MICROEMULSION FLOODING MECHANISM FOR OPTIMUM OIL RECOVERY ON CHEMICAL INJECTION

MEKANISME PENDESAKAN MIKROEMULSI PADA INJEKSI KIMIA UNTUK MENGHASILKAN PEROLEHAN MINYAK YANG OPTIMUM

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ABSTRAK

Terbentuknya mikroemulsi pada penerapan teknologi enhanced oil recovery (EOR) injeksi kimia di reservoir minyak sangat diperlukan agar efektifitas proses injeksi kimia tersebut dapat dicapai. Mikroemulsi dapat diperoleh dengan dua cara yaitu mencampurkan antara surfaktan dan minyak di permukaan atau dengan menginjeksikan surfaktan ke batuan berpori di dalam reservoir supaya terbentuk mikroemulsi "in situ". Campuran yang homogen dan transparan antara minyak dan air serta adanya surfaktan tersebut dipercaya dapat mendesak sisa minyak yang tertinggal di dalam reservoir. Kajian sebelumnya menunjukkan pengaruh formulasi surfaktan yang membentuk mikroemulsi terhadap penurunan tegangan antarmuka antara minyak dan air ke tingkat ultralow dapat mengatasi pengaruh tekanan kapiler pada batuan berpori untuk dapat mengalirkan minyak. Akan tetapi pada kajian tersebut, efektifitas injeksi mikroemulsi untuk meningkatkan perolehan minyak melalui uji core flooding belum dilakukan. Pada kajian ini, kemampuan formula mikroemulsi surfaktan untuk meningkatkan perolehan minyak pada kondisi reservoir pada skala laboratorium dipelajari melalui uji core flooding. Formula berbasis mikroemulsi yang terdiri dari 2% surfaktan A dan 0.85% natrium karbonat (Na_2CO_3) disiapkan dengan mencampur synthetic soften brine (SSB) pada beberapa variasi konsentrasi polimer untuk meningkatkan mobilitas minyak. Viskositas surfaktan-polimer dengan penambahan alkali (ASP) dan polimer tunggal sebagai bahan pendorong diukur. Uji perolehan minyak dilakukan menggunakan alat core flooding untuk mempelajari kemampuan surfaktan berbasis mikroemulsi untuk meningkatkan produksi minyak. Hasil pengujian menunjukkan bahwa polimer pada larutan ASP dengan konsentrasi 2200 ppm menghasilkan viskositas 12.16 cP, dua kali lebih tinggi daripada viskositas minyak untuk dapat mencegah terjadinya fingering. Polimer tunggal pada konsentrasi 1300 ppm mampu menghasilkan larutan dengan viskositas 15.15 cP. Hasil pengujian core flooding dengan desain slug injeksi 0.15 PV diikuti dengan 1.5 PV polimer menunjukkan bahwa penambahan perolehan minyak setelah injeksi air mencapai hasil yang tertinggi yaitu sebesar 93.41% dari sisa saturasi minyak setelah injeksi air (Sor) atau 57.71% dari saturasi minyak mula-mula (Soi). Dari hasil kajian tersebut dapat disimpulkan bahwa injeksi surfaktan berbasis mikroemulsi merupakan mekanisme yang paling efektif untuk mendapatkan perolehan minyak yang optimum pada reservoir target.

Kata Kunci*: injeksi mikroemulsi, surfaktan, ASP, injeksi kimia, EOR.*

ABSTRACT

The formation of microemulsion in the injection of surfactant at chemical flooding is crucial for the effectiveness of injection. Microemulsion can be obtained either by mixing the surfactant and oil at the surface or injecting surfactant into the reservoir to form in situ microemulsion. Its translucent homogeneous

mixtures of oil and water in the presence of surfactant is believed to displace the remaining oil in the reservoir. Previously, we showed the effect of microemulsion-based surfactant formulation to reduce the interfacial tension (IFT) of oil and water to the ultralow level that sufficient enough to overcome the capillary pressure in the pore throat and mobilize the residual oil. However, the effectiveness of microemulsion flooding to enhance the oil recovery in the targeted representative core has not been investigated.In this article, the performance of microemulsion-based surfactant formulation to improve the oil recovery in the reservoir condition was investigated in the laboratory scale through the core flooding experiment. Microemulsion-based formulation consist of 2% surfactant A and 0.85% of alkaline sodium carbonate (Na_2CO_3) were prepared by mixing with synthetic soften brine (SSB) in the presence of various concentration of polymer for improving the mobility control. The viscosity of surfactant-polymer in the presence of alkaline (ASP) and polymer drive that used for chemical injection slug were measured. The tertiary oil recovery experiment was carried out using core flooding apparatus to study the ability of microemulsion-based formulation to recover the oil production. The results showed that polymer at 2200 ppm in the ASP mixtures can generate 12.16 cP solution which is twice higher than the oil viscosity to prevent the fingering occurrence. Whereas single polymer drive at 1300 ppm was able to produce 15.15 cP polymer solution due to the absence of alkaline. Core flooding experiment result with design injection of 0.15 PV ASP followed by 1.5 PV polymer showed that the additional oil recovery after waterflood can be obtained as high as 93.41% of remaining oil saturation after waterflood (Sor), or 57.71% of initial oil saturation (Soi). Those results conclude that the microemulsion-based surfactant flooding is the most effective mechanism to achieve the optimum oil recovery in the targeted reservoir.

Keywords: microemulsionflooding, surfactant, ASP, chemical flooding, EOR.

I. INTRODUCTION

Microemulsion flooding technique has been introduced along with the other methods to extract the residual oil from natural oil reservoir (Santanna et al. 2009; Bera et al. 2014) since the conventional techniques start to become unprofitable. Its isotropic, and translucent molecule is thermodynamically stable generated from the dispersion of surfactant, oil and water (Dungan et al. 1997). The formation of microemulsion was believed to be able to reduce the IFT to the ultralow level (Kayalia et al. 2010; Bera et al. 2014; Bera & Mandal 2015). The ultralow level at 10^{-2} until 10^{-3} dyne/cm was required to overcome the pore size capillary pressure by increasing the Capillary Number (N_c) until four to five orders of magnitude that has been proved to be effective to reduce the remaining oil in the reservoir (Subhash & Dandina 2004; Spildo et al. 2012), and well represented by as:

$$Nc = \frac{\mu v}{\gamma} \qquad (1)$$

where μ is the dynamic viscosity of the liquid, υ is the velocity, and γ is the IFT between oil and water phases.

There are two distinct ways of microemulsion flooding that has been introduced for chemical flooding in enhanced oil recovery (EOR) application. In the first method, microemulsion were prepared on the surface by mixing oil and water in the presence of surfactant prior the injection (Santanna et al. 2009).

Whereas in the second method, microemulsion were prepared in the reservoir pore (in situ) by injecting surfactant slug that expected to react with oil and brine (Zhao et al. 2008; Wang et al. 2010).

Previously, we investigated the effect of optimum salinity on microemulsion formation to attain ultralow IFT for chemical flooding application. It showed that the formation of microemulsion is a salinity function of aqueous phase due to the difference mechanism of solubility by altering the polar area of surfactant (Alli & Tobing 2016). At optimum salinity of anionic surfactant in the presence of 0.65% Na_2CO_3, microemulsion was formed between oil and water and were able to decrease the IFT to be around 10^{-3} dyne/cm.

The main object of this paper is to study the performance of microemulsion flooding for increasing the recovery factor through the core flooding experiment. Anionic surfactant with optimum salinity that expected to produce microemulsion in the porous media was injected into the standard core that has been reached Sor. In order to increase the volumetric efficiency, polymer was added into the surfactant in the presence of alkaline (ASP) slug, followed by single polymer injection as thickened chemical drive to prevent the fingering issues.

II. METHODOLOGY

A novel anionic surfactant which expected to formmicroemulsion with oil and water in the porous media in the presence of 0.85% sodium carbonate

was used as injected chemical. Polyacrylamide, PA, was used as polymer drive in tertiary oil recovery experiment. Synthetic Soften Brine (SSB) was used to dissolve the chemical, whereas Synthetic Hard Brine (SHB) was used for core saturation. Intermediate crude oil was used for oil saturation. Crude oil and brine characteristic used for the experiment were described in the previous study (Alli & Tobing 2016).

A. Rheology

Viscosity of polymer solution without and with surfactant alkali solution at various concentration was measured using Brookfield Rheometer DVIII Ultra with shear rate 7 s^{-1} at 85°C. Polymer thermal stability was investigated by measuring polymer viscosity after several days stored in the reservoir temperature.

B. Filtration

Filtration analysis of polymer in the presence and absence of surfactant were carried out by utilizing filteration unit and calculating the filtration ratio. A 300 mL of sample was allowed to flow into the 3.0 µm filter paper under pressurized 30 psi nitrogen. The cumulative flow time was recorded in every 50 mL collected sample. The filtration ratio was then calculated by:

$$F_R = \frac{T_{300}-T_{250}}{T_{100}-T_{50}} \qquad (2)$$

where T$_x$ is the time to collect x ml of polymer mixture.

C. Core Flooding Experiment

Core flooding experiment was conducted on standard core bentheimer using high pressure and high temperature. Routine core analysis was firstly conducted which included measuring the dimensions, air permeability and porosity. The petrophysical parameters was presented in Table 1. The oil displacement performance of chemical combination flooding systems was tested. Core flooding experiment procedure was described as: vacuuming the weighing core at -1 atm for several hours, followed by saturation with SHB for 3 hours. Wetted core was then weighted. Mass difference was determined as water pore volume (PV). Core was put in the core holder and injected with SHB, water phase permeability was measured. The drainage process was started by injecting crude oil with gradient rate from 0.1 to 10 mL/min until surely no more brine produced. The Soi was calculated by using material balance method. The core was placed in a 85°C oven for aging interaction between crude oil and the core as long as 3 days. A water flooding was injected with SHB until water cut more than 98%, followed by pre-flush with SSB. Then the ASP chemical flooding slug was injected for 0.15 PV, followed by polymer protective slug for 1.50 PV (Fig. 1).

Core flooding experiment was conducted at reservoir temperature, 85°C, with fluid injection rate of 0.1 mL/min, which simulating displacement velocity of chemical flooding in oil reservoir. During the experiments, the pressure drop, oil production and total fluid production were recorded timely in order to calculate the incremental oil recovery and water cut of flooding precisely.

Table 1
Physical properties and mineralogical compositions of bentheimer core

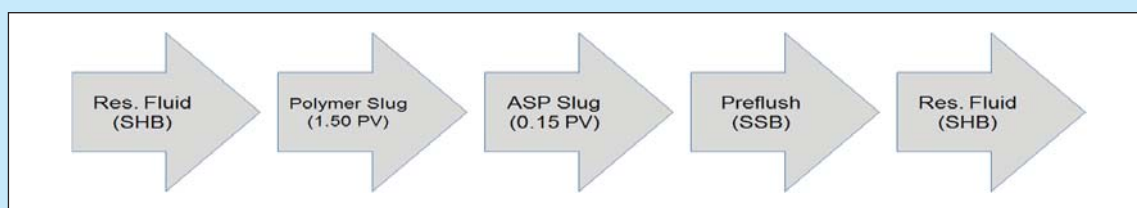| Physical Properties					Mineralogy			
Diameter cm	Length cm	Porosity %	PermeabilitymD	Pore Volume cc	Quartz weight %	Clay weight %	Feldspar weight %	Carbonate weight %
3.76	30.5	23.5	2615.11	79.63	94.4	2.7	2.4	0.5

Figure 1
Slug design of core flooding experiment.

III. RESULTS AND DISCUSSION

A. Viscosity of Polymer Slug

It is well known that the use of polymer slug in chemical flooding could be significantly increase the macroscopic or volumetric sweep efficiency refers to the effectiveness of the displacing fluids in contacting the reservoir in a volumetric sense by reducing the mobility ratio which is defined as the mobility of water devided by the mobility of oil. Thus, a large viscosity difference between water and oil causes a large unfavorable mobility ratio which promotes the fingering of water. It is therefore important to inject polymer in ASP flooding to obtain the maximum oil recovery.

Viscosity of PA used as chemical drive were described in the Figure 2. As can be seen, the viscosity of polymer in the presence of surfactant and alkaline lower than polymer alone at the same concentration. The viscosity of polymer at 1000 ppm reached about 9.10 cP, three times higher than ASP at the same concentration which only obtained 3.42 cP. The increasing amount of electrolyte from alkaline has a great effect to the viscosity of polymer associated with the presence of electrolytes that shield the mutual repulsion form carboxylic groups along the polymer skeleton, leading to the decreasing the hydrodynamic volume and ultimately lowering the solution viscosity (Francois et al. 1997). However, to attain piston-like drive mechanism for the effectiveness of chemical flooding, viscosity of ASP should be higher than oil and lower than polymer drive. Based on the oil viscosity 6.7 cP (Alli & Tobing 2016), ASP with twice higher viscosity 12.16 cP at 2200 ppm was selected for tertiary recovery process, then followed by a higher viscosity of polymer drive at 1300 ppm with 15.15 cP solution.

B. Filtration Ratio of Polymer Slug

Filtration ratio of polymer was investigated prior to the injection to make sure the flow of chemicals in the porous media. Polymer PA with 2200 ppm concentration was filtered through 3 μM

filter paper and recorded the time to collect the solution. The result at Figure 3 showed that the flow rate of polymer tends to be stable, indicated by the straight line of the graph between volume and time. However, to quantify the stability of polymer flow rate in the pore size, filtration ratio was calculated and found to be around 1.18, which is lower than upper limit F_R that identified at 1.20.

C. Microemulsion Flooding and Recovery

Standard core bentheimer was flooded with ASP which was expected to form microemulsion in the presence of oil and water in the porous media, followed by the tickening chemical polymer PA for increasing the volumetric sweep efficiency. Figure 4 shows the oil recovered with pore volume using
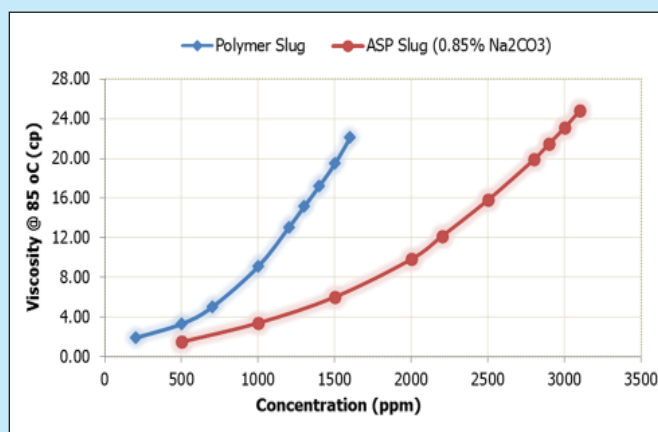
Figure 2
Viscosity of polymer in the presence and absence of alkaline, denoted as ASP slug and polymer slug, respectively.
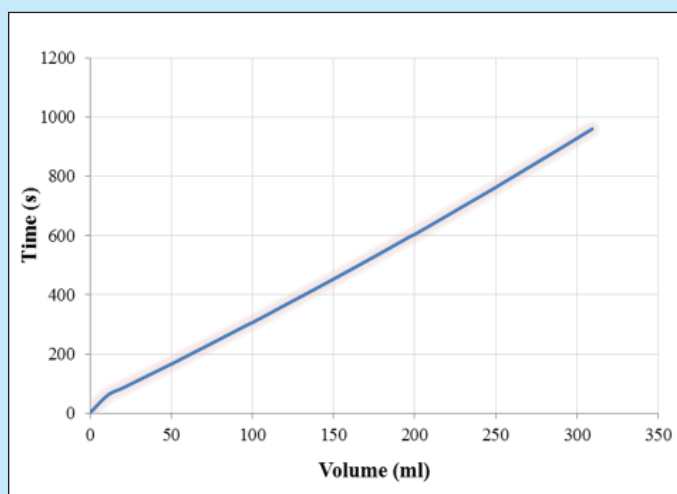
Figure 3
Filtration analysis of polymer "A" to calculate the F_R of chemical drive.

the slug design at Figure-1 of chemical injection. The injection was started by flooding the standard core with preflush SSB prior ASP injection for conditioning the salinity and hardness intereferences to the microemulsion formation.

The optimum formulation for creating microemulsion was obtained by mixing 2% surfactant with 0.65% Na_2CO_3. However, in order to encounter the difference salinity with brine and minimize the effect of dilution, a higher amount of Na_2CO_3 at 0.85% was added to the prepared-ASP along with 2200 ppm polymer. Standard core bentheimer was found to have 79.69 cc PV with water permeability 2615 mD and oil permeability 1668 mD. The Soi was calculated to be around 57.70 cc or 72.46% PV.

The total cumulative oil recovery in secondary and tertiary recoveries for microemulsion flooding with optimum aqueous phase formulation was presented in the Figure 4. The cumulative total oil recovery is the ratio of the produced oil to the Soi expressed as percentages. Recovery factor of oil is the multiple of displacement efficiency and volumetric efficiency (Ev), where Ev is the multiple of areal sweep efficiency and vertical sweep efficiency. The secondary oil recovery includes waterflooding, and the tertiary oil recovery includes the injection of microemulsion-formulation ASP, followed by polymer. The experimental results was consider the

displacemet efficiency, without volumetric recovery, which only applied to the reservoir through injection well or production well. It showed that 38.21% of the Soi was recovered after the secondary recovery with 0.7 PV water flooding. About 61.79% of the oil still remained in the bentheimer core after the initial water flooding. To recover the remaining oil, tertiary recovery was carried out. After the injection of 0.15 PV ASP, only slightly oil was recovered, whereas the result of polymer injection yield the highest oil recovery, could be recover about 93.41% of the remaining trapped oil after water flooding with the total cumulative oil recovery reached 95.93% of the Soi. The lower oil recovery by ASP flooding indicated that ASP injection works in the microscopic displacement efficiency that able to release the trapped oil, however, to moving out the oil to the core outlet, the injection of polymer as macroscopic displacement is required.

The studies of microemulsion flooding has been reported by Kumar et al. (2012) that using sodium dodecyl sulfate, propan-1-ol and heptane for producing microemulsion. After water flooding, 0.5 PV microemulsion slugs with 2 until 9% wt% brines were injected followed by 2.0 PV chasing water, resulting the additional oil recovery of oil over water flooding is in the range of 22.63 until 22.87% of OOIP (Kumar et al. 2012). Whereas in
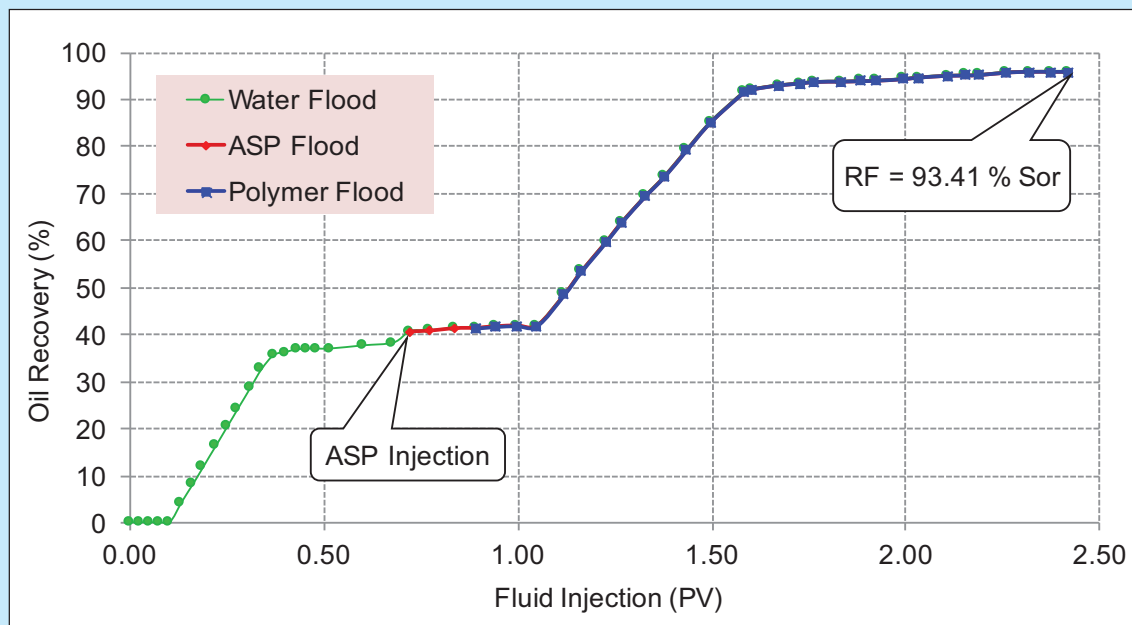

Figure 4
Cumulative total oil recovery in secondary (water flooding) and tertiary
(microemulsion and polymer flooding) recoveries.

the other recent study, the optimum formulation for generating microemulsion was consist of 3 wt% glyceryl monooleate and 1 wt% alkyl polyglycosides in 3 wt% NaCl brine. The injection of 1 PV microemulsion, followed by 1 PV polymer, and subsequent 1 PV water flooding can recover the oil around 66.8% of remaining oil after water flooding, thus yield the total oil recovery 87% of the Soi (Jeirani et al. 2013). Therefore, the relatively high total oil recovery suggests the effectiveness of the optimum microemulsion formulation for improving oil recovery.

Furthermore, based on the laboratory experiment results, the dynamic condition of reservoir can then be modelled in three dimensional geometry utilizing numeric reservoir simulator, which can be developed in pilot scale with the certain well injection-production path or in a full scale. It is therefore the performance of reservoir to achieve the maximum results with the economical consideration can be predicted.

IV. CONCLUSIONS

The formation of microemulsion for chemical flooding is crucial to achieve the optimum recovery factor of oil. Core flooding experiment result showed that the injection of microemulsion formula ASP around 0.15 PV, followed by the injection of polymer 1.5 PV were able to increase the oil recovery to the level of 93.41% Sor or 57.71% Soi. It is conclude that the formulation of chemical which generates microemulsion is proved to be effective to obtain the maximum oil recovery, and the dynamic condition of reservoir can also be simulated.

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