

Study of Polymer Flooding Behavior in Heterogeneous Two-Layered Porous Media

(Studi Perilaku Pembanjiran Polimer Dalam Media Berpori Heterogen Dua Lapisan)

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Abstract

In this paper, a numerical study was conducted to investigate the effect of spatial heterogeneity of multiple porosity fields on oil recovery, residual oil saturation, polymer retained, and polymer adsorption. The generated porosity fields were applied to UTCHEM for simulating polymer and water flooding in heterogeneous two-layered porous media. From the analysis, the increase of reservoir heterogeneity resulted in higher polymer retention and lower polymer adsorption. In general, polymer flooding results in more balance residual oil saturation in the upper and lower layer than water flooding. This indicated that the vertical sweep efficiency of polymer flooding was better than water flooding. Residual oil saturation ratio between layers after water or polymer flooding was about equal along with the increase of reservoir heterogeneity. Spatial heterogeneity of multiple porosity fields had only a small effect on recovery factor. The variation of the recovery factor of polymer and water flooding due to the reservoir heterogeneity was under 1%.

Keywords: Heterogeneity, Porosity, Polymer Flooding, Recovery Factor

Sari

Dalam makalah ini, kajian numerik dilakukan untuk menyelidiki efek heterogenitas spasial dari berbagai bidang porositas pada perolehan minyak, saturasi minyak sisa, penahanan polimer, dan adsorpsi polimer. Bidang porositas yang dihasilkan diaplikasikan pada UTCHEM untuk mensimulasikan pembanjiran polimer dan air dalam media berpori dua lapis yang heterogen. Dari analisis, peningkatan heterogenitas reservoir menghasilkan penahanan polimer yang lebih tinggi dan adsorpsi polimer yang lebih rendah. Secara umum, pembanjiran polimer menghasilkan saturasi minyak sisa yang lebih seimbang di lapisan atas dan bawah daripada pembanjiran air. Ini menunjukkan bahwa efisiensi sapuan pembanjiran vertikal polimer lebih baik daripada pembanjiran air. Rasio saturasi minyak sisa antara lapisan setelah pembanjiran air atau polimer hampir sama dengan peningkatan heterogenitas reservoir. Heterogenitas spasial dari beberapa bidang porositas hanya memiliki efek kecil pada faktor pemulihan. Variasi faktor perolehan polimer dan air karena heterogenitas reservoir adalah di bawah 1%.

Kata-kata kunci: Heterogenitas, Porositas, Pembanjiran Polimer, Faktor Perolehan

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I. INTRODUCTION

The remaining oil after secondary recovery depends on several factors such as oil in place at the start of water flooding, reservoir sweep efficiency, and microscopic displacement efficiency. Reservoir sweep efficiency is a key factor which is dependent upon the reservoir heterogeneity and mobility ratio. Water flooding usually has low sweep efficiency since water is frequently less viscous than the heavy oil. Polymer flooding is able to minimize the problem since polymer increases the viscosity of the injecting water and decreases its mobility [1, 2]. The reduction in water mobility improves the displacement conditions for increasing oil recovery. The displacement conditions are improved cover viscous fingering reduction,

fractional flow improvement, and the increase of area and vertical sweep efficiency [3, 4].

During polymer flooding, the phenomena of polymer adsorption and retention reduce the water mobility further [5]. The retention and adsorption of the polymer changes the porous medium and effectively reducing its permeability. In an experiment, this phenomenon is observed in the laboratory as an increase in the pressure gradient of the post-flush water relative to the pre-flush water. This is named the residual resistance factor (RRF) [6]. Retention is affected by polymer concentration, flow rate, mechanical entrapment, and mineral type. The reversibility of adsorption is almost negligible [7, 8], while retention has a level of reversibility [9, 10]. The entrapment of polymer occurs in porous media as its molecules are large

relative to the size of the pores. Based on several reports, adsorption may be dominant in high permeability sand, while mechanical entrapment is dominant in low permeability rock [11].

Polymer flood will be more effective if applied early when oil saturation is well above residual oil saturation. It is generally believed that polymer flooding cannot reduce the residual oil saturation, but it can help reaching residual oil saturation in a shorter time [12]. However, some researchers have found methods to reduce residual oil saturation by combining glycerin flooding, low salinity and high salinity polymer flooding [13, 14].

In this paper the effect of spatial heterogeneity of multiple porosity fields on polymer and water flooding was studied. For the purpose, heterogeneous two-layered reservoir models were generated. Permeability of the two layers was set to be equal in order to focus on porosity parameter effect. The porosity values followed a normal distribution, while its spatial structure was described by a variogram.

II. METHOD

UTCHEM is a three-dimensional, three-phase, compositional Chemical flood simulator. The simulator was originally developed by Pope and Nelson (1978). The numerical model used for the polymer flooding simulation is an extension of the model used in the simulator. The simulator takes into account polymer retention, water, and oil saturation. In this study, UTCHEM was applied to investigate the effect of the spatial distribution of heterogeneity on adsorption and retention of polymer, and residual saturation, and oil recovery [15].

The parameters of polymer flooding simulation which were taken from Dakhli (1995) are presented as follows. The dimensions of the porous media were 500 ft in the x-direction, 500 ft in the y-direction, and 60 ft in the z-direction. The numbers of grid blocks in the x, y, and z directions were 10, 10, and 2, respectively. The porosity of porous media was 0.2. The permeability of the porous media along x and y directions was kept to be constant at 50 mD. The vertical to horizontal permeability ratio was equal to 0.1. The initial water saturation was 0.3. Water viscosity was 0.75 cp and oil viscosity was 8 cp at reservoir conditions. The properties of the polymer are listed in Table 1.

For each case, a quarter five-spot was set with initial water saturation. A production well was located near the north-east corner with X and Y coordinates of 475 ft and 475 ft. While, an injection well was located near the south-west corner of the X-Y plane, with X and Y coordinates of 25 ft and 25 ft. The wells were vertical and connected to all layers in the Z direction. The boundaries were

modeled as a closed reservoir system.

Table 1. Data used in the simulation [16]

Property	Value
Polymer type	Xanthan gum
Polymer concentration in solution	0.1 wt%
Polymer solution injected	0.25 PV
Chase water injected	1.00 PV
Specific weight	Water = 0.433 psi/ft, Oil = 0.3882 psi/ft

The simulations of polymer flooding were carried out by injecting 0.25 pore volume (PV) of the polymer solution and followed by 1 PV of chase water. After that, all of the simulations with the same fields were repeated for water flooding. In each simulation of water flooding, 1.25 PV water was injected. The results of polymer flooding and water flooding simulations were then compared and analyzed.

Random Fields of Rock Porosity. The variogram is a measure of variation between two points in space separated by a distance h [17]. A variogram is a geostatistical tool for modeling spatial variability [18]. It can be used to predict the random function at an unsampled location. Matheron (1965) proposed a method of moments approach to approximate the variogram [19, 20]:

$$2\gamma(h) = \frac{1}{N(h)} \sum_{i=1}^{N(h)} [z(u_i) - z(u_i + h)]^2 \quad (1)$$

where γ is the variogram; h is the separation vector; $N(h)$ is the number of pairs of data separated by vector h ; u is location and z of a random variable of a rock property

The mean of porosity was set equal to the porosity of the homogeneous rock (0.20). Four values of the standard deviation of porosity (2.5, 5.0, 7.5, and 10) were selected to generate random fields of the rock porosity. The correlation lengths in the X and Y directions were chosen as 50 m that was the same as the grid block size. For each simulation, two layers of the random field were generated for X and Y directions independently. Porosity fields in the Z direction was then calculated according to the anisotropy ratios. For the same set of values of mean, variance, and correlation lengths, different porosity fields were generated by setting different seed values for the random number generator in the program. For each simulation, a generated porosity field was incorporated into UTCHEM to simulate polymer flooding in a heterogeneous porous medium.

III. RESULTS AND DISCUSSION

Two runs were conducted to simulate polymer flooding (PF) and water flooding (WF) on homogeneous porous media. Ten randomly distributed porosity fields were generated for each of the four values of the standard deviation of porosity. Every random porosity field was included for simulations of PF and WF in heterogeneous porous media. The simulation results of PF and WF were then used to investigate the effect of the spatial distribution of heterogeneity on the flooding.

Figure 1 shows the fraction of polymer retained in porous media after injecting 0.25 PV of the polymer solution and 1 PV of water. As heterogeneity increases, more pores become inaccessible for polymer molecules. However, the correlation between the porosity deviation standard and the number of inaccessible pores is not linear. In addition, the fraction of polymer retained in porous media is also affected by the distribution of the inaccessible pores. The curve in the figure indicates a logarithmic correlation between the fraction of polymer retained and the porosity deviation standard.

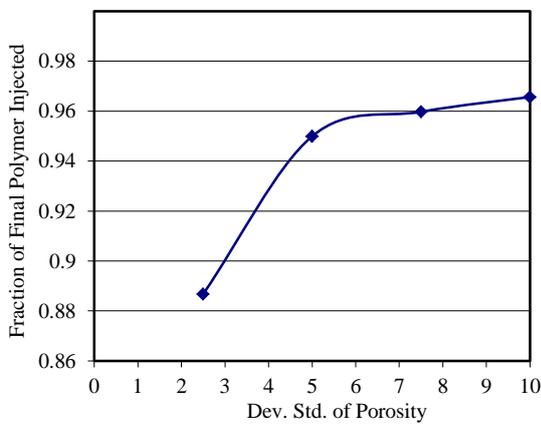


Figure 1. Polymer retained during polymer flooding

Figure 2 shows the profile of polymer adsorption after injection. A porous medium with a low variation of pore size allowed the flow of polymer solution injected was well distributed. It made the interaction between polymer molecules and the solid surface adsorption process was more intense and widely spread. Therefore the polymer adsorbed tended to increase as the standard deviation of porosity decreases as shown in the figure. Although less polymer fraction was adsorbed in the porous media with a higher deviation standard of porosity more polymer fraction was retained due to polymer entrapment.

Figure 3 shows the residual oil saturation ratio between the first and the second layers after

injection. The figure shows that polymer flooding results in more balance residual saturation in the two layers than water flooding, where residual oil saturation ratio of polymer flooding was closer to one than that of water flooding. It indicated that polymer flooding slightly improved the vertical sweep efficiency of water flooding. Further results presented in Figure 3 indicate that the effect of the spatial distribution of multiple porosity fields on the residual oil saturation ratio between layers is small. The heterogeneity tended to be proportional to the ratio for PF, but it tended to be reverse to the ratio for WF. The increase of the residual oil saturation ratio for PF at the deviation standard of 10 was 0.77%, while the decrease of that for WF at deviation standard of 10 was 1.01%.

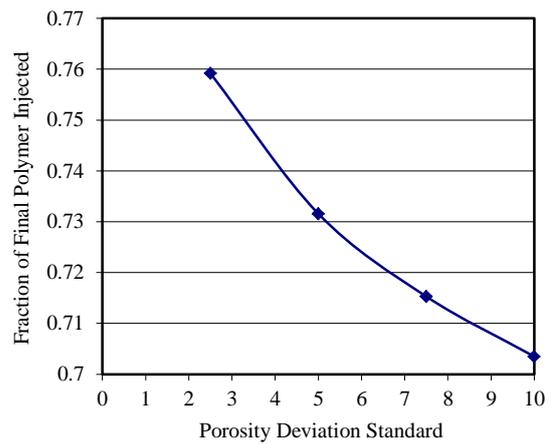


Figure 2. Polymer retained during polymer flooding

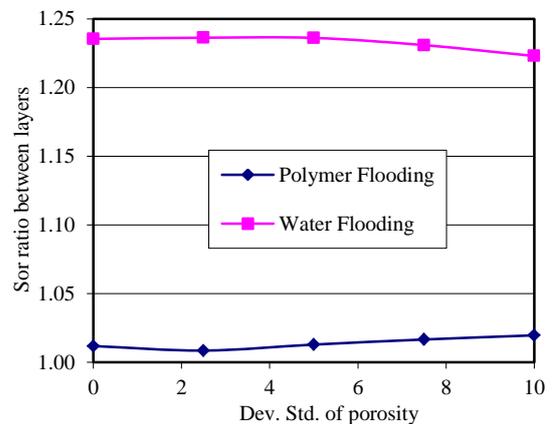


Figure 3. Residual oil saturation ratio between layers

Figure 4 shows oil recovery for various porosity deviation standards for WF and PF. The figure indicates that the oil recovery of PF was higher than that of WF within the range studied. The oil recovery of WF tended to increase as the porosity deviation standard increased. This alteration of the oil recovery has a correlation with the alteration of

vertical sweep efficiency. Figure 3 shows that sweep vertical efficiency improved as the heterogeneity increase since residual oil saturation of WF approached to one. The increase of the oil recovery of WF at a deviation standard of 10 compared to homogeneous rock is 0.92%.

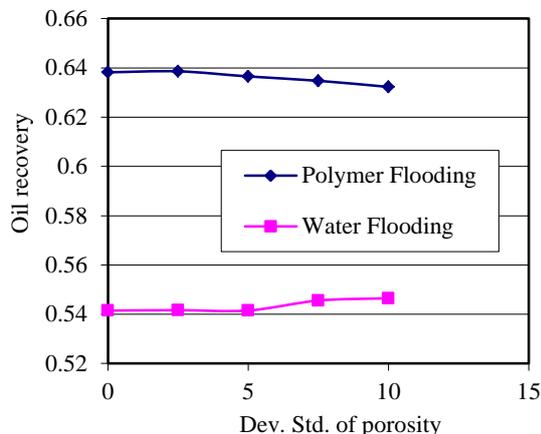


Figure 4. Average oil recovery after injecting 1.25 PV

On the other hand, the oil recovery of PF tended to decrease as the porosity deviation standard increased. There were correlations of oil recovery of PF to polymer retention, polymer adsorption and residual oil saturation ratio between layers. As the heterogeneity increased more polymer retained (Figure1), this lead to permeability reduction which give a proportional effect to oil recovery reduction. Figure 2 shows a reverse correlation between polymer adsorption and heterogeneity. Polymer adsorption which decreased the permeability of the water phase has a beneficial effect on displacement efficiency and oil recovery. This explained the correlation between polymer adsorption, heterogeneity, and oil recovery. Figure 3 shows that the amount of oil swept between the two layers after PF was more different as the increase of porosity deviation standard. This means that vertical sweep efficiency which had a proportional correlation to oil recovery decreased as the increase of heterogeneity. The decrease of the oil recovery at the deviation standard of 10 compared to homogeneous rock is 0.93%.

IV. CONCLUSIONS

The conclusions of the research are as follows:

1. Polymer flooding results in more balance residual saturation in the two layers than water flooding. This indicated that the vertical sweep efficiency of PF was better than WF.
2. The heterogeneity resulted in more different residual oil saturation between layers for polymer flooding but the inverse condition was observed for water flooding.

3. The effect of spatial heterogeneity of multiple porosity fields on the oil recovery of WF and PF was small. The variation of the recovery factor of WF and PF due to the reservoir heterogeneity was under 1%.

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