Scientific Contributions Oil & Gas, Vol. 43. No. 3, December 2020: 143 - 152

SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Research and Development Centre for Oil & Gas Technology
"LEMIGAS"

Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

Sensitivity Analysis Comparisson of Synthetic Polymer and Biopolymer using Reservoir Simulation

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Manuscript received: October, 5th 2020; Revised: December, 7th 2020
Approved: December, 30th 2020; Available online: January, 4th 2021

ABSTRACT - With a simultaneous increasing demand for oil and large decreases worldwide in newly discovered oil reserves in the past few decades, much attention has been paid to more efficient production approaches such as enhanced-oil-recovery (EOR) methods for developing oil and gas from existing reservoirs (Li *et al.*, 2014). Basically, there are two types of polymers; biopolymers and synthetic polymers (Cenk *et al.*, 2017). Method used for this study is reservoir simulation by Computer Modeling Group (CMG) STARS simulator. The study concerns to investigate and analyze the polymer sensitivity on two different types of polymer: synthetic polymer and biopolymer. The simulation is done on 15x15x4 grid for 3653 days (10 years). The simulation indicates that the biopolymer injection shows more stable result in compare to synthetic polymer. The biopolymer's adsorption occurs on smaller area and takes longer time. Conversely, the adsorption of synthetic polymer goes on bigger area of the reservoir and transpire on shorter time. Considering these facts, the use of biopolymers is more effective in order to increase the sweep efficiency by reducing viscous fingering of chemical injection in reservoir.

Keywords: chemical injection, synthetic polymer, biopolymer, polymer adsorption, sweep efficiency.

How to cite this article:

Romal Ramadhan, Muslim Abdurahman and Falan Srisuriyachai, 2020, Sensitivity Analysis Comparison of Synthetic Polymer and Biopolymer using Reservoir Simulation, *Scientific Contributions Oil and Gas*, 43 (3) pp., 143-152.

INTRODUCTION

The three stages of recovery from an oil reservoir during its life are primary, secondary, and tertiary. Enhanced Oil Recovery (EOR) techniques offer the promise of improving oil recovery from existing oil fields. Most EOR techniques use existing well stock and basic infrastructure although they may require the installation of extra equipment to enable the injection of the chosen EOR fluid. The evaluation and design of any particular EOR project using numerical simulation is typically more complex and time-consuming than for a traditional waterflood (Smalley, *et al*., 2018). Various EOR techniques are being tested and used for recovering some of the oil left behind after conventional waterflooding. Among the EOR approaches, polymer flooding may be one of the most widely used, promising, and cost-effective methods. The preinjection of polymers has been proposed as a means for improving reservoir sweep efficiency by reducing permeability contrasts (Li, *et al.*, 2014).

Chemical EOR is an increasingly employed approach used to enhance oil recovery by combining changes in fluids mobility, macroscopic sweep, interfacial tension, etc. to essentially improve, or extend the economic life of a waterflood (Graham & Frigo, 2019). It includes flooding with polymer, surfactant, alkaline/surfactant, alkaline-surfactant-polymer (ASP), CO_2 and/or other miscible gases which are often combined with waterflood (e.g., CO_2 WAG) etc. (Graham & Frigo, 2019). Polymer flooding was initially used in the 1960s and since then has been used frequently to increase sweep efficiency by reducing the mobility mismatch of oil and aqueous phase. It helps in near wellbore region to improve the waterflooding process. In water flooding projects, an increase in injected water viscosity is expected. The key measure of the success of these projects is the stability of the displacement process during water injection (Cenk, *et al.,* 2017). Water-soluble polymers are used to increase the viscosity of injected water that is a requirement for better sweep efficiency, but accelerated production due to polymer flooding may be limited by reduced injectivity (Al-Shakry, *et al.*, 2018).

With a simultaneous increasing demand for oil and large decreases worldwide in newly discovered oil reserves in the past few decades, much attention has been paid to more-efficient production approaches such as enhanced-oil-recovery (EOR) methods for developing oil and gas from existing reservoirs. Various EOR techniques are being tested and used for recovering some of the oil left behind after conventional waterflooding. Among the EOR approaches, polymer flooding may be one of the most widely used, promising, and cost-effective methods (Li, *et al.*, 2014). The principle of polymer flooding is to reduce the mobility ratio of the displacing fluid to the displaced fluid to result in a more favourable mobility ratio. The mobility reduction of the displacing fluid can be achieved by adding soluble polymer to the injected water, which will increase its viscosity. The mobility ratio reduction is expected to improve the overall sweep efficiency and result in higher oil recovery (Hidayat & ALMolhem, 2019).

The vast majority of polymer flood used partially hydrolysed polyacrylamide, HPAM (hence, a hetero-polymer of polyacrylamide and polyacrylate), though some have investigated the use of biopolymers (Agi, *et al*., 2018) or variations on synthetic polymers to make them more tolerant of alkaline-earth-metal cations (Graham & Frigo, 2019).

According to (ESDM, 2018) fossil fuel is still number one source of energy. It contributes 38.79% for oil and 11.01% for natural gas to the total energy consumption. On the other hand, the oil production has been declining 3.6% from 2016 of decline rate estimated in 2017 (SKK Migas, 2017). Therefore, further efforts are needed to increase oil and gas production.

Primary and secondary production stages have been implemented in almost of every oil fields in Indonesia. However, by using these methods, it is still leaving considerable amount of oil in the reservoir (Abdurrahman, 2017). The common way to increase oil production quickly is by drilling new or infill wells. However, drilling costs are considerably expensive and tend to increase every year not to mention the difficulty in finding new drilling spot in mature fields. The cost for drilling new wells was averaged as a million dollars per well in 2014. Despite the high success rate for exploration well, which was about 74% in 2013 as mentioned, the ratio of discovery to production has been quite low. The chance to increase production then comes from EOR applications. In fact, after the primary recovery stage, the oil recovery process is traditionally continued to secondary recovery and/or enhanced oil recovery (EOR) stages (Abdurrahman, *et al.*, 2017).

Many EOR methods have been devised to recover more oil from the reservoir. Starting with the injection of water to various types of gases and liquids, many studies have reported success, but the additional cost of injecting chemicals and gases in relation to the cost of oil often kept the study at laboratory stage. But the present state of modern industrial development is characterised by the consumption of enormous quantities of petroleum products (Agi, *et al.*, 2018) .

This study presents the predicted application of chemical EOR methods, especially about the implementations of synthetic polymers and bio-polimers. Moreover, according to (Abdurrahman, *et al.,* 2017) nowadays, some notable progress in chemical flooding field trials and pilot projects have been reported such as those implemented in Minas, Kaji, Semoga, Meruap, Tanjung, Handil, Widuri, Zamrud, Pedada, and Limau Fields.

METHODOLOGY

Polymers for EOR

There are two types of polymers used for EOR: synthetic polymers (HPAM and derivatives of it) and biopolymers (polysaccharides). Biopolymers are originally from biomass or living organisms (microorganisms). It is eco-friendly, non-toxic and renewable. The most commonly used biopolymers in EOR is Xanthan gum. Synthetic polymers, as the name suggested, are man-made and derived from petroleum oil. Another type of polymer that has been used in EOR projects is gel polymers, which is formed by biopolymers and/or synthetic polymers (Cenk, *et al.,* 2017).

Synthetic Polymers

Most synthetic polymers are made from materials originally from petrochemicals, natural gas, crude oil, coal, and sugar or corn cane. Synthetic polymers are synthesized in industrial reactors from their monomers by a polymerization reaction. Poly-acrylamide, PAM, was the first polymer that has been used in oil recovery, as water thickening. PAM is used as a model polymer in EOR studies with a high molecular weight. PAM is stable up to 90°C at normal water salinity and up to 62°C at seawater salinity. PAM has chemically, mechanically, and thermally sensitive degradation properties (Cenk, *et al.*, 2017).

HPAM is the most extensively used synthetic polymer for EOR application. HPAM is composed of a flexible hydrophilic chain which elongates in solution. The viscosifying power of HPAM is a function of molecular weight and degree of hydrolysis, which has been reported to range from 20-25 million Daltons and 25% to 35%, respectively. Larger molecular weight HPAM polymers result in more viscous solutions. Nevertheless, they can have poor injectivity and lead to plugging of pore throats in porous media. HPAM polymers are very sensitive to temperature and salinity. HPAMs are stable up to 90°C in the absence of divalent cations (Ca2+ and Mg2+) and at anaerobic conditions. At high temperature and salinity, the rate of hydrolysis is much greater which leads to compression and distortion of the polymer chains. Compared to biopolymers, HPAMs are less expensive and resistant to bacterial attack (Elhossary, *et al.*, 2020).

Biopolimers

The most widely used biopolymer for EOR application is the Xanthan biopolymer. Xanthan is an anionic polysaccharide produced by the bacteria Xanthomonas Campestris through fermentation of glucose or fructose. This biopolymer has a very high molecular weight (2-50 million Dalton) and rigid polymer chains, which make Xanthan relatively insensitive to high salinity and hardness. The thermally stability of Xanthan (70°C to 90°C) is similar to that of HPAM. However, its application is not as popular as HPAM due to its high susceptibility to bacterial degradation and poor injectivity. Other promising biopolymers that have been studied for EOR application include Schizophyllan and Scleroglucan (Elhossary, *et al.*, 2020).

In EOR applications, such as waterflooding, Xanthan gum is the most commonly used bio-polymer; It has suitable viscosity, shear resistance, temperature, and salinity. Xanthan gum has high salt tolerance, high temperature and shear resistance compared to synthetic polymers. Xanthan gum biopolymer is produced from the microorganism Xanthomonas Campestris in industrial fermenters. Xanthan gum has been fermented and becomes commercially available by The Kelco since 1964. Xanthan gum is polyhydroalkanote biodegradable biopolymer (Vroman, 2009). Xanthan gum is synthesized by Xanthomonas campestris bacteria through fermentation of glucose or fructose. The molecular weight of Xanthan gum varies between 2000-5000 kDa. It is thermally stable at temperatures between 70° C to 90° C. The structure of Xanthan gum is a combination of mannose, glucuronic acid and glucose monosaccharides. However, Xanthan gum is not resistant to bacterial degradation and is also expensive. Xanthan gum has some injection problems, such as plugging by cellular debris, thus, its injection is not easy (Cenk, *et al.*, 2017).

Polymer Adsorption

Polymer adsorption is the adhesion of the polymer molecules onto the rock surface. Because EOR polymers have high molecular weights and extended chains, many polar groups along the polymer chain will attach to many different polar points on the rock surface. Consequently, for practical purposes, polymer adsorption is irreversible. Although a given polar group of a polymer may detach from the rock, other points of attachment will stay in place. By the time additional polar groups detach, it is likely that the previously detached group will reattach to the rock. It is statistically very unlikely that a polymer molecule would release all points of attachment at the same time (Manichand & Seright, 2014) polymer retention can have a major impact on the rate of polymer propagation through a reservoir, and consequently, on oil recovery. A review of the polymer-retention literature revealed that iron and high-surface-area minerals (e.g., clays. Polymer adsorption can simply be defined as the interac- tion between the solid surface (soft rock) and the polymer molecules. It allows the polymer to be physical adsorbed to the surface of the solid, hydrogen bond and van der Waal's forces acting on the molecules and solid surface. The polymer usually adsorbs on the surface of the solid, and if the surface area of the solid is large, the higher the level of adsorption (Agi, *et al.*, 2018).

All the studies indicate a selective action of the polymer with a significant reduction in the relative permeability to water with respect to the relative permeability to oil. Based on the fact that the wall effect is the dominant action of the polymer, polymer adsorption thus, plays a significant role in relative permeability modification, resulting in permeability reduction of porous media. The objective of polymer adsorption in production wells is to reduce water production without damaging oil productivity (Ogunberu & Asghari, 2004).

Accordingly, to build the model on reservoir simulation method, this research needs some fluid characteristic and petrophysic data. The data below is retrieved based on Pertamina SCAL (special core analysis) data in 2016. From the fuild sample obtained reservoir fluid characteristic as shown on table 1. The density of fluid is about 46.9 with viscosity 11.5 cp dan formation volume factor around 1.16 rb/stb. The fluid API Gravity is 37 API mean it tends to light oil inside the reservoir and bubble point pressure of 2398 psi.

Table 2 shows the reservoir rock characteristic. The reservoir expected has thickness 100 ft, with porosity about 29.4%, and vertical and horizontal permeability, both are around 706 mD. The rock compressibility of the reservoir is about 4.E-06 with reservoir temperature 110ºF.

Reservoir simulation method used for this research is supported by Computer Modeling Group (CMG). This study using 3D numerical model on CMG STARS simulator. The choosen simulator used because of the design and evaluate the effectiveness of all chemical additives based chemical EOR processes. STARS is the only simulator that accounts for the complex phenomena required to accurately model processes such as Alkaline-Surfactant-Polymer (ASP) flooding, low salinity water injection, and foam flooding. The approachment used has been applied by many previous studies, such as; Temizel, *et al.*, 2016 and Erfando, *et al.*, 2019.

Sensitivity study on this research focuses on the effectivity of polymer injection on polymer adsorption. Reservoir grid used is multilevel homogeneous reservoir 15x15x4 assuming single production well and one injection well. Futhermore, the driving mechanism considered is only solution gas drive without examining the possibility of faults or other geological conditions. Moreover, injection pattern utilized is ¼ five spot with the polymer injection carried out for 3653 days (10 years).

RESULTS AND DISCUSSION

Reservoir rock adsorption on polymer injection occurs due to the attractive forces between polymer molecules and the rock reservoir and many of these forces depend on the magnitude of the affinity of the reservoir rock to the polymer. If the adsorption is very strong, the polymer becomes thinner, as a result, the ability to increase sweep efficiency decreases (Rita, 2012).

The simulation results indicate that polymer adsorption strongly depends on the polymer concentration, shear rate, pH, salt concentration, and reservoir heterogeneity. An effective controlling of such parameters can reduce the effect of polymer adsorption so that it helps minimize the mass of chemical loss and improve the economic efficiency of the chemical flooding process. Physical adsorption occurs when polymer molecules are adsorbed onto the rock surface by virtue of a lower overall free energy. This lower free energy is due first to an entropic contribution, where water molecules are previously bound to the polymer or the rock surface is liberated as the polymer is adsorbed causing an entropy increase. Polymer adsorption onto the pore walls may lead to a significant permeability reduction as well as a loss of the polymeric additive (Dang, *et al.*, 2011).

This refers to an interaction between polymer molecules and rock surface. When a polymer solution is injected into the reservoir, some of the polymers is absorbed onto the rock surface. The adsorption reduces viscosity of the solution. The absorption decreases as the rock permeability increases. Adsorption is treated as an instantaneous effect in the simulation model. A table of values is required for each rock region. Each table represents the equilibrium

Table 1
Reservoir fluid characteristic (Pertamina 2016; Erfando, *et al.,* 2019)

Oil Properties	Value	Unit
Density	46.9	-
Viscosity	11.5	cp
Formation Volume Factor	1.16	rb/stb
API Gravity	37	API
Oil Type	Light Oil	-
Bubble Point Pressure	2398	psi

Table 2
Reservoir rock characteristic (Pertamina 2016; Erfando, *et al.,* 2019)

Rock Properties	Value	Unit
Thickness	100	ft
Porosity	29.4	%
Horizontal Permeability	706	mD
Vertical Permeability	706	mD
Rock Compressibility	4.10^{-6}	Psi^{-1}
Reservoir Temperature	110	F

Table 3
Polymer properties (Temizel, *et al.,* 2016)

Parameter	Synthetic Polymer	Biopolymer
Molecular Weight	10,206 lb/lbmole	10,000 lb/lbmole
Viscosity	70 cp	4 cp

Table 4
Polymer flooding injection parameter

Parameter	Synthetic Polymer	Biopolymer
PV	1/4 PV	1/4 PV
Injection Rate	890 bpd	890 bpd
Injection Time	3,653 days	3,653 days
Injection Pressure	2,000 Psi	2,000 Psi

concentration of polymer adsorbed on the rock and the concentration of polymer in the surrounding water phase (Hidayat & ALMolhem, 2019).

Figure 1 shows the base case of the reservoir with only 1 production well. The figure indicates there is no polymer adsorption in the reservoir because there is no injection of polymer yet. This case only represents the injection well in the area of reservoir using primary recovery (natural flow).

Normally, after the primary recovery, the next stage of the recovery is secondary recovery. And the most common secondary recovery used is waterflooding. However, this study only focuses on the differences of the base case and two types of polymers.

When waterflooding is no more effective, as a result of early water production and low oil recovery at the break- through time, the next option is polymer flooding. Polymer flooding has been successful in terms of the economy and the technicality. When a polymer flooding is performed, the mobility ration between the displaced fluid and the displacing fluid become favourable compared to the normal water flooding, therefore, the sweep efficiency and the cumulative oil recovery is improved (Agi, *et al.*, 2018).

Figure 2 displays the polymer adsorption on synthetic polymers. As pointed out in the Figure 2. the adsorption of synthetic polymer almost reaches the production well in production period.

The polymer adsorption in Figure 2 indicates in 10 years of production, synthetic polymer has been adsorbed in the almost entire area of the reservoir.

Figure 3 demonstrates the adsorption of xanthan polymer. As represented in Figure 3 the adsorption in 10 years of production period only reaches the middle of reservoir total area.

Based on simulation done, polymer adsorption on synthetic polymer is greater than xanthan polymer. As shown in Figure 2 and Figure 3, the comparison among base case, synthetic polymer, and xanthan polymer after 10 years injection. It occurs because of significant difference of their viscosities. The result of this research is similar to previous research done by (Temizel, *et al*., 2016). Adsorption of synthetic polymer nearly approaches production well after 10 years of injection, whereas biopolymer adsorption only touches half of reservoir (grid). It indicates biopolymer injection is better in polymer adsorption optimization, because it results less adsorption and in a longer period of time. It is led by lower molecular weight and viscosity value of biopolymer compared to synthetic polymer.

In additon, the difference of adsorption between synthetic polymer and xanthan polymer could happen due to the molecule size of synthetic polymer is higher than xanthan polymer. This study's result is same as the explanation of research by (Agi, *et al.*, 2018). It also can occur due to the molecular weight of synthetic polymer is higher than the xanthan polimer's, as explained in (Dang, *et al.*, 2011) as well as the explanation in (Elhossary, *et al.*, 2020).

As shown in the Figure 4, the effect of synthetic polymer injection and biopolymer on the reservoir recovery factor. On the base case chart without polymer injection, the reservoir can only produce 3.5% of the total OOIP for one year, after one year, field production will decrease until it reaches zero production in middle of 2020. At the same injection time for ten years, the two types of polymers, the results produced were not much different, synthetic polymers could produce 46.4% of OOIP, whilst biopolymers could produce oil 42.7% of total OOIP.

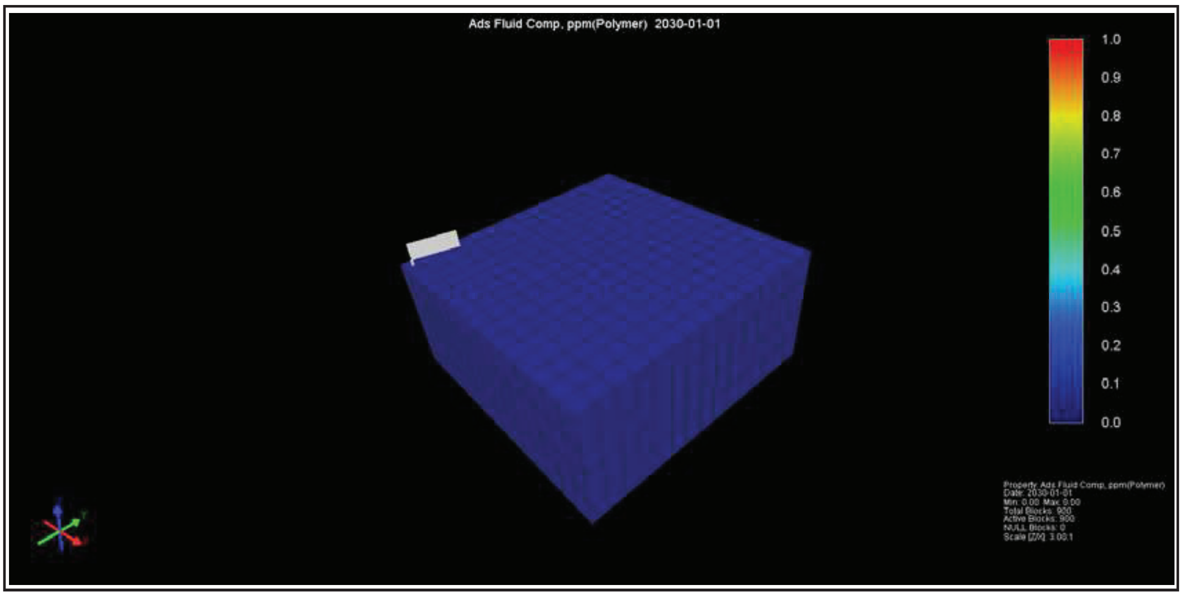

Figure 1
Base case.

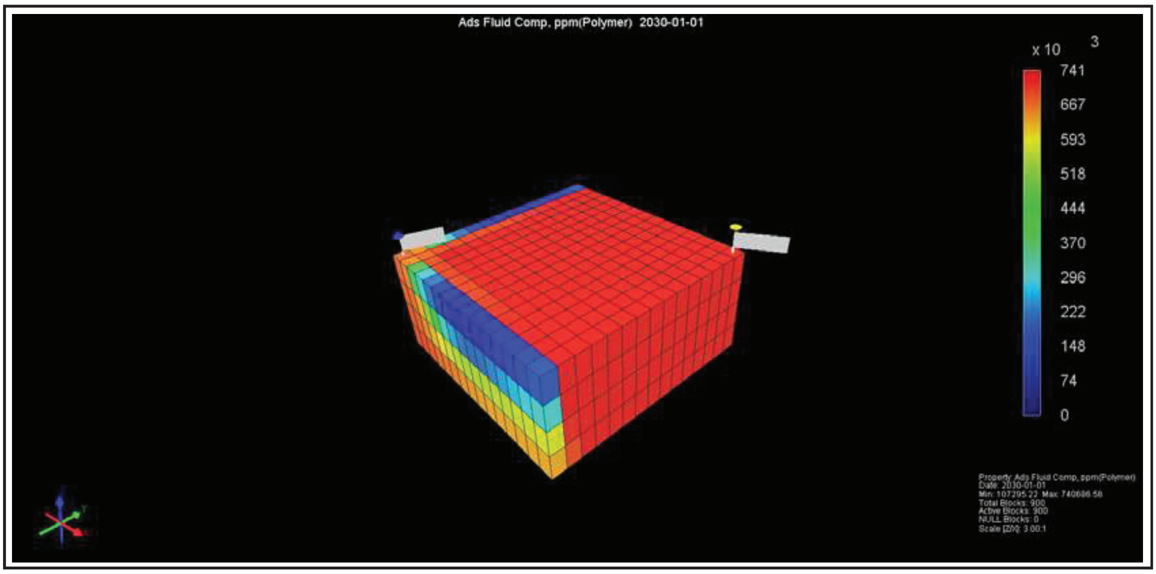

Figure 2
Synthetic polymer.

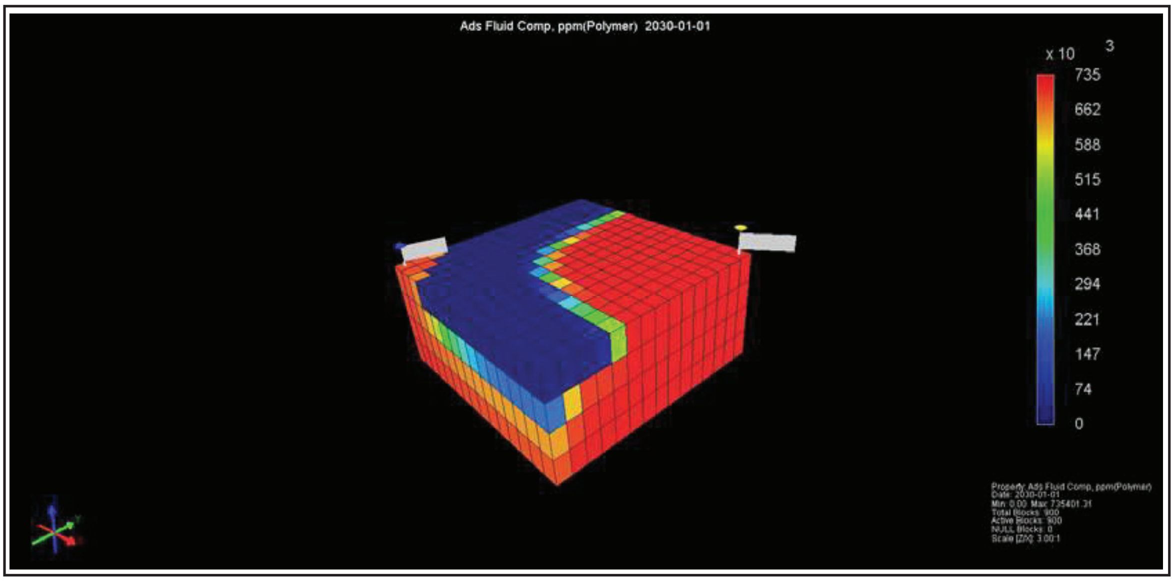

Figure 3
Xanthan polymer.

According to (Juárez, *et al.*, 2020) the sweep efficiency can be related to the dispersion coefficient of the aqueous phase that is experimentally determined at the end of the water displacement when the oil is immobile.

This confirms that a better sweep efficiency was achieved when viscosity ratio was decreased and viscous fingering was minimized. Oil mobilization throughout the porous medium is easier when viscosity ratio is smaller by reducing the dispersion of the aqueous phase and insuring a sharper displacement front (Juárez, *et al.,* 2020).

Effect of Polymer Viscosity

The polymer-solution viscosity is a key parameter to improve the mobility ratio between oil and water and to adjust the water-intake profile. As injection viscosity increases, the effectiveness of polymer flooding increases. The viscosity can be affected by a number of factors. First, for a given set of conditions, solution viscosity increases with increased polymer molecular weight. Second, increased polymer concentration leads to the higher viscosity and increased sweep efficiency. Third, as the degree of HPAM-polymer hydrolysis increases

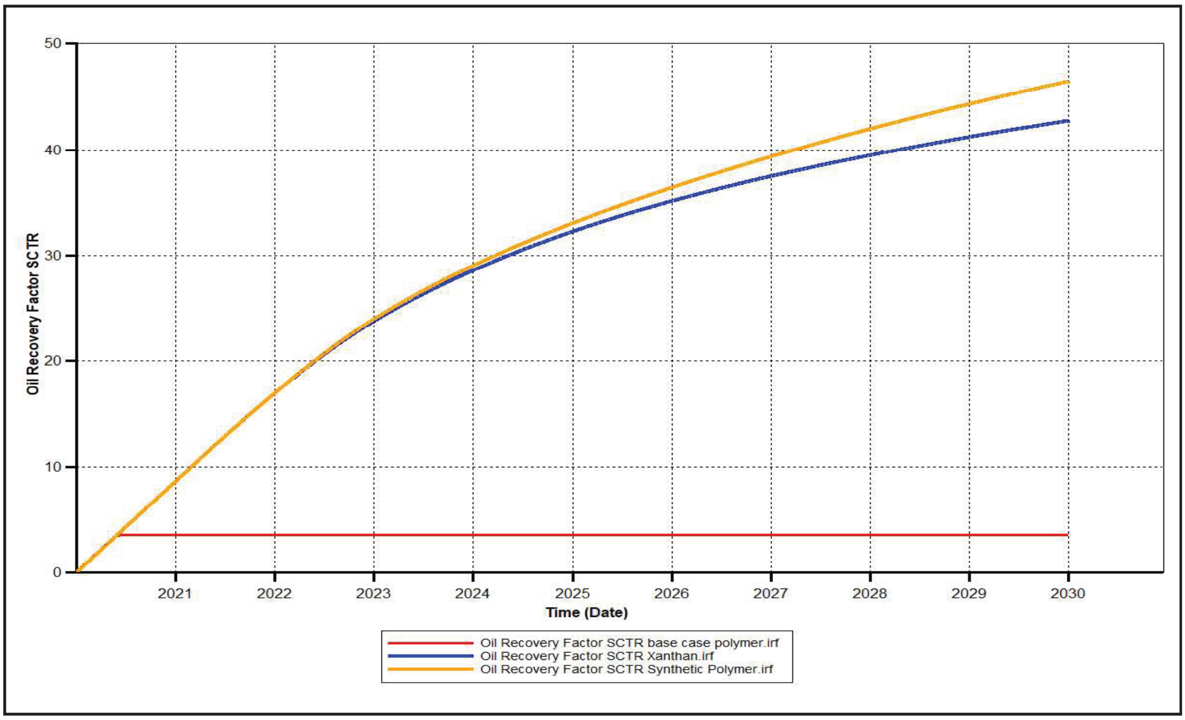

Figure 4
Effect of polymer injection on oil recovery factor.

up to a certain value, viscosity increases. Fourth, as temperature increases, solution viscosity decreases. Polymer degradation can also decrease viscosity. Fifth, increased salinity and hardness in the reservoir water also decreases solution viscosity for anionic polymers. The effectiveness of a polymer flood is determined directly by the magnitude of the polymer viscosity. The viscosity depends on the quality of the water used for dilution. A change in water quality directly affects the polymer solution viscosity (Wang, *et al.*, 2008).

Polymer injection is an enhanced water injection to improve oil recovery by increasing its viscosity. Polymer injections of different concentrations will cause an increase in different water viscosity. Typically, these two parameters are directly proportional to each other. Low-concentration polymer injections will lead to a low increase in value when compared to higher concentration injections (Erfando, *et al.*, 2019).

B. Effect of Polymer Molecular Weight

The molecular weight of polymer was proven to affect the adsorption level. The highest adsorption level is obtained with the lowest molecular weight. lowest molecular weight. Thus, it is recommended to use the high molecular-weight polyacrylamides in order to reduce the loss of permeability induced by polymer adsorption on pore walls. The high molecular weight polymer fluid may show the lower adsorption, the better mobility control, higher volumetric sweep efficiency, and of course higher recovery. However, there is an upper limit of Mw of polymer; the high Mw polymer presents a more viscous solution. Therefore, this fluid cannot penetrate deeply into a reservoir or polymer can be plugged in small pores. Consequently, it lowers the benefit of the polymer flooding process. An experiment has tested the relationship between the hydrodynamic radius of polymer and pore size. It has shown that the size of polymer must be smaller than 1/5 of the radius of pore (Dang, *et al.*, 2011). Polymer injectivity for high molecular weight polymer in linear cores at 100% Sw was underestimated compared to that where oil was present in porous media. Polymer injectivity was improved at the presence of oil and in non-water wet condition. This is due to lower retention which is economically favoured (Al-Shakry, *et al.*, 2018).

The effectiveness of a polymer flood is affected significantly by the polymer Mw. Polymers with higher Mw provide greater viscosity. For many circumstances, larger polymer Mw also leads to improved oil recovery. The reason is simply that for a given polymer concentration, solution viscosity and sweep efficiency increase with increased polymer Mw. Stated another way, to recover a given volume of oil, less polymer is needed using a high Mw polymer than a low Mw polymer. Two factors should be considered when choosing the polymer molecular weight. First, choose the polymer with the highest Mw practical to minimize the polymer volume. Second, the Mw must be small enough so that the polymer can enter and propagate effectively through the reservoir rock. For a given rock permeability and pore throat size, a threshold Mw exists, above which polymers exhibit difficulty in propagation (Wang, *et al.*, 2007).

CONCLUSIONS

Reservoir simulation was successfully conducted to evaluate the sensitivity of synthetic polymer and biopolymer injection in an oil field. Conducting a sensitivity analysis aids to identify polymer adsorption both on synthetic polymer and biopolymer. Nonetheless, modelling process could be diverse from one field another since the modelled reservoir in this study based on 3D numerical model.

Based on simulation managed using CMG STARS, biopolymer shows the tendencies to be more stable compared to synthetic polymer. It occurs because of the value of molecular weight and viscosity are smaller at biopolymer than synthetic polymer. However, recovery factor on synthetic polymer is slightly higher than biopolymer recovery factor in original oil in place drainage of the reservoir. The chemical EOR method has proved to increase oil production based on the simulation. After primary and secondary recovery, chemical EOR can improve the production to 42.7% (biopolymers) and 46.4% (synthetic polymers) of total OOIP. Nevertheless, the implementation of chemical injection needs more effort from laboratory studies to field implementations. To determine the adsorption of synthetic polymer and biopolymer, polymer's viscosity, molecular weight, and molecule size have significant result. These crucial factors need to be considered during the polymer injection. Not only for the adsorption of the polymer, but also for the incremental of oil recovery factor in a field. Hence, the determination of the polymer's properties is necessary for both synthetic and biopolymer.

ACKNOWLEDGEMENT

Author would like to thank Reservoir Simulation Laboratory of Department of Petroleum Engineering, Faculty of Engineering, Universitas Islam Riau grant by Computer Modelling Group (CMG) Ltd and Department of Mining and Petroleum Engineering, Faculty of Engineering, Chulalongkorn University in order to support this research.

GLOSSARY OF TERMS

Symbol	Definition	Unit
API	American Petroleum Institute	
ASP	Alkaline - Surfactant - Polymer	
CMG	Computer Modeling Group	
CO2	Carbon Dioxide	
EOR	Enhanced Oil Recovery	
HPAM	Hydrolyzed Polyacrylamide	
Mw	Molecular Weight	kg/mole
OOIP	Original Oil in Place	
PAM	Polyacrylamide	
pH	Potential Hydrogen	
PV	Pore Volume	
SCAL	Special Core Analysis	
Sw	Water Saturation	
WAG	Water Alternating Gas	

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