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A Simulation Study on Polymer Mobility Design Strategies and Their Impact on Oil Recovery Efficiency and Displacement Mechanisms

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ABSTRACT - Polymer flooding is an effective enhanced oil recovery (EOR) technique, particularly when waterflooding alone proves insufficient in improving oil recovery. It is prominent to acquaint the principle of mobility control to understand the ability of polymer to overcome the oil displacement inefficiency of waterflooding, a requirement for a better sweep efficiency. This paper presents a comparative study of mobility control methods as critical parameters for polymer design. This paper investigates a simulation study of different simulation model to optimize polymer mobility design by comparing various mobility control methods. In this study, a compositional simulation model was built based on previous laboratory experiments validated by matching simulation results. Furthermore, to visualize the polymer displacement process, this study performs 1D, 2D, and 3D simulation models. The results indicates that polymer mobility design could affect the upstream viscosity, leading to high sweep efficiency and higher oil recovery. The study also suggests that the unit mobility ratio from the existing concept of conventional mobility control has invalid criteria to distinguish favourable and unfavourable conditions. The comparison with various mobility design methods reveals differences in recovery factors, influenced by some factors such as underlying assumptions and the specific conditions favoured by each method.

Keywords: mobility design, comparative study, polymer displacement process, simulation study, oil recovery factor.

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INTRODUCTION

The indication of either considerable heterogeneity of reservoirs or unfavourable mobility ratio conditions potentially leads to inefficiency of the oil displacement mechanism in waterflooding (Dyes et al. 1954). Consequently, these obstacles cause early water breakthrough and lowering the oil recovery factor. Therefore, polymer injection has become one of the top solutions as an enhanced oil recovery method to overcome the problems by reducing the mobility ratio (Al-Shakry et al. 2018; Carcoana 1992; Hendraningrat & Zhang 2015; Lake 1989). The unit of mobility ratio is an indicator of the stability of the displacement front in the oil recovery process. The addition of polymer solution in the displacing fluid is to generate a favourable mobility ratio between the displacing and the displaced phase (Gbadamosi et al. 2019; Sorbie 1991). The purpose is to generate a stable front of the displacing phase, developing a more identical reservoir volumetric sweep, both areally and vertically (Green & Willhite 1998). Mobility control is any process to fix the sweep efficiency to achieve the desired condition. In polymer flooding, mobility control is achieved by adding polymer to the injected fluid, which increases the apparent viscosity of the displacing fluid, resulting in a more stable displacement front. However, mobility control has widely different methods from various researchers. Therefore, it becomes necessary to apply the comparative study to learn the preferable conditions for each method.

This study aims to examine the effects on the oil recovery factor by comparing various mobility design methods through a numerical approach and simulation study (Ramadhan et al. 2020; Sugihardjo 2022). Moreover, to investigate the efficiency of displacement process, physical models using 1-D, 2-D, and 3-D simulation are performed by applying sensitivity on various variables such as polymer concentration and polymer scheme injection.

Review on past studies

An understanding of the principle and method description shows that polymer flooding improves oil recovery over waterflooding by increasing the reservoir volume contacted through better sweep efficiency (Auni et al. 2023). The successful application of polymer flooding in a given field must be evaluated based on several factors, including mobile oil saturation, oil viscosity, and reservoir heterogeneity (Alli 2019; Siregar et el. 2022). Therefore, proper evaluation and polymer flood design require a comprehensive view of reservoir characterization, laboratory testing, reservoir simulation, facilities design, and field testing (Kaminsky et al. 2007; Ramadhan et al. 2020). The detailed polymer flood guidelines were given on various studies (Saputra et al. 2022; Thomas et al. 2012; Wang et al. 2008) that assemble polymer implementation and screening criteria, which is not discussed in this paper.

Nevertheless, all fundamental theories and established guidelines are served as the fundamental principle in this study, which focuses on investigating polymer mobility design methods. This will be accomplished by analysing the effects on polymer recovery mechanisms and displacement efficiency through a numerical approach and simulation study.

Polymer characterization

It is always necessary to recognize polymer properties since it plays an essential role during a polymer flood design (Hidayat & ALMolhem 2019; Liu et al. 2017). Several prominent factors that need to be optimized on formulating the polymer solutions include polymer concentration, polymer molecular weight, polymer volume, polymer solution viscosity, and injection rate (AlSofi et al. 2018; AlSofi & Blunt 2014; Musa et al. 2023; Wang et al. 2008). The rheological properties of polymers in dilute solutions become an interest in EOR applications. Solution of both poly-acrylamides and xanthan biopolymers typically exhibit non-newtonian rheological behaviour (Green & Willhite 1998). The polymer solution viscosity is one of the critical parameters in the polymer flooding design, which can remedy the mobility ratio between oil and water (Delamaide 2024; Mansour et al. 2025). Typically, the viscosity of polymer solution used in EOR applications decreases as the shear rate increases, known as shear thinning in terms of rheological characteristics. It is frequently feasible to express a shear-thinning fluid rheological properties by the Power-law model which describes the pseudoplastic region given by equation 1.

$$\mu = K\gamma^{n-1} \tag{1}$$

Where μ presents viscosity, K is Power-law constant, n indicates Power-law exponent, and γ is shear rate. Typically, the Newtonian fluid has n= 1 and K is the constant value. In this case, the polymer solution exhibits pseudoplastic region, characterized by a value of $n \leq 1$.

Polymer characterization

For clarity in discussion, it is useful to define the mobility ratio (M), which represents the ratio of the mobility of the displacing phase (upstream) to that of the displaced phase (downstream):

$$M = \frac{\lambda u}{\lambda d} = \frac{(\frac{kru}{\mu u})}{(\frac{krd}{\mu d})} \quad (2)$$

Here, λ_u and λ_d respectively represent upstream and downstream mobilities. Specifically, kru and krd denote the relative permeability of the displacing and displaced phases, while µu and µd refer to the viscosity of the the displacing and displaced phases.

Conventionally, a mobility ratio equal to or less than one (M ≤ 1) is considered as favourable condition, and a mobility ratio that exceeds one (M > 1) is an unfavourable condition (Craig 1970). The unfavourable condition in waterflood is a critical situation where the applications of a polymer may fluid causes an increment of water viscosity and a high front stability of the displacing phase, which denudes viscous fingering.

James Sheng method

James Sheng's study has found a better criterion to describe the unit mobility ratio by justifying the proposed idea from the displacement front stability. The approach assumes that the oil and the displaced water flow through two separate channels, one for water and one for oil. This assumption of the flow model is schematically illustrated in Figure 2.

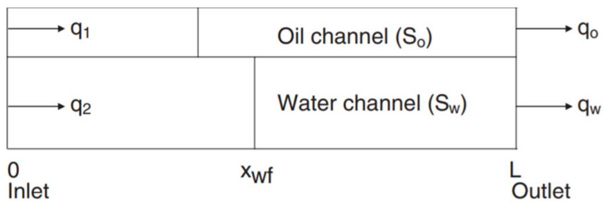
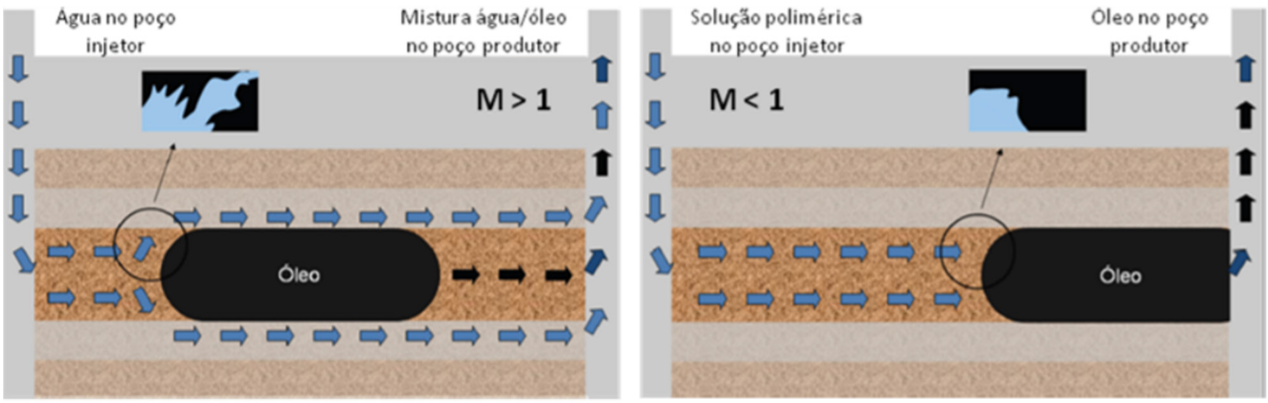


Figure 2. Schematic of flow channels (Sheng 2010)



(a) (b)

Figure 1. Schematic of typical mobility ratio in flooding processes, a) Waterflood (M > 1); and b) Polymer flooding (M ≤ 1)

be considered. This case depicts the unfavourable mobility ratio (M > 1), indicating the waterflood volumetric sweep inefficiency due to viscous fingering. This condition encourages early water breakthrough, resulting in lower oil displacement efficiency, as schematically illustrated in Figure 1 a). It always becomes the requirement of mobility control in any EOR processes by designing the favourable mobility ratio (M ≤ 1) to secure a high volumetric sweep efficiency. The role of polymer is to increase the displacement efficiency through the reduction of mobility ratio. It can be seen in Figure 1 b) which illustrates the way polymer flood improves oil recovery. The presence of polymer in the injected

Based on that proposed criterion, James Sheng has applied a further theoretical investigation, in which the details are expressed in (Sheng 2010). From the displacement front stability point of view, the mobility ratio should be equal to or less than 1. In other words, the criterion for the mobility control requirement in EOR processes should be:

$$M = \frac{k_{rw} / \mu_u \overline{S_o}}{k_{ro} (S_w) / \mu_o} \leq 1 \quad (3)$$

The physical definition of M defined by equation 3 is the mobility ratio in the assumed oil channel defined as the ratio of displacing fluid mobility to the displaced oil phase mobility multiplied by the normalized movable oil saturation (So). The subsequent numerical simulation results from Sheng's study also show that the unit mobility ratio in equation 3 can be considered the best formula to define a criterion for the mobility control requirement (Sheng 2010).

End-point method

The definition of mobility ratio derived by the end-point method is described as the use of relative permeabilities at end-point conditions such as water relative permeability at residual oil saturation and oil relative permeability at connate water saturation. Accordingly, the end-point mobility ratio can be expressed in equation 4 below:

$$M = \frac{(k_{rw} @ S_o / \mu_w)}{(k_{ro} @ S_{wc} / \mu_o)} \quad (4)$$

It is found that a significant limitation affects the unit mobility ratio given by this method when compared to others. This limitation arises because the value of water relative permeability behind the front is significantly lower than water relative permeability at residual oil saturation (end-point). Besides, another limitation also occurs at the end-point method due to the implementation of end-point relative permeabilities with a constant value. Consequently, there are no changes in the amount of mobility ratio under various saturation.

Gomaa method

The required polymer solution concentration is usually specified by viscosity characteristics, shear rate, reservoir oil viscosity, water viscosity, reservoir relative permeability characteristics, and fair value of mobility ratio for polymer flood (Gomaa & Ezzat Gomaa 2015). Polymer mobility ratio can be determined by total fluid mobility behind the flood front divided by minimum total mobility ahead of the front:

$$M = \frac{\left[(k_{rp}/\mu_p) + (k_{rw}/\mu_w)\right]^{behind}}{\left[(k_{ro}/\mu_o) + (k_{rw}/\mu_w)\right]^{minimum}} \quad (5)$$

Krp, Kro, and Krw respectively refer to polymer, oil and water relative permeability. Then, µp, µo, and µw refer to the polymer viscosity, oil, and water. Moreover, superscripts (behind) and (minimum) refer to conditions within the mobility fluid and minimum total mobility ahead of the flood front. This equation is to determine the required viscosity of polymer solution, which is applied to specify the required concentration based on a laboratory study (Golab et al. 2024). However, Gomaa proposes a more conservative criterion, suggesting a favourable mobility ratio of 0.35, as opposed to the conventional criterion which recommends a value equal to or less than 1.

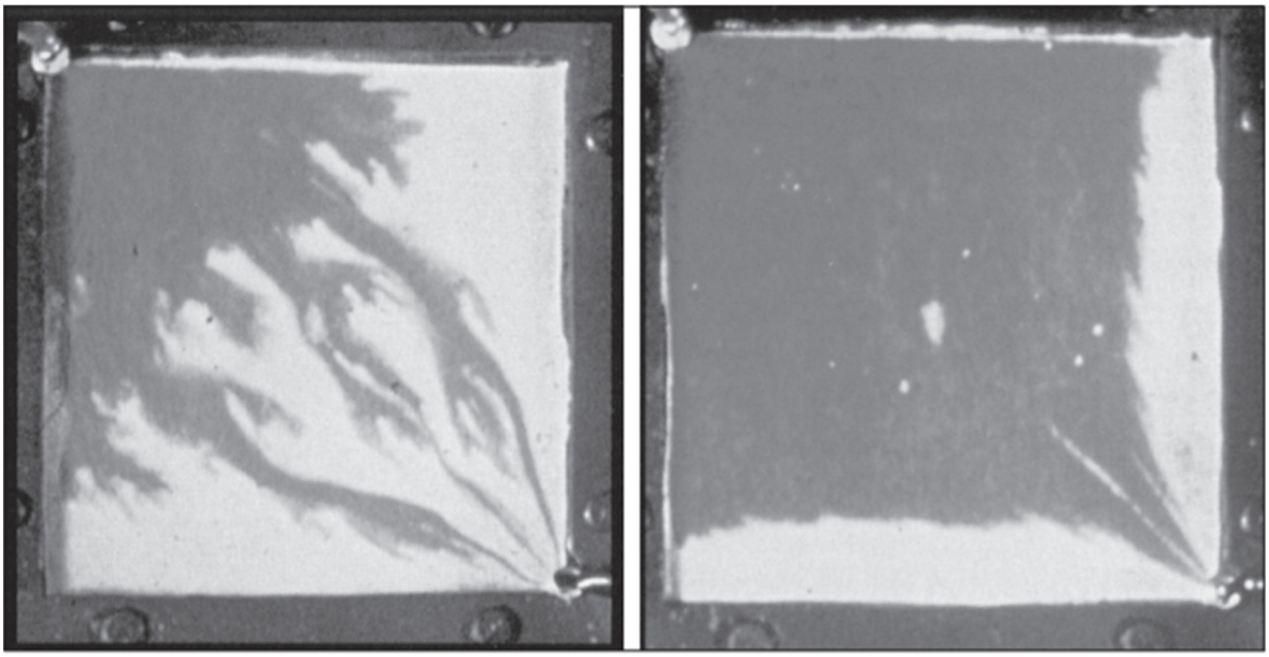
Volumetric displacement efficiency

Volumetric sweep is defined as the portion of reservoir pore volume invaded by the injected fluid. The volumetric sweep efficiency, Ev, describes a quantitative measurement of the contact between injected fluid and volume of the reservoir determining how effectively the oil recovery in any displacement process, both areally and vertically. Therefore, volumetric sweep efficiency can be identified conceptually as the output of areal and vertical sweep efficiencies, expressed by equation 7:

$$E_V = E_A E_I \quad (6)$$

E_A presents the areal sweep efficiency in an idealized model reservoir and E_I shows the vertical sweep efficiency in all layers behind the front. Practically, volumetric displacement efficiency is often determined by applying appropriate correlations or physical models with a basis of 3D model systems instead of by calculating the E_A and E_I independently. Nevertheless, it is beneficial to express volumetric sweep as an output of areal and vertical sweep efficiencies to comprehend volumetric sweep efficiency parameters.

Macroscopic displacement efficiency is based primarily on the mobility control process, mainly applied by maintaining a favourable mobility ratio. The main contribution of a favourable mobility ratio is to increase both areal and vertical sweep efficiencies. This phenomenon is provided in Figure 3, which demonstrates the polymer flooding resulting an improvement of volumetric displacement efficiency in the waterflooding.



(a) (b)

Figure 3. Schematic of macroscopic displacement efficiency by a) over waterflood; and b) polymer flooding leading to improved sweep efficiency and higher oil recovery (Sheng 2010)

This study particularly concerns about displacement efficiency expressed as a performance of the simulation study of displacement efficiency by investigating the visualization of the polymer displacement process through various simulations of two-dimensional and three-dimensional models. However, an understanding and appreciation of the principle of polymer displacement efficiency must comprehend the recovery mechanism implicated in the polymer flood process.

METHODOLOGY

This paper focuses on a simulation study using various models to specify the appropriate polymer mobility design by comparing various mobility control methods such as James Sheng, End-Point, and Gomaa methods. The measured properties from previous laboratory experiments such as polymer, brine, oil, and core are used in this study as input parameters for the simulation study. A coreflood simulation was conducted using CMG advanced compositional simulator, STARS, to shed light on the history matching process and generate the validated SCAL properties used in the prior laboratory experiment. Subsequently, the numerical approach was applied to determine the upstream viscosity of each method and assist the understanding of the comparative study of polymer mobility design methods. The simulation studies were, then, performed with various scenarios using different models such as one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) to analyze the recovery factors of various mobility design methods. The significant methodology to accomplish this study with various scenarios has been summarized as a flowchart in Figure 4.

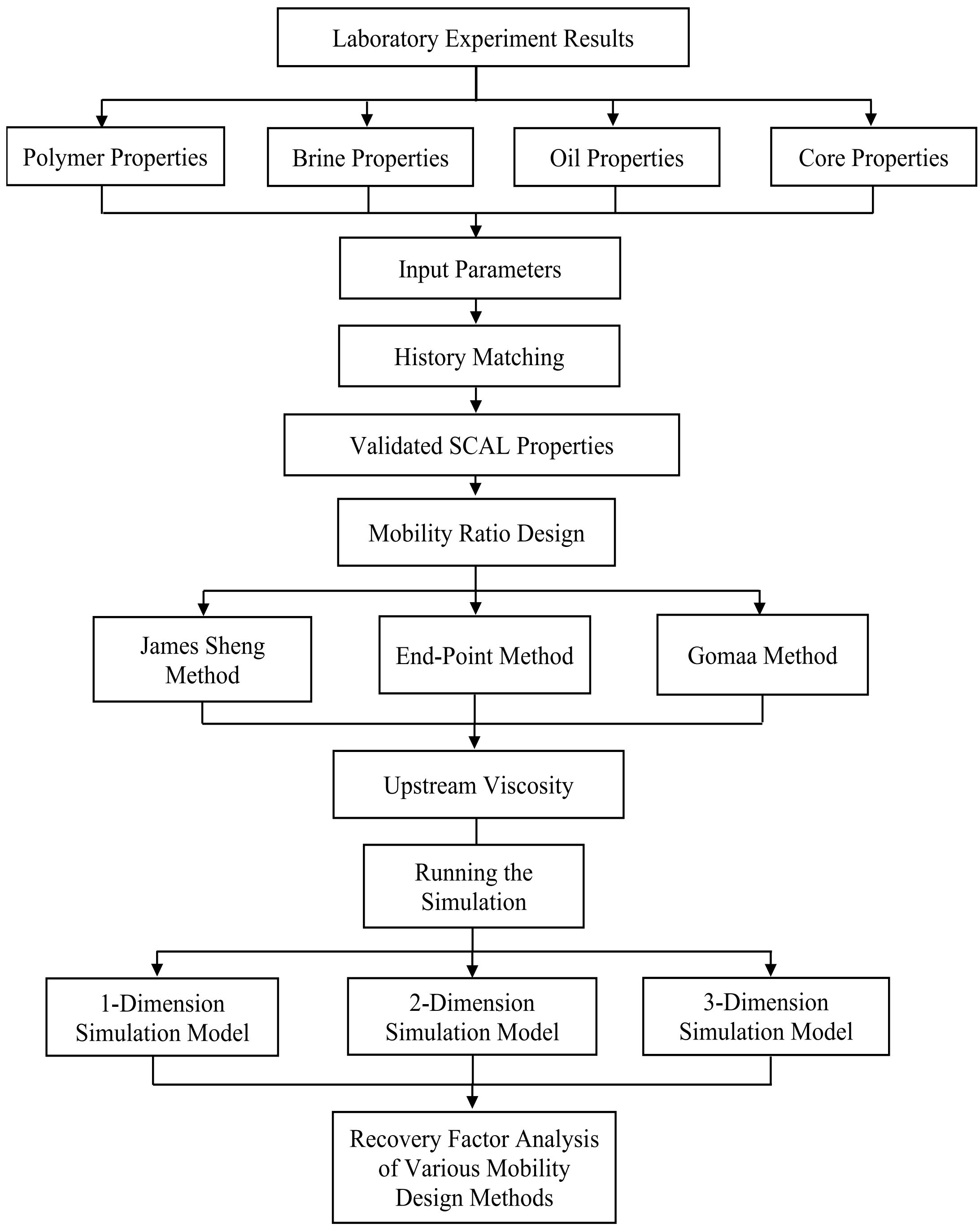


Figure 4. Study flowchart

Coreflood simulation

All the scenarios of laboratory work, including injectivity and coreflood tests, were performed on synthetic Bentheimer cores. The results of the experiment are represented and discussed elsewhere (Abbas et al. 2018; Park et al. 2015). However, it was observed that the relative permeability curves or SCAL properties of the synthetic cores used in the experiment have been not defined yet. Consequently, sensitivity studies on the matching parameters through coreflood simulation are required to specify the core samples of SCAL properties. Primary matching parameters, including pore volume, initial oil in place, and recovery performance, have to be historically aligned with the previous experiment to amplify the polymer process and calibrate the simulator of polymer flood parameters.

Although the dimension of core samples used in the experiment is radial, it is frequently feasible that coreflood simulation is applied through linear simulation models and built-in Cartesian grids, indicating that the core dimension is necessarily converted while conserving the volume. The coreflood simulation model is a linear model (one-dimensional of flow), which has the direction of flow assumed to be in the I-Direction. Consequently, all measured dimensions of the laboratory cores are implemented as the basis for constructing the one-dimensional linear model, as shown in Figure 5. Furthermore, laboratory core properties measured in the previous experiment are applied as physical properties of the constructed model listed in Table 1.

Table 1. Physical properties of one-dimensional model

Properties	Value
Grid Length, cm	7.27
Grid Thickness, cm	3. 34664
Porosity (ø), %	0.2116
Permeability (I, J, K), mD	3303.64
Pressure, psi	150
Temperature, °C	70

The simulation model included polymer, brine and oil components were required in the coreflood simulation to model the polymer flood mechanism adequately. In the laboratory experiment, the polymer was tested at various concentrations to highlight its rheological behaviour, specifically its shear-thinning

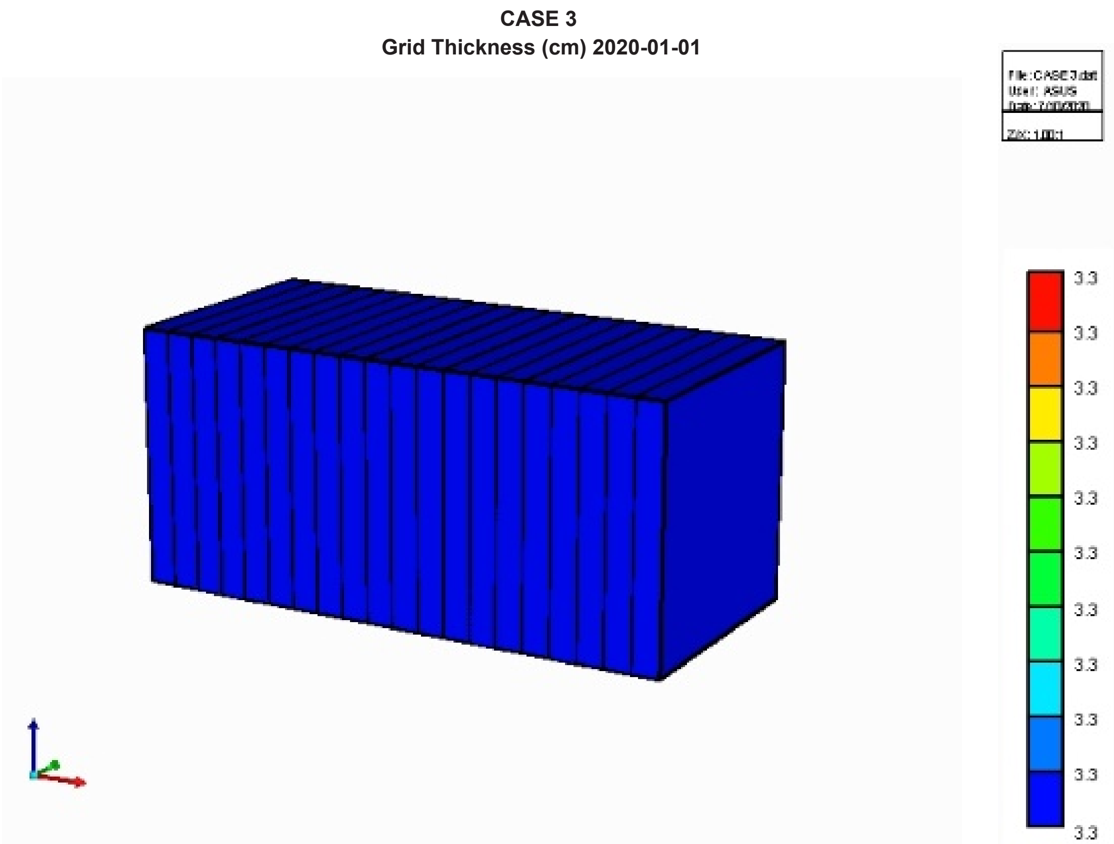


Figure 5. One-Dimensional linear model

characteristics, which are summarized as a curve in Figure 6. The brine used in the experiment was synthetic and dissolved in demineralization water. All laboratory measurements of the required components (Abbas et al. 2018; Park et al. 2015) specify the simulation component properties, as listed in Table 2.

Table 2. Component properties

Properties	Polymer	Brine	Oil
Concentration, ppm	2000	1000	-
Density, g/cm^3	1	0.9949	0.8436
Apparent Viscosity, cP	111.81	0.65	11.7479

The coreflood test results from the experiment were implemented as the base case scenario in the coreflood simulation. It was expressed in the experiment that the coreflood test was carried out with a total of 6.3 pore volume (PV), which were comprised of 3.9 PV of waterflood and followed by 2.4 PV of polymer flood. All coreflood experiments were conducted at the average reservoir temperature of 70˚C and with an injection rate of 0.3cc/min. All the parameters were then applied to set up the coreflood simulation.

History matching

The main coreflood simulation objective is to determine the validated SCAL properties from the previous experiment through history matching. As mentioned earlier, the relative permeability curves of the core sample used in the experiment were not defined yet. Since it has an essential role in examining the polymer mobility design method in the numerical approach, it becomes necessary to specify the SCAL properties through sensitivity analysis to validate the relative permeability curves. The process requires the availability of data from the experiment to generate a table using correlation. The related data is initial water saturation from the laboratory coreflood test so that the data can be used as a reference in developing the relative permeability table. However, it does not contribute sufficiently to achieving an accurate match. Hence, it is necessary to perform a sensitivity analysis on the relative permeabilities of both oil and water at absolute saturation to achieve accurate matching results.

Before analysing the waterflood and polymer flood recovery performance as the principal history matching approach, it is also necessary to cross-check the initial matching. The laboratory core properties

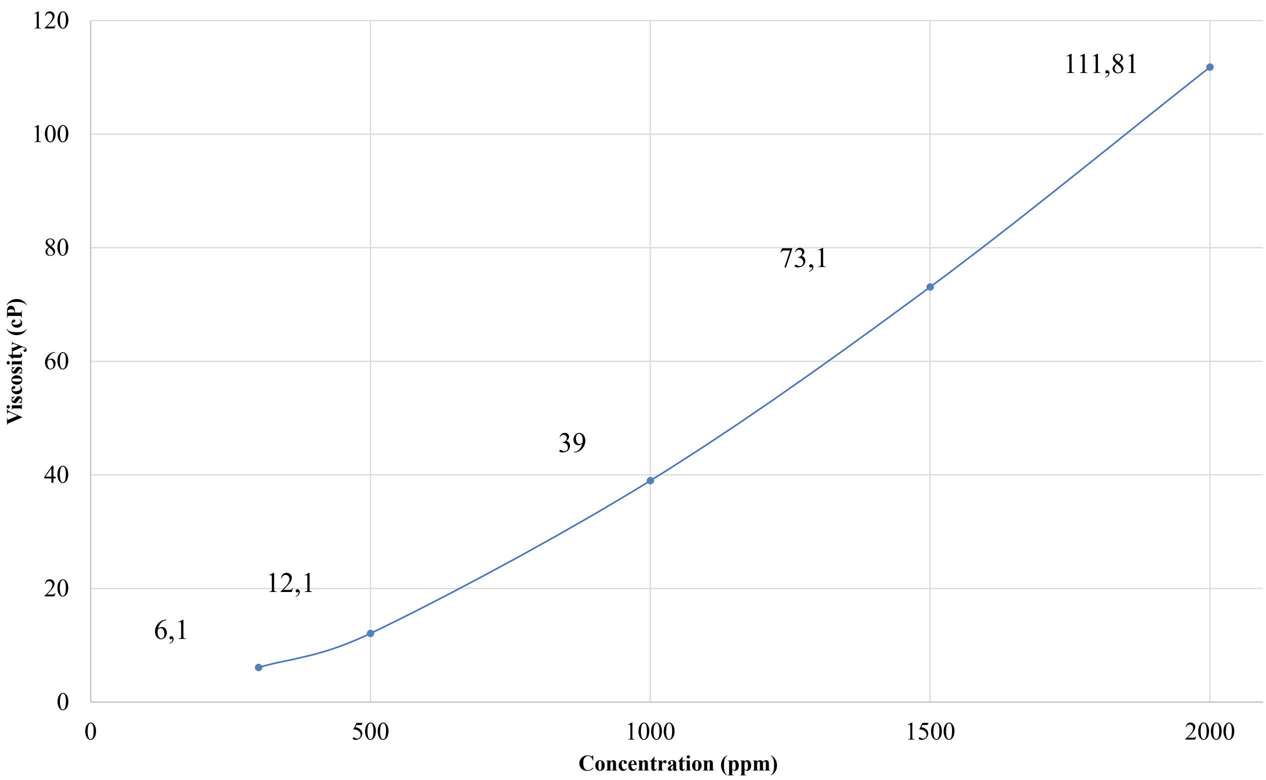


Figure 6. Viscosity vs concentration of polymer solution in polymer flooding

and inputted physical properties on the constructed model will match the initialization results. The initial matching parameters, including pore volume and initial oil in place (IOIP), have been matched in this process, as shown in Table 3.

Table 3. Initial matching

Parameter	Initial Oil in Place (IOIP)	Pore Volume (PV)
Simulation Initialization, cc	10.768	17.229
Laboratory Data, cc	10.76	17.23
Error Percentage, %	-0.0743	0.0058

After attempting the sensitivity on the relative permeabilities table by adjusting both water and oil relative permeabilities at a certain point of saturation, the validated SCAL properties are finally obtained (see Figure 7) after the laboratory coreflood recovery process, and the coreflood simulation recovery profile was historically matched as shown in Figure 8. The validated permeability curve was then undertaken to determine the upstream viscosity of various mobility control methods through a numerical approach.

Numerical approach

The numerical approach was carried out before running the simulation study on various scenarios. The main objective of numerical approach is to calculate the upstream viscosity through mathematical models of each mobility control method. Each target viscosity results defined the polymer concentration later used as input parameters in the simulation scenarios. This section displays the calculation results carried out as part of the numerical approach.

In the previous section, various mobility design methods have been described in terms of the detailed description of the equations and the assumption and limitations contained in each method. As such, the numerical approach was carried out by applying calculation using equations applied in each method. The main parameters used in the calculation are water and oil relative permeabilities at the saturation condition at the end of a waterflood, carried out in the history matching process.

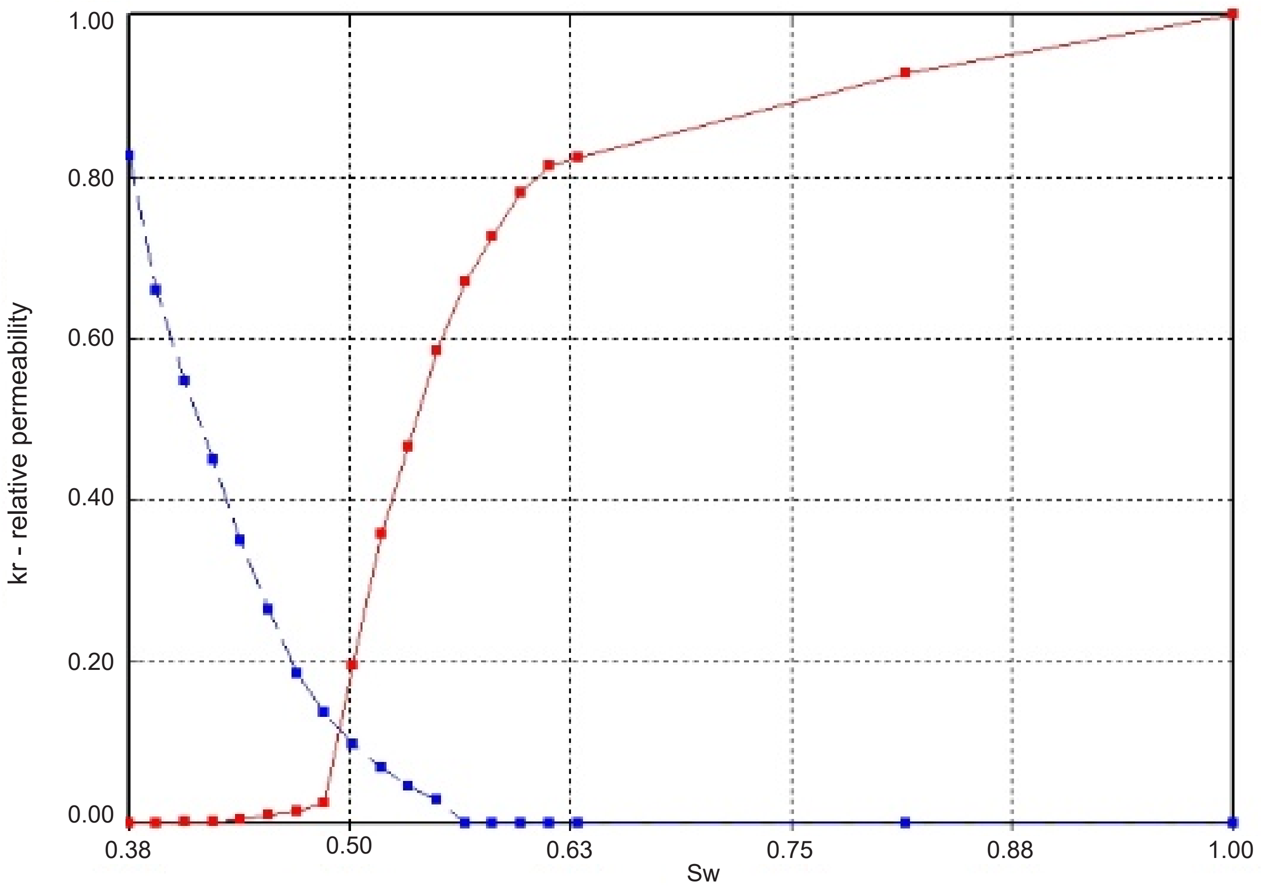


Figure 7. Validated relative permeability curve

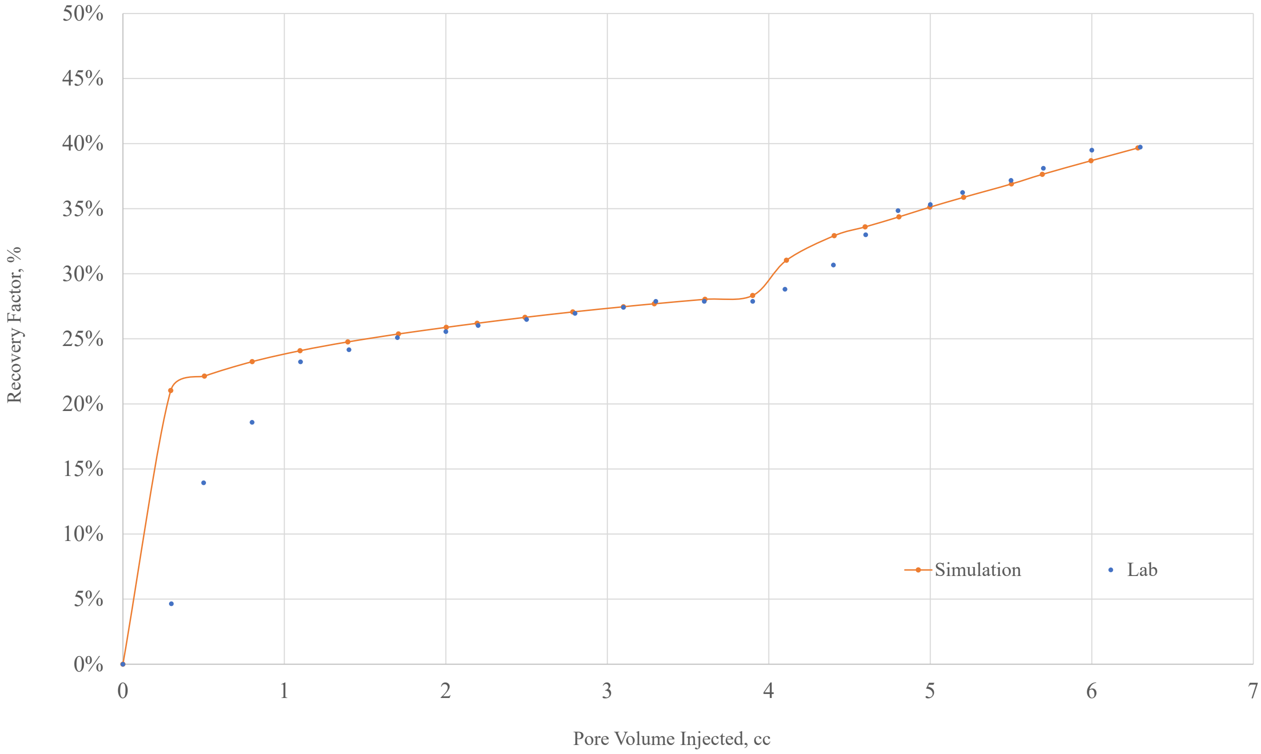


Figure 8 Recovery factor profile

This condition is applied due to the mobility ratio at the end of the waterflooding process often showing an unfavourable condition. Table 4 summarizes the unfavourable mobility ratio at the final waterflood condition of each mobility design method.

Table 4. Unfavorable mobility ratio of each method at the final waterflood condition

Mobility Design Method	Mobility Ratio
James Sheng	70.261
End-Point	20.304
Gomaa	21.106

The improvement of those unfavourable mobility ratios is obtained by assuming the mobility ratio unit into 1, which is conventionally considered as a favourable condition to ensure a high sweep efficiency for polymer injection. Thus, the results achieved at this numerical approach process are the upstream viscosity value designed to acquire the favourable mobility ratio resulting in higher oil recovery and polymer displacement efficiency. Furthermore, the predetermined viscosities were then used to determine the polymer concentration of each method. The polymer concentration calculation was carried out based on the data from a laboratory measurement of polymer viscosity under various concentrations shown in Figure 6 using the Power-law model. Table 5 shows the results of the calculation of polymer viscosity and concentration values for each mobility design method.

Table 5. Polymer viscosity and concentration of each mobility design method

Mobility Design Method	Upstream Viscosity (cp)	Polymer Concentration (ppm)
James Sheng	45.670	1121.275
End-Point	13.197	506.421
Gomaa	126.971	2157.974

Simulation study

This paper presents the simulation study on compiled scenarios and performs on the idealized of 1D, 2D and 3D homogeneous simulation models to facilitate the comparative study of polymer mobility design methods. The main simulation study objective is to analyse the effects of mobility design methods on oil recovery by evaluating the recovery factor of each mobility design method.

Both models of the homogeneous reservoir in 2D and 3D were constructed in Cartesian grids, while the 1D model used is the same as discussed in the previous section. The idealized 2D model attenuates its thickness to minimize the role of gravity segregation which allows the areal sweep to be determined independently of the vertical sweep. The homogeneous reservoir in the 3D model was ideally constructed with vertical length, thus, it correctly interprets the field-scale reservoir. It is considered that the models used in this study are saturated with oil in the entire reservoir and being unconsidered by the presence of aquifer and gas cap. Furthermore, the properties are set up as the same properties as in the history matching process to lock the variables resulting an appropriate simulation study. The grid systems of the models have been summarized in Table 6 and structurally shown in Figure 9.

Table 6. Grid system of two-dimensional and three-dimensional models

Grid Systems	2D Model (I × J × K)	3D Model (I × J × K)
Grid Configuration	40 × 20 × 1	40 × 20 × 20
Grid Size, ft	2000 × 2000 × 1	1000 × 1000 × 100

The scenario in the simulation study focuses on compiling the injectivity scheme on the constructed models. It starts with analysing the waterflood performance on the base case model that has been shown an insignificant increase, which means that the waterflooding process in that model is not efficient enough in oil displacement resulting in low oil recovery. After analysing the waterflood production performance, it was found that the cumulative oil production curve began to flatten after 5 PV water injection was performed. Thus, the waterflood injection scheme of 5 PV can be used as the basis for arranging the injectivity scheme scenario in this simulation study. All scenarios of the injectivity scheme have been listed in Table 7.

Table 7 Injectivity scheme scenario

Scenario	Injectivity Scheme
1	Waterflood 5 PV
2	Waterflood 5 PV + Polymer Flood 0.3 PV
3	Waterflood 5 PV + Polymer Flood 0.6 PV
4	Waterflood 5 PV + Polymer Flood 1 PV

RESULT AND DISCUSSION

The simulation study results using various scenarios were then undertaken to analyse the recovery performance, both for waterflood and polymer flood, calculated as the recovery factor of each scenario. The incremental recovery factor of polymer flood, the main focus of this study, is calculated by two parameters included Original

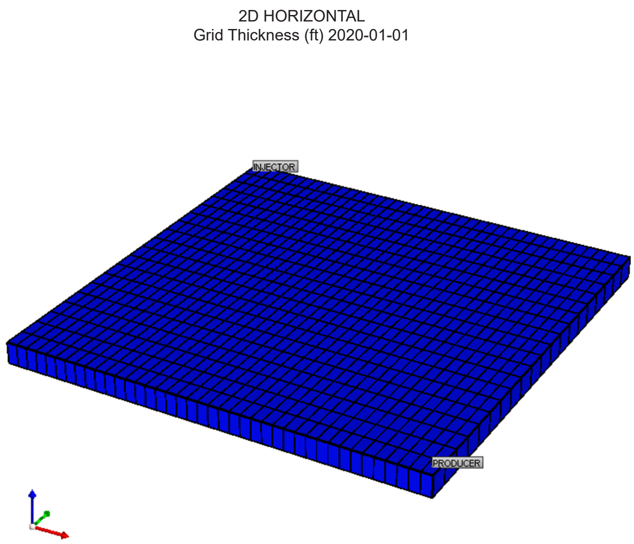


Figure 9. Idealized homogeneous simulation models a) two-dimensional (2D) horizontal grid showing areal sweep efficiency; and b) three-dimensional (3D) grid representing full reservoir volume for displacement analysis.

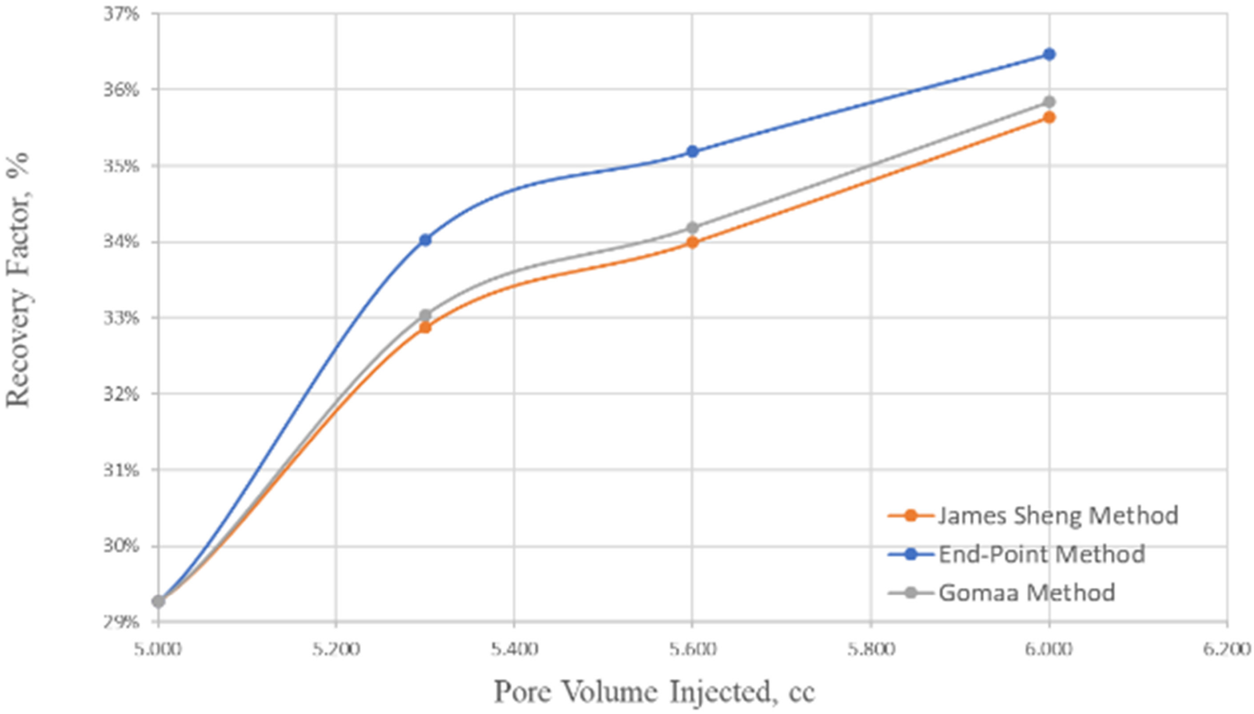
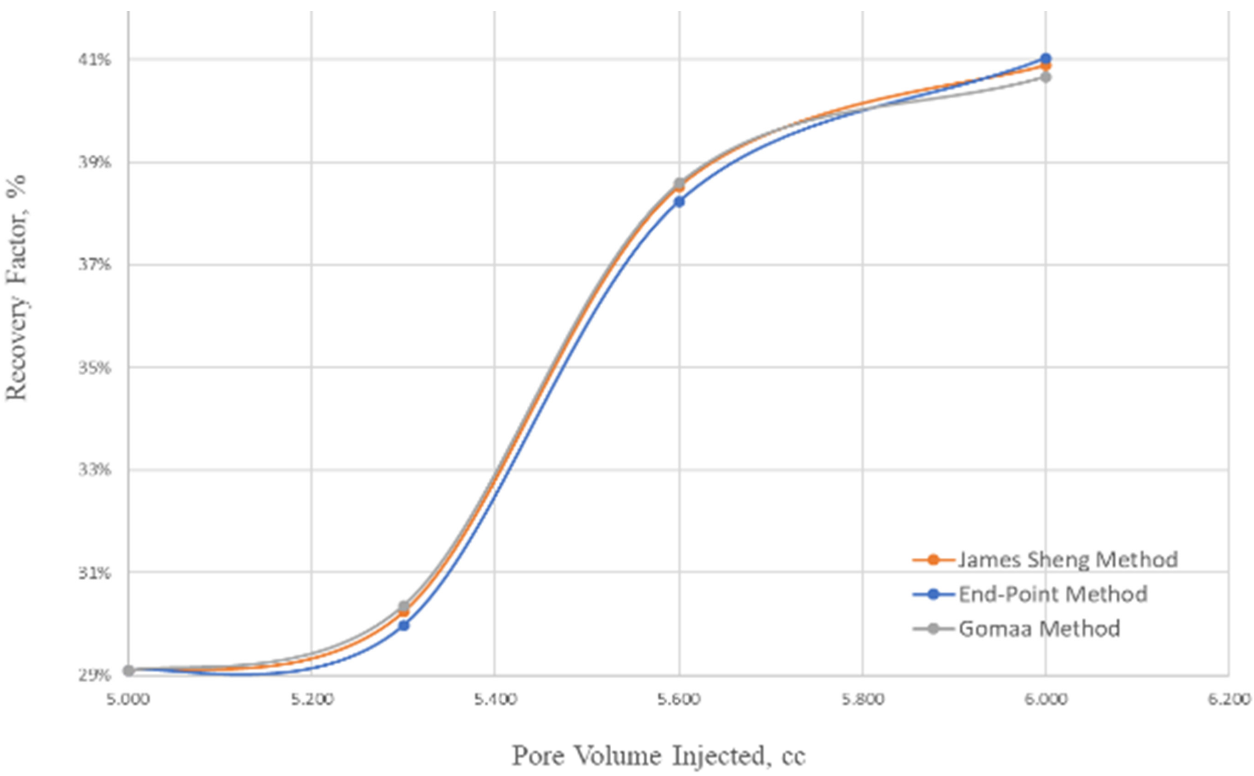
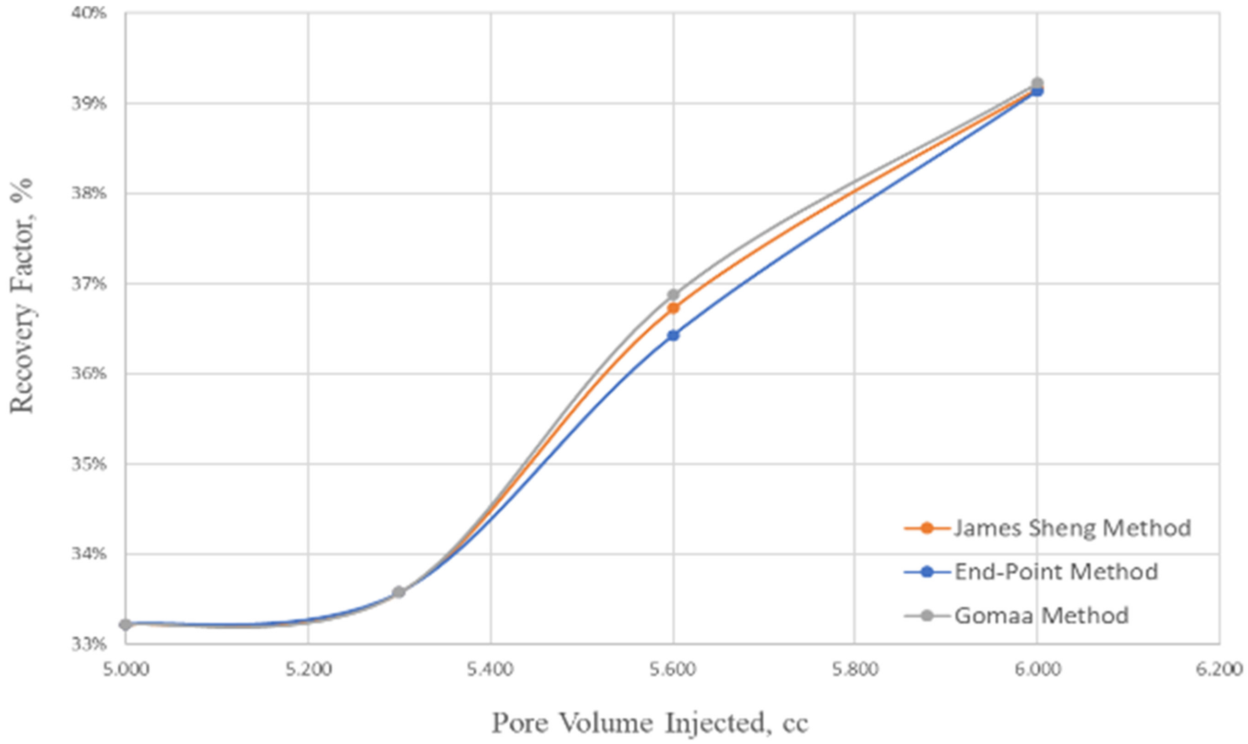


Figure 10. Incremental recovery factor by polymer flood on one-dimensional model under various scenarios

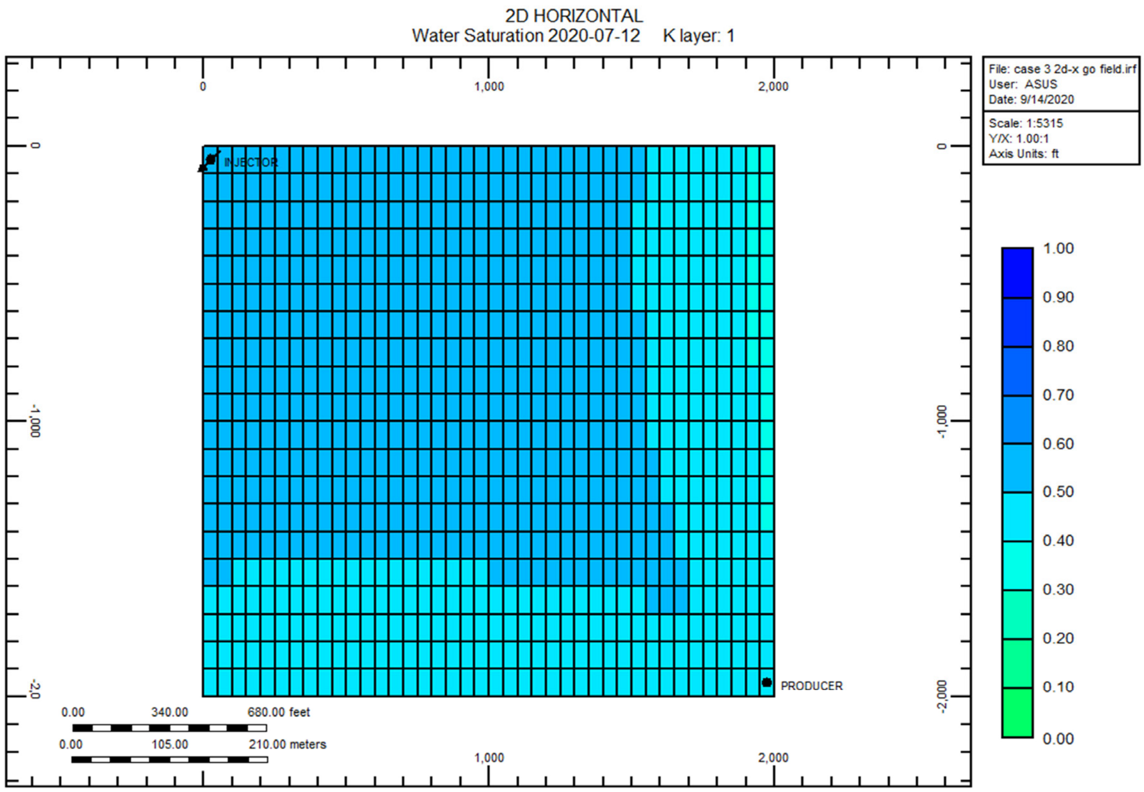


(a)



(b)

Figure 11. Incremental recovery factor on a) two-dimensional; and b) three-dimensional models under various scenarios



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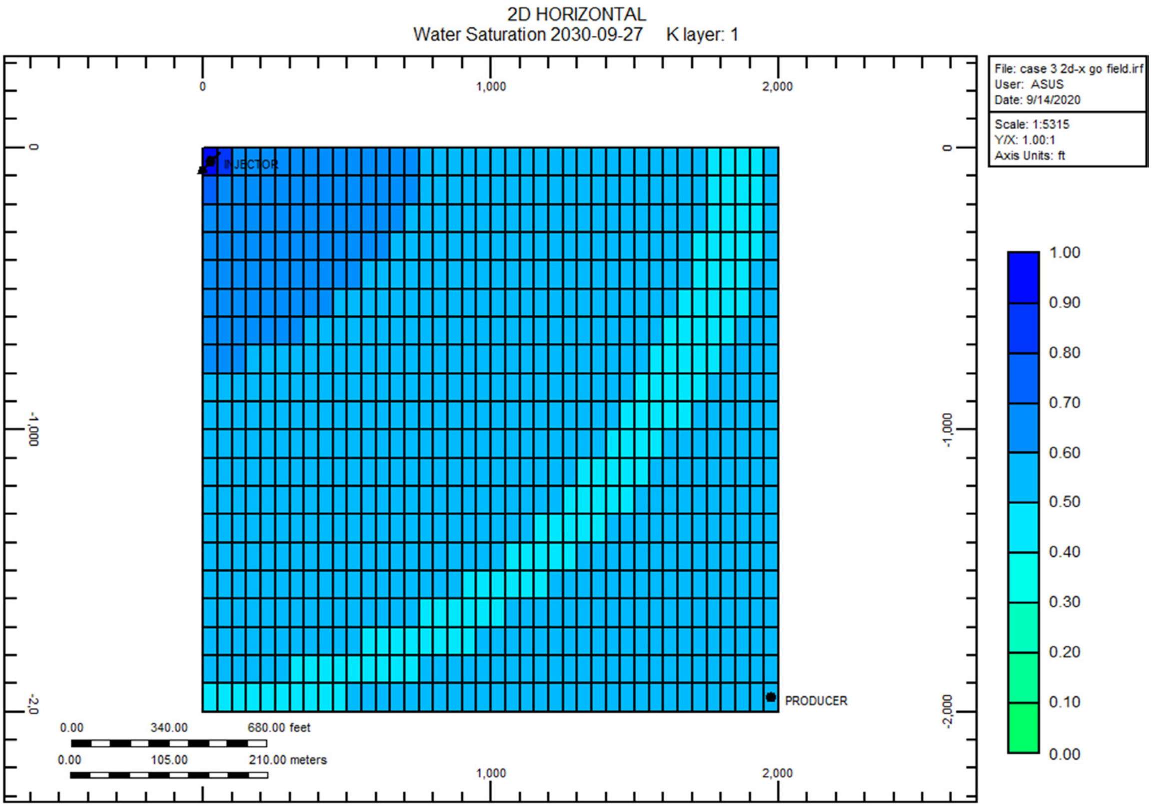
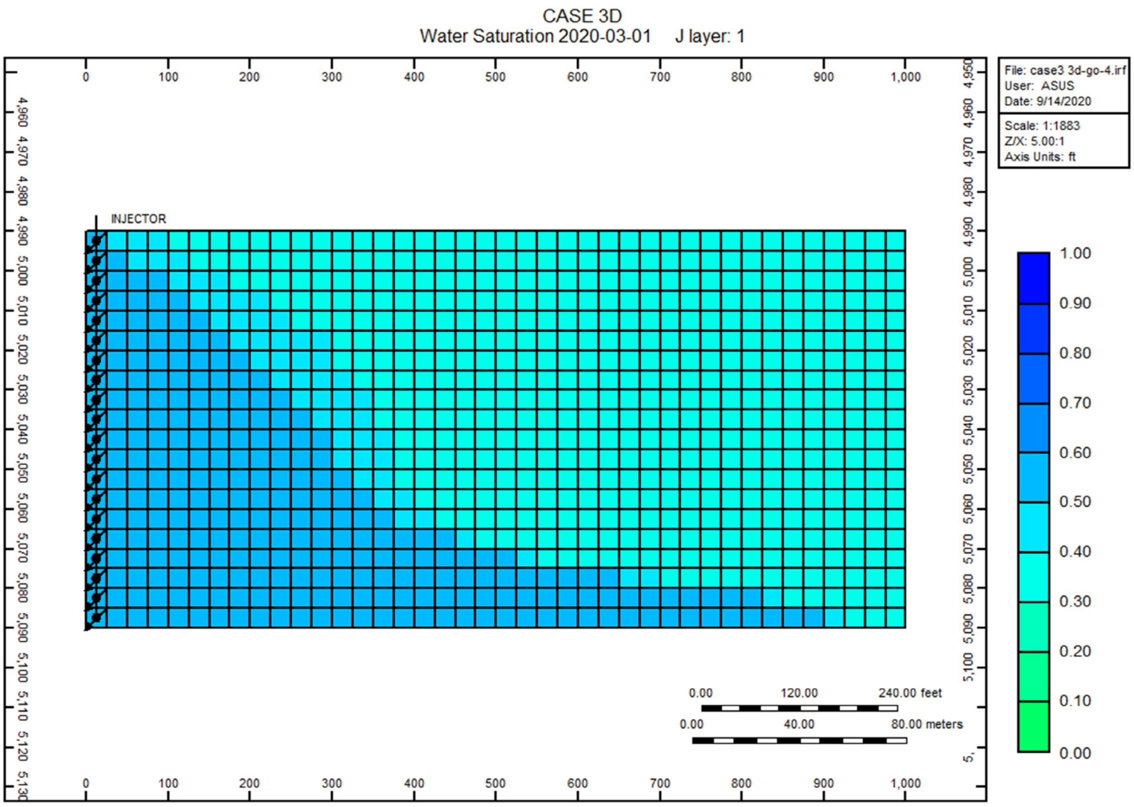
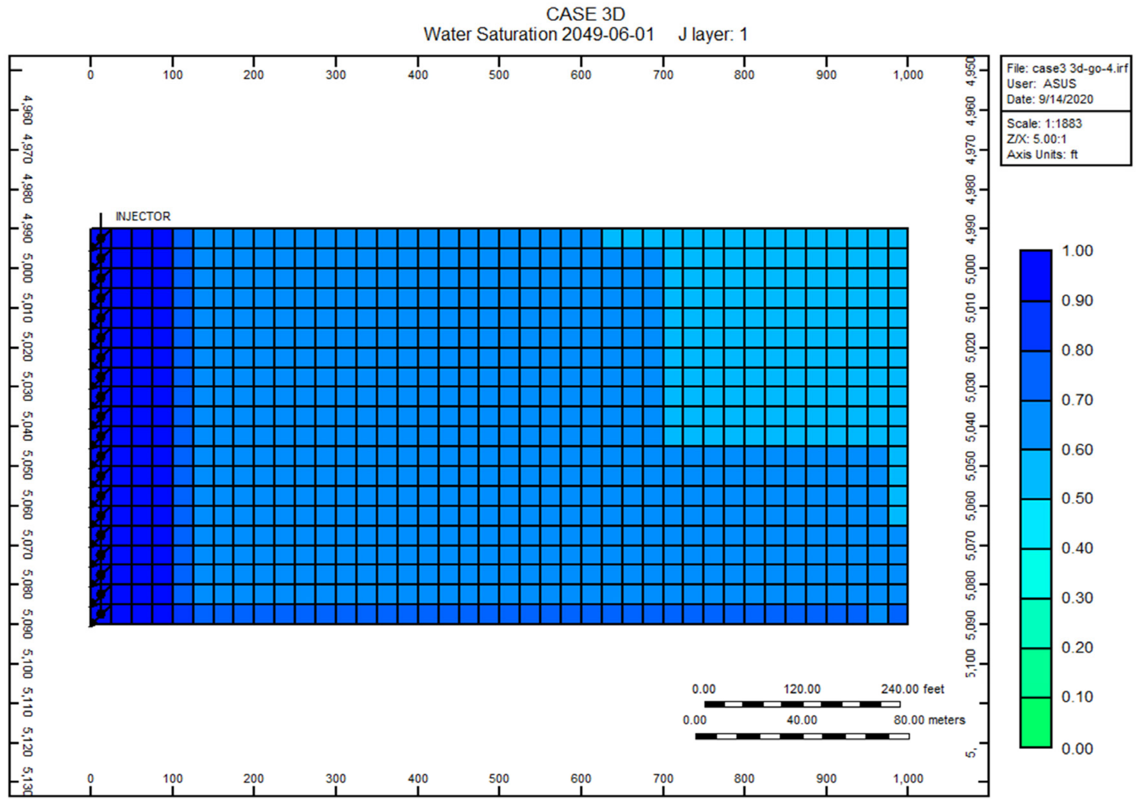


(b)

Figure 12. Schematic of areal sweep efficiency improvement by b) polymer flood; and a) over waterflood





(b)

Figure 13. Schematic of vertical sweep efficiency improvement by polymer flood b); and over waterflood a)

Oil in Place (OOIP) and Remaining Oil in Place (ROIP). Since the recovery factors of waterflood from all scenarios in each simulation models show the constant value, the discussion focuses on the incremental recovery factors by polymer flood exerted as charts for the convenience of discussion, presented in Figure 10, Figure 11 a) and b).

By analysing the mobility ratio unit at the end of the waterflooding process presented in Table 4, it has been found that the mobility ratio from the numerical approach results present a different value in each method. It can be seen that the resulting mobility ratio in the James Sheng method shows a relatively high value and is significantly different from other methods. Meanwhile, the End-Point and Gomaa methods produce almost the same mobility ratio. Generally, all the mobility ratio results at the end of the waterflood condition showed low values. According to the conventional concept, the mobility ratio unit exceeds one ($M > 1$) is considered an unfavourable condition. It can be observed from Figure 10 that the End-Point method shows the highest oil recovery factor, followed by Gomaa and James Sheng method, respectively. By evaluating the sequence of the incremental recovery factor, it depicts the reverse sequence of unfavourable mobility ratio described in Table 4, which shows the lowest mobility ratio comes from the End-Point method. In contrast, the highest mobility ratio belongs to the James Sheng method. From this phenomenon, it can be analysed that various mobility design methods in the 1D model do not have a significant effect on the recovery factor due to its linear flow. Thus, the results are still only influenced by the current mobility ratio situation.

Unlike the 1D model results which shows the significant gap of incremental recovery factors, the simulation results from 2D and 3D models generate very slight differences in the incremental recovery factors. Nevertheless, it is noticeable that diverse mobility design methods are able to affect the recovery factors on 2D and 3D simulation models. Overall, the simulation results in three polymer flood scenarios, either for 2D or 3D models, as shown in Figure 11 (a) and (b). It is found that the highest oil recovery factor is broadly dominated by the Gomaa method, followed by James Sheng and End-Point method, respectively. However, on the other hand, it is recognized that the Gomaa method requires a higher polymer concentration compared to other methods. It means that it requires more polymer to develop a favorable mobility ratio in the displacing phase. Even though the James Sheng method shows a lower oil recovery compared to the Gomaa method, it takes less polymer concentration to reduce a much greater value of the unfavorable mobility ratio.

Based on the results obtained from the simulation study across various scenarios, the results indicate that reducing mobility ratio does not necessarily require higher polymer concentration. This method yields the most relevant results by addressing key factors such as the reduction of the mobility ratio, the necessity of polymer solution, and the oil recovery factor. However, each method carries its own assumptions, limitations, and optimal application conditions. Therefore, different methods can be adapted to polymer flooding by considering specific field characteristics and requirements.

Furthermore, this study includes a visual investigation of the displacement process to illustrate the unfavourable mobility ratio observed in waterflooding, where oil displacement becomes inefficient due to low sweep efficiency caused by water fingering. The improvement of mobility ratios, and hence, sweep efficiency through polymer injection, can be visually examined by analysing the displacement patterns in the area and vertical cross-sections of the models, as presented in Figure 12 and Figure 13.

CONCLUSION

The comparative study of various mobility design methods, through a series of compiled simulation scenarios, yields several noteworthy conclusions. Firstly, the waterflooding process consistently resulted in an unfavourable mobility ratio, with all evaluated methods showing values greater than one. This outcome aligns with the traditional understanding of the mobility ratio as a critical indicator of sweep efficiency.

Among the methods assessed, the James Sheng approach demonstrated the most unfavorable initial mobility ratio. However, when polymer solutions were introduced to enhance mobility control, an interesting pattern emerged: a higher initial mobility ratio did not necessarily correspond to a need for higher polymer concentration. For example, despite starting with a highly unfavorable mobility of 70.261, the James Sheng method effectively reduced it using only 1121.27 ppm of polymer. In contrast, the Gomaa method began with a more moderate mobility ratio of 21.106 but required a substantially higher polymer concentration of 2157.97 ppm to achieve a favorable result. In one-dimensional (1D) simulation models, the choice of mobility design method had an insignificant impact on the overall oil recovery factor. Instead, it was the current (or post-treatment) mobility ratio that appeared to play a more decisive role in influencing the outcome. However, this trend shifted when two-dimensional (2D) and three-dimensional (3D) models were employed. In these more complex scenarios, the Gomaa method stood out by consistently delivering the highest incremental oil recovery, albeit with the highest polymer usage required to attain a favorable mobility ratio.

Despite this, the James Sheng method offered a notable trade-off. While its oil recovery factor was only marginally lower than that of the Gomaa method, it achieved significant improvements in mobility control using much less polymer. This finding suggests that, in specific contexts, the James Sheng method may present a more cost-effective solution without substantially compromising recovery performance.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
EOR	Enhanced Oil Recovery	
M	Mobility ratio	
Ev	Volumetric sweep efficiency	
EA	Areal sweep efficiency	

Ei	Vertical sweep efficiency	
SCAL	Special Core Analysis	
Ø	Porosity	%
k	Permeability	mD
IOIP	Initial oil in place	
PV	Pore volume	

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