Surfactant Polymer Flooding EOR : Slug Scheme Affected Oil Recovery

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***Abstract*— Surfactant Polymer (SP) flooding is a chemical EOR method involves the injection of surfactants and polymer into the reservoir to enhance oil recovery. However, problem such as performance aggregation, adsorption and dissemination in porous media can be arises depend on the chemical involved. The effectiveness of industrial water treatment surfactant is studied as potential materials for EOR process alongside the conventional polymer while identifying the effect of different injection scheme of surfactant and polymer on oil recovery. Three different scheme implementing surfactant polymer flooding has been carried out. From BK80-XG formulation result, 0.3% of Sulfocat BK80 concentration and 400 ppm Xanthan Gum concentration is appear to be the optimum parameter for sandpack flooding experiment. The result of sandpack flooding shows that Sulfocat BK80 is a good potential material to be use in chemical EOR as it increase the performance of oil recovery and Scheme C which is soaking the sandpack with Sulfocat BK80 followed by Xantan Gum flooding is found to give the highest incremental of oil recovery compared to other schemes.**

Keywords*— *Surfactant polymer flooding, surfactant flooding Sulfocat BK80, Xanthan Gum, EOR.

I. Introduction

In oil and gas industry, oil production can be classified into three phases which are primary, secondary and tertiary (Enhanced Oil Recovery). Technically, the complexity of each stage is increasing than previous stage thus more expensive [1]. Primary oil recovery refers to the process of producing oil from an oil reservoir by natural drive of reservoir. The secondary oil recovery method refers to the gas or water injection in the reservoir adding energy to the natural system to helps displace the oil and forcing it to move towards the production well. Enhanced Oil Recovery (EOR) is the final option implemented after primary and secondary recovery to produce the total possible oil from an oil reservoir [2].

EOR process can be classified into three methods including thermal method, gas injection miscible and immiscible method, and chemical method [3]. Chemical flooding method is classified into a special group of EOR processes to produce residual oil which helps to free trapped oil in order to increase oil recovery after water flooding. Surfactant-polymer (SP) flooding is one of the chemical EOR methods that involve the injection of surfactants and polymer into the reservoir. This method is use to increase the sweep efficiency, thus improves the oil recovery. Usually, chemicals are injected with waterflood to improve the displacement efficiency. Surfactant is introduce to reduce the interfacial tension between the oil and water, while polymers help to improve the sweep efficiency and reduce water breakthrough [4].

In chemical EOR method, the problems arise from the surfactant and polymer itself. The interactions between polymer and surfactant can causes the lost of surfactant due to solubilization in oil phase or adsorption on rocks which can be unfavorable to the entire process [5]. In addition, due to the different properties involves in surfactant-polymer (SP) flooding, the mixture usually separate into two phases in a flow stream. Surface tension between rock-water interface will caused another issues that lead to loss of surfactant to reservoir rock by adsorption [5]. The incompatibility between surfactant and polymer will affect the nature of polymer that causes it to degrade. This includes the performance of aggregation, adsorption, and dissemination in porous media [5].

This research aims to study the effectiveness of industrial water treatment surfactant as potential materials for EOR process alongside the conventional polymer by performing a sandpack flooding with different surfactant-polymer (SP) flooding slug scheme. The effect of different injection scheme of surfactant and polymer was determined since it may affect the effectiveness of oil recovery. Sulfocat BK80 was chosen as the surfactant and Xanthan Gum as the polymer. Sandpack flooding experiment was conducted by using sandpack model and the three different slug schemes were considered.

II. Methodology

A. Materials

The materials used for this research are Sulfocat BK80, Xanthan Gum, paraffin oil and Sodium Chloride (NaCl). Sulfocat BK80 is a cationic surfactant that mainly being used in applications of water treatment, sugar industry, dairy and pulp industry, paper and pulp industry, and for general industrial usages. For this research, Sulfocat BK80 is used as a substitute of conventional surfactant. It comes in liquid form with density of 0.95 g/cm^3. The surfactant was purchased from Aarti Industries Limited (Surfactant Specialities Div). Xanthan Gum is a biopolymer comes with solid state of white free-flowing powder. Pure Xanthan Gum was purchased from R&M Chemicals and being used as polymer for this research. Sodium Chloride (NaCl) is used for brine preparation of sandpack flooding while paraffin oil is used as a constituent of crude oil. Both Sodium Chloride and paraffin oil were purchased from Sigma-Aldrich.

B. Sample Preparations

Brine solution was prepared for 20,000 ppm concentration. 20 g of NaCl was weighted and thoroughly mixed with 1 L of de-ionized water by using magnetic stirrer [6].

To prepare Sulfocat BK80 solutions, the Sulfocat BK80 was dissolved in 20000 ppm brine solution, stirred with magnetic stirrer until it completely dissolved. A varies of 0.1%, 0.2%, 0.3% and 0.4% Sulfocat BK80 concentration were prepared.

The same method was used to prepare Xanthan Gum solution. The Xanthan Gum was dissolved in 20000 ppm brine solution to get a different concentration of 200 ppm, 400 ppm, 600 ppm and 800 ppm. The polymer solutions were left mixed for about 24 hours to ensure the solutions completely dissolved.

Sixteen BK80-XG formulations were also prepared. For the first formulation (A), 0.1% Sulfocat BK80 and 200 ppm Xanthan Gum was dissolved in brine, and stirred properly with magnetic stirrer. The step was repeated for the rest of BK80-XG formulations. Table 1 shows the list of SP formulation considered.

Table 1 Sulfocat BK80-Xanthan Gum (SP) Formulation in Brine

Sulfocat BK80 (weight %)	Xanthan Gum concentration (ppm)/ Formulation No.			
0.0	200	400	600	800
0.1	A	B	C	D
0.2	E	F	G	H
0.3	I	J	K	L
0.4	M	N	O	P

C. Screening Procedures

The screening procedures were conducted to find the optimum parameter for the input for the flooding procedures. The paramaters including IFT, viscosity and density, shear rate measurement were conducted along with the solubilization test. Contact angle measurement was carried out by using video contact angle goniometer equipment from brand Anton Paar. The results from contact angle obtained were correlated with wettability alteration in the reservoir. Density measurement was conducted by using pycnometer while viscosity measurement was conducted at various shear rates by using rheometer from brand Anton Paar.

Solubilization test was conducted to examine the effectiveness of the surfactant on surfactant-polymer flooding system to get the optimum oil emulsification. The total of sixteen BK80-XG formulations mixed with paraffin oil and brine were prepared and placed into sixteen test tubes. The tubes were left for 7 days and were observed on which formulations produced a Winsor III behavior which forming a three phase microemulsions in order to use as optimum condition for SP flooding [7].

D. Flooding Procedures

The apparatus consists of syringe pump, syringe, pressure gauge, sandpack column and measuring cylinder to collect effluent samples. The apparatus set up is shown in Figure 1.

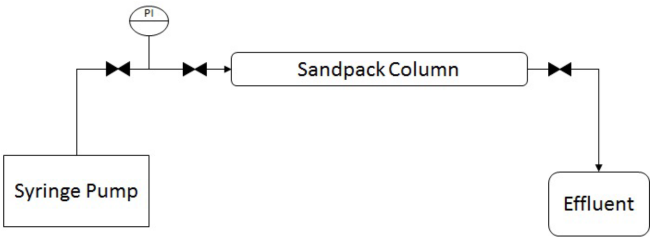

Figure 1 Sandpack Flooding Apparatus Set Up

Sandpack flooding tests was performed by (i) preparing a sandpack with grain sizes less than 300 µm using Digital Sieve equipment. The sands were packed in the holder and vibrated for about 1 hour until the sands is properly settled. (ii) The sandpack then was saturate with brine at flowrate of 5 ml/min. The pore volume and porosity were calculated. (iii) Paraffin oil was flooded in the sandpack to displace the brine with constant injection of 2 ml/min until the oil constantly produced as effluent. The initial oil saturation was calculated based on the volume of brine displaced. (iv) Water flooding was conducted by injecting 1.5 PV water at 0.5 ml/min. The residual oil saturation was calculated at this point. (v) After waterflooding, three different BK80-XG schemes were injected into the sandpack. For Scheme A, 0.5 PV of Sulfocat BK80 slug was injected into the sandpack followed by 0.5 PV of Xanthan Gum slug afterward. The injection of chemical slug was followed by an extended period of water flooding until the oil production become negligible [8]. For Scheme B, 0.5 PV of SP slug (mixture of Sulfocat BK80 and Xanthan Gum solution) was injected into the sandpack model. The effluent was collected continuously until the oil production become insufficient. Lastly for Scheme C, 0.5 PV of Sulfocat BK80 solutions were left to soak in the sandpack model for about 24 hours. Then 0.5 PV of Xanthan Gum slug was injected into the sandpack model. Again, the effluent will be collected continuously until the oil production become insufficient [9]. Table 2 below shows the procedures for each injection schemes used for this research.

Table 2 Procedures Description for Each Injection Scheme

Scheme	Procedure
A	0.5 PV Sulfocat BK80 slug → 0.5 PV Xanthan Gum slug
B	0.5 PV mixture of Sulfocat BK80-Xanthan Gum slug
C	0.5 PV Sulfocat BK80 slug (soak 24 hours) → 0.5 PV Xanthan Gum slug

III. RESULTS AND DISCUSSION

A. Phase Behavior Observation of SP Formulation

Phase behaviors of sixteen SP formulations were observed after leaving it at rest for 7 days. The red color indicates the paraffin oil while the clear one indicates the SP formulations. Figure 2 shows the phase behavior of different BK80-XG formulations in paraffin oil.

An optimum oil recovery can potentially achieved when Winsor Type III is formed in SP formulation. Winsor Type III is a condition where a three phase behavior formed, contains the surfactant added has the same amount as oil and water. This type indicates the lowest IFT which facilitates a better hydrocarbon recovery [10][11]. However, from the observation made, all of the SP formulations only formed a two phase behavior as shown in Figure 3. The two phase behavior formed is called as Winsor Type II. According to result obtained, it can be said that the surfactant is preferably solubilized in oil phase and form water-in-oil microemulsion due to high salinity [12][13].

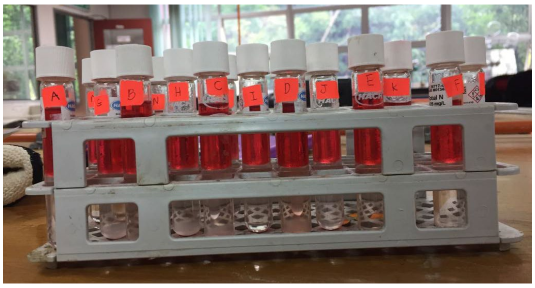

Figure 2 Phase Behavior of Sulfocat BK80-Xanthan Gum Formulation

Figure 3 Winsor Type II

B. Effect of Xanthan Gum and Sulfocat BK80 Concentration on Viscosity Measurement

Figure 4 shows the effect of Xanthan Gum concentration on viscosity measurement. The figure clearly shows that the viscosity of Xanthan Gum depends on its concentration. The viscosity increases as the Xanthan Gum concentration increases. The same behavior has been observed in a previous study which the viscosity of HPAM polymer increases linearly with polymer concentration [6]. This is why the polymer was used in oil recovery as the viscosity increment helps to control the mobility of water thus improved the sweep efficiency.

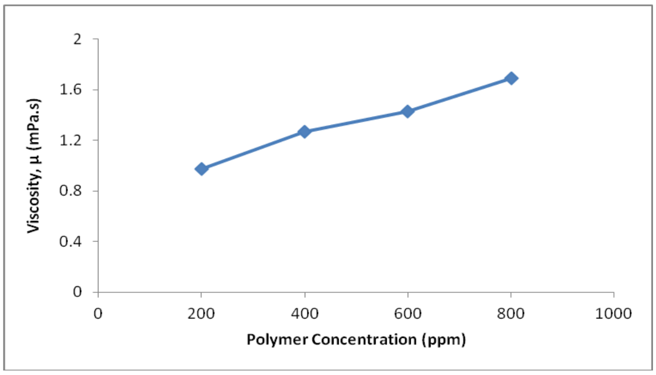

Figure 4 Effect of Xanthan Gum Concentration on Viscosity Measurement

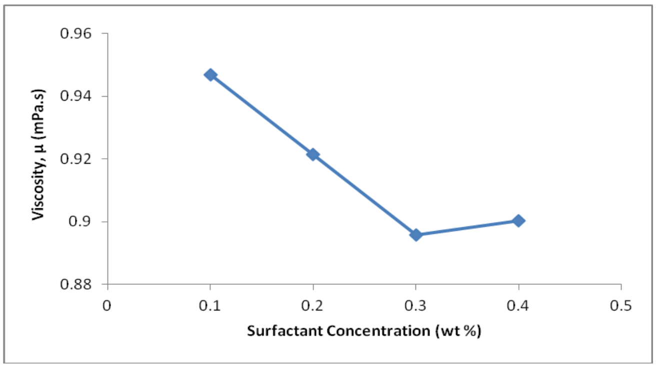

Figure 5 Effect of Sulfocat BK80 Concentration on Viscosity Measurement

Figure 5 shows the effect of Sulfocat BK80 concentration on solution viscosity. The graph shows that the viscosity is higher at lower surfactant concentration. The viscosity value decreases as the surfactant concentration increases up to 0.3% and increases slightly when reach 0.4% concentration. The trend obtained is different from previous study which typically, the increases of surfactant concentration increases the viscosity [14]. The reason of higher viscosity value is because of the suspended particles in the solution [15]. The different could be due to surfactant (Sulfocat BK80) used in this study is cationic type compared to surfactant used in previous study is anionic type. Since Sulfocat BK80 is a new material studied, the effect of surfactant concentration on viscosity measurement cannot be proved in this studied.

C. Effect of Xanthan Gum and Sulfocat BK80 Concentration on Wettability

Table 3 shows the results of contact angle measurement for different concentration of Sulfocat BK80 and Xanthan Gum respectively. The contact angle measurement was chosen to be done because it can be used to analyze the alteration of surface wettabilty.

Table 3 Contact Angle Measurement on Different Sulfocat BK80 Concentration

Sulfocat BK80 Concentration (wt. %)	ϴ (°)	ϴ (°)	ϴ (°)	Average ϴ (°)
0.1	18.10	24.20	21.20	21.17
0.2	14.80	21.00	17.30	17.70
0.3	12.00	14.20	15.10	13.77
0.4	10.90	17.40	15.10	14.47

Surfactant was used to alter the wettability from strongly oil-wet to water-wet in order to reduced capillary forces that retain oil in porous medium [16]. When the reservoir wettability changes to more water-wet state, it can easily assist to displaced the oil attached on the pore wall thus enhance the oil recovery [11].

The level of wettability can be described through high contact angle or lower contact angle. High contact angle (> 90°) value can be classified as oil-wet state while low contact angle (< 90°) value indicates a water-wet formation [16]. Reduction in contact angle means that wettability of the surface has altered the condition from less oil-wet to more water-wet [16]. From the result obtained, all Sulfocat BK80 concentration produced a low contact angle value which is less than 90° thus it has the ability to change the wettability of the surface from less oil-wet to more water-wet. However, Sulfocat BK80 concentration of 0.3% has the lowest contact angle compared to other concentration as shown in Figure 6, thus this concentration was chosen as the optimum surfactant value of SP flooding for oil displacement experiment.

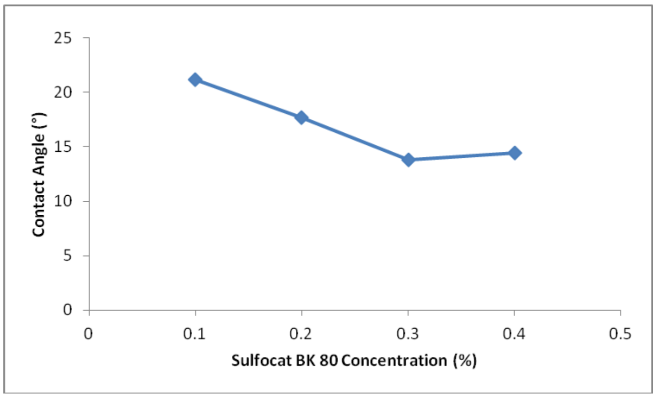

Figure 6 Effect of Sulfocat BK80 Concentration on Contact Angle Measurement

D. Effect of Shear Rates on SP Formulation Viscosity

Figure 7 illustrate the effect of shear rates on SP formulations viscosities. SP formulation shows a pseudo-plastic (shear thinning) behavior where the viscosity decreases at higher shear rates. The same trend also being proves from previous study conducted [6].

Higher shear rates resulting in reduction of viscosity due to molecular mechanism [6][17]. The random ground state will remains constant if very low shear rates applied to a solution up to some shear rate range. The shear rates reaches the critical value when the random ground state is being disturbed, thus the molecules arrange themselves in a way to present the least resistance to flow [6]. In reservoir condition, the viscosity degradation can be related with chemical, mechanical or thermal degradation during EOR flooding operations [18]. In this case, the degradation occurs due to the high shear rates or high velocity. The degradation of solution viscosity in field application will eventually decreases the efficiency of oil recovery. Thus it is important to maintain a reasonable viscosity of a solution to maximize the additional oil recovery.

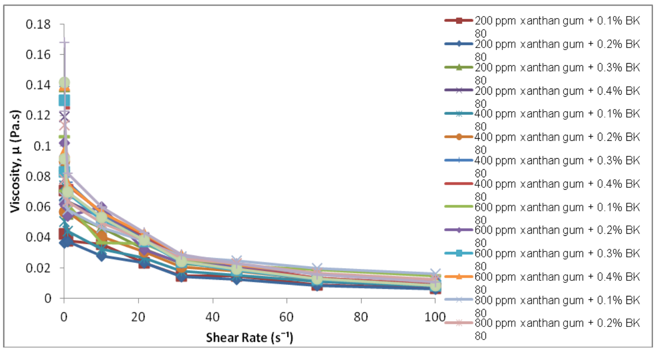

Figure 7 Effects of Shear Rates on SP Formulation

E. Effect of Sulfocat BK80 Concentration on Xanthan Gum Viscosity

Figure 8 shows the effect of Sulfocat BK80 concentration on Xanthan Gum viscosity. The different of viscosity trend can be observed at different Xanthan Gum concentration. From the graph, it shows that the viscosity of each polymer concentration does not produce a constant trend with increasing of surfactant concentration. For 200 ppm and 600 ppm Xanthan Gum concentration, the viscosity decreases at 0.2% surfactant concentration. For 400 ppm Xanthan Gum concentration, the viscosity starts to decreases at 0.4% surfactant concentration while for 800 ppm of Xanthan Gum concentration, the viscosity decreases at 0.3% surfactant concentration.

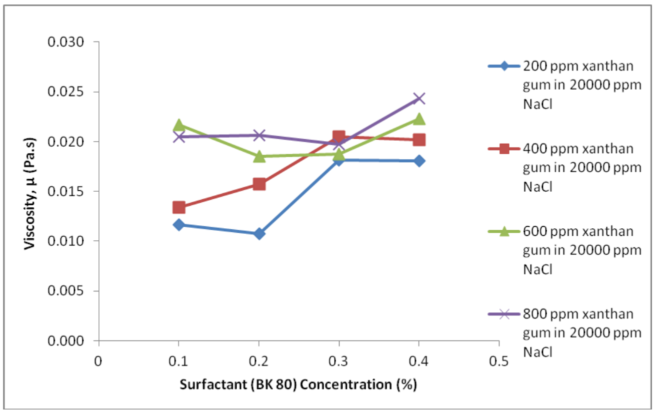

Figure 8 Effect of Sulfocat BK80 Concentration on Xanthan Gum Viscosity

Conversely, different result is obtained from a previous study of the effect of surfactant (AOS) concentration on polymer (HPAM) viscosity [6]. The study found that the viscosity decreases when the surfactant concentration increases for each different polymer concentration. The graph trend is constant for each polymer concentration. Another study also proved the same trend where the increasing of surfactant concentration makes the viscosity decreases at fixed polymer concentration. At very high shear rate, the viscosity is almost the same for all surfactant concentrations due to the dominance of the effect of shear in comparison to charge interactions [19]. The possible reason for the opposite result obtained is might be due to the different of surfactant used thus affected the result of the study and produced the different trend.

The optimum surfactant concentration has been chosen at the previous discussion which is 0.3% concentration. By comparing the result of each polymer concentration at 0.3% surfactant concentration obtained, the viscosity is the highest at 400 ppm polymer concentration. For 400 ppm polymer concentration, the graph clearly shown that the viscosity keep increasing with increasing of surfactant concentration and the viscosity reached the highest value at 0.3% surfactant concentration. Since the range of polymer concentration used for this study is not that high, the highest polymer concentrations could help to improve the mobility of oil displacement and increase the efficiency of oil recovery without clogging problem. Thus, 400 ppm of Xanthan Gum concentration was chosen to be use as the optimum concentration value of SP flooding for oil displacement experiment.

F. Effect of Slug Scheme on Oil Recovery

The optimum surfactant concentration of 0.3% and polymer concentration of 400 ppm that were selected during screening result previously was used in the surfactant polymer flooding (tertiary recovery) as an EOR method. The slug size of 0.5 PV was chosen for SP flooding after 1.5 PV of waterflooding (secondary recovery). Table 4 shows the summary of sandpack flooding result of three different schemes.

Table 4 Summary of Sandpack Flooding Result

Scheme	A	B	C
Pore volume (cc)	81.84	82.21	77.40
Porosity (%)	42.69	42.89	40.38
Initial oil saturation, Soi (%)	86.51	85.63	90.05
Initial water saturation, Swi (%)	13.49	14.37	9.95
Waterflood recovery (%)	57.06	59.09	55.09
Incremental oil recovery by SP flooding (%)	3.39	3.98	4.88
Total recovered oil in place, ROIP (%)	60.45	63.07	59.97

For the first sandpack flooding experiment, Scheme A, the Sulfocat BK80 and Xanthan Gum slug was injected consecutively after waterflooding. The first sandpack flooding has an initial oil saturation (Soi) of 86.51% and 57.06% was recovered by waterflooding. After SP flooding, an additional of 3.39% oil was recovered resulting in a total of 60.45% oil in place recovered as shown in Figure 9.

For Scheme B, Sulfocat BK80 and Xanthan Gum slug was co-injected in the sandpack after waterflooding. For this scheme, the oil that able to recover during waterflood was 59.09%. Another 3.98% of oil was recovered by SP flooding and the total recovered oil in place was 63.07%. The graph of oil in place recovered is shown in Figure 10.

In Scheme C, the surfactant was left soak for 24 hours the followed by polymer injection after waterflooding. 55.09% of oil was recovered during waterflooding. An additional oil recovery of 4.88% was done by SP flooding make a total of oil recovered to 59.97%. Figure 11 below illustrate the ROIP (%) versus pore volume injected for Scheme C.

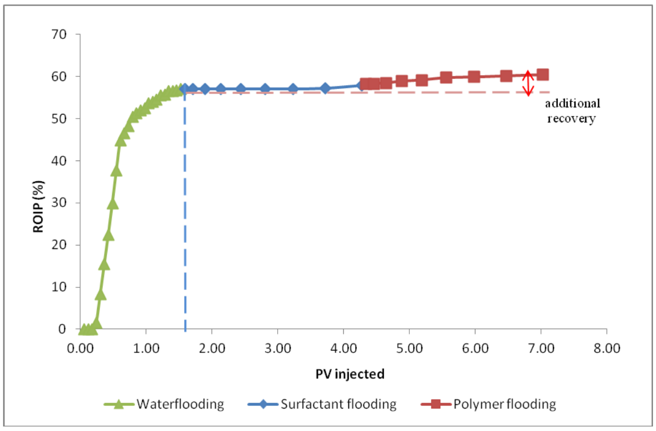

Figure 9 ROIP (%) versus PV Injected for Scheme A

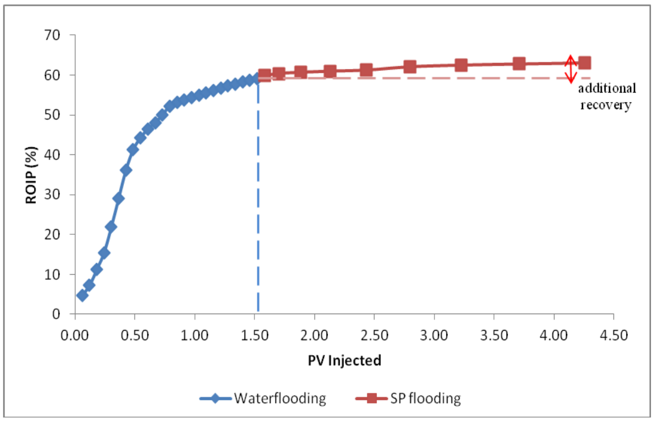

Figure 10 ROIP (%) versus PV Injected for Scheme B

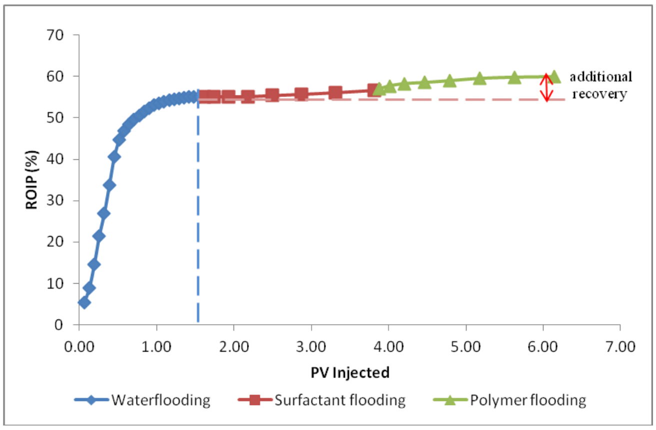

Figure 11 ROIP (%) versus PV Injected for Scheme C

From the result obtained, the total oil recovery for Scheme B is the highest compared to the other scheme. However, Scheme C has the highest additional oil recovery of 4.88% by SP flooding compared to Scheme B that has 3.98% oil recovery and Scheme A with the lowest recovery of 3.39%. Figure 12 shown the incremental of oil recovery by SP flooding after waterflooding. The graph clearly shown that Scheme C has the highest incremental of oil recovery followed by Scheme B and C. The high recovery of oil by waterflood in Scheme B was take into account as it effect on the high total recovery due to the high porosity compared to the other two scheme.

Comparing the three methods used, Scheme A and Scheme C were similar in terms of the slug flooding scheme. The only different is, in Scheme C, the Sulfocat BK80 slug was left soak for 24 hour in the sandpack in order to allow enough time for reducing the cappilary pressure to be mobilized easily by Xanthan Gum slug later. This is why the incremental oil recovery is higher than Scheme A and B.

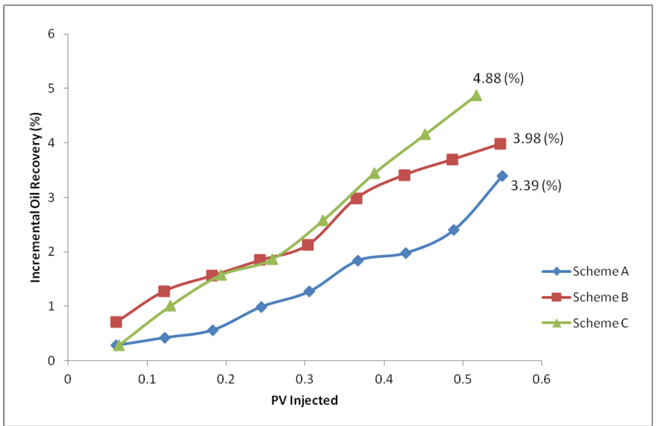

Figure 12 Incremental Oil Recovery by SP Flooding after Waterflooding

IV. Conclusion

The main objective of this experimental study is to study the effectiveness of industrial water treatment surfactant as potential materials for EOR process alongside the conventional polymer and to study the effect of different injection scheme of surfactant and polymer on oil recovery.

A series of flooding experiments have been conducted by using Sulfocat BK80 and Xanthan Gum slug to determine the additional oil recovery after waterflooding. Based on the results obtained, the following conclusion can be made:

1. Sulfocat BK80 can be a good potential material to be use in chemical EOR with a further study to prove the performance in increasing oil recovery.
2. Different slug scheme gives a different result on oil recovery. Scheme C is found to give the highest incremental oil recovery among the other schemes as it allow enough time for reducing the cappilary pressure to be mobilized easily by Xanthan Gum slug.

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References

[1] A. Abramova and V. O. Abramov, “Analysis of the Modern Methods for Enhanced Oil Recovery,” no. January, 2014.
[2] P. Zitha, R. Felder, D. Zornes, K. Brown, and K. Mohanty, “Increasing Hydrocarbon Recovery Factors,” 2008.
[3] R. Gharbi, A. Alajmi, and M. Algharaib, “The Potential of a Surfactant/Polymer Flood in a Middle Eastern Reservoir,” pp. 58–70, 2012.
[4] A. Samanta, K. Ojha, A. Sarkar, and A. Mandal, “Surfactant and Surfactant-Polymer Flooding for Enhanced Oil Recovery,” vol. 2, no. 1, pp. 13–18, 2011.
[5] P. Raffa, A. A. Broekhuis, and F. Picchioni, “Journal of Petroleum Science and Engineering Polymeric surfactants for enhanced oil recovery : A review,” vol. 145, pp. 723–733, 2016.
[6] A. Supee and A. Kamal, “Effects of Surfactant-Polymer Formulation and Salinities Variation Towards Oil Recovery,” pp. 4251–4260, 2014.
[7] R. Solatpour and S. Regina, “Alkaline-Surfactant-Polymer Flooding to Improve Heavy Oil Recovery,” 2015.
[8] Y. Du, G. Zhang, J. Ge, G. Li, and A. Feng, “Influence of Oil Viscosity on Alkaline Flooding for Enhanced Heavy Oil Recovery,” vol. 2013, 2013.
[9] U. Felix, T. O. Ayodele, and O. Olalekan, “Surfactant-Polymer Flooding Schemes (A Comparative Analysis),” 2015.
[10] P. D. Chauhan, “Data analysis and summary for surfactant-polymer flooding based on oil field projects and laboratory data,” 2014.
[11] C. Negin, S. Ali, and Q. Xie, “Most common surfactants employed in chemical enhanced oil recovery,” *Petroleum*, no. 2, pp. 197–211, 2017.
[12] A. Bera, K. Ojha, A. Mandal, and T. Kumar, “Colloids and Surfaces A : Physicochemical and Engineering Aspects Interfacial tension and phase behavior of surfactant-brine – oil system,” *Colloids Surfaces A Physicochem. Eng. Asp.*, vol. 383, no. 1–3, pp. 114–119, 2011.
[13] L. Quintero, G. Pietrangeli, J. Salager, and A. M. Forgiarini, “Optimization of Microemulsion Formulations with Linker Molecules SPE 165207 Optimization of Microemulsion Formulations with Linker Molecules,” no. June, 2013.
[14] W. Yanti, S. Kasmungin, R. Adawiyah, and B. Kolanus, “Laboratory study of salinity and surfactant concentration effects on oil recovery,” vol. 02008, 2017.
[15] R. Esteves, R. Esteves, N. Onukwuba, and B. Dikici, “Determination of Surfactant Solution Viscosities with a Rotational Viscometer Determination of Surfactant Solution Viscosities with a Rotational Viscometer,” vol. 1, no. January, 2016.
[16] M. Mohammed and T. Babadagli, “Wettability alteration : A comprehensive review of materials / methods and testing the selected ones on heavy-oil containing oil-wet systems,” *Adv. Colloid Interface Sci.*, vol. 220, pp. 54–77, 2015.
[17] C. Gao and D. Á. Power, “Viscosity of partially hydrolyzed polyacrylamide under shearing and heat,” pp. 203–206, 2013.
[18] A. Thomas, “Polymer Flooding,” 2016.
[19] I. A. Hussein and A. Sultan, “Rheological Study on ATBS-AM Copolymer-Surfactant System in High- Temperature and High-Salinity Environment Rheological Study on ATBS-AM Copolymer-Surfactant System in High- Temperature and High-Salinity Environment,” no. July, 2013.