process in micromodel, the polymer solution often encounters an area having high permeability compared to an area with low permeability, then the oil recovery obtained will be higher. The experiments of Emami et al. (2008) also showed that it is not recommended to do polymer injection on a layer with an inclination angle of 0° because it doesn't give significant oil recovery compared to water injection.

V.CONCLUSION

The limitation of the core as the porous medium for visualizing the mechanism of oil displacement at pore scale made researchers decide to use a micromodel as an alternative porous medium to represent the real reservoir condition, but it needs more effort to create a micromodel that has the same characteristics with the actual condition. The transparency of micromodel is very useful for researchers to visualize and analyze the flow behavior of polymer injection. There are several factors affecting the performance of polymer injection on oil recovery, which are polymer concentration, injection rate, and heterogeneity of the micromodel (layer orientation). Polymer concentration is directly proportional to viscosity. Thus, the higher polymer concentration will result in higher viscosity. It will affect the mobility of the polymer solution, in which if the mobility of the polymer solution is lower than oil mobility, the sweep efficiency will be better and reduce the effect of viscous fingering. Therefore, by increasing polymer concentration, the oil recovery obtained will be higher. The injected polymer at a lower rate will make the polymer displacement in the model is more piston-like, while at a high injection rate, it is having an unstable flood front with less piston-like displacement. This is because, at low injection rates, the fluid has time to distribute areally and minimize inaccessible pore volume. Thus, the oil recovery will be higher at a lower rate. For the layer orientation effect, the highest oil recovery will be obtained in the layer with an inclination angle of 90° (perpendicular to the flow direction) if the polymer solution is injected from a high permeability zone.

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