Examining the Performance of Palm-Oil-Based Surfactant in Increasing Oil Recovery Through Spontaneous Imbibition Test : A Case Study in Light Crude Oil

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Abstrak

Seiring dengan meningkatnya kebutuhan minyak dan produksi yang makin menurun setiap tahun,, kita dihadapkan pada tantangan untuk bisa memaksimalkan potensi sumber daya minyak yang kita miliki. Penurunan produksi yang terjadi di Indonesia sebagian besar umumnya disebabkan oleh kenyataan bahwa lapangan-lapangan minyak Indonesia yang masih beroperasi hingga sekarang adalah lapangan tua yang produksiya sudah sangat rendah. Enhanced Oil Recovery (EOR) adalah salah satu metode yang sudah terbukti mampu dalam memproduksikan minyak sisa disuatu lapangan. Salah satu jenisnya ialah Chemical Enhanced Oil Recovery (CEOR) yang menginjeksikan bahan kimia untuk dapat meningkatkan mobilitas minyak. Surfaktan merupakan bahan kimia yang telah banyak diaplikasikan untuk injeksi kimia. Kemampuannya dalam menurunkan tegangan antarmuka (IFT) dan mengubah kebasahan batuan merupakan mekanisme utama dari surfaktan. Dalam pengujian ini, surfaktan yang digunakan merupakan surfaktan berbasis kelapa sawit dan akan diaplikasikan pada minyak ringan. Pengujian seperti uji kompatibilitas, uji IFT, uji sudut kontak, dan uji imbibisi spontan dilaksanakan untuk bisa mendapatkan kesimpulan mengenai kinerja suatu surfaktan. Secara kompatibilitas, sampel pada studi ini semuanya membentuk larutan hazy (keruh) pada semua konsentrasi uji. Pengukuran IFT yang dilakukan menunjukkan bahwa surfaktan mampu mencapai nilai IFT 10^{-3} (ultralow pada konsentrasi 0.5%. Selain itu, berdasarkan uji sudut kontak , sampel surfaktan X 0.5% dan 0.3% mampu membentuk sudut kontak yang lebih kecil daripada brine. Untuk mengukur kinerja surfaktan dalam meningkatkan perolehan minyak, uji imbibisi spontan dilakukan dan hasilnya kedua sampel surfaktan X 0.3% dan X 0.5% mampu menghasilkan recovery factor sebesar 53.5% dan 54.2% yang nilainya lebih besar dibandingkan recovery factor brine yaitu 43.7%.

Kata kunci : *EOR surfaktan, recovery , spontaneous imbibition, light oil*

Abstract

Along with the increasing demand for oil and decreasing production every year, we are faced with the challenge of being able to maximize the potential of our oil resources. The decline in production in Indonesia is largely due to the fact that Indonesia's oil fields which are still operating today are mature fields whose production is already very low. Enhanced Oil Recovery (EOR) is one method that has been proven capable of producing residual oil in a field. One type is Chemical Enhanced Oil Recovery (CEOR) which injects chemicals to increase oil mobility. Surfactants are chemicals that have been widely applied for chemical injection. Its ability to reduce interfacial tension (IFT) and alter rock wettability is the main mechanism of surfactants. In this test, the surfactant used is a palm-based surfactant and will be applied to light oil. Tests such as compatibility test, IFT test, contact angle test, and spontaneous imbibition test were carried out to get a conclusion about the performance of a surfactant. In the compatibility test, the samples in this study all formed a hazy solution at all test concentrations. IFT measurements carried out showed that surfactants were able to achieve an IFT value of 10-3 (ultralow) at a concentration of 0.5%. In addition, based on the contact angle test, samples of surfactant X 0.5% and 0.3% were able to form a smaller contact angle than brine. To measure the performance of surfactant in increasing oil recovery, a spontaneous imbibition test was carried out and the results were that both samples of surfactant X 0.3% and X 0.5% were able to produce recovery factors of 53.5% and 54.2%, which were greater than the recovery factor of brine, which was 43.7%.

Keywords: EOR, surfactant, recovery, spontaneous imbibition, light oil

I. Introduction

With the consistent decline of national oil production and ever-increasing oil consumption, Indonesia is challenged to provide accessible and affordable energy. As a result, Indonesia has become net oil importer since 2003. This fact has forced Indonesia to discover solution in lowering our dependence on imported crude oil by maximizing our resources. Based on the report issued by Dewan Energi Nasional (DEN) 2019, crude oil still contributes to the total energy consumption with a percentage of 28.82%. Indonesia’s crude oil reserves faced a significant decrease from 8.21 billion barrels in 2008 to 3.8

billion barrels in 2019. The declining production of oil in Indonesia is also affected by the fact that most of the oil fields existing are mature or brown fields. Mature fields are oil fields that have been produced for a certain period. Declining production is the most distinctive characteristic of a mature field. Generally, an oil field can be categorized as a mature field if it has exceeded its economic limit (Babagdali, 2006).

The Government of Indonesia has set an ambitious goal to achieve 1 million barrels of oil production in 2030. There are four strategies made by our government to achieve its objective. Those four strategies are (1) maintaining production from existing fields; (2) accelerating the conversion of resources to production; (3) massive implementation of enhanced oil recovery (EOR); and (4) encouraging exploration to discover giant discoveries of oil and gas reserves. In this study, the author wants to focus on the third strategy of intensifying EOR applications to increase oil recovery. For an EOR project to be implemented in full-field scale, extensive research and study are needed to assess the performance of the EOR project starting from laboratory study to pilot project that sometimes can be extremely expensive and time-consuming.

Chemical Enhanced Oil Recovery (CEOR) is a type of EOR that utilizes the injection of certain types of chemicals to displace residual oil in a reservoir. In general, chemicals used in CEOR are surfactant, polymer, and alkaline. The injectants can consist of a single type of chemicals or a combination of them (SP or ASP for example). The polymer in chemical processes is injected to improve sweep efficiency (as a mobility control agent) (Sheng, 2015). Another type of chemical EOR is surfactant flooding which works with the principle of reducing IFT into ultra-low levels and altering the wettability state of reservoir rock (Sheng, 2015). The reduction of IFT in surfactant flooding will increase the capillary number that will contribute to the increase of oil mobility. In the alkaline process, alkaline is injected into the reservoir to generate in-situ surfactants and reduce surfactant and/or polymer adsorption (Sheng, 2015).

In this study, the author will focus on the implementation of natural-based surfactant in increasing the oil recovery through spontaneous imbibition test. Spontaneous imbibition is conducted to examine the ability of surfactant in recovering the residual oil in a static manner. The test is carried by replacing the saturation of wetting phase with non-wetting phase within the core. From this study, we can know the effectiveness of tested surfactant for potential application of enhanced oil recovery.

II. Metode

This study will be entirely based on laboratory studies. Preliminary screening tests such as compatibility test, IFT test, thermal stability test, and phase behavior test are conducted first to select the best formulation of surfactant that passes abovementioned tests. The selected formulations then will be brought to other tests which include contact angle test (wettability test) and spontaneous imbibition test. From these two tests, we can obtain the conclusion regarding the ability and performance of surfactant solution in lowering the interfacial tension and altering the wettability of oil-rock system.

The surfactant employed in this study is derived from natural resources which are palm oil. Thus, the surfactant used can be classified as natural-based surfactant. The author labeled the surfactant as surfactant X. In total, there were six surfactant formulations with six different surfactant concentrations. The six concentrations were 0.1%, 0.3%, 0.5%, 1%, 1.5%, and 2%. Those surfactants were mixed with reservoir brine. Complete list of surfactant samples can be seen in Table 1.

Table 1. List of Surfactant Solutions

No	Sample
1	Surfactant X 0.1% + Brine
2	Surfactant X 0.3% + Brine
3	Surfactant X 0.5% + Brine
4	Surfactant X 1% + Brine
5	Surfactant X 1.5% + Brine
6	Surfactant X 2% + Brine

III. Result and Discussion

3.1 Compatibility Test

Compatibility test is aimed to determine whether the surfactant is compatible with reservoir brine. The result of compatibility test can be an indication that the mixtures of surfactant with reservoir brine do not possibly precipitate or coagulate (Sugihardjo and Eni, 2014). The formation of precipitation is a sign that the surfactant solution has improper compatibility. In general, there are four different types of compatibility surfactant which are clear, cloudy, hazy, and precipitation (LEMIGAS, 2021). It is highly desirable, that the surfactant solution can have clear compatibility. Clear compatibility can be an indication that the possibility of blockage or plugging is low.

This test is carried out by observing the surfactant solution that is already put in the bottle. In this study, the compatibility of all samples is hazy. It is mainly because of the color of the surfactant itself which is brown. Table 2 and Figure 1 show us the complete result of compatibility test.

Table 2. Compatibility Test Results

No	Sample	Compatibility
1	Surfactant X 0.1% + Brine	Hazy
2	Surfactant X 0.3% + Brine	Hazy
3	Surfactant X 0.5% + Brine	Hazy
4	Surfactant X 1% + Brine	Hazy
5	Surfactant X 1.5% + Brine	Hazy
6	Surfactant X 2% + Brine	Hazy

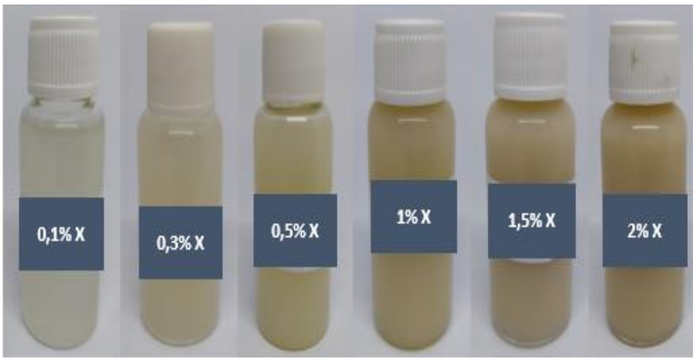

Figure 1. The Appearance of All Samples in Compatibility Test

3.2 Interfacial Tension Test

The main mechanism of surfactant in increasing oil recovery is by lowering the interfacial tension between oil and water. The common value of IFT between crude oil and water is in the range of 20-30 dynes/cm (Sagir et al., 2020). This high IFT causes the oil and water become like two immiscible phases. In surfactant flooding activity, it is highly required that the surfactant can reach ultralow IFT value (10^{-3}). To achieve such decrease, surfactant is implemented and injected to lower the IFT which has implications for the increase of capillary number. The higher the capillary number, the higher oil recovery will be.

In this study, the IFT between oil and water is measured using spinning drop tensiometer. This instrument is used because of its excellent ability in measuring the IFT in ultra-low level. The IFT of all six samples are measured carefully and the complete results are shown on Table 3. The concentration versus IFT is also plotted and depicted on Figure 2. This plot can be a helpful way to determine the Critical Micelle Concentration (CMC).

Table 3. IFT Test Results

No	Sample	IFT (dynes/cm)
1	Surfactant X 0.1% + Brine	2,30E-02
2	Surfactant X 0.3% + Brine	1,00E-02
3	Surfactant X 0.5% + Brine	6,40E-03
4	Surfactant X 1% + Brine	1,60E-02
5	Surfactant X 1.5% + Brine	1,00E-01
6	Surfactant X 2% + Brine	3,50E-01

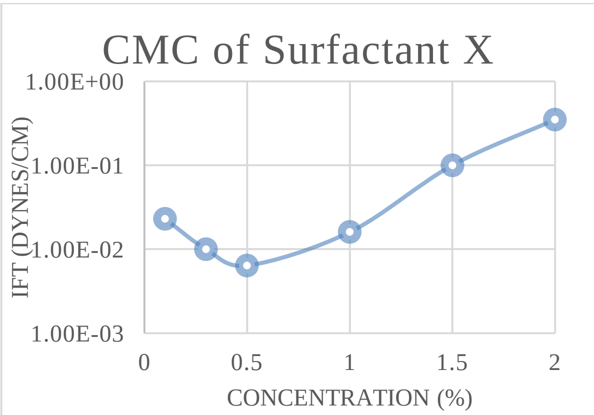

Figure 2. Plot of IFT vs Concentration

From the result presented previously, it can be seen that the surfactant samples could yield ultralow IFT at concentration of 0.5% (6,40E-03). It is also indicated that the addition concentration does not further lower the IFT. Thus, it can be said that 0.5% is the critical micelle concentration (CMC) of our surfactant. It means that at this concentration, micelles start to form itself (Sagir *et al*., 2020). This is the proof that the surfactant solution is able to perform its function as interfacial tension (IFT) reducing agent. This IFT reduction between oil and water will result in a near-miscible solution. This near-miscible behavior will be really helpful in mobilizing the residual oil because it can progress through the porous rock together and result in oil recovery increase

3.3 Wettability Test (Contact Angle Test)

The purpose of the wettability test is to determine the wettability of rock and to assess the tendency of surfactants to alter the wettability of rock samples. The presence of surfactants is expected to change the characteristics of the rock from "oil-wet" to "water-wet". With this change, the mobility of the oil will be easier, so it can increase the recovery factor. Here, the wettability state of the rock is determined by a contact angle test using a pendant drop tensiometer.

In this study, the contact angle of both rock-brine and rock-surfactant are measured. It is intended to investigate the decrease of contact angle. The contact angle is measured using pendant drop test method. There are only three fluids used here which are brine, sample 0.3%, and sample 0.5%. Brine is used here as the baseline in order to compare the contact angle reduction. The results of the contact angle test show that all surfactant samples have the ability to decrease the contact angle and turn the wettability into a more water-wet state. Table 4 below show us the result of contact angle measurement.

Table 4. Contact Angle Test Results

No	Fluid	Contact Angle	Contact Angle Difference
1	Brine	61.143°	-
2	0.3% X	57.045°	4.098°
3	0.5% X	54.104°	7.039°

3.4 Spontaneous Imbibition Test

Spontaneous imbibition test is a test conducted to examine the ability of surfactants to increase oil recovery under static conditions. Three displacing fluids were used as the displacing fluid in this spontaneous imbibition test, including brine, surfactant X 0.3%, and surfactant X 0.5%. Table 5, 6, and 7 show the complete record of spontaneous imbibition test of brine, X 0.3%, and X 0.5%, respectively.

Table 5. Results of Spontaneous Imbibition Test of Brine as The Displacing Fluid

Time (hrs)	Brine	
	Cum oil (cc)	RF (%)
0	0	0
1	0.1	1.1
2	0.3	3.3
3	1.3	14.2
4	2.5	27.3
5	3,3	36.1
6	3.4	37.2
7	3.6	39.3
8	4.0	43.7
9	4.0	43.7
10	4.0	43.7
11	4.0	43.7
12	4.0	43.7
24	4.0	43.7
36	4,0	43.7
48	4.0	43.7
72	4.0	43.7
96	4.0	43.7

Table 6. Results of Spontaneous Imbibition Test of Surfactant X 0.3% as the Displacing Fluid

Time (hrs)	X 0.3%	
	Cum oil (cc)	RF (%)
0	0	0
1	0.65	7.5
2	1.2	13.8
3	2.2	25.4
4	3.5	40.4
5	4	46.1
6	4.1	47.3
7	4.2	48.4
8	4.3	49.6
9	4.4	50.8
10	4.6	53.1
11	4.7	54.2
12	4.7	54.2
24	4.7	54.2
36	4.7	54.2
48	4.7	54.2
72	4.7	54.2
96	4.7	54.2

Table 7. Results of Spontaneous Imbibition Test of Surfactant X 0.5% as the Displacing Fluid

Time (hrs)	X 0.5%	
	Cum oil (cc)	RF (%)
0	0	0
1	0.4	4.4
2	1.5	16.4
3	2.7	29.5
4	3.8	41.5
5	4.5	49.2
6	4.8	52.5
7	4.9	53.5
8	4.9	53.5
9	4.9	53.5
10	4.9	53.5
11	4.9	53.5
12	4.9	53.5
24	4.9	53.5
36	4.9	53.5
48	4.9	53.5
72	4.9	53.5
96	4.9	53.5

After observing for 96 hours, Figure 3 below shows a plot between recovery factor and time. In this case, brine can be said as a baseline and can be used as a comparison to see how effective the surfactant is. For brine, the resulting RF value is 43.7%. As for the 0.3% surfactant X solution, the highest recovery factor value was obtained at 54.2%. Then, surfactant X 0.5% produces a smaller recovery factor (with a slight difference) compared to surfactant X 0.3%, which is 53.5%. This indicates that surfactant has the ability to increase X though the increase is not too significant.

IV. Conclusion

Based on the tests conducted, it can be concluded that the surfactant is able to yield ultralow IFT at a concentration 0.5% (the CMC). In addition, the surfactant solution could also lower the contact angle (alter the wettability). Lastly, the surfactant solution has proven its ability in increasing oil recovery through spontaneous imbibition test where sample X 0.3% has the highest recovery factor

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