

RESEARCH ARTICLE

The Key Parameter Effect Analysis of The Polymer Flooding on Oil Recovery Using Reservoir Simulation

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Abstract

As time goes by, there will be decreasing of production rates of a field along with decreasing pressure. This led to the necessity for further efforts to increase oil production. Therefore, pressure support is required to improve the recovery factor. Supportable pressure that can be used can be either water flooding and polymer flooding. This study aims to compare recovery factor to scenarios carried out, such as polymer flooding with different concentrations modeled in the same reservoir model to see the most favorable scenario. The method used in this research is reservoir simulation method with Computer Modeling Group (CMG) STARS simulator. The study was carried out by observing at the pressure, injection rate, and polymer concentration on increasing field recovery factor. This study used cartesian grid with the assumption of homogeneous reservoir, there are no faults or other geological condition in the reservoir, and driving mechanism is only solution gas drive. This reservoir, oil type is light oil with API gravity 40.3°API and layer of conglomerate rock. The simulation result performed with various scenarios provides a good result. Where the conditions case base case field recovery factor of 6.7%, and after water flooding produced 25.5% of oil, whereas with tertiary recovery method is polymer flooding was carried out with four concentrations of 640 ppm, 1,500 ppm, 3,000 ppm, and 4,000 ppm obtained optimum values at 4,000 ppm polymer concentration with recovery factor 28.9%, SOR reduction final value 0,5255, polymer adsorption of 818,700 ppm, reservoir final pressure 1,707 psi, and an increase in water viscosity to 0.94 cP.

Keywords: Polymer flooding, SOR reduction, polymer adsorption

1. Introduction

The rate of oil production will decrease over time, due to reduced reservoir pressure and reduced amount of oil reserves in the field. In early stages of primary recovery, several oil wells used artificial technology lift, but this technology was no longer optimal in producing oil to the surface (El-Khatib, 2001). Therefore, efforts are needed to increase oil production and recovery factors from the area, the effort to be carried out is water injection or waterflood (Erfando et al., 2017; Erfando and Herawati, 2017; Rita, 2016).

Water flooding is a proven method for improving offtake rate and ultimate recovery from conventional oil reservoirs. Although relatively inexpensive and straightforward to operate, the dynamics and eventual performance of waterflooded reservoirs are controlled by complex interactions of several factors. Due to this complexity, it has been challenging to develop a robust, consistent and yet simple normalizing parameter for comparing the performances and recoveries of different reservoirs under waterflood (Tetegan et al., 2015).

The conversion of conventional waterflood to a polymer flood entails significant injectivity reduction, up to 50% or more. The maintenance of complete voidage replacement (VRR = 1) would thus require an

increase in the number of injectors or a reduction of total production rate or both. As both interventions reduce the economic returns (San Blas and Vittoratos, 2014).

Polymer flooding was initially used in 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 water flooding process. In waterflooding projects, an increase in injected water viscosity is expected. The key measure of success of these projects is the stability of the displacement process during water injection (Temizel et al., 2017).

Polymer flooding has been used to enhance oil production and reduce water cut for a long time. However, there are still many fundamental challenges in characterizing the multiphase-fluid flow, even the single-phase-fluid flow, associated with polymer flooding. 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).

Hydrocarbon recovery increases when oil is displaced by fluid and water as the displacing fluid has a mobility ratio near one. When volumetric sweep efficiency increases, the mobility ratio decreases. If the mobility ratio is higher than one, polymers or gels can help to increase the viscosity of injected fluids for increasing oil recovery. Polymer flooding and gel treatment are one of the most common EOR techniques that have been used over four decades due to its reasonable recovery rates and suitable application. Polymers are added to the injection fluid to increase its viscosity, thereby reducing their mobility ratio, and resulting in increased oil recovery (Cenk et al., 2017).

Recently, there is increasing interest in polymer flooding due to its high enhanced oil recovery (10%-20% OOIP in field tests in Daqing) and much lower cost compared to surfactant-polymer (SP) flooding and alkali-surfactant-polymer (ASP) flooding (Guo, 2017).

This study was carried out without considering the cost of polymer prices and polymer flooding process, the only focus on which concentration worked best on increasing oil recovery.

2. Materials and Methods

2.1. Reservoir Fluid and Reservoir Rock Characteristics

Table 1. Reservoir fluid characteristics (Pertamina, 2016)

Oil Properties	
Density	0.835
Viscosity	1.13 cp
Formation Volume Factor	1.14 rb/stb
API Gravity	40.3° API
Specific Gravity	0.82
Oil Type	Light Oil
Bubble Point Pressure	993 psig

Table 2. Reservoir rock characteristics (Pertamina, 2016)

Parameter	Value	Unit
Rock Type	Conglomerate	-
Thickness	20	Ft
Porosity	16.5	%
Horizontal Permeability	100	mD
Vertical Permeability	100	mD
Rock Compressibility	5.10^{-6}	psi ⁻¹

2.2 Methods

The method used in this research is reservoir simulation method with Computer Modeling Group (CMG) STARS simulator. This research was conducted by taking field data on Barito Basin, Borneo Island, Indonesia

3. Polymer Properties

This study used gel polymer (Pregel) with a molecular weight of 10,206 lb/lb mole, the density of 1,000 [lb/ft³] and viscosity of 20 cP. Analysis of concentration is polymer needed to optimize oil

recovery in the process of polymer flooding. The concentration polymer used in this study was 640 ppm, 1,500 ppm, 3,000 ppm, and 4,000 ppm. The parameter of polymer flooding: injection is carried out 1.2 PV, with the total fluid injected 614,473 barrels of polymer solutions for 2.5 years, with polymer solutions injected per day is 670 barrels for 916 days' injection. Injection pressure is set at 2,000 psi.

The selection of polymer flooding concentrations is based on Gao, Jiang, Zhang, et al., 2016 paper, according to them, oil displacement experiment results show that when the polymer solution dosage is 640 ppm, the incremental oil recovery is only 1.98% with polymer concentration increasing from 1000 ppm to 3000 ppm. When the polymer dosage is reach 1280 ppm. PV, the incremental oil recovery is also only 2.2% with polymer concentration increasing from 1000 ppm to 3000 ppm. Only increasing both polymer concentration and dosage, can good oil displacement effect be obtained when the polymer dosage reaches up to 1280 ppm. PV and polymer concentration increases to 2000 ppm; the incremental oil recovery can reach above 10%. Thus, the incremental oil recovery can be increase greatly by increasing both polymer concentration and dosage after polymer flooding.

Table 3. Polymer flooding parameters of injection

No	Parameter	Value
1	PV	1.2 PV
2	Injection Rate	670 bpd
3	Injection Time	916 days
4	Injection Pressure	2,000 psi

4. Result and Discussion

4.1. Polymer Concentration Analysis

According to (Gao et al., 2016) high concentration polymer flooding can further enlarge sweep volume and improve mobility ratio between the displacing fluid and crude oil, which is effective to exploit the remaining oil after polymer flooding. High concentration polymer flooding after polymer flooding has good mobility control ability and can enlarge swept volume to enhance oil recovery. Meanwhile, High concentration polymer has good viscoelasticity, which is able to pull residual oil and reduce all kinds of residual oil volume, thus increases microscopic displacement efficiency.

High concentration polymer flooding (HCPF) has been one of the enhanced oil recovery (EOR) methods since conventional polymer flooding because its higher viscoelasticity can improve the oil displacement efficiently. HCPF produced liquid is characterized by high viscosity, and strong emulsification tendency and stability. The emulsification effect of the low water cut produced liquid is more obvious as the polymer-containing concentration rising up, leads to the phase inversion point, at which the emulsion transformed from water-in-oil (W/O) to oil-in-water (O/W) or water-in-oil-in-water (W/O/W) (Yang et al., 2015).

Polymer flooding is an advanced stage that is carried out after water flooding as tertiary oil recovery. The polymer is injected to reduce water mobility as a

driving fluid by increasing its viscosity. For this reason, it is necessary to regulate concentration polymer in an effort to reduce water mobility so that it is more optimal in the oil pressing process.

Fig. 1 shows that for each increase in concentration polymer, the recovery factor for the field also increases. polymer flooding 640 ppm of produces recovery oil of 28.5% of the total OOIP. While polymer flooding with a concentration of 1,500 ppm can increase oil production to 28.6%. For injection with a concentration of 3,000 ppm can produce oil of 28.8% from OOIP, and a concentration of 4,000 ppm can increase oil recovery by 28.9%.

Table 4. Comparison of polymer concentration on oil recovery

Polymer concentrations, Ppm	Oil production cumulative, BBL	Oil recovery factor, %
640	90,306	28.5
1,500	90,723	28.6
3,000	91,219	28.8
4,000	91,332	28.9

RF increase is not too significant for polymer flooding even though the concentration polymer that has been injected has been increased with a large enough value, because injection with concentrations above 640 ppm requires greater pressure to reach the production well, this is related to the injection viscosity

polymer which is increasingly thick with increasing concentration, because concentration polymer too high can cause blocking in small permeability.

Based on the value of RF and the cumulative production obtained in this study, the maximum results were shown on polymer flooding with a concentration of 4,000 ppm which resulted in RF of 28.9% of total reserves with cumulative production of 91,332 barrels of total OOIP on the field.

This study was carried out without considering the cost of polymer prices and polymer flooding process, the only focused on which concentration worked best on increasing oil recovery.

4.2. SOR Reduction Analysis

According to [Sheng et al., 2015](#) Technical screening criteria for polymer flooding are empirical, mainly based on field-project data and technical knowledge describing polymer flooding. Many parameters can affect the polymer-flooding process, but the most critical are reservoir temperature, formation-water salinity, divalent contents, clay contents, oil viscosity, and formation permeability. Most polymer-flooding projects were carried out in sandstone reservoirs. Fewer applications were carried out in carbonate reservoirs because anionic polymers such as hydrolyzed polyacrylamide (HPAM) have high adsorption in carbonates. Also, various carbonate reservoirs have a low-permeability matrix, which large polymer molecules may not be able to enter.

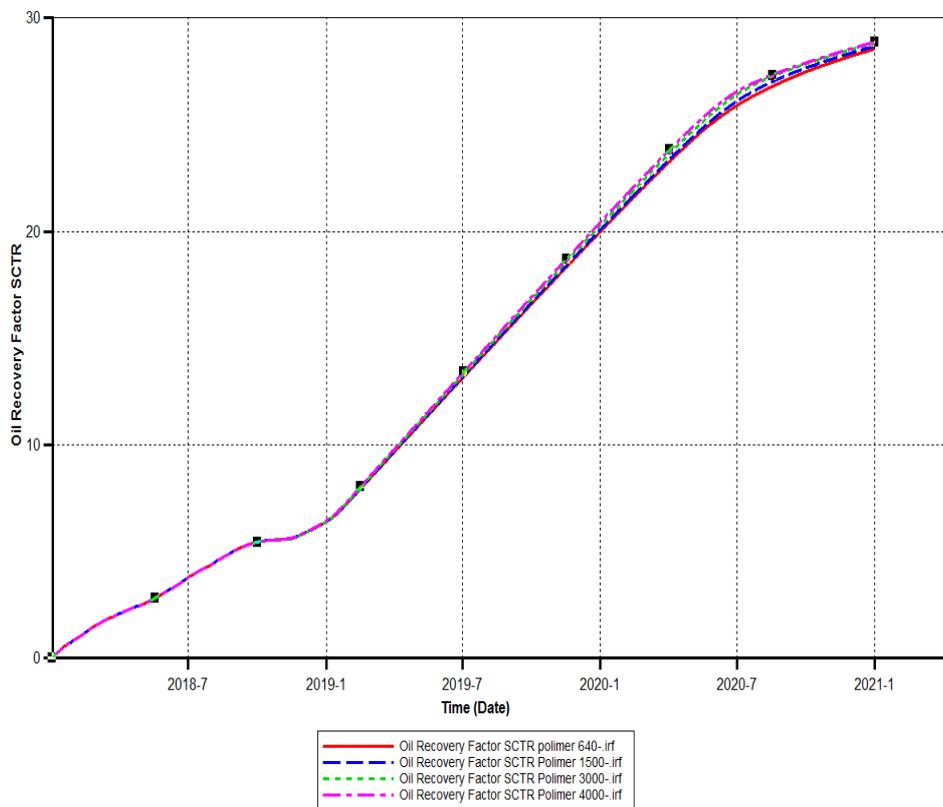


Fig 1. Effect of polymer concentration on oil recovery factor

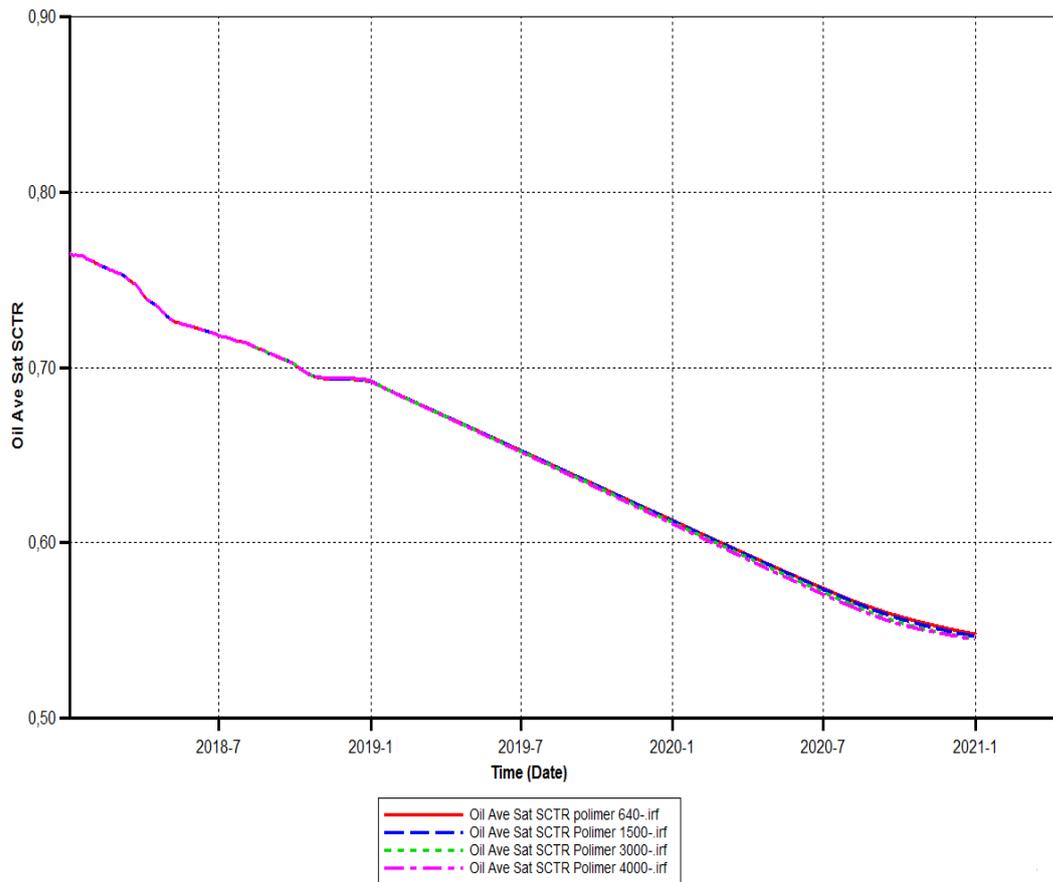


Fig. 2. SOR reduction after polymer flooding by various concentrations

Fig. 2 shows the deployment in the conditions initial and final after three years of production. Based on picture 4.8 the SOR condition of the initial field is at a value of 0.765. Then after producing for three years the final saturation of the field decreases. The difference in oil saturation values in the final condition on the entire field is caused by oil pressure by polymer flooding two and a half years. Thus, oil saturation in the reservoir is reduced. Reducing the oil saturation value in the final condition shows the amount of oil that has been produced from the field.

Oil saturation in this reservoir is equal until it is produced, after production the saturation will decrease. The higher the concentration of polymer injection, the more oil production will be.

Table 5 – The Initial and final SOR differences after polymer flooding

Scenarios	SOR Initial	SOR Final
Polymer 640 ppm	0.7650	0.5275
Polymer 1500 ppm	0.7650	0.5266
Polymer 3000 ppm	0.7650	0.5257
Polymer 4000 ppm	0.7650	0.5255

4.3. Polymer Adsorption Analysis

Adsorption is a process whereby contact between the fluid in the form of gas and liquid, with solid, where

the substances in the fluid are absorbed by the surface of the solid, resulting in changes of the composition of the unadsorbed fluid. The adsorption process is usually characterized by mass transfer from liquid to solids. A liquid concentration higher before flowing in solid pores will cause higher adsorption on solid surface. Commonly used material as adsorbent are very ingredients porous, and adsorption takes place on pore walls or in certain locations within particles (Widyarso et al., 2006).

According to Rita, 2011 the adsorption of reservoir rocks in polymer injection occurs due to the attraction between polymer molecules and reservoir rock and the magnitude of this force depends on the magnitude of the affinity of the reservoir rocks affinity the polymer. If the adsorption is very strong, the polymer becomes thinner, consequently the ability to increase the sweep efficiency decreases.

The polymer concentration is directly proportional to the polymer adsorption of rock gradually, the higher concentration, the greater the adsorption occurring to the polymer solution on a rock surface. Conversely, the lower the concentration, the smaller the adsorption that occurs to the polymer solution on a rock surface.

Polymer adsorption that occurs in all four concentrations carried out by the above polymer adsorption theory. Polymers with a concentration of 640 ppm resulted in the lowest polymer adsorption, whereas polymers with 4,000 ppm concentrations resulted in the highest polymer adsorption.

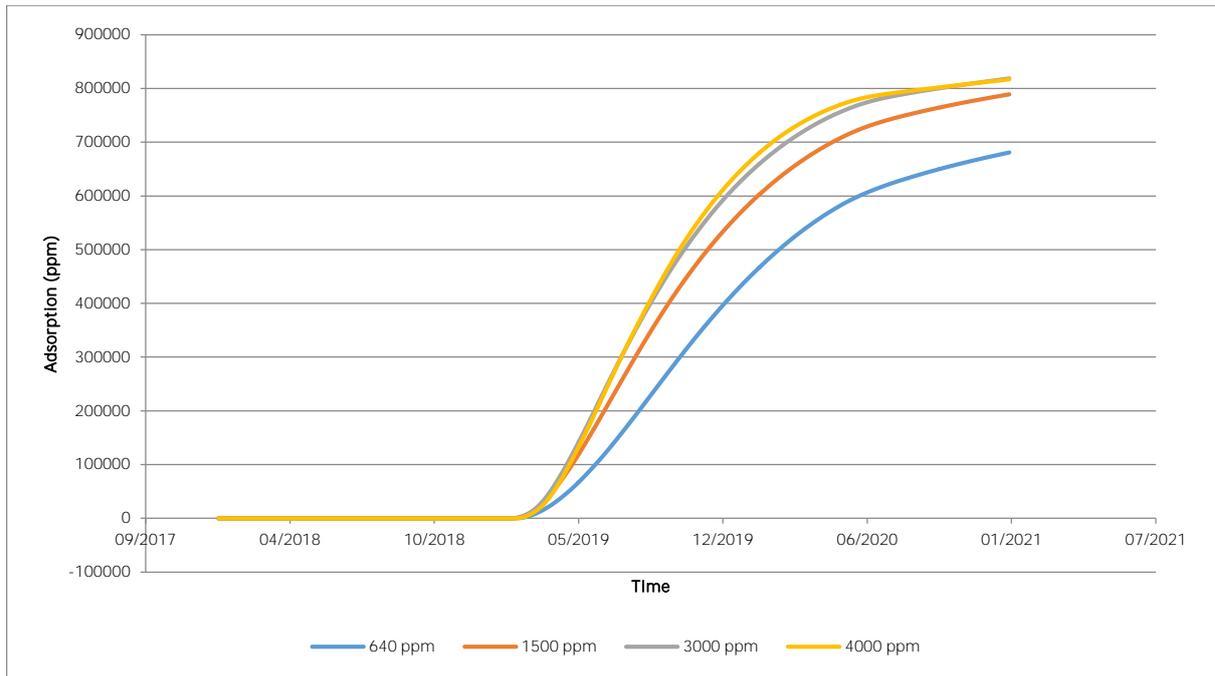


Fig. 3. Polymer adsorption at various polymer concentrations

Table 6. Polymer adsorption at various concentration

Scenarios	Polymer adsorption (ppm)
Polymer 640 ppm	680,000
Polymer 1,500 ppm	790,000
Polymer 3,000 ppm	818,500
Polymer 4,000 ppm	818,700

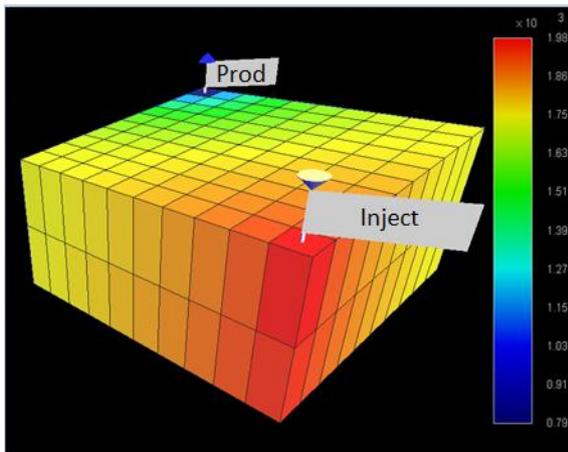


Fig. 4. Pressure final condition after polymer flooding

Fig. 4 shows the deployment value of pressure on the field in the final condition. Observable from the color of its spread, there is a pressure difference in the reservoir. The highest pressure is on the injection wells with values ranging from 1,800 psi, then increasingly

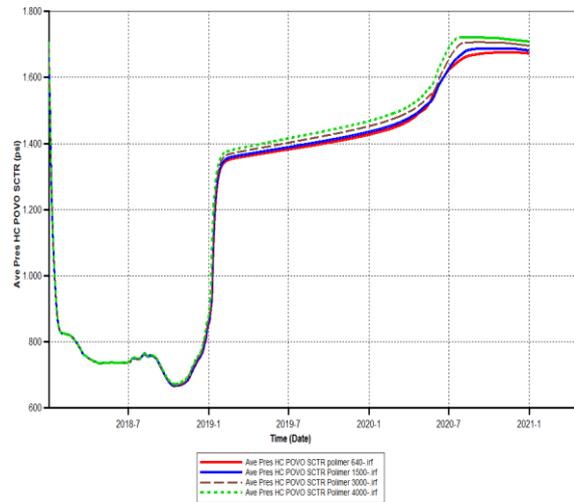


Fig. 5. Pressure on some concentrations of polymer flooding

towards the production well the pressure decreases. This pressure drop is what causes the production to drop in the field. Therefore, polymer injection is required with the aim of keeping the pressure at a sufficient level in order to produce oil no less than the minimum production limit.

There was a difference in reservoir pressure after polymer flooding at different concentrations. At polymer concentration of 640 ppm final pressure reservoir is 1,671 psi, while for polymer concentration 1,500 ppm, 3,000 ppm, and 4,000 ppm are 1,681 psi, 1,696 psi, 1,707 psi. Fig. 5 shows the higher the polymer concentration injected, the greater the pressure increases.

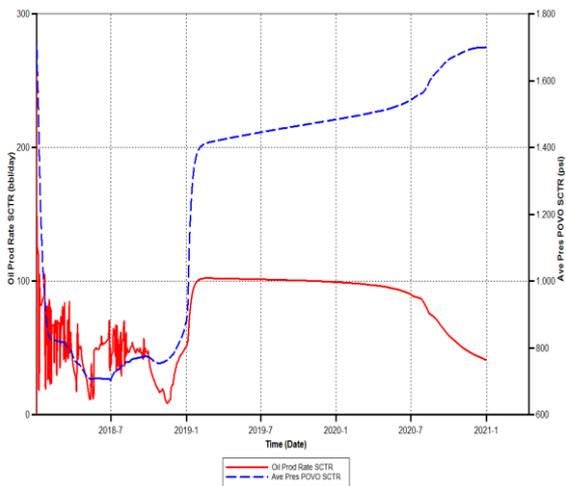


Fig. 6 Pressure effects on production rate

Fig. 6 shows that simultaneous pressure changes follow oil production fluctuations. Changes in pressure from January 2018 to July 2018 occurred sharply as production relied only on reservoir pressure without any effort to maintain reservoir pressure. In July 2018, after polymer flooding, it can be seen in Fig. 7, that constant pressure changes until September 2020, then increased until 2021. The temporary increase in chart shows the decrease in oil production can be caused by water breakthrough that has reached well production, so oil production decreases because there is water produced at the same time.

4.4 Increasing of Water Viscosity Analysis

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.

Increased viscosity is very important due to: one way to avoid the early breakthrough and high water-cut is to deploy a polymer flood rather than a waterflood. Polymer flooding is an enhanced oil recovery technique that aims at improving the mobility ratio between the injected and in-situ fluids by viscosifying the injected water. Moreover, the increased viscosity also results in improved volumetric sweep efficiency (Anand and Ismaili, 2016). Increasing flooding-solution viscosity with polymers provides a favorable mobility ratio compared with water flooding and hence improves volumetric sweep efficiency. Flooding with a polymer solution exhibiting elastic properties has been reported to increase displacement efficiency, resulting in a sustained doubling of the recovery enhancement compared with the use of conventional viscous-polymer flooding (Clarke et al., 2016).

In this study, polymer flooding was performed at a reservoir temperature of 122° F or about 50° C, which means that the viscosity of pure water under these conditions is 0.5 cP. So by doing polymer flooding, the water viscosity will increase along with the polymer concentration injected.

Polymer flooding has been used to improve the development effect and to enhance oil recovery for dozens of years, which is a type of common and matured technology. Polymers cannot be used on ideal conditions to sweep oil if the reservoir temperature exceeds 70 °C if it exceeds that temperature it will cause rapid thermal degradation (Wu et al., 2015).

Scenarios above were done by comparing the four concentrations performed under the same conditions. At a concentration of 640 ppm, the viscosity value was 0.55 cP, for a concentration of 1,500 ppm the viscosity increased to 0.59 cP, whereas for a concentration of 3,000 ppm the viscosity increased by 0.82 cP, and for a concentration of 4,000 ppm the viscosity increased to 0.94 cP.

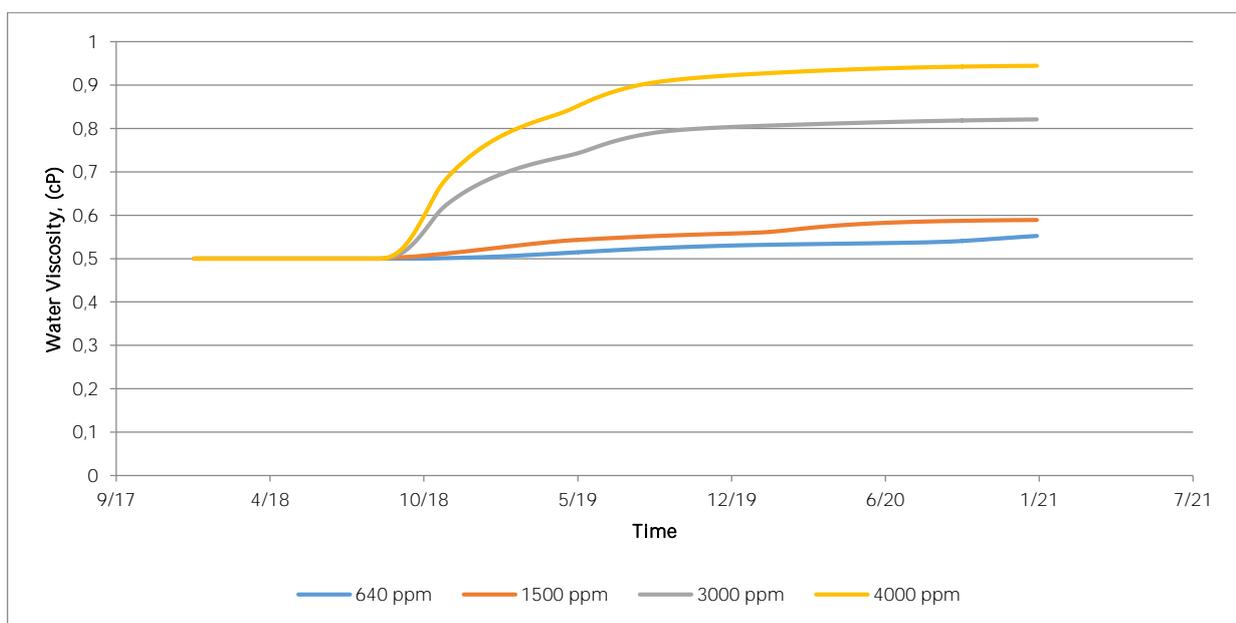


Fig. 7. Increasing water viscosity by various concentrations of polymer flooding.

Table 7. Polymer Viscosity at various concentration

Polymer Concentration	Polymer Viscosity
640 ppm	0.55 cP
1,500 ppm	0.59 cP
3,000 ppm	0.82 cP
4,000 ppm	0.94 cP

5. Conclusion

The most critical factor in the polymer flooding process is the injection concentration, because it will have impacts on SOR reduction and increased pressure from the reservoir, on the adsorption of polymers in rock matrix, and an increase in water viscosity which helps in increasing sweep efficiency.

Based on the results of research and discussion that has been done, then the conclusions obtained from this study is the tertiary recovery method of polymer flooding conducted with four concentrations, the optimum value obtained at 4,000 ppm polymer concentration with recovery factor 28.9%, SOR reduction with final value 0.5255, polymer adsorption of 818,700 ppm, final reservoir pressure 1.707 psi, and water viscosity increase to 0.94.

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