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Surfactant Flooding Performance Between Carbonate Reservoir and Sandstone Reservoir

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Abstract. High energy consumption must be balanced with an increase in oil reserves. One of them is to increase reserves from existing fields. So far, abundant oil production is still sourced from old or brownfields. This makes many oil companies still make efforts to increase their production on the brownfields. One of these efforts is implementing Enhanced Oil Recovery (EOR), intending to maximize recovery (RF) from the oil field. Enhanced Oil Recovery (EOR) can be categorized as a tertiary production stage to obtain oil in various types of reservoirs, especially heavy oil reservoirs. Around 60% of the world's oil reserves are in carbonate reservoirs, and the rest is sandstone and other lithologies. Therefore, it is crucial to know the characteristics of the reservoir to support the success of the EOR carried out. The stages of tertiary oil production are mainly carried out by chemical means. One widely used method in the field is surfactant injection or surfactant flooding. Surfactant flooding is an EOR method by injecting a surfactant-brine solution into a reservoir filled with oil that the previous step cannot wash away. Of course, surfactant injection carried out in both types of reservoirs will give different results considering the characteristics of each rock. The parameters examined were surfactant adsorption ability by both rocks, alteration of wettability after surfactant was injected, and recovery factor after injection. It was found that the surfactant adsorption on sandstone was low compared to carbonate rock; the wettability alteration was also more effective on sandstone compared to carbonate rock. So that from these two parameters, a higher recovery factor value is obtained in sandstone than carbonate rock reservoir.

INTRODUCTION

Fossil energy, known as fossil fuels (coal, oil, gas), has played a significant role in the energy world. In 2020, fossil fuels still supplied 84% of the world's primary energy, with oil accounting for 33% of all energy consumption [1]. The world's fossil energy consumption continues to increase from 53,147 TWh in 2018 to 53,303 TWh in 2019, and a slight decrease due to COVID-19 to 48,259 TWh in 2020. This must be balanced with the discovery of new oil reserves as well as increasing the acquisition of oil reserves from existing fields. Looking at Indonesia itself, SKK Migas (2019) states that 72% of oil production in Indonesia still comes from brownfields or old fields operating for more than 30 years. Since 2017 the rate of production has decreased quite drastically, reaching 29% per year for oil, and for natural gas itself, it has reached 18% per year.

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In addition, seeing Indonesia's reserves depleting from 8.21 MMSTB in 2008 to 3.8 MMSTB in 2019 should be an eye opener to continue to innovate increasing its production. This decline automatically encourages Indonesia to become an importer of petroleum even though this country is rich in oil. In fact, import dependency reached 35% in 2018 [3]. Indonesia's national oil and gas company, PT Pertamina (Persero), has taken strategic steps to secure upstream and downstream oil and gas businesses. Explicitly speaking, at the upstream part, the strategy installed was to increase production and add new oil and gas reserves, which was achieved by implementing Improved Oil Recovery (IOR) and Enhanced Oil Recovery (EOR) also carrying out a merger and acquisition (M&A) strategy for oil and gas blocks, carry out selective exploration, and restrain the natural decline in crude oil production by applying the latest technology [4].

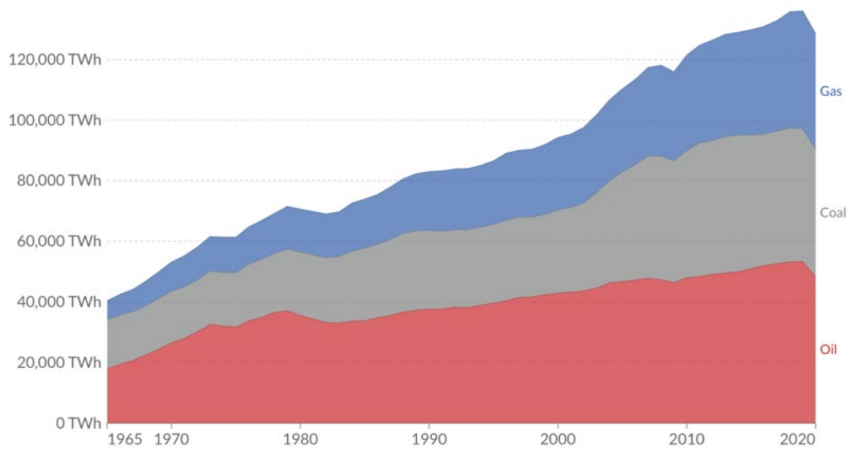

FIGURE 1. World Fossil Consumption Based On Its Type [5]

In the second stage of oil production, water flooding is commonly applied in many reservoir formations as an inexpensive and straightforward secondary method. The secondary production method uses fluid injection (gas, water, and gas water flooding) to add energy to produce oil. However, water flooding does not have sufficient oil production performance in the long term for reservoirs with heavy oil characteristics. This is mainly due to the unfavorable mobility ratio, which is generally because of the reservoir heterogeneity and the reservoir fluid characteristics [6]. Therefore, the Enhanced Oil Recovery (EOR) chemical technique is a part of the production plan as a tertiary production stage to obtain oil in various types of reservoirs for heavy oil. About 60% of the world's oil reserves are in carbonate reservoirs, and the rest is sandstone and other lithologies. This reservoir type is considered more heterogeneous than sandstone reservoirs, especially when considering porosity and dual permeability characteristics. This heterogeneity sometimes causes difficulties and low management efficiency in producing carbonate reservoirs. Therefore, the effectiveness of surfactant injection will be analyzed for these two types of reservoirs [7].

REVIEW OF LITERATURE

The tertiary recovery or Enhanced Oil Recovery (EOR) process includes all approaches used to obtain non-recoverable oil during the first two production phases. In several cases of reservoirs,

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such as high viscosity oil reservoirs or very low porosity reservoirs, they need tertiary auxiliary power to produce oil to the surface. Nearly all methods classified in these categories can be categorized into four major groups, namely thermal injection (TEOR or Thermal Enhanced Oil Recovery), chemical (CEOR or Chemical Enhanced Oil Recovery), microbial (MEOR or Microbial Enhanced Oil Recovery), and miscible [8], [9]. Chemical EOR or CEOR is a term used to describe the addition of chemicals into the water to be injected into the reservoir. In the process, the injection of these chemicals can alter the interfacial tension of water with oil (generally injection of surfactants and alkalis) and make the viscosity of water similar to oil (injection of polymers). Chemical EOR itself has been the choice for EOR since the mid-1960s [10]. CEOR method involves chemical injection, for example dissolved polymers, cross-linked polymers, surfactants, alkaline, and their combination. CEOR proves to enhance microscopic or macroscopic sweep efficiency and even altogether. For example, surfactants are often mixed with water in flooding stage to increase the microscopic sweep efficiency by forming an emulsion at the oil-water contact. This emulsion decreases interfacial tension and mobilizes oil in a considerable way. Surfactants also reduce capillary forces and change the contact angle [11]–[13]. It was stated by Druetta & Picchioni (2020) that the surfactant has hydrophilic and lipophilic parts which make it beneficial when used in immiscible and multiphase environments. The hydrophobic tail appears in a form of branched hydrocarbon; fluorocarbon; straight chain made up of 8–18 carbon atoms, and the hydrophilic head is grouped into cationic, anionic, non-ionic, amphoteric, or zwitterionic [15]. Surfactant flooding is done by injecting chemical slug (surfactant and co-surfactant slug) into the reservoir and later replaced by aqueous phase slugs or, sometimes, polymer banks that are replaced by water. The main goal when performing surfactant injection is to achieve low interfacial tension using a low surfactant concentration and low adsorption rate on the rock formations. So far, in its implementation, surfactant injection has been applied to all types of reservoirs, both sandstone and carbonate [14], [16].

Looking at the reservoir, there are two most common reservoir, which are carbonate reservoir and sandstone reservoir. Carbonate rock and sandstone have different contents and characteristics, so it is necessary to have an overview of the petrophysical properties and rock composition to perform surfactant injection effectively and efficiently. Carbonate reservoirs have several specific characteristics that pose tricky reservoir characterization, exploitation, and control challenges. Those characteristics are complex textures and pores formed by deposition and diagenesis. Carbonates heterogeneousness can be present in pores, grain, and texture at all scales. The porosity of carbonate rocks is classified into connected porosity, in which the porosity formed in-between carbonate grains; vugs, porosity in the form of non-connected pores formed by calcite dissolution during the formation of rock; and fracture porosity which is formed by stress after deposition. Diagenesis can construct stylolite structures that embody horizontal flow barriers that dramatically affect-field performance. In addition, fractures are able to cause water breakthroughs, gas coning, and heavy mud loss also stuck pipes. The existence of these three forms of porosity will create a very complex path for fluids and directly affect the well's productivity. Apart from porosity variations, wettability is another heterogeneous characteristic in carbonates. Thus, given the complex structure, formation heterogeneity, oil-wet or mixed-wet conditions, and other factors, carbonate reservoirs' oil recovery is deficient, perhaps under 35% on average, and below sandstone reservoirs [17], [18]. The type of carbonate rock that generally has oil reserves and is often used for core flooding experiments is limestone. Limestone has clean coarse oolitic grains (oosparite), including some bivalves, and is made of different minerals calcite (more than 99% - primary calcite

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forms ooids and debris, secondary euhedral calcite is deposited to porosity during burial). Limestone has a dual-porosity balanced between micro-pores (between 0.1 and 0.7 m) and intergranular macro-pores (between 10 and 20 m) [19].

Meanwhile, silica, feldspar, clay minerals (typically illite, kaolinite, montmorillonite, and chlorite), carbonates as cementing agents, and iron oxides make up sandstone formations. Because silica (SiO2) minerals are negatively charged for pH values over 3 and have a poor surface area, they are not a preferred adsorption site for anionic surfactants in sandstones. Finely scattered clay particles, on the other hand, have a significantly larger surface area and can be positively charged at the margins, making them suitable anionic surfactant adsorption sites [20]. The existence of this charged surface is a key component in causing changes in reservoir rock wettability. Later, it will play a role in selecting surfactants [21]. Sandstone reservoirs are generally also homogeneous, so they are suitable for CEOR. In addition, reservoir rocks generally have characteristics that must be possessed, namely large porosity values. Rocks that have such characteristics are sandstones. That is why sandstones are usually targeted as a reservoir [22]. The type of porosity possessed by most sandstones is primary porosity, but in sandstones deposited at a reasonably deep depth, the dominant type of porosity tends to be secondary porosity in the presence of dissolved feldspar grains. In addition, the porosity can also be caused by fractures. This fracture can be a critical factor in tight gas sandstone reservoirs. In addition, the detrital mineralogy is also more complex, so the iron content may be high. Although it has good characteristics, fines migration is a problem that often occurs in sandstone formations due to clay and feldspar [23].

METHODOLOGY

This research on Surfactant Flooding Performance Between Carbonate Rock Reservoir and Sandstone Reservoir was conducted using secondary data. The secondary data are articles and research related to the application of surfactant flooding in carbonate and sandstone reservoirs for the past ten years. All articles and data obtained are screening results from several predetermined criteria obtained from Google Scholar, Science Direct, Elsevier, and Springer. Furthermore, articles originating from valid sources and scientific journals are completed into a paper.

DISCUSSION

On this paper, there will be three parameters that will be analyzed further. The parameters analyzed were surfactant adsorption ability by rocks, alteration of wettability after surfactant was injected, and recovery factor after injection.

Surfactant Adsorption Ability by Rock

Surfactant adsorption on reservoir rocks can lower surfactant concentrations in injected solutions, reducing its effectiveness in reducing oil-water interfacial tension (IFT). As a result, it will reduce the effectiveness of surfactant-based EOR in mobilizing stored oil, making it economically ineffective [24]. Later, the type of surfactant will affect the adsorption of surfactants on carbonate rocks and sandstones. In comparison to sandstone reservoirs, anionic surfactants are highly adsorbed on carbonate reservoirs. Then, cationic surfactants usage in carbonate rocks has a better effect (less adsorption), and conversely, the adsorption of surfactants is more significant in sandstone reservoirs, so cationic surfactants are not suitable if used in sandstone reservoirs.

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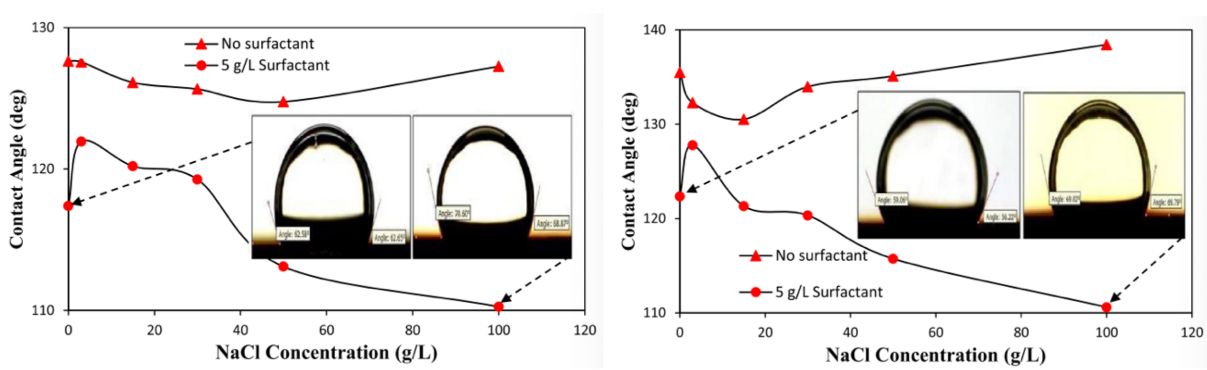
Identically, in charged reservoir rocks that uses zwitterionic surfactants, undergoes adsorption caused between the charges on the rock surface and the inversely charged groups against the hydrophilic head that forms by the electrostatic force. Nevertheless, electrostatic repulsion can happen when the same polarity of the charged groups meets the surface charge of the adsorbent. If one surfactant molecule has an opposite force, it can cause differences in the position of the adsorbed surfactant molecules on the rock surface. Sandstones with negative charge will attract ammonium group with positive charge and repulse carboxylic group of the surfactant with negative charge. Consequently, the zwitterionic surfactant adsorbed will make a 'V'-shaped molecular structure from the sandstone surface.

To the contrary, the positively charged carbonate surface attracts the negatively charged carboxylate groups from the surfactant and repels the positively charged ammonium groups. Hence, the zwitterionic surfactant is adsorbed on the carbonate surface in a vertical 'I' shaped molecular orientation. So overall, this experiment shows that surfactant adsorption is higher in carbonate rock reservoirs than sandstones [21], [24]. It was found that the absorption or adsorption of surfactants in both rock types will increase along with the high level of salinity [15], [25], [26].

Alteration Wettability of Rock

Conducted studies show that brine composition, crude oil polar components, surface roughness, reservoir temperature, and minerals in rock all influence wettability in reservoir rock [12]. In wettability changes, related to the adsorption of surfactants, alteration from oil-wet to neutral-wet or water-wet can occur, which is indicated by a reduction in the contact angle. Interactivity of NaCl ions and minerals in the two types of rocks is one of the reasons why NaCl concentration affects brine. The increasing concentration of NaCl will increase ionic bonds, providing enough capability to set apart water from the crystal surface [15]. This is proven by experiments conducted by [15], where the contact angle of the sandstone core slowly decreases from 127.63° to 124.73°. The carbonate rock showed a faster decrease with a decrease of 5° after injection of about 5g/L surfactant in the core sample.



(a) (b)

FIGURE 2. Contact Angle Respective to NaCl Concentration with And Without Surfactant on CMC

(a) sandstone core (b) carbonate core [15]

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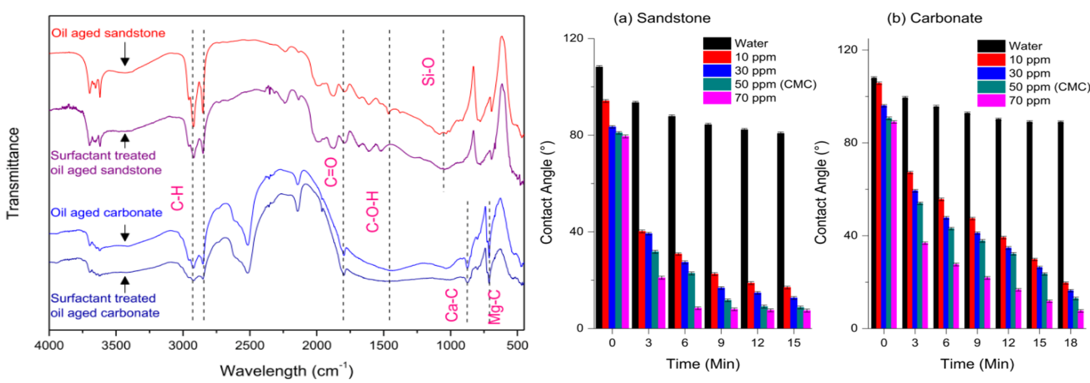
Further research was carried out by Kumar & Mandal (2019), on the alteration of wettability using FTIR spectra. Based on Figure 3 (a), it can be seen that in the early stages, oil saturation was carried out on the cores of both rock types. The FTIR spectra of the sample after surfactant flooding revealed a peak that corresponded to the C-H bond and the C=O bond, yet the peak that indicated the C-O-H bond was missing. The loss of the C-O-H peak indicates the desorption of the previously adsorbed crude oil component. Whereas the carboxylate group of the surfactant and carbon chain cause the C-H and C=O bond peaks. As seen in the figure, crude oil molecules that was adsorbed before having been replaced by the surfactant molecules and a change of wettability to water-wet is detected. Looking at Figure 3 (b), the sandstone and carbonate samples were initially oil-wet before surfactant injection because the contact angle decreased from 110° to 70° in 15 minutes intervals. Furthermore, 15 minutes after surfactant injection, the contact angle was lowered by roughly 15°. The decline in contact angle indicates that the surfactant has had a considerable impact on the rock sample's wettability. This decrease happens because a formation of ion pairs between the surfactant molecules' hydrophilic heads and the adsorbed oil's charged components. One thing to be concerned is irreversible desorption can happen when ion pairs are created from surfactant molecules and crude oil. Hence, with such escalation in the concentration of surfactant, it will be followed with a rise in crude oil desorption and cause substantial water wetting of the sample. It is also visible in the figure wherein the contact angle obtained after 15 minutes decreased with increasing surfactant concentration. It can be stated that the reduction in the contact angle is more effective on sandstones when compared to carbonate rocks [21].



(a) (b)

FIGURE 3. (a) FTIR Spectra Reading (b) Contact Angle on Sandstone and Carbonate Rock Based on Time [21]

Recovery Factor After Injection

Injection of surfactants can help increase oil extraction percentage by lowering the interfacial tension, altering wettability, also forming water-oil emulsions, which will ultimately increase sweeping efficiency [15]. In their experiment, Khayati et al. (2020) performed surfactant injection after waterflooding on two types of samples with sandstone and carbonate lithology. Figure 4 compares the total pore volume injected by water followed by surfactant with the total oil recovery. Waterflooding achieved ultimate oil recovery of 45.75 percent OOIP for sandstone and 50.81 percent OOIP for carbonate rock. Afterwards surfactant pooling was done on both cores in a continuous manner. The results shown an oil increase to 54.15 percent for sandstone and 57.04

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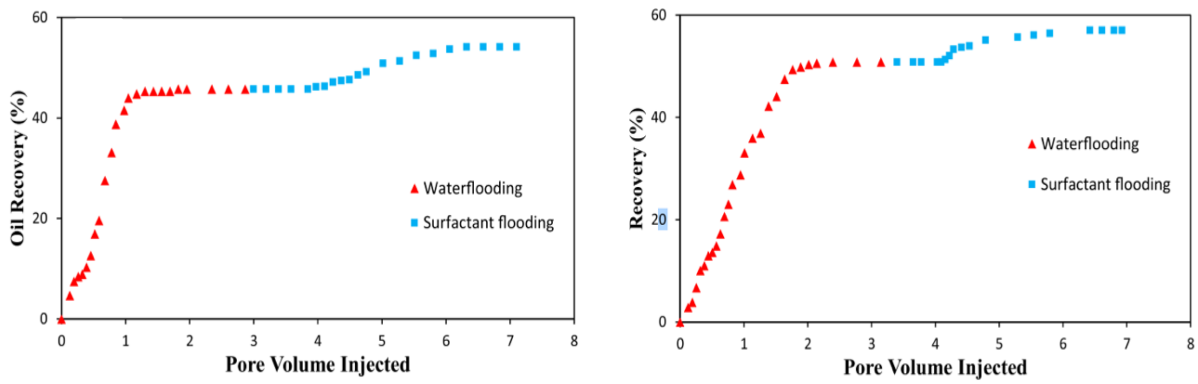
percent for carbonate rock. As a result, surfactant injection boosted oil recovery by 8.4 percent for sandstone cores and 6.23 percent for carbonate cores. Surfactants can maximally boost oil recovery in sandstone oil reservoirs, according to the results of the core flood experiment.



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(a) (b)

FIGURE 4. Oil Recovery (%) Respective to Pore Volume Injected When Waterflooding and Surfactant Flooding (a) Sandstone Core (b) Carbonate Core [15]

Furthermore, there is an experiment conducted by [21] which also predicts the success of total oil sweeping in the end which is expressed in oil recovery. The initial and final conditions of the two types of cores can be seen in Table 1.

TABLE 1. Property and Imbibition From Core Samples [21]

Type of Core	Porosity (%)	Permeability (mD)	Initial Oil Saturation (%)	Oil Recovery (% OOIP)	
				Brine	Surfactant
Sandstone	20.40	218	76.49	0	18.95
Carbonate	22.69	7	66.26	0	3.09

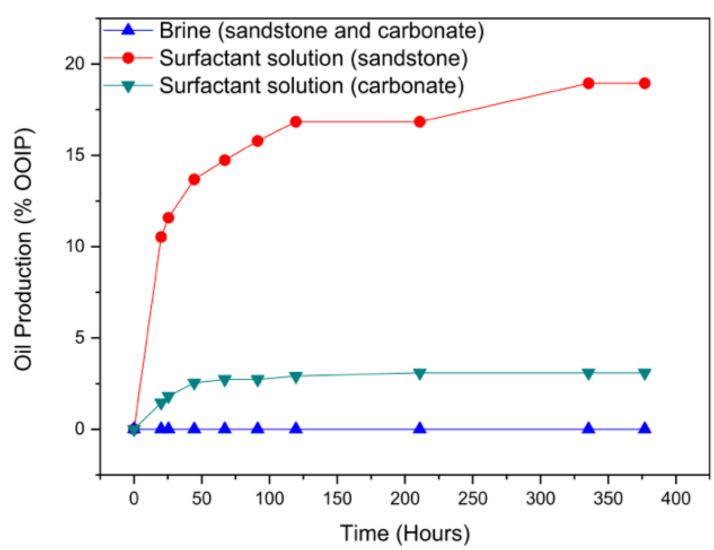

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FIGURE 5. Oil Production (% OOIP) Respective to Time With Brine Imbibition and Surfactant Solution on Sandstone Core and Carbonate Core [21]

It is apparent from Figure 5 that the oil was not successfully removed from the sample when treated with imbibition in the form of brine. However, when the surfactant was acting as the imbibition fluid, 18.95 percennt OOIP was obtained for sandstone sample and 3.09 percent OOIP was for carbonate samples. The recovery of oil done by imbibing surfactant into the samples is influenced by the synergism of the decreasing of interfacial tension also wettability alteration by surfactants. In addition, it leads to the conclusion that sandstone sample has higher recovery percentage than carbonate sample. This is caused by the vugs' existence that trap oil in large pores or vugs. Crude oil transfer under this condition is rather a tricky process because capillary forces dominate the flow. As a result, oil recovery at the final stage of imbibition showed a low value of the carbonate sample. But a high value of porosity is not a guarantee that there will be a great permeability condition in the rock. Carbonate sample described to have a low permeability in comparison to sandstone sample. Low permeability is also one of the crucial factors effecting the smaller percentage in oil recovery. This low permeability causes lower mobility and, of course, a small oil recovery value compared to oil recovery from sandstone cores with higher permeability. From the graph, when comparing the recovery with the brine solution, the surfactant solution imbibition has a higher oil production (% OOIP). This indicates the change in wettability of the core sample with the surfactant solution [21]. Overall additional oil recovery achieved by surfactants typically ranges between 7 percent and 26 percent of OOIP, with some cases exceeding 50 percent of OOIP. As for its application in the field, the experiment shows that surfactants can achieve an additional 16 percent-30 percent oil recovery from OOIP [24].

CONCLUSION

The performance of surfactants as an Enhanced Oil Recovery (EOR) method in both sandstone and carbonate reservoir was studied further. Further analysis was carried out on the adsorption ability of surfactants by both rocks, alteration of wettability, and recovery factor. Based on the results, several conclusions can be drawn:

1. Adsorption of surfactants is higher in carbonate rock reservoirs than sandstones and increases with higher salinity levels.
2. Wettability alteration can occur, which is characterized by a reduction in the contact angle, and the reduction is more effective in sandstones when compared to carbonate rocks.
3. Recovery factor by injection of surfactant in sandstone is higher than that of carbonate rock, and the main effect is the presence of secondary porosity in carbonate rock.
4.

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