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The Effect of Inaccessible Pore Volume and Adsorption on Polymer Flooding for Field Scale Injection in RZ Field

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Abstract. Polymer flooding is an Enhanced Oil Recovery method to get better sweep efficiency when water flooding operations did not give good results for the oil displacement process in the reservoir. Based on the theory, the objective of polymer flooding is increasing injected water viscosity to make the mobility ratio decreases. Then, oil sweep efficiency becomes improved. As a result, the oil recovery factor becomes higher than water flooding. However, there is a case that polymer with higher viscosity does not always give the result oil recovery improvement. Two of the factors that affect the case are Inaccessible Pore Volume (IPV) and Adsorption. This paper aims to give a comparative analysis of the effect of IPV and Adsorption parameter on polymer displacement mechanism for field-scale polymer injection. The study of this paper was carried out by compositional reservoir simulation of field-scale polymer injection to specify the optimization of polymer IPV and Adsorption parameter. Two types of data inputted in compositional reservoir simulation are laboratory data and field data. Laboratory data represents the properties of polymer FP3630S, which include polymer concentration and rheology, polymer IPV and polymer adsorption. Polymer FP3630S has been used as an injected polymer in this simulation study. Field data represents the reservoir characteristics in RZ field, including geological reservoir model, reservoir PVT fluids, routine core and special core data, initial condition data, and production history data. Several scenarios have been applied for this investigation. The scenarios are set by the sensitivity of IPV and Adsorption parameter to analyze the polymer displacement mechanism based on sensitivity. The result of several scenarios gives various Recovery Factor (RF).

Keywords: inaccessible pore volume, adsorption, recovery factor, compositional reservoir simulation, polymer flooding, field-scale polymer injection, sensitivity

INTRODUCTION

Primary and secondary oil production stages have been carried out to produce oil from the reservoir. However, there is still oil remaining in the reservoir that is not produced. Therefore, Enhanced Oil Recovery method is needed to produce the remaining oil reserve. One Enhanced Oil Recovery method is polymer injection. Polymer injection is one of chemical EOR method for displacing oil in some reservoir areas not swept by water flooding. The polymer works by increasing the viscosity of the injection water so that the sweep efficiency is better. This is expected to increase the Recovery Factor of oil production.

The polymer's viscosity has an essential role in designing the mobility ratio of injection water and oil for better sweep efficiency. Based on the mobility theory, when the polymer viscosity increases, the mobility ratio of injected water and oil will decrease. As a result, the oil sweep efficiency becomes more even, which affects the oil recovery

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factor. However, the viscosity of the polymer is not the only parameter affecting the oil Recovery Factor. Other parameters involving polymer retention also greatly influence the oil recovery factor. Two of the factors are Inaccessible Pore Volume and Adsorption[7]. This paper focuses on studying the effect of Inaccessible Pore Volume and adsorption on field scale polymer injection.

THEORITICAL BACKGROUND

Mobility Ratio

Mobility ratio is the ratio between rock relative permeability at absolute saturation to fluid viscosity of two fluids. Mathematically, mobility ratio (M) is defined as the ratio of displacing fluids mobility (polymer) to displaced fluid mobility (oil). This is the mathematical equation of the mobility ratio[8].

$$M=\frac{\left(\frac{krw}{\mu_w}\right)}{\left(\frac{kro}{\mu_o}\right)} \quad (1)$$

Inaccessible Pore Volume (IPV)

Inaccessible pore volume is a phenomenon that occurs in polymer flow in porous media. Inaccessible pore volume is defined as the amount of pore volume of rock that the polymer cannot pass through. The Inaccessible pore volume phenomenon is characterized by polymer molecules that propagate faster on porous media than the solvent. Several mechanisms that cause the IPV phenomenon can be divided into total pore exclusion and pore wall exclusion[2].

Total pore exclusion explains the mechanism between polymer and rock pore. In case polymer molecules cannot enter the pore throat of the rock due to the size of the polymer molecules is larger than the radius of the pore throat of the rock. This mechanism gives a result to inaccessible pore volume phenomenon in case the polymer has no ability to enter the pore throat of rock to displace oil in the pore throat.

Pore wall exclusion is the mechanism between the polymer and the velocity of the distribution of molecules in the pore, which is, the distribution velocity of the polymer is greater than that of the solvent. In rock pores, the maximum velocity occurs at the center of the pore, and the minimum velocity occurs at the pore wall. Because the polymer molecules' size is larger than the size of the solvent molecules, the center of the polymer molecules tends to be far from the pore wall and is more dominant in the center of the pore. This causes the distribution speed of the polymer to be more significant. It makes polymer has a tendency to flow faster than solvent in result the inaccessible pore volume phenomenon occurred.

Adsorption

Adsorption is molecular interaction between polymer molecule and grain surface of reservoir rock. This interaction causes polymer molecules to be bound to the surface of the solid, mainly by physical adsorption, van der Waals forces, and hydrogen bonding. Essentially, the polymer occupies surface adsorption sites. Adsorption depends on the surface area exposed to the polymer solution, and it is the only mechanism that removes polymer from the bulk solution if a free solid powder, such as silica sand or latex beads, is introduced into the bulk solution and stirred until equilibrium is reached [4].

OVERVIEW OF RESERVOIR CHARACTERISTIC

RZ field geologically located at Jatibarang sub-basin, West Java, Indonesia. Location of RZ Field is ± 50 km northwest from the city of Cirebon, West Java. Reservoir rock in RZ field is located in Talang Akar formation as sandstone. The reserves in reservoir of RZ field has estimated OOIP 44.661 MMSTB. The reservoir has a range of effective porosity between 0 – 31% and permeability ranges from 10 – 586 mD. Fluid properties in the reservoir is categorized as a light oil with oil gravity of 30 ^{0}API. RZ field has 3 wells as existing production well. The grid of geological model of the reservoir in the RZ field is shown by Figure 1.

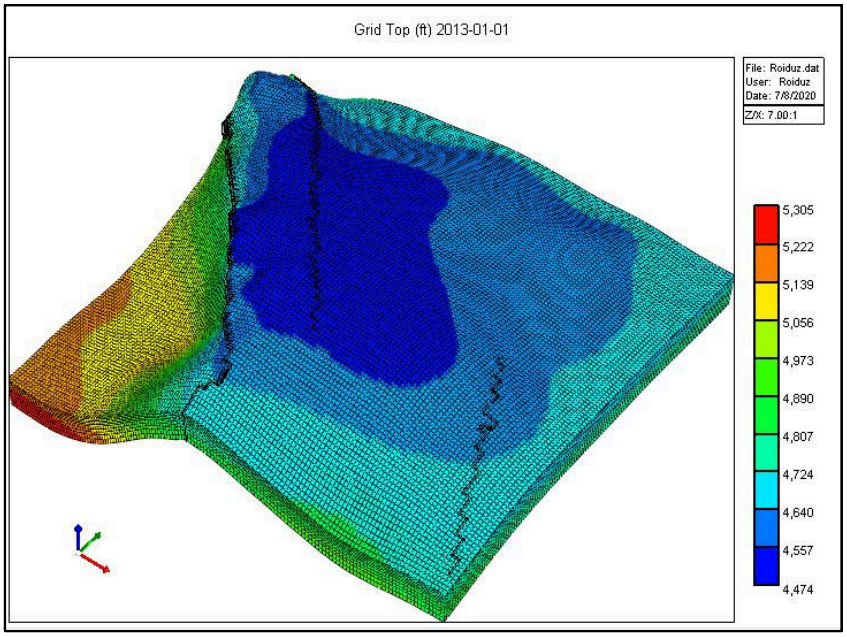

FIGURE 1. Grid Top of RZ Field Reservoir

LABORATORY EVALUATION

The laboratory evaluation records the polymer rheology properties. The type of polymer tested in the laboratory is FP3630S. The test was carried out to measure the polymer's viscosity in various polymer concentrations at a certain shear rate. The viscosity measurement was carried out at 70^{0}C using an instrument named Viscometer Brookfield LVDV3T with specification Spindle CV40. The instrument fundamental is to measure the polymer's resistance to get shear stress result to hold at given shear rate. Torque is a parameter that is also measured to calculate polymer viscosity at a given condition. Figure 2 shows the rheology properties of FP3630S as viscosity vs polymer concentration. The recorded rheology of FP3630S polymer was inputted to reservoir simulation as injected fluid in polymer injection operation of RZ field.

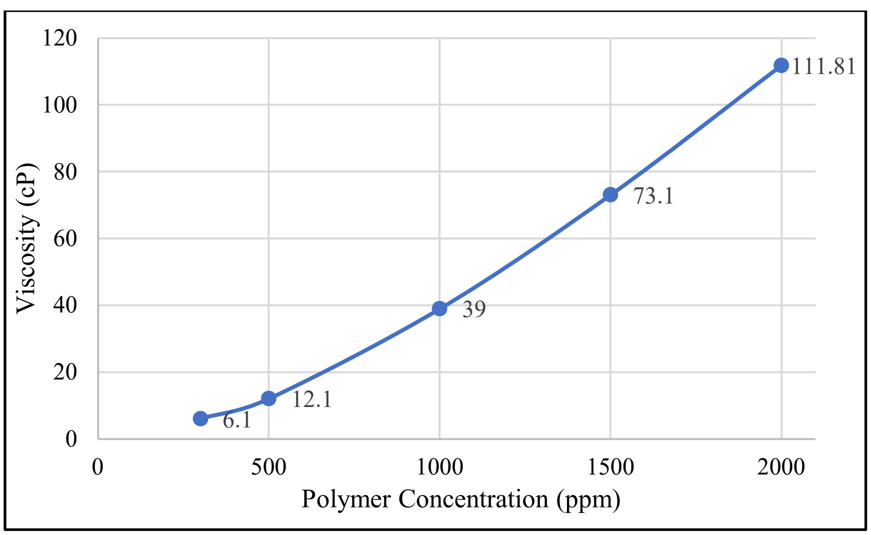

FIGURE 2. Viscosity vs Concentration of FP360S Polymer

FIELD SCALE SIMULATION

The field-scale simulation was carried out to forecast polymer flooding performance in the reservoir of RZ field. Simulation is started from input data, continues with initialization, history matching, and ended by forecasting. Initialization was carried out to equalize oil in-place of simulation to oil in-place from existing data. The history matching stage was carried out to match reservoir performance from production data to reservoir production performance in simulation. History matching was carried out from January 2007 until December 2017. The production data used to match reservoir performance was from 3 existing wells in RZ field. Figure 3 shows the field scale simulation timeline of RZ field.

The last stage of field scale simulation is forecasting. The forecasting stage has two parts of the scenario which are water flooding and polymer injection. Water flooding carried out from January 2018 until December 2026 (shown by Figure 3). Water flooding scenario was done by produce oil from 3 existing wells and water injection from 9 new injection wells. Figure 4 shows the location of production wells and injection wells. Injection rate for water flooding scenario is constant on 100 bbl/day for each wells.

Second part of forecasting stage is polymer injection which was carried out from January 2027 to December 2037 (shown by Figure 3). Polymer injection was carried out through the same injection wells as water flooding shown by Figure 4. The injection rate applied for polymer injection is also the same as water flooding which is constant on 100 bbl/day of each wells. Injected polymer into RZ field is FP3630S polymer with concentration 2,000 ppm which has been tested for its rheological properties in the laboratory. The rheology data was inputted to simulation to represent properties of injected polymer in polymer injection scenario in RZ field. Main objective of polymer injection scenario is to observe the sensitivity analysis of polymer parameters, namely inaccessible pore volume and adsorption. These two parameters are subjected to do sensitivity from lower to upper range for each parameters. Table 1 represents the inputted value for each parameter and range. Each of these value is input into the simulation as object for further analysis for the effect of inaccessible pore volume and adsorption on oil recovery factor in field scale polymer injection.

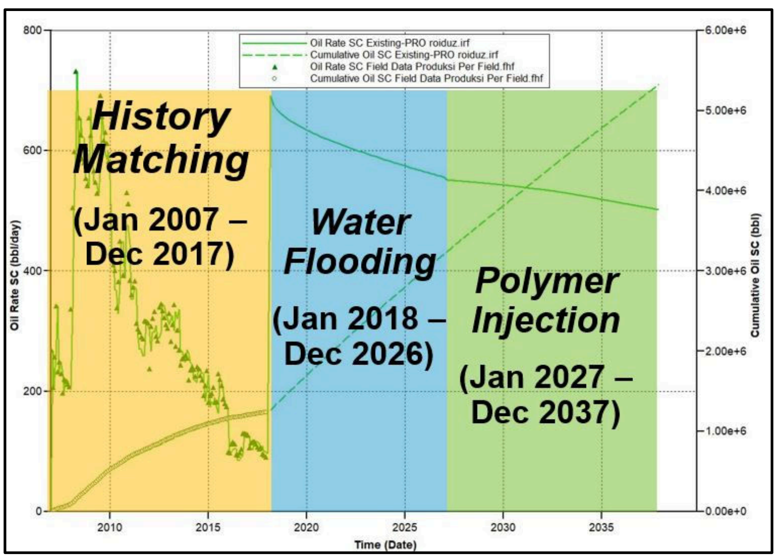

FIGURE 3. Timeline of RZ Field Scenario

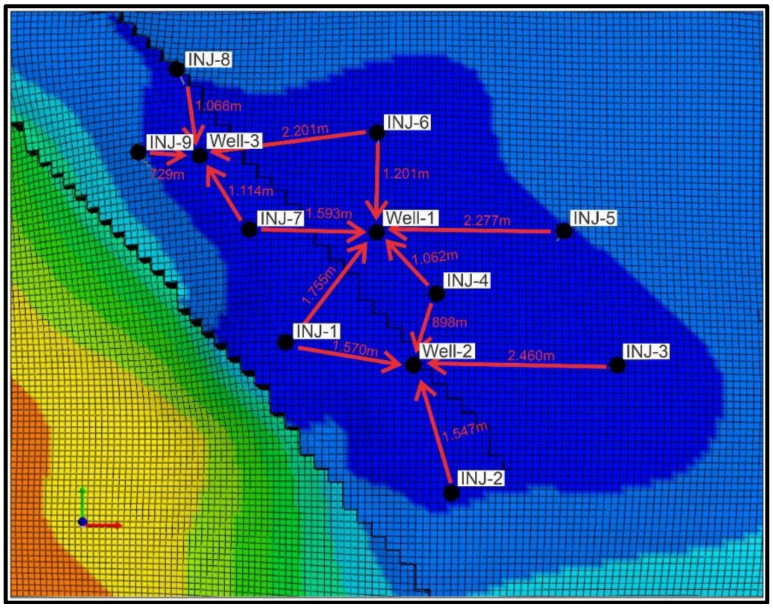

FIGURE 4. Location of Production and Injection Wells of RZ Field

TABLE 1. Inputted Value for IPV and Adsorption Sensitivity Scenario

Scenario	Range		
	Lower	Middle	Upper
1. Polymer Injection for Adsorption Sensitivity	197.6	435.83	674.06
2. Polymer Injection for IPV Sensitivity	11.9	23.2	34.5
3. Polymer Injection for Adsorption and IPV Sensitivity	197.6 and 11.9	435.83 and 23.2	674.06 and 34.5

RESULT AND DISCUSSION

Sensitivity scenarios have been run using reservoir simulation so that further analysis can be carried out regarding the oil recovery obtained. From each scenario, various recovery factors were obtained depending on the sensitivity value. The scenarios are analyzed and compared for each oil recovery factor obtained at the end of forecasting, dated December 2037.

Effect of Adsorption on Oil Recovery Factor

The first scenario is adsorption sensitivity. The result obtained from this scenario is shown by Table 2. The result shows that higher polymer adsorption value gives result lower oil recovery factor. Based on mechanism in polymer adsorption, the higher adsorption value, then more polymer molecules are attracted or adsorbed to reservoir rock surfaces. More polymer molecules are adsorbed to the reservoir rock, causing the polymer concentration to decrease. This decrease in polymer concentration will result in worse performance of the polymer itself. With poor polymer performance, the recovery factor obtained also decreases. Figure 5 shows a plot between polymer adsorption to oil recovery factor in RZ field.

TABLE 2. Result of Polymer Injection Scenario 1: Adsorption Sensitivity

Scenario 1: Polymer Injection for Adsorption Sensitivity	Range		
	Lower	Middle	Upper
Inputted Adsorption Value (µg/gr)	197.6	435.83	674.06
Oil Recovery Factor	11.8711%	11.8666%	11.8544%
Delta Oil Recovery Factor from Lower Range	0%	-0.0045%	-0.0167%

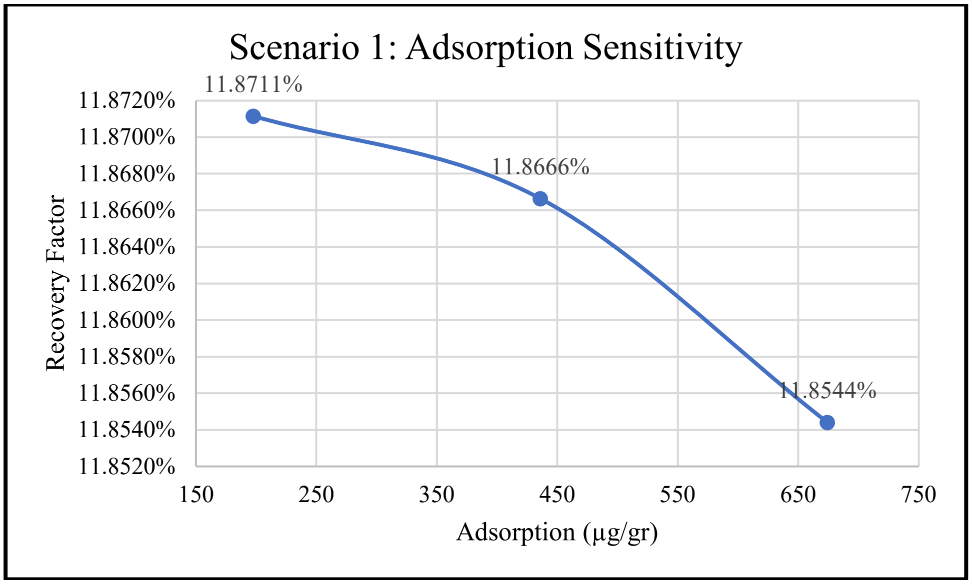

FIGURE 5. The Effect of Adsorption Sensitivity on Oil Recovery Factor of RZ Field

Effect of IPV on Oil Recovery Factor

The next scenario is inaccessible pore volume sensitivity. Result obtained from this scenario is shown by Table 3. It can be seen that the higher IPV does not necessarily give the lower recovery factor results. When IPV value in range lower, it gives result recovery factor 11.8711%. The next sensitivity, IPV value is increased to be middle range, it gives result recovery factor 11.8707%. But, when IPV value is increased again to be upper range, recovery factor is increased to be 11.8714%, indeed the increase is more significant than the recovery factor at IPV value in the lower range. The plot of IPV sensitivity is shown in Figure 6.

This phenomenon is an anomaly which indicates that IPV is not a parameter that is directly proportional to or inversely proportional to the recovery factor but there is a certain optimum point. This anomaly in IPV Sensitivity can be explained by two mechanisms: total pore exclusion and pore wall exclusion. In total pore exclusion mechanism, the mechanism that occurs between polymer and pore is that polymer molecules cannot enter the pore throat of the rock due to the size of the polymer molecules is larger than the radius of the pore throat. The phenomenon that occurs in Scenario 2 if explained by the total pore exclusion mechanism, it is possible that when the IPV value is Middle, the recovery factor will decrease (compared to the recovery factor in Lower range) because the pore volume accessed by the polymer is less so that less oil is swept by polymer. Meanwhile, when the IPV is Upper, the recovery factor is the highest because the more pore volume (which is relatively small) that is not accessed by the polymer, the more uniform the polymer molecules are to carry out sweeping oil in the reservoir area.

The next mechanism is pore wall exclusion. This mechanism describes that the size of the polymer molecules is larger than the solvent, resulting in polymer molecules tending to be in the center of the pore so that the speed of the polymer to pass through the porous medium is greater than the solvent. The polymer, which flows faster than the solvent, makes adsorption minimum because the interaction between the polymer and the rock surface is relatively fast. Scenario 2, if explained by the pore wall exclusion mechanism, only applies to the sensitivity from Middle to Upper, namely by increasing the IPV value, the recovery factor increases due to the minimum Adsorption.

TABLE 3. Result of Polymer Injection Scenario 2: Inaccessible Pore Volume Sensitivity

Scenario 2: Polymer Injection for IPV Sensitivity	Range		
	Lower	Middle	Upper
Inputted IPV Value (%)	11.9	23.2	34.5
Oil Recovery Factor	11.8711%	11.8707%	11.8714%
Delta Oil Recovery Factor from Lower Range	0%	-0.004%	+0.0002%

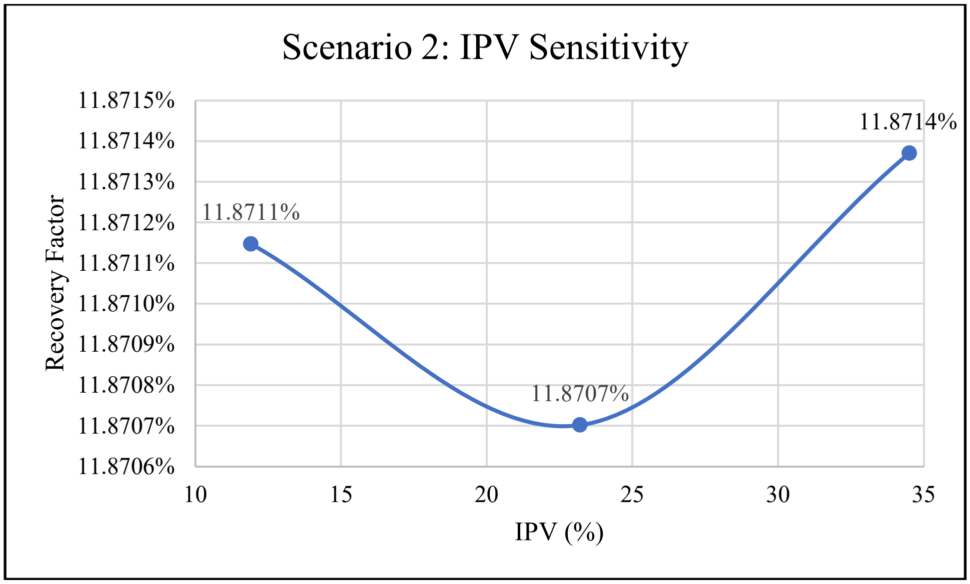

FIGURE 6. The Effect of IPV Sensitivity on Oil Recovery Factor of RZ Field

Effect of Adsorption and IPV on Oil Recovery Factor

The last scenario is adsorption and IPV sensitivity. The results obtained by Scenario 3 show that the greater Adsorption and IPV values that are inputted to reservoir simulation, the smaller oil recovery factor. It can be seen in Table 4. This shows that the parameter that has more influence on polymer injection is Adsorption than IPV due to the Adsorption parameter trend gives smaller oil recovery factor when adsorption value gets greater. Meanwhile, IPV parameter trend is that if the greater IPV value, the recovery factor will not necessarily be smaller. At the same time, the results obtained in the scenario shows that the trend follows the Adsorption parameter, which means that the IPV parameter has less effect on the sensitivity. So it can be concluded that IPV is a parameter that is not sufficiently influential compared to adsorption on the performance of field-scale polymer injection.

TABLE 4. Result of Polymer Injection Scenario 3: Adsorption and Inaccessible Pore Volume Sensitivity

Scenario 3: Polymer Injection for Adsorption and IPV Sensitivity	Range		
	Lower	Middle	Upper
Inputted Adsorption Value (µg/gr)	197.6	435.83	674.06
Inputted IPV Value (%)	11.9	23.2	34.5
Oil Recovery Factor	11.8711%	11.8688%	11.8598%
Delta Oil Recovery Factor from Lower Range	0%	-0.0024%	-0.0113%

CONCLUSIONS

1. Scenario 1, namely Polymer Injection with Adsorption Sensitivity, shows that the greater Adsorption value, the smaller oil recovery factor obtained. This is because the greater the adsorption value, the more polymer

molecules are attracted to the rock so that the concentration decreases that makes performance of the polymer injection gives results in decreased recovery factor.

2. Scenario 2, namely Polymer Injection with IPV Sensitivity, shows that the greater the IPV value that is input into reservoir simulation does not necessarily indicate the lower oil recovery factor.
3. Scenario 3, namely Polymer Injection with Adsorption and IPV sensitivity, shows that IPV is a parameter that is not sufficiently influential for oil recovery factor compared to Adsorption on the performance of field-scale polymer injection.
4. It is recommended to do further study on the proxy-model which represents the equation of relationship between Adsorption and IPV on oil recovery factor due to the effect of IPV and Adsorption has been seen in this study but it is not yet clear, especially in the IPV phenomenon.

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