Compatibility Test for Screening Surfactant Flooding

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Abstract. Surfactant flooding is one of the methods used in Enhanced Oil Recovery. The purpose of this study was to determine the suitability of a reservoir to the surfactant injection that will be carried out in that reservoir. Surfactants are used as a method to increase oil recovery because they are able to reduce the surface tension between the injecting fluid and the oil. Before selecting the surfactant material to be used, screening criteria must be done between the reservoir data and the surfactant. Reservoir data must match the requirements required for surfactant injection. After screening criteria, the next step is to test the compatibility of the surfactant fluid to the reservoir fluid. At this stage, it consists of a compatibility test, interfacial tension (IFT) test, and phase behavior test with the middle phase emulsion. Laboratory screening tests using test tubes, ovens and spinning drop. The fluids tested include the types of surfactants and crude samples. From the observations in this study, there are several results that can guide surfactant screening. Compatible surfactants are surfactants that clearly, form a middle phase emulsion and low IFT values. By conducting screening criteria, it can be concluded that the suitability of the reservoir represented by the crude oil sample against the surfactant that will be applied as the injection fluid.

1. Introduction
Petroleum industry in Indonesia is on a critical phase, where its oil production is not comparable to its annual oil reserve discovery. With the existence of this problem, there are numerous efforts implemented to help discover new oil reserves, one of which is the Enhanced Oil Recovery (EOR). EOR is an oil exploitation method utilized in the petroleum industry that can be defined as an optimization process on oil wells with condensed, heavy, poor permeability, and irregular fault lines natures, so it can be extracted and produced. EOR is one out of three commonly used oil exploitation methods in petroleum industry. Generally, the exploitation activity is divided into three phases which are primary, secondary, and tertiary phases. Primary phase happens when the field is being developed. When production level decrease similarly to reservoir pressure level, exploitation enters secondary phases where water or oil will be injected on oil reservoirs to push the oil towards production wells. After secondary phase, exploitation enters tertiary phase where EOR is implemented. There are several known EOR methods which are thermal recovery, gas miscible and chemical flooding. Thermal and gas miscible flooding methods is chosen to alter fluid’s characteristic, meanwhile chemical flooding is applied to alter fluids and rocks’ characteristics. The method focused in this article is chemical flooding, specifically surfactant. In surfactant injection, a test is required. In this
article, two tests on this method which are interfacial tension (IFT) and compatibility tests between formation water and injected surfactant will be elaborated.

2. Methods
Enhanced Oil Recovery is a common term that pictures a method to recover oil production from oil reservoirs after it finishes with primary and secondary phases [1]. On a simple way, the main goal of EOR method is to enhance volumetric sweeping efficiency (macroscopically) and to improve fluid movement efficiency (microscopically), which is different as water flood method [2]. Oil residual in the reservoir on production process that cannot be produced is between 60-70 percent of the original oil volume [3]. When natural enhancer (primary recovery) and secondary recovery are unable to pushes oil on the surface, an advanced level of oil recovery enhancement method, such as EOR, is required to produce the remaining oil.

One of commonly used EOR method is chemical injection by using surfactant [4]. Surfactant injection is a method to extract remaining oil in the reservoir by injecting an active compound in the reservoir to lower water-oil surface tension [5]. With the lowered surface tension, the capillary pressure on reservoir’s rock pores can be decreased so that oils trapped in the rock pores can be pushed and extracted. To optimally drain the remaining oil in a specific reservoir, a specific type of surfactant that is appropriate with the condition of formation water and the reservoir itself is vital. Nowadays, the commonly used surfactant in oil industry is a petroleum-based surfactant. The nature of petroleum-based surfactant cannot be optimally used on formation water with high salinity and temperature. Meanwhile the majority of oil refineries in Indonesia possess high salinity (up to 40,000 ppm) and temperature (60 – 1200 C) characteristics [6]. Surfactant (surface active agent) is an active compound designed to lower interface tension between oil and water due to its amphiphilic structure, which contains two clusters with different polarity on the same molecule [7]. Hydrophilic cluster is highly dissolvable on water meanwhile hydrophobic cluster is highly dissolvable on oil. Surfactants are commonly amphiphilic, which means that it is made of hydrocarbon chain containing hydrophobic cluster (tails) and hydrophilic cluster (heads). Because of that, they are highly dissolvable on organic and water solvents. Surfactant molecule can be visualized as a tadpole with head and tail. The head, which is the polar part is hydrophilic (prefer water), meanwhile the tail, which is the non-polar part is hydrophobic (prefer oil). The head can be cation or anion meanwhile the tail can be a linear chain or hydrocarbon branch [8]. Adhesion force of surfactant (cluster-R) on oil will lower cohesion force between RSO3 of the surfactant that lowers surface tension between oil and water, and free the oil out of its core [9].

This surfactant adsorbed or concentrated in the surface of fluids and alters the surface nature significantly, and especially lower interface tension (IFT) [11]. Anionic surfactant in EOR chemical injection is highly preferable because the show a relatively low adsorption on rock sand with a
negative surface charge. Non-ionic surfactant functioned as co-surfactant to correct phase behavior. Even though non-ionic surfactants are more tolerant on high salinity, most of them are unable to survive on high temperature. This causes higher IFT on high temperature condition. Anionic and non-ionic mixture is commonly used to improve tolerance against salinity. Cationic surfactant is rarely used on sand rock reservoir due to its high adsorption on sand rock. Cationic surfactant is more common on carbonate rock to alter wettability of oil wet into water wet. Zwitterion surfactant contains two active clusters. A zwitterion surfactant can be either anionic or non-ionic, depends on the media’s pH. This surfactant is highly tolerance to temperature and salinity, but the cost is relatively high.

Out of the available EOR methods, we have to determine which method is the most suitable with reservoir’s characteristic. The factors that needs to be accounted to choose EOR method are [11]; (1) depth, which is an important factor to determine EOR success both from technical or economical perspectives. From technical perspective, when the reservoir is shallow, injection pressure on the reservoir should be at low level because it is limited by fracture pressure; (2) slope, which has important when there is a significant mass density difference. If the pressure speed is high, the influence of slope is not significant. If water is used to push fluid, the lower lever tends to move faster; (3) reservoir heterogeneity, which determined by pore size non-uniformity level, stratigraphic/rock type, and continuity that is influenced by structure; (4) petro physic nature, which are porosity, permeability, effective permeability as saturation function (kro and krw), capillary pressure and wettability; (5) driving mechanism, which is highly important on EOR. For example when a reservoir possess a strong water drive mechanism), then water or chemical injections would not make any difference; (6) the remaining oil reserve, which possess a direct relationship with economic value of EOR implementation. The larger the reserve, the higher probability that EOR can produce profit; (7) Saturation of the remaining oil (Sor), which determines difficulty of driving or draining practiced by injection fluid. This situation is caused by two things which are oil draining will require an expensive method and the oil volume used to pay for it is getting lower; (8) oil viscosity, which in an unmixed driving, the factor that determine driving effectiveness is the ratio of driving fluid and driven oil, which is highly influenced by viscosity. Besides these factors, there are several parameters that need to be analyzed or accounted such as areal sweeping by water flooding before surfactant injection should not be more than 50%, the formation should be homogeneity, the compound should not contain too much anhydrite, phylum or clay and salinity that should be lower 20,000 ppm with divalent (Ca and Mg) ion content which should be lower than 500 ppm.

3. Result and Discussion
On this opportunity, we will discuss the compatibility between the utilized surfactant with formation water located in the reservoir, and the optimum concentration to be injected to the reservoir through injection well is also analyzed. Preliminary, a compatibility test was conducted on screening criteria and reservoir data. The following data shows compatibility test result with brine.

| Surfactant Concentration (%) | Brine Concentration (Ppm) | Information |
|-----------------------------|---------------------------|-------------|
|                             | 1000 | 2000 | 3000 | 4000 | 5000 |
| 0.1                         | clear | clear | clear | clear | clear | pass |
| 0.5                         | clear | clear | clear | clear | clear | pass |
| 1                           | clear | clear | clear | clear | clear | pass |
| 1.5                         | clear | clear | clear | clear | clear | pass |
| 2                           | clear | clear | clear | clear | clear | pass |

The goal of compatibility test is to acknowledge surfactant solubility with formation water. The solutions that pass this test are solutions with clear condition after it is being mixed. This test was conducted by mixing 0.6 ml of surfactant and 9.4 ml of formation water, and then the solution was set aside and observed for 3 days.
After the surfactant passes compatibility test, a phase behavior test was conducted to determine whether the surfactant will experience emulsification and create emulsion when it is mixed with oil. The emulsion will influence surface tension. On surfactant flooding, the expected emulsion is a middle or lower phase with a Winsor I type.

| Surfactant Concentration (%) | Winsor Type |
|-----------------------------|-------------|
| 0.1                         | -           |
| 0.5                         | I           |
| 1                           | I           |
| 1.5                         | I           |
| 2                           | II          |

The optimum formulation for chemical injection can be determined both minimum with interface tension measurement or with three phases behavior area test. Regarding desaturation cure, the lower the interface tension level, the lower the remaining oil saturation. Type III microemulsion based on Winsor classification is a condition where interface tension is at the lowest position if compared to type I and type II. This condition is also known as optimum salinity. Optimum salinity is highly influenced by chemical interaction between surfactant-oil and surfactant-water. Meanwhile regarding gradient salinity on surfactant injection design, the expected optimum salinity should be achieved to optimize oil recovery.

One of the most important considerations to choose surfactant type on EOR application is surfactant compatibility with formation water of a certain reservoir. Formation water collected from oil well contains a number of ions such as Ca$^{2+}$, Mg$^{2+}$, Fe$^{2+}$, CO$_3^{2-}$, SO$_4^{2-}$, and Cl$^-$
. The samples that pass aquades dissolving phase are made into surfactant and dissolved on formation water. After that, observation was conducted on a certain period of time for 3 days. Solution that passes compatibility test is a perfectly dissolved solution, clear solution, not a hazy solution and the one that does not contain sediment [12].

Surfactant-water-oil mixture phase behavior determination is an important factor to measure oil extraction level on surfactant injection process. Emulsification process can lower interface tension between driving fluid and oil. Basically, surfactant-water-oil mixture can form several types of emulsion, one of which can lower interface tension at a very low level with 10-2 until 10-4 dyne/cm order that is usable on chemical injection [13].
After that, interfacial tension test is conducted on every surfactant concentration level. The objective of this test is to determine optimum concentration in surfactant injection. Along with the escalation of surfactant concentration, IFT value will decrease and create a more effective oil driving. The recommended IFT value is at 10-3 dyne/cm. However, there is a limit where surfactant concentration is added but does not affect IFT value. This event is known as Critical Micellar Concentration (CMC). IFT test was conducted by using a spinning drop tensiometer. The following figure describes the IFT test result.

![Figure 3. IFT Curve with Surfactant Concentration](image)

Based on the data, we can conclude that the optimum concentration is at 0.6% with IFT value of 0.00025 dyne/cm. Interfacial tension is an important parameter to determine whether a type of surfactant is suitable as injection chemical. On this chemical flooding technique, IFT value should be very low (ultralow IFT), between 10-2 and 10-3 dyne/cm. The lower the interface tension of oil and water, the easier the extraction process of oil drops trapped on rock pores [14].

4. Conclusion

Based on the discussion in this research, we can conclude several points such as: before conducting compatibility and IFT tests, the reservoir data is measured through screening criteria and the result shows that this reservoir is suitable for surfactant injection. Compatibility test is conducted to determine whether the utilized surfactant is suitable with the brine in the reservoir. The objective of phase behavior test is to determine whether the surfactant can be associated with oil and create emulsion. A decent emulsion phase to conduct surfactant injection is a middle or lower phase, because it can decrease IFT value and reach critical micellar concentration level. Formation water and surfactant can be said as compatible when the mixture is clear and shows no sediment.

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