Effects of Polymer Adsorption and Desorption on Polymer Flooding in Waterflooded Reservoir

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Abstract— **Polymer Flooding is one of the most well-known methods in Enhanced Oil Recovery (EOR) technology, resulting in favorable conditions for displacement mechanism to lower residual oil in the reservoir. Polymers can lower mobility ratio by increasing the viscosity of injected water, hereby increasing volumetric sweep efficiency. Moreover, polymer adsorption onto the rock surface can help decrease reservoir permeability contrast. Due to absolute permeability reduction, the effective permeability to water is also reduced. Once the polymer is adsorbed onto the rock surface, polymer molecules can be desorbed with a chaser. This study is performed to further evaluate the effects of the adsorption and desorption process of polymer solutions to yield benefits on the oil recovery mechanism. A reservoir model is constructed by the reservoir simulation program called STAR® from Computer Modeling Group (CMG). Various polymer concentrations, starting times of polymer flooding process and polymer injection rates were evaluated with selected degrees of polymer desorption including 0, 50 and 100%.**

According to the results, polymer desorption lowers polymer consumption, especially at low concentrations. Polymer desorption causes polymer re-employment that is previously adsorbed onto rock surface, resulting in an increase of sweep efficiency in the further period of polymer flooding process. Furthermore, the results show that waterflooding followed by earlier polymer flooding can increase the oil recovery factor whereas the higher injection rate also enhances the recovery. Polymer concentration has relationship with polymer consumption due to the two main benefits described above. Therefore, polymer slug size should be optimized based on polymer concentration.

Index Terms: **Enhanced oil recovery technology, polymer adsorption and desorption, polymer flooding, reservoir simulation.**

I. INTRODUCTION

In oil production, oil recovery efficiency from natural drive mechanism is estimated to be only 10-20% of Original Oil In Place (OOIP). Waterflooding as secondary recovery can further recover oil of about 10-40% OOIP. However, this technique is sometimes insufficient to lower residue oil in the reservoir due to several unfavorable conditions. Tertiary recovery or so-called Enhance Oil Recovery should be therefore implemented.

Polymer Flooding is one of methods in enhanced oil recovery technology. Polymer can decrease mobility ratio by increasing viscosity of injected water. Therefore, polymer flooding can increase volumetric sweep efficiency. Moreover, polymer adsorption onto rock surface can reduce permeability contrast of reservoir with high heterogeneity and due to reduction of absolute permeability, effective permeability to water which represents flow ability of injected fluid is also reduced, resulting in more favorable conditions for displacement mechanism [1-2]. Polymer adsorption is defined as physical or chemical interactions between polymer molecules and pore surface of rock. Physical adsorption is caused due to tortuous paths with surface of pores together with complex structure of polymer molecule. Some polymers contain charge property and this attracts chemical adsorption onto rock surface containing the opposite charge [3]. Polymer molecule can be desorbed when different fluid is injected. For example, if water is utilized as chasing phase after a designed slug is injected, previous adsorbed polymer may desorb due to diluting of polymer concentration at the rock surface compared to bulk solution. From this, the reversible process may result in benefit for oil recovery mechanism.

This study is performed to evaluate effects of polymer adsorption/desorption on polymer flooding. To study polymer adsorption/desorption behavior in the reservoir, reservoir model is constructed using reservoir simulation called STAR® commercialized by Computer Modeling Group (CMG). The study is performed to optimize operating conditions of polymer flooding including polymer slug size together with polymer concentration, starting time of polymer flooding and polymer injection rate, for selected values of polymer adsorption/desorption. Oil recovery factor is a major consideration for effectiveness of the process. The obtained results will help to understand effects of polymer adsorption/desorption which would provide new points of view of polymer flooding project.

II. RESERVOIR MODEL

Reservoir model is generated by using reservoir simulator called STARS® commercialized by Computer Modeling Group Ltd. (CMG) in order to develop simulation study of polymer flooding process. The model is constructed in Cartesian coordinates to represent a quarter 5-spot flood pattern. Producer and injector are located at the opposite corners of reservoir as shown in Fig. 1.

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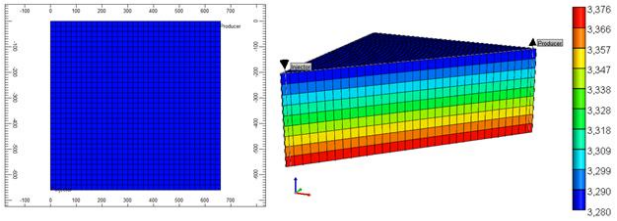


Fig. 1. 2D Topview and 3D cross section reservoir constructed in the simulation.

Table I summarizes expected properties to represent reservoir model in this study as well as the values of input parameters necessary for PVT data generation by correlations in STARS®. Refer to EOR Screening Criteria of Taber [4], crude oil gravity of 25 °API is chosen for this study.

Table I: Reservoir Preference in the Simulation

Parameters	Values
Grid dimension (block)	33×33×9
Grid size (ft)	20×20×12
Top of reservoir (ft)	3,280
Porosity	0.20
Horizontal permeability (mD)	500
Reservoir temperature (°F)	150
Initial gas oil ratio (SCF/STB)	206.3
Oil gravity (°API)	25
Gas specific gravity	0.7
Initial water saturation	0.2
Reference pressure at datum depth (psia)	1,435
Water salinity (ppm)	1,000
Bubble point pressure (psia)	1,350

III. RESERVOIR SIMULATION

Waterflooding process is performed at the beginning of the reservoir simulation. Total production period of 30 years is used to represent normal concession period for this study. In the simulation, well safety and economic constraints are set to control the termination of simulation as well as concession period. The water cut and surface oil rate are the constraints which are set as 0.95 and 25 bbl/d, respectively.

For polymer flooding process, hydrolyzed polyacrylamide polymer (HPAM) represents polymer in this study. Flopaam 3330S is a commercial polymer that its properties are widely studied. Choi et. al. [5] had experimented to study on adsorption of Flopaam 3330S.

Reservoir simulation with polymer flooding process is run to select optimum polymer slug size as a function of polymer concentration. The following shows ranges of operating parameters:

- Polymer concentration: 500, 750 and 1,000 part per million.
- Polymer slug size ranging from 0.05 to 0.50 of pore volume (PV).

Time to implement polymer flooding and polymer injection rate are investigated with 3 different degrees of desorption which are 0, 50 and 100 percent.

- Time of polymer flooding process: 0.05PV of water injection, at breakthrough and 50% water cut.
- Polymer injection rate: 300, 500 and 700 barrel per day.

Effects of studied parameters on polymer flooding process are analyzed and optimum operating parameters are identified as the results.

IV. RESULTS AND DISCUSSION

A. *The Effect of Polymer Concentration on the Optimum Polymer Slug Size*

There is a relationship between oil recovery factors and polymer slug size with different polymer concentrations, as shown in Fig. 2. It can be observed that polymer concentration has an impact on the optimum polymer slug size. Higher polymer concentration results in the smaller slug size of polymer to attain constant oil recovery factor. This can be summarized that the optimum slug size is changed due to difference of polymer mass injected into the system.

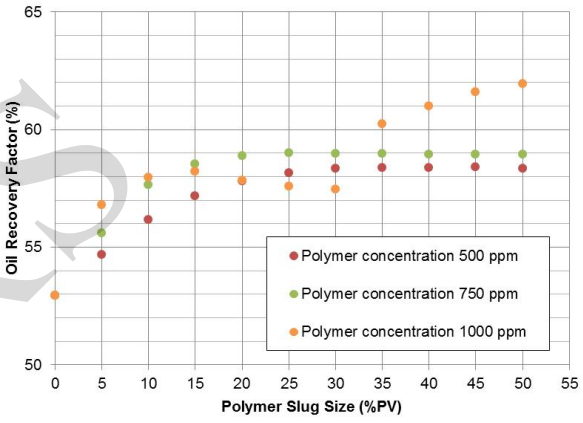


Fig. 2. Oil recovery factors as a function of polymer slug size with various polymer concentrations at injection rate 300 bbl/day.

Nevertheless, the only exception is observed for the case of polymer concentration of 1,000 ppm. As the highest oil recovery factor is attained at 0.15 PV, oil recovery factor starts decline when slug size is increased. As polymer concentration is high and slug size is too large, the total time to complete desire slug can be long. Effects of polymer slug are obscured by early attainment of production termination.

In case of polymer concentration 1,000 ppm with total polymer slug size of 0.50 PV, there are three inclinations of oil production as illustrated in Fig. 2 which are from polymer flooding, from chasing water and from the polymer breakthrough.

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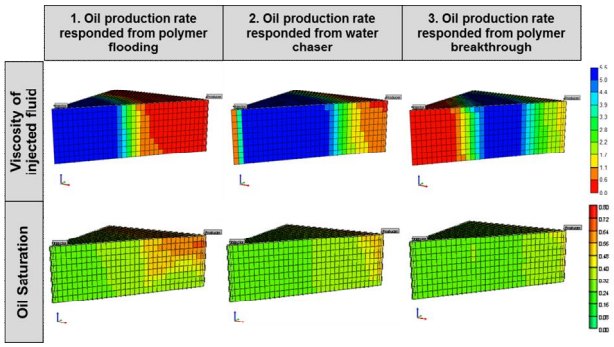


Fig. 3. Viscosity profile of injected fluid and oil saturation profile during polymer flooding using polymer concentration of 1,000 ppm and polymer slug size of 0.5 PV at different interest periods.

Even polymer slug size of 0.5 PV yields the highest oil recovery factor which is 62% in case of polymer concentration 1,000 ppm, the optimum polymer slug size is placed in this study at 0.15 PV. The reason is in case of polymer slug size 0.5 PV comparing with 0.15 PV, it is required more than 3 times of polymer mass to obtain 4% incremental oil recovery factor. The estimated optimum polymer slug size with the oil recovery factor in each polymer concentration is summarized in TABLE II.

Table II: Summary of optimum polymer slug size and corresponding oil recovery factor

Polymer concentration (ppm)	Optimum Polymer Slug Size (%PV)	Oil Recovery Factor at the Optimum point (%)
500	30	58.4
750	20	59
1000	15	58.3

B. Effects of Degree of Polymer Desorption

Fig. 4 depicts profile of polymer adsorption in different polymer desorption degrees. From the figure, there is an impact of polymer desorption on the oil production. At lower polymer concentration of 500 and 750 ppm, the effect of polymer desorption is less than the case of high concentration 1,000 ppm as it can be seen in Fig. 5. At the 100% degree of polymer desorption, the polymer is less retained at the border of the farther away from of the wells. This results in lowering of the volumetric sweep efficiency. The change of the sweep efficiency affects the oil recovery factor. As polymer adsorption is very high especially at the directly line from injection to production well, highly desorption results in chasing fluid to flow to less adsorbed area but with high desorption which is the border of the reservoir. This causes water to by-pass polymer slug.

It can be explained that polymer desorption causes polymer re-employment that is previously adsorbed onto rock surface, resulting in an increase of sweep efficiency in the further period of polymer flooding process. However, beyond the optimum degree of adsorption, several drawbacks appear. In this study, it shows that total desorption in high polymer concentration causes chasing water to bypass polymer slug, resulting in breaking of mobility control slug and as a consequent, oil recovery factor is lower than other cases.

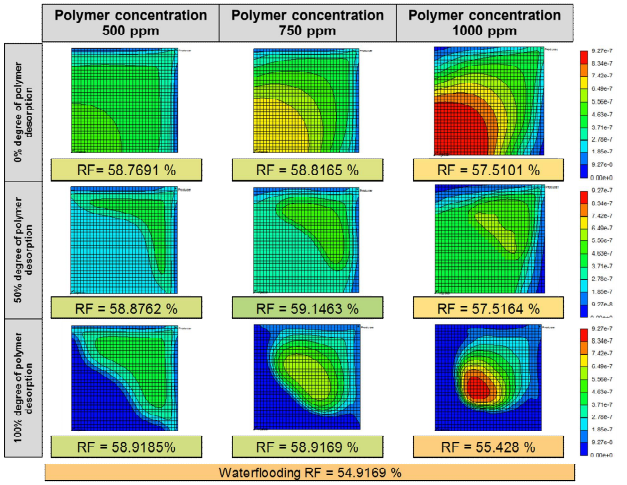


Fig. 4. Top view of polymer adsorption profile at the end of production obtained from cases with different degrees of polymer desorption and various polymer concentrations.

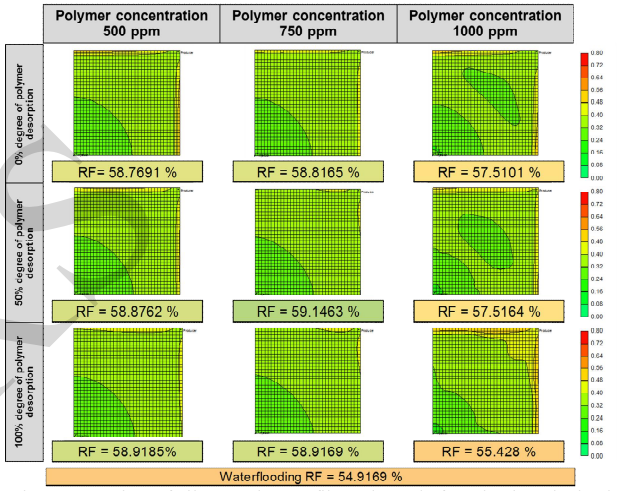


Fig. 5. Top view of oil saturation profile at the end of production obtained from cases with different degrees of polymer desorption and various polymer concentrations.

C. The effect of starting time of polymer flooding

The earliest starting time of polymer flooding after waterflooding obtains the highest oil recovery factor. For example as shown in Fig. 6, in case of polymer concentration of 750 ppm cases with injection rate 500 BPD, injected water in the beginning phase can obviously improve oil recovery for all cases. Implementing polymer flooding after waterflood breakthrough also increases oil recovery factor but the production time is extended. By the way, the longer polymer flooding starting time results in oil production period extension with only a slight effect on oil recover factor.

In summary, starting time of polymer flooding after pre-water injection of 0.05 PV is the most suitable.

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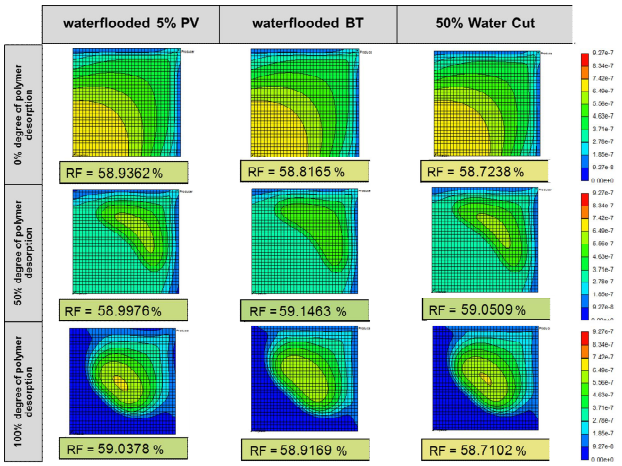


Fig. 6. Two-dimension, top view of polymer adsorption profile at the end of production comparing between different starting time of polymer flooding with various polymer desorption at polymer concentration 750 ppm with injection rate 500 bbl/d.

D. *The effect of injection rate*

Injection rate affects the oil recover factor in straight forward way that the higher rate can accelerate the oil recovery in shorter production period as shown in Fig. 7 to Fig. 9. However, the breakdown occurs at certain polymer concentration. Increasing of injection rate increases oil recovery factor for polymer concentration of 500 ppm, whereas increasing of injection rate in case of polymer concentration 750 ppm the results are reversed. For polymer concentration of 1,000 ppm, the earliest polymer starting time with the highest rates results in the highest oil recovery.

The effects of injection rate can be explained by polymer injectivity. Fig. 7 to Fig. 9 show as the examples for explanation: injection rate and production bottomhole pressure are plotted as a function of production time with starting time of polymer flooding after 0.05 PV water pre-injection and 0% degree of polymer desorption for cases with polymer concentrations of 500, 700 and 1,000 ppm, respectively.

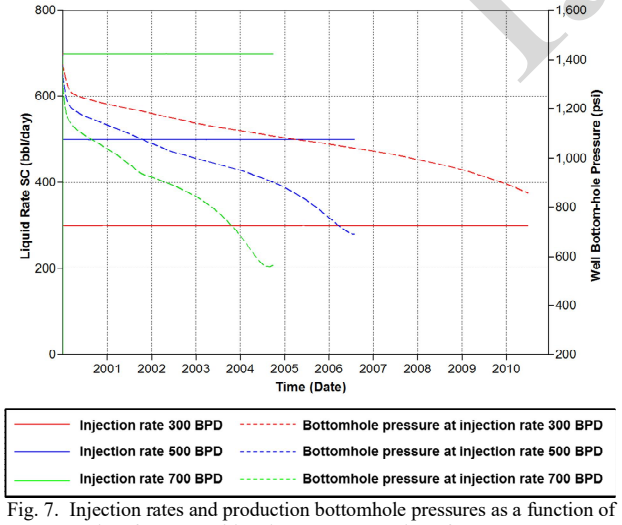


Fig. 7. Injection rates and production bottomhole pressures as a function of time for cases with polymer concentration of 500 ppm.

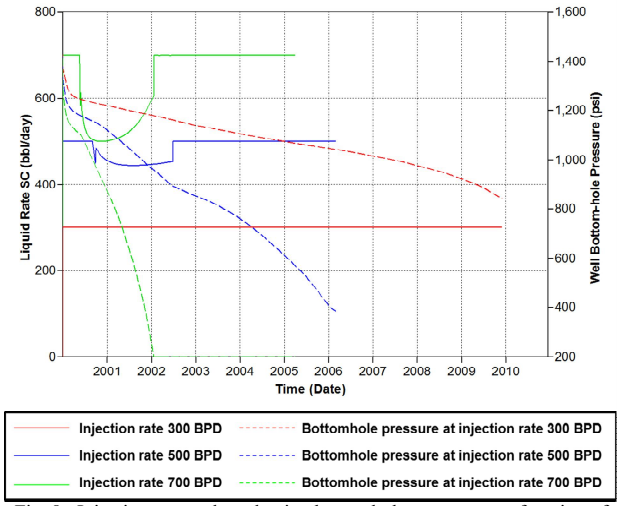


Fig. 8. Injection rate and production bottomhole pressure as a function of time for cases with polymer concentration of 750 ppm.

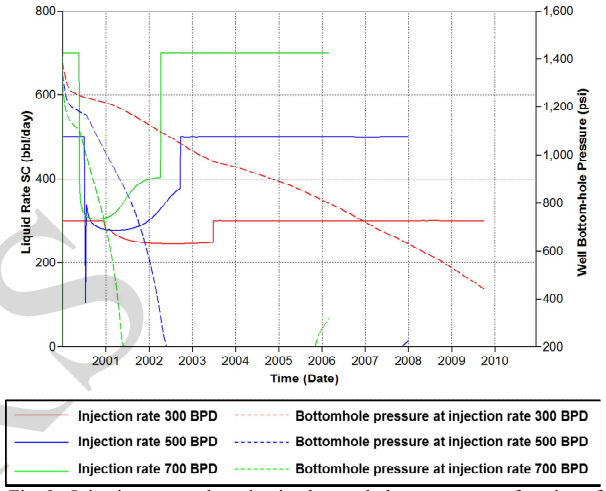


Fig. 9. Injection rate and production bottomhole pressure as a function of time for cases with polymer concentration of 1,000 ppm.

Fig. 7 shows that polymer solution can be injected with sustainable rate at from the first day of all injection rates with polymer concentration of 500 ppm. This means it is recommended to inject polymer at higher injection rate when low polymer concentration is applied. For polymer concentration of 750 ppm, polymer can be injected constantly from the first day only in case of low injection rate of 300 BPD, while the higher injection rate; injection rate is reduced during polymer injection period.

When polymer concentration of 1,000 ppm is applied, the injection rate cannot reach the desired rate at the beginning of polymer flooding for all the injection rates. Similar explanation, polymer is a viscous fluid and hence, desired injection rate is not balanced with injectivity of the wellbore. Interestingly, polymer flooding at this polymer concentration with injection rate of 700 BPD and starting time after 0.05 PV of injected waterflood results in the highest oil recovery. The

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optimum operating conditions together with degree polymer desorption are summarize as TABLE III.

Table III: Summary of the Optimum Operating Conditions of Polymer Flooding Cases

Parameter	Polymer concentration (ppm)		
	500	*750*	*1,000*
Polymer slug size (% PV)	30	20	15
Starting time (PV of pre-water injection)	0.05	0.05	0.05
Polymer Injection Rate (BPD)	700	300	700
Degree of Polymer Desorption (%)	100	50	50
Oil Recovery Factor (%)	59.58	59.34	59.86

V. Conclusion

- The difference of polymer mass injected into the process, representing as polymer concentration, affects the optimum polymer slug size. The higher polymer concentration requires smaller slug size of polymer to attain constant oil recovery factor and vice versa.
- Polymer desorption causes polymer re-employment of adsorbed polymer onto rock surface. This results in maintaining viscosity of polymer slug and hence increases sweep efficiency. However, certain optimum degree of polymer desorption exists in difference polymer concentration and it should be thoroughly investigated.
- When high polymer concentration is used, total desorption would cause flow resistance in diagonal line between injector and producer. This causes chasing water to bypass the polymer slug and results in low sweep efficiency.
- The earliest time to perform polymer flooding after waterflooding shows the great benefit on both oil recovery factor as well as total production period. Performing polymer flooding at late time after waterflooding together with high polymer concentration would cause problem related to injectivity. Lack of supporting pressure would terminate the production once minimum oil rate constraint is attained.
- Even, higher injection rate can accelerate the production; it should be optimized based on polymer concentration due to polymer injectivity.

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