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Scoring Method for Polymer Screening in Chemical EOR Application

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Abstract. Chemical Enhanced Oil Recovery (EOR) is one of the major methods by injecting selected chemicals to implemented reservoir. Types of commonly chemical are surfactant, polymer, alkaline. These chemicals are considerably used to enhance the oil displacement and volumetric efficiency through an extensive investigation into the applicability of EOR technology. In this research, polymer screening was conducted to select the best polymer in combination with a surfactant (Surfactant – Polymer/SP) formulation. The aim of this combined technique is to find the great potential to improve the remaining oil in L field and at high temperature of 107°C. salinity of brine L field was investigated at around 20,000 ppm. There are 4 stages in this polymer screening; pre-screening, pre-scoring, continues screening, and final scoring. Pre-screening consists of rheology, filtration test, screen factor, and thermal stability. Pre-scoring was conducted based on the result of pre-screening test. Continues screening consists of injectivity test, static adsorption, and dynamic adsorption test. Final scoring was performed after the result of continues screening. The experiment shows 6 polymer which were analyzed in the first stage: P1, P2, P3, P4, P5, and P6. The rheology of 6 polymers showed the viscosity decreased as the increasing shear rate were applied. In compatibility test, P2 were observed turbid over the time period of aging. Filtration ratio value for each of 6 polymers were performed <1.2. The screen factor test was measured with relatively range of 30 – 80. However, P6 had the highest screen factor value. The result of thermal stability test presented P1 had < 5% loss of polymer viscosity during 3 months aging. The second step of pre-scoring showed P1, P2, and P4 had passed to the next stage in continues screening with the highest value of 86.75%, 72.75%, and 74.5%. Furthermore, the injectivity test presented the resistance residual factor (RRF) of P1, P2, and P4 performed high adsorption value. However, the result of dynamic adsorption test presented P1 with the lowest value of 117 µg/g. The final scoring showed P1 was performed excellent result of 95% and thus to be preferred polymer for SP formulation.

Keyword(s): Enhanced oil recovery, chemical, polymer, screening, viscosity

1 Introduction

Chemical injection is one of general methods of EOR application by injecting selected chemical into the depleted reservoirs. The chemical which are generally used are surfactant, polymer, and alkali. Those chemical have the role of increasing both displacement and volumetric sweep efficiency, in order to optimum oil recovery from old oil fields.

On this study, polymer screening is conducted with scoring method with the purpose of selecting the best polymer which will be mixed with surfactant. Moreover, polymer will also be used as post flush in the SP chemical injection design at L field which has a relatively high reservoir temperature at 107°C with brine salinity formation at around 20,000 ppm. The use of polymer solutions in the application of chemical EOR injection technology have a role in increasing oil recovery effort by improving oil mobility in porous media (1). The addition of the polymer solution in surfactant-polymer (SP) chemical injection is expected to increase the viscosity value of the displacement fluid so that it can form a "piston like" effect with the aim of increasing volumetric sweep efficiency of the oil reservoir (2). The goal of this study is to select the best polymer for optimizing surfactant-polymer formula on the L field, in order to gain the optimal oil recovery on the field. There are 4 stages in this polymer screening; pre-screening, pre-scoring, continues screening, and final scoring. Pre-screening consists of compatibility test, rheology, filtration test, screen factor, and thermal stability. Pre-scoring was conducted based on the result of pre-screening test. Continues screening consists of injectivity test, static adsorption, and dynamic adsorpstion test. Final scoring was performed after the result of continues screening. Based on the final polymer scoring, polymer with the highest value of scoring will be chosen, where it will be used for surfactant-polymer (SP) formula optimization. The selected polymers are expected to be resistant to high-temperature L field reservoir conditions. In this study, polymer 2-acrylamido-2-methylpropane sulfonic acid (AMPS) with acrylamide monomers was widely implemented for chemical applications of EOR at high temperatures (3).

2 Research Metodology

2.1 Materials

The following materials were used are brine water, AMPS polymer which consists of 6 polymer samples; P1, P2, P3, P4, P5, and P6, crude oil, and native core samples. The reservoir characterizations of L field are shown in **Table 1**.

Table 1. Reservoir characterization of L Field

Parameters	Unit	Value
TDS of Brine Water	mg/L	20,000 - 21,400
Hardness of Brine Water (Ca & Mg)	mg/L	60 - 145
Oil Gravity	°API	24.8
Wax Content	%wt	11.95
Total Acid Number (TAN)	mg KOH/g	0.16
Oil Viscosity (Live Oil)	cP	1.1
Average Permeability	mD	9,171
Average Porosity	%	29.6
Hydrocarbon Composition	-	$C_{14}H_{30}$ - $C_{18}H_{38}$

2.2 Methodology

2.2.1 Pre-screening test

2.2.1.1 Compatibility test

The first approach of screening test is to see polymer candidate are compatible with 20,000 mg/L salinity brine in various concentrations of polymer. This test was carried out to observe the suitability of polymer which have the good performance to dissolve in brine with no precipitation and sediment as one of the criteria of EOR. The test is conducted on polymer concentration of 2500 ppm with aging method inside glove box. Intensive observation periods were carried out in sealed tube from day 0 to day 90 at reservoir (107°C) temperature.

2.2.1.2 Rheology

The test consists of a viscosity vs. concentration test, and a viscosity vs. shear rate test. The test was carried out on variations in polymer concentrations of 500 ppm, 1000 ppm, 1500 ppm, 2000 ppm, and 2500 ppm which were dissolved into L field brine. The viscosity vs concentration test aimed to determine the concentration with the optimal viscosity for the polymer as a mixture of surfactants (SP) and as a post flush while still considering economical aspect. Viscosity measurements were carried out using a capillary viscometer at a temperature of 107 °C and at a shear rate of 25, 50, 75, 100, 125, 150, 200, 250 and 500 s^{-1}. Then extrapolated to the shear rate to get the viscosity value at a shear rate of 10 s^{-1}. The viscosity vs shear rate test aims to ensure that the tested polymer samples are pseudoplatic fluid, which means the viscosity value of the fluid is decreased when its shear rate is increased. On this test, viscosity measurement is conducted at shear rates of 25, 50, 75, 100, 125, 150, 200, 250, and 500 s^{-1} at temperature of 107°C.

2.2.1.3 Filtration Test

The filtration test aims to determine the flow rate of polymer within porous media and to ensure no plugging. This test is conducted by passing through 120 ml polymer solution into a series of filtration devices equipped with 3 micron membrane paper and 2 bar pressure, where every 10 ml of filtrate that comes out of the equipment, its time will be recorded, then the data will be used for a volume vs time chart. It is expected that the graph formed is a straight line which shows that the flow rate is stable and does not indicate a blockage in the rock. In addition, another parameter is the value of the filtration ratio (FR) should not be more than 1.2.

2.2.1.4 Screen Factor

This test is conducted by passing 25 ml polymer solution through 4 layers of 100 mesh membrane on a series of screen factor equipments, where its flow time when it passes through two certain points will be recorded. Then this value will be compared with the taken time of injection water when it passes the same membrane. The higher the polymer screen factor value is, the slower its flow rate.

2.2.1.5 Thermal Stability

This test is conducted on six polymer samples with a concentration of 2500 ppm in L field injection water. Those polymer solutions are kept within glove box in anaerobic condition and at reservoir temperature for 3 months. Each sample is taken periodically, where its viscosity will be measured at shear rate of 10 s^{-1} and at temperature of 107°C.

2.2.2 Pre-scoring Polymer

Pre-scoring polymer is conducted based on the results of pre-screening test which has been done on 6 polymer sample types in order to obtain the value of each polymer. Three polymer samples with the highest scores were selected for the continues screening test.

2.2.3 Continues Screening Test

2.2.3.1 Static Adsorption Test

The polymer static adsorption test was carried out by submerging the native core grain of L field into polymer solution with certain concentration and under reservoir temperature conditions (107°C). This test is conducted to 3 polymer types which are chosen from pre-scoring polymer, which are P1 with concentration of 1000 ppm, P2 with concentration of 1500 ppm, and P4 with concentration of 1500 ppm. Total nitrogen detection method using a spectrophotometer and two-phase titration were carried out to measure the static adsorption value obtained from the effluent of the three polymer samples. The set adsorption value parameter limit is not to exceed 400 µg/g.

2.2.3.2 Dynamic Adsorption Test

This test is conducted with coreflooding equipment and done simultaneously with injectivity test. A certain amount polymer solution is injected into core plug at reservoir conditions (107°C), where the resulting effluent is collected into vial periodically. The next step is measuring the concentration of polymer which still exists inside the solution (the concentration that was not absorbed by the rock) with total nitrogen detection using spectrophotometer and two-phase titration methods. The adsorption limit value cannot exceed 400 µg/g. Three polymer samples which are tested to dynamic adsorption test are 1000 ppm P1, 1500 ppm P2, and 1500 ppm P4.

2.2.3.3 Injectivity Test

The injectivity test was carried out on the polymer to determine the possibility of plugging in the reservoir rock. The test is conducted to polymer P1 with concentration of 1000 ppm, polymer P2 with concentration of 1500 ppm, and polymer P4 with concentration of 1500 ppm. This test uses the same native core stacking with the one used on dynamic adsorption test. The test is conducted at temperature of 107°C, with injection rates of 0.3 cc/min, 0.6 cc/min, and 1 cc/min.

2.2.4 Final Polymer Scoring

This test is conducted based on the results of continues screening test on the previously chosen three types of polymer sample. Polymer with the highest score based on this test will be chosen for the optimization of surfactant polymer (SP) formula.

3 Result and Discussion

3.1 Pre-screening Test Result

3.1.1 Compatibility Test

The compatibility test of the six sample polymer types is conducted in aging condition inside glove box. The results of the test is shown that polymer P2 becomes cloudy after 90 days of aging, whereas the other polymer solutions are clear and have no precipitation.

3.1.2 Rheology

In the rheology test, the results of viscosity vs concentration test suggest that polymer viscosity should be equal to or exceeding oil viscosity at reservoir temperature and pressure, so mobility control problems can be avoided. L field has light crude oil and has a viscosity of 1.1 cP at reservoir conditions (107°C), so based on this it was decided to design an SP formulation with a viscosity of 2×µ (live oil) and postflush polymer 4×µ (live oil). Therefore a target viscosity of more than 2.2 cP was considered as the selected criteria for the SP formulation and 4.4 cP was considered for the postflush polymer. Based on the result of the rheology test of viscosity vs concentration, it can be seen that polymer P1 shows the highest viscosity values at the same concentration compared to other polymers. However, the final choice of polymer is determined after a series of polymer screening tests, while still considering economical aspects, such as cost and concentration needed for achieving the viscosity target. The results of the viscosity vs. shear rate test for all six polymer samples showed that viscosity values decrease as their shear rates increase, which shows that those samples are pseudoplatic fluids.

3.1.3 Filtration Test

Filtration test is conducted in order to discover the ability of polymer getting through porous media such as rock pores without causing plugging. Based on the results of the filtration test, it appears that all polymers have a stable flow rate with the FR value for the entire polymer sample also below 1.2 which means it meets the requirements as a chemical for EOR.

3.1.4 Screen Factor

Screen factor is an EOR chemical screening parameter which is carried out with the aim of characterizing polymer solutions based on the weight and molecular size of the polymer. The screen factor test is used to predict the ability of a polymer solution to form a flow resistance as it passes through a porous medium (6). These measurements related to the viscoelasticity properties of some synthetic polymer solutions such as polyacrylamide, and is heavily affected by the size of polymer molecule. The results of the screen factor test of the six polymer samples had almost the same screen factor values around 30 - 80 at concentration of 1000 - 3000 ppm, with the exception of P3 which has the highest screen factor value at around 100 - 150. This means that polymer P3 is far more difficult to flow inside porous media when compared to other samples.

3.1.5 Thermal Stability

Thermal stability test is conducted for 3 months at temperature of 107°C in order to find any chemical degradations on polymer molecule structures of the tested polymer samples. The results of the test are shown on **Figure 1**. As seen on the figure, each and every sample experiences different degradation values. The polymer sample with the lowest decrease of viscosity value (<5%) due to the polymer hydration process after it has been aged for 90 days is polymer P1. The conclusion of the results is polymer P1 is guaranteed to maintain enough viscosity without a significant decrease after it has been aged for 90 days at temperature of 107oC. Therefore, polymer P1 is the best candidate to choose as the polymer which will be used as formulation design.

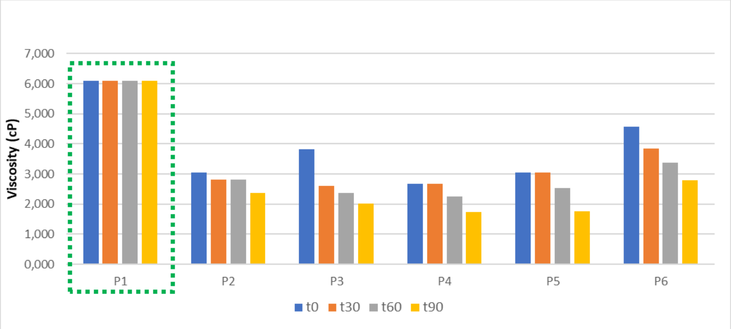

Figure 1. Thermal stability test graph of 6 polymer samples

3.2 Pre-scoring Polymer

The parameters for pre-scoring polymer are comprised of price, concentration, filtration ratio, screen factor, and thermal stability test results. The weighting of polymer scoring parameters is determined based on the conditions in the reservoir (temperature, brine salinity, rock and fluid characteristics) and fluid-to-fluid relationship between polymer to be injected and reservoir fluid characteristics. L field has relatively high reservoir temperature at 107°C. Therefore, the thermal degradation scoring parameter becomes the biggest critical point in the initial polymer scoring. The reason for that is the thermal stability of the polymer in the high temperature field is more difficult when compared to the low temperature field. Thereafter, the concentration becomes the scoring parameter with the second largest weighting (20%), because the smaller the target polymer concentration value, the more economical the polymer is to be applied to the reservoir. The result of pre-scoring polymer for 6 polymer samples are shown in **Table 2**. Based on these results, 3 candidate polymers with the highest scores were selected, namely P1, P2, and P4 for further polymer screening tests (continues screening test).

Table 2. Pre-scoring polymer test result

Parameters	Category	Score (%)	Percentage (%)	P1		P2		P3		P4		P5		P6	
				Test Result	Score	Test Result	Score	Test Result	Score	Test Result	Score	Test Result	Score	Test Result	Score
Price (US$/kg)	<3 3 - 4 4 - 5 >5	15	15 11,25 7,5 3,75	5	7,5	5	7,5	3,3	11,25	4	7,5	4	7,5	5	7,5
Concentration, (%)	≤ 0,15 0,15 - 0,2 0,2 - 0,3 0,3 - 0,5 > 0,5	20	20 16 12 8 4	0,1	20	0,15	20	0,1	20	0,15	20	0,15	20	0,1	20
FR	≤ 1,1 1,1 - 1,2 1,2 - 1,3 >1,3	15	15 11,25 7,5 3,75	1,19	11,25	1,157	11,25	1,051	15	1,017	15	1,032	15	1,114	11,25
Screen Factor	< 30 30 - 50 50 - 75 75 - 100 > 100	10	10 8 6 4 0	43,2	8	24,467	10	101,826	0	37	8	37,433	8	47	8
Thermal Degradation (%)	0 - 10 10 - 20 20 - 40 40 - 50 > 50	40	40 32 24 16 8	0	40	25	24	52	16	40	24	35	16	35	16
Total Score		100		86,75		72,75		66,5		62,25		74,5		62,75	

3.3 Continues Screening Test Result

3.3.1 Static Adsorption & Dynamic Adsorption Test

The results of static and dynamic adsorption tests of three selected polymer samples are shown in **Table 3**. As seen on the table, static adsorption values of the samples are around 1000 - 1500 µg/g. These values far exceed the required value of 400 µg/g. Meanwhile, in the dynamic adsorption test, it is known that the dynamic adsorption value of the three types of polymer samples has a relatively low value below 400 µg/g which means it meets the requirements as a chemical for EOR. From the tested samples, Polymer P1 has the lowest dynamic adsorption value of 117 µg/g, with low concentration value of 1000 ppm.

Tabel 3. Static and dynamic adsorption test result

Polymer	Concentration (ppm)	Adsorption (µg/g)	
		Static	Dynamic
P1	1000	1047	117
P2	1500	1693	178
P4	1500	1524	138

3.3.2 Injectivity Test

Injectivity test is conducted by using step-up rate schemes of 0.3, 0.6, and 1 cc/min for each concentration of polymer solution. The purpose of this test is to know the performance of polymer samples when they are injected to rock media. Based on the results of the injectivity test of the three types of polymers, the RRF values of polymers P1, P2, and P4 were 1.02, 1.15, and 1.1, respectively. This indicates that the permeability of the rock after polymer injection tends to not experience plugging due to the injection of polymer solution. Thus, it can be concluded that the three types of polymer samples passed the injectivity test.

3.4 Final Scoring

The final polymer scoring was then made to select the best one type of polymer with the highest value for further formulation with surfactants to determine the most optimal SP formula. The Parameters for this final scoring include pre-scoring value, static adsorption test results, dynamic adsorption test results, RF and RFF values (injectivity test results). Based on **Table 4**, it is known that polymer P1 has the highest value of 96.25%, followed by polymer P4 at 77.5% and at the bottom is polymer P2 at 71.25%. thus based on the results, polymer P1 is determined to be the best polymer which will be formulated with surfactant in order to obtain the optimal SP formula.

Table 4. Final scoring polymer test result

Parameters	Category	Score (%)	Percentage (%)	P1		P2		P4	
				Test Result	Score	Test Result	Score	Test Result	Score
Initial Scoring	> 80 75 - 80 70 - 75 < 70	70	70 52,5 35 17,5	86,75	70	72,75	52,5	74,5	52,5
RF	≤ 1,5 1,5 - 1,7 1,7 - 2 > 2	5	5 3,75 2,5 1,25	1,9	2,5	1,65	3,75	1,4	5
RFF	≤ 1,1 1,1 - 1,2 1,2 - 1,3 >1,3	10	10 7,5 5 2,5	1,02	10	1,15	7,5	1,1	10
Static Adsorption	≤ 400 400 - 1500 1500 - 2000 > 2000	5	5 3,75 2,5 1,25	1900	2,5	1693	2,5	1524	2,5
Dynamic Adsorption	≤ 125 125 - 150 150 - 400 > 400	10	10 7,5 5 2,5	117	10	178	5	138	7,5
Total Score		100		95		71,25		77,5	

4 Conclusion

Based on the results of entire test parameters which are comprised of initial polymer screening, initial polymer scoring, advanced polymer screening, and final polymer scoring, a conclusion is drawn, where polymer P1 fulfill the criteria to be chosen as the best polymer for the optimization of surfactant polymer (SP) formula. The optimal concentration value of polymer P1 is obtained from polymer screening and performance tests which have been conducted. Based on the results of the tests, the optimal concentration of polymer P1 is determined to be 1500 ppm, with viscosity value which are three times higher than oil viscosity of 1.1 cP. Therefore, polymer P1 has a good potential to be subjected to the next steps of coreflooding tests. From these result, the scoring polymer method can be applied to reservoir fields with a certain range of reservoir temperature and brine salinity. However, this scoring method has several limitations which are no standard value applied and it is still subjective because the weighting of the scoring parameters is based on reservoir field conditions (temperature, salinity, rock characteristics, fluid to fluid) and based on experience that has been done.

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