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The Effect of MES-Ethanol Formulation in Enhancing Surfactant Flooding Efficiency – A Laboratory Scale Perspective

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ABSTRACT - Surfactant flooding is an Enhanced Oil Recovery (EOR) technique aimed at improving oil displacement efficiency by reducing the interfacial tension (IFT) between oil and water. This study investigates the performance of palm oil–based Methyl Ester Sulfonate (MES) surfactant combined with 96% ethanol as a co-surfactant for EOR applications. The surfactant formulations are prepared at MES concentrations ranging from 0.5% to 2.0% and evaluated through density, viscosity, aqueous stability, phase behavior, interfacial tension, and coreflooding experiments. The aqueous stability test showed that all formulations remained clear without precipitation, indicating good thermal stability. Viscosity measurements showed that solution viscosity increased with higher surfactant concentrations but consistently declined as the temperature rose from 30°C to 60°C. Phase behavior analysis demonstrated that ethanol enables the formation of emulsions at all concentrations, with middle-phase microemulsions observed at MES concentrations of 1.25% and 1.5%. The largest middle-phase emulsion volume of 3.00% was obtained at 1.25% MES, indicating the optimal formulation. Interfacial tension measurements showes a reduction to 0.521 mN/m, confirming the effectiveness of the co-surfactant in lowering IFT. Coreflooding results indicate that surfactant injection yielded an incremental oil recovery factor of 29.24% over conventional waterflooding, achieving a total cumulative recovery factor of 45.90%.

Keywords: Enhanced oil recovery, surfactant flooding, methyl ester sulfonate, co-surfactant, microemulsion.

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INTRODUCTION

Enhanced oil recovery (EOR) has been widely applied to increase oil production from reservoirs that have experienced declining performance after primary and secondary recovery stages. Among various EOR techniques, surfactant flooding has been recognized as an effective method to enhance oil recovery by reducing the interfacial tension (IFT) between oil and water, thereby improving oil mobilization through the pore spaces of reservoir rocks (Lake 1989; Green & Willhite 1998; Fathaddin et al., 2019). However, the practical implementation of surfactant flooding is often constrained by several factors, including surfactant stability under reservoir temperature and salinity conditions, adsorption onto rock surfaces, and overall economic feasibility (Rakhmanto et al., 2021; Sheng 2010; Taber et al., 1997).

Methyl ester sulfonate (MES) has attracted increasing attention as a promising surfactant for EOR applications. MES is an anionic surfactant derived from renewable feedstocks such as palm or coconut oil through transesterification and sulfonation processes (Tobori & Kakui 2019; Jin et al., 2016). Compared to conventional petroleum-based surfactants, MES offers several advantages, including good biodegradability, environmental compatibility, and effective performance in reservoirs with moderate to high salinity (Ridaliani et al., 2025; Fathaddin et al., 2026a). These characteristics make MES a potential alternative surfactant for sustainable and cost-effective EOR operations, particularly in regions with abundant vegetable oil resources (Ridaliani et al., 2025; Maulida & Fathaddin 2024).

Laboratory investigations conducted at Universitas Trisakti have demonstrated the effectiveness of palm-oil-based MES in improving oil recovery performance under controlled coreflooding conditions, showing measurable increases in recovery factor and reduction in residual oil saturation (Ridaliani et al., 2025). These findings confirm the technical feasibility of MES as a biodegradable and locally sourced surfactant for chemical EOR applications.

Despite its advantages, the application of MES in surfactant flooding does not always result in optimal oil recovery. The effectiveness of MES is strongly influenced by formulation parameters such as surfactant concentration, reservoir brine composition, temperature, and interactions with reservoir rock. In some cases, MES alone may not sufficiently reduce interfacial tension to the ultra-low levels required for efficient displacement of residual oil, typically on the order of 10^{-3} dyne/cm. In addition, limitations in microemulsion formation and surfactant loss due to adsorption can reduce the overall efficiency of the flooding process. Therefore, formulation optimization remains a critical aspect in maximizing the performance of MES-based surfactant systems (Fikri et al., 2025; Belhaj et al., 2019; Leng et al., 2024; Sainuka et al., 2021).

The use of co-surfactants has been proposed as an effective approach to enhance surfactant performance in EOR applications. Co-surfactants play an important role in improving interfacial flexibility, stabilizing microemulsion structures, and facilitating the formation of middle-phase microemulsions, which are known to be most favorable for achieving ultra-low interfacial tension. Alcohols, in particular, have been widely employed as co-surfactants due to their ability to partition at the oil–water interface and enhance the solubilization of oil and water phases. Ethanol is considered a suitable co-surfactant because of its availability, low cost, and compatibility with environmentally friendly EOR formulations (Fattahanisa et al., 2018; Swadesi et al., 2025).

Although several studies have investigated the use of MES as a surfactant for EOR, including laboratory-scale studies conducted at Universitas Trisakti which evaluated palm-oil-based MES both as a standalone surfactant and in combination with ethanol additive, comprehensive evaluations of MES combined with ethanol as a co-surfactant remain limited, especially in laboratory-scale studies that integrate phase behavior analysis, interfacial tension measurement, and coreflooding performance. A clear understanding of how the MES–ethanol system influences microemulsion formation, interfacial properties, and oil recovery efficiency is still required to support its potential field application (Bantacut & Darmanto 2014; Setiati et al., 2023).

Therefore, this study aims to evaluate the performance of a MES–ethanol surfactant system for Enhanced Oil Recovery through a series of laboratory experiments. The study focuses on investigating aqueous stability, phase behavior, and interfacial tension characteristics, as well as assessing oil recovery improvement through coreflooding tests under controlled conditions. The results of this research are expected to provide insights into the feasibility of using MES combined with ethanol as an effective and environmentally friendly surfactant formulation for EOR applications (Pal et al., 2018; Zhao et al., 2022; Chen et al., 2024).

METHODOLOGY

This study employs a series of laboratory experiments to evaluate the performance of the MES–ethanol surfactant system for enhanced oil recovery. The methodology is systematically arranged into material and apparatus, solution preparation, preliminary evaluation of surfactant properties, and coreflooding experiment.

Materials and apparatus

The materials used in this study were MES which was derived from palm oil, distilled water, NaCl, crude oil, ethanol and Berea core. The materials were available in EOR laboratory Universitas Trisakti as can be shown in Figure 1.

The Methyl ester sulfonate (MES) utilized in this study is an anionic surfactant derived from palm oil. In general chemical processing, MES is synthesized from renewable vegetable oil feedstocks, such as palm or coconut oil, through a sequence of transesterification and sulfonation processes. In this study, the surfactant was obtained

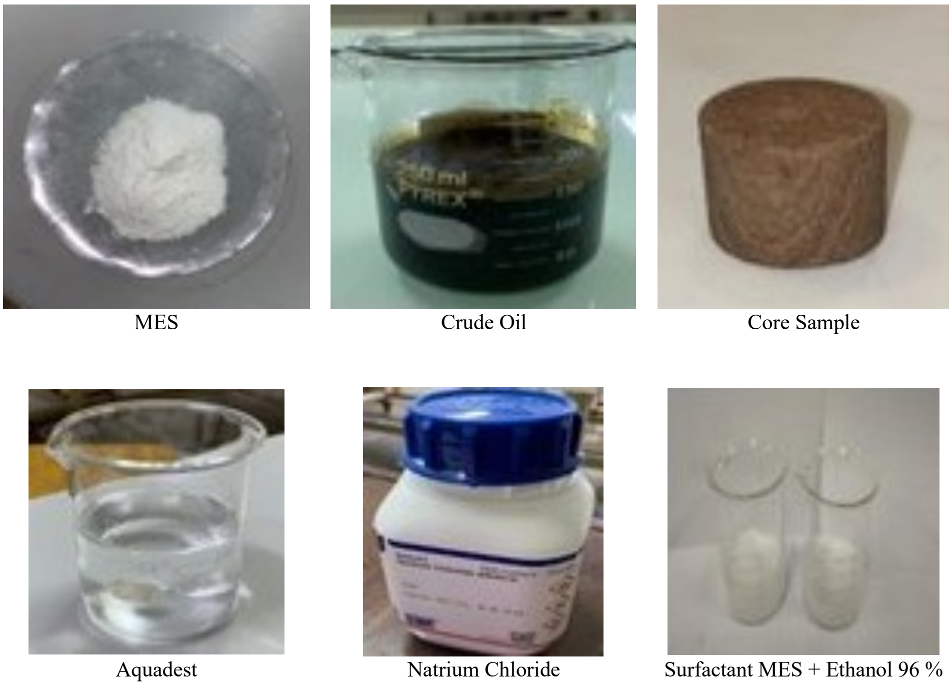


Figure 1. Materials: MES; crude oil; core sample; aquadest; natrium chloride.

as a ready-to-use material from PT Wilmar Nabati. The specific surfactant used was MES in powder form under the trademark WILFAMES™ C16 PR-10. The properties of this surfactant are provided in Table 1 (Wilmar Trading Pte Ltd., 2022).

As a core sample; Berea core is used as the porous media for core-flooding experiments, representing standard and homogeneous reservoir rocks. These core samples consist of homogeneous sandstone with specific physical properties, measuring 2.5 cm in diameter and 2.8 cm in length. Based on measurements conducted at the Reservoir Rock Characterization Laboratory, Universitas Trisakti, the core exhibits a porosity of 0.21 and a permeability of 59 md.

Prior to testing, the core was dried in an oven and saturated with brine. Specifically, the core was initially saturated using a desiccator under vacuum conditions for 24 hours, followed by brine flooding through the core-flooding apparatus to ensure that all pore spaces were fully filled. The prepared core was then utilized in experiments conducted at room temperature, which consisted of two primary stages: waterflooding and surfactant injection.

All materials were handled and formulated according to standard procedures to ensure consistency and reproducibility of the experimental results. Several apparatuses were used to perform this research including digital balance, magnetic Stirrer, DMA 4100 density meter, viscometers, oven, glass tubes for phase behavior measurement, spinning drop tensiometer, desiccator and core flooding apparatus. All of apparatus can be shown on Figure 2.

Solution preparation

In this study, brine and surfactant-ethanol solutions were prepared with varying and concentrations. The goal was to obtain a solution compatible for use in surfactant flooding. This experiment used crude oil with a specific gravity of 36 API. In addition, brine was made with a salinity of 12,000 ppm. After that, a methyl ester sulfonate (MES) surfactant solution was prepared which was mixed with ethanol 96% (v/v) as a co-solvent. The concentration of surfactant and ethanol varied from 0.5% to 2.0% at temperatures ranging from 30°C to 60°C. The samples of the surfactant-ethanol solution prepared are shown in Table 2.

Measurements

The measurements performed in this study were as follows:

- Density measurement

  The density of the surfactant solution was measured with a DMA 4100 density meter. The instrument was turned on and allowed to warm up for approximately 5 minutes. It was then set to measure water density at 60°C and calibrated with distilled water using a syringe. After calibration, the equipment was cleaned with alcohol before injecting the surfactant sample into the instrument for measurement (Wijayanti et al., 2023; Rachman et al., 2020).
- Aqueous stability test

  Testing was conducted at 60°C in an oven to determine whether the surfactant solution was

Table 1. Surfactant composition of WILFAMES™ C16 PR-10

Composition / technical parameter	WILFAMES™ C16 PR-10
Physical Appearance	Off-White Powder
Active Matter Content	Min. 78%
Zeolite Content	8% – 12%
Moisture Content	Max. 6%
pH Value (Aqueous Solution)	5.0 – 8.0
Bulk Density	0.5 – 0.8 kg/L

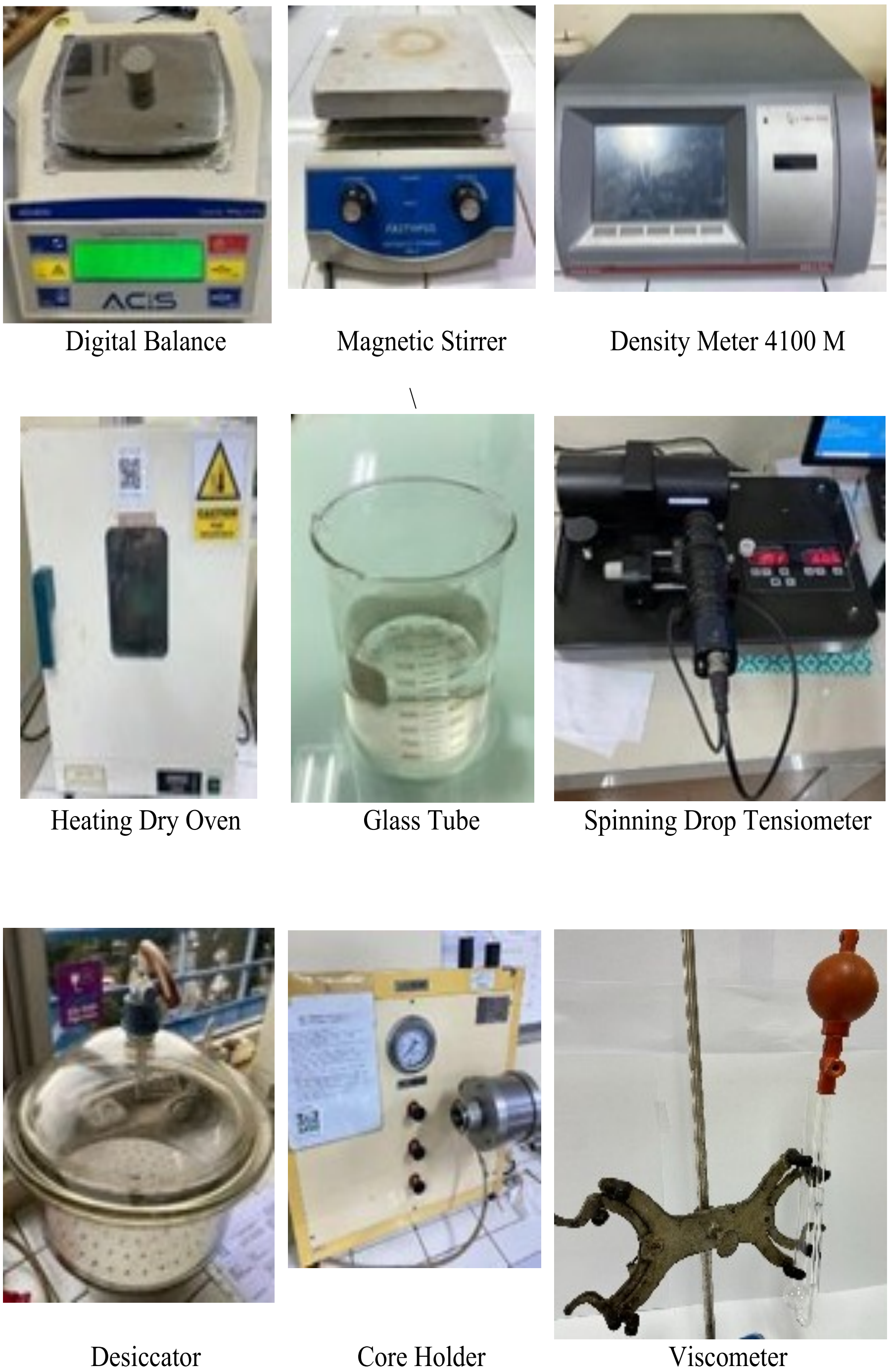


Figure 2. Experimental apparatus.

Table 2. MES-ethanol solutions

Solution	MES conc., %	Ethanol conc., %
A	0.50	0.50
B	0.75	0.75
C	1.00	1.00
D	1.25	1.25
E	1.50	1.50
F	1.75	1.75
G	2.00	2.00

suitable for injection. Fluid samples were prepared with MES concentrations ranging from 0.50% to 2.00%. Fluid samples were also prepared with MES and ethanol 96% (v/v) concentrations ranging from 0.50% to 2.00%, respectively. Visual inspection was performed. The solutions were observed for 48 to 72 hours to see if they remained clear or became cloudy (Setiati et al., 2023).

- Viscosity measurement

  Viscosity measurements were performed on MES surfactant solution samples with concentrations ranging from 0.5% to 2% with a salinity of 5000 ppm. Measurements were made using an Oswald viscometer at temperatures of 30, 40, and 60°C. This measurement was carried out to determine the effect of concentration and temperature on viscosity (Ulfah et al., 2023;Fathaddin et al., 2026b).

- Phase-behavior test

  The phase behavior test is conducted to determine whether the two fluids (surfactant and oil) can form a Winsor Type III emulsion. The volume of the emulsion will then be measured using a pipette tube. The steps are as follows (Ristawati et al., 2019; Maulida et al., 2024). Each of the seven surfactant-ethanol solutions is placed into a 2 ml pipette tube. Then, add 2 ml of light crude oil to the pipette tube previously filled with the surfactant solution, bringing the total solution volume to 4 ml. Gently shake the seven pipette tubes until the two fluids, surfactant and oil, are thoroughly mixed, creating a complete emulsion. Place the pipette tubes on a test tube rack to secure the solution and place them in an oven at 60°C. Observe and record the emulsion formation from the beginning of the experiment until 504 hours (21 days) have elapsed.

- Interfacial tension measurement

  The TX500D series Spinning Drop Tensiometer was used as a technical aid in the IFT test to examine the effect of MES-ethanol surfactant on the IFT between brine formation and crude oil. This instrument used the ADSA (axisymmetric drop shape analysis) technique to measure the IFT between two immiscible fluids. IFT measurements in this study were carried out only on a selected solution at a temperature of 60 °C. The measurements were carried out in the Ogrindi laboratory at the Bandung Institute of Technology (Fathaddin et al., 2025).

- Coreflooding test

  Coreflooding experiments were conducted to determine the recovery factor (RF) of the surfactant formulation. Initially, the dry weight and volume of the core sample were measured. The core was then saturated with 12,000 ppm brine by soaking for at least 24 hours until no air bubbles were observed. After saturation, the core was reweighed to calculate the volume of brine absorbed. Oil saturation was performed by placing the core in a core holder under a confinement pressure of 100 psi and injecting oil at a flow rate of 0.3 ml/min at 60 °C. The volume of brine displaced during this process was used to determine the original oil in place (OOIP). The core was subsequently aged in oil at 60 °C for 24 hours (Budhya et al., 2018; Tetelepta et al., 2024).

Waterflooding was carried out by injecting brine under the same flow rate and temperature conditions until two pore volumes (PV) were reached. The produced fluids were collected to calculate the recovery factor. This stage was followed by surfactant flooding using identical injection parameters. The additional oil produced was recorded to determine the incremental recovery factor. Finally, a post-flush with brine was performed to remove any remaining surfactant from the core. The recovery factor (RF) was calculated by dividing the cumulative oil released from the Berea core sample with the initial oil volume in the core sample.

RESULT AND DISCUSSION

The experiment began with the preparation of brine and a MES-ethanol surfactant solution. Then, measurements of density, aqueous stability, viscosity, phase behavior, interfacial tension (IFT), and core flooding were performed. The results of the measurements and analysis are as follows.

Density measurement

The densities of solution samples shown in Table 1 were measured using a DMA 4100 density meter. The density was influenced by the densities of each component forming the solution: pure water (0.9970 g/cm^3), NaCl (2.165 g/cm^3), MES surfactant (1.100 g/cm^3), and ethanol (0.789 g/cm^3).

The density of the solution varied from 1.007 g/cm^3 for a solution with a concentration of MES surfactant and ethanol of 0.5% each to 1.005 g/cm^3 for a solution with a concentration of MES surfactant and ethanol of 2 % each. The results of density measurements for seven solutions are shown in Figure 3.

Although the concentration of MES and ethanol was increased to 2%, the density of this solution actually decreased slightly compared to the previous 0.5% variation. This occurred because the effect of decreasing the density by 2% ethanol was slightly more dominant than the effect of increasing the density of 2% MES.

Aqueous stability test

The MES surfactant solution without ethanol addition exhibits a cloudy white color. This indicates that the solution experiences phase instability. The presence of high levels of salt (NaCl) reduces the hydration of the surfactant's hydrophilic groups (a salting-out effect). As a result, the surfactant micelles form aggregates, making the solution appear cloudy. The experimental results are shown in Figure 4.

To address the turbidity issue, 96% (v/v) ethanol was added to the solution at the same concentration as the MES surfactant. Visual observation showed that all solutions listed in Table 1 were clear as shown in Figure 5. With ethanol acting as a co-solvent, the MES surfactant was completely dissolved, thereby preventing the aggregation of surfactant micelles.

Viscosity measurement

Experimental data demonstrate a relationship where an increase in MES surfactant concentration is directly proportional to the rise in solution viscosity across all temperature levels as illustrated in Figure 6. For example, at a temperature of 30°C, the viscosity gradually increases from 1.689 cP (at

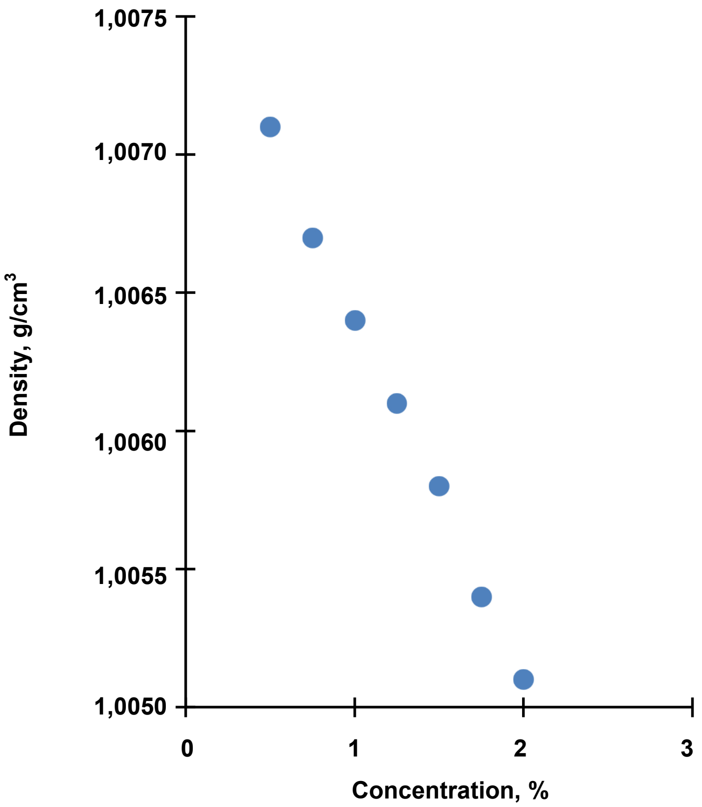


Figure 3. The density of MES-ethanol surfactant solutions decreases with increasing concentration of MES and ethanol because the effect of density decrease due to adding ethanol was slightly more dominant than the effect of increasing the density by MES.

Figure 4. Visual appearance of the MES surfactant solution without ethanol, exhibiting high turbidity and precipitation caused by the salting out effect across tested formulations.

Figure 5. The addition of ethanol as a co-solvent caused the MES surfactant solution to remain clear on the 3rd day, demonstrating significantly improved aqueous stability and prevention of the salting out effect.

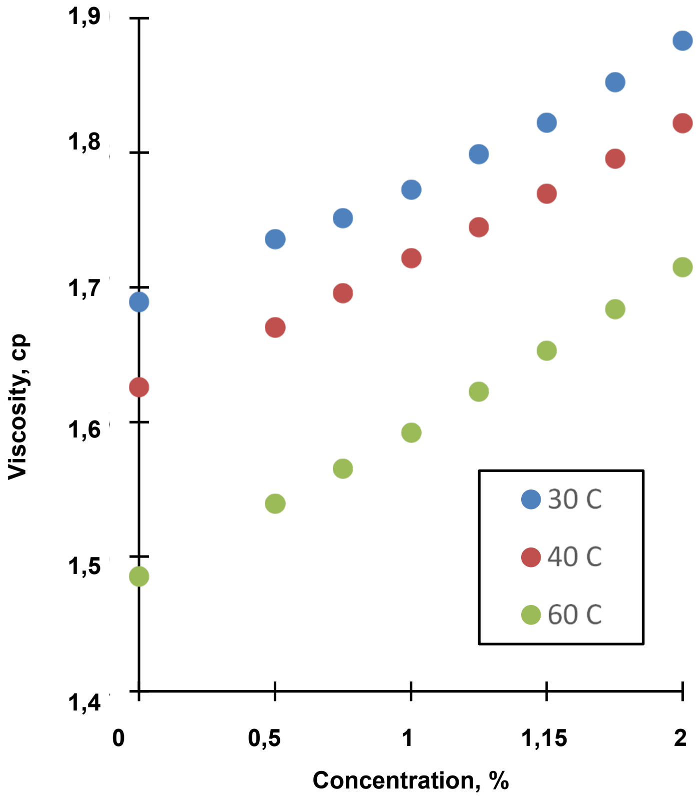


Figure 6. Rheological behavior of the MES surfactant solution as a function of temperature and concentration, demonstrating a characteristic thermal thinning trend with increasing temperature and a concentration-dependent viscosity enhancement.

0% concentration) to a peak value of 1.883 cP at a 2% concentration. In terms of chemical mechanism, this phenomenon occurs because as more MES surfactant molecules dissolve in water, the intensity of intermolecular interactions increases drastically. When the concentration exceeds its critical limit, these surfactant molecules associate with each other to form micelles. The increasingly dense presence of micelles causes the solution to become more compact, slowing down molecular movement, increasing fluid thickness, and ultimately raising the viscosity of the fluid system.

Conversely, temperature has an inversely proportional relationship with the viscosity of the MES solution. When the temperature is raised from 30°C to 60°C, a consistent decrease in viscosity values occurs across all concentration variations. For instance, at an MES concentration of 1%, the viscosity drops from 1.772 cP (30°C) to 1.721 cP (40°C), and further declines to 1.592 cP at a temperature of 60°C. This can be explained by the molecular kinetic theory. An increase in temperature provides greater kinetic energy to the molecules within the solution, causing them to move much faster. This high kinetic energy weakens the hydrogen bonds and attractive forces between surfactant molecules. Consequently, the initially stable micellar structure becomes more dynamic, stretches, and easily breaks down (crumbles). The effect of this weakened internal structure makes the solution thinner, thereby decreasing its viscosity.

Phase-behavior Test

Phase behavior testing was carried out for 504 hours (21 days) at an oven temperature of 60°C in a pipette tube to observe the formation and stability of the microemulsion volume from a mixture of surfactant solution and crude oil. The test results shown in Table 3 show the formation of a middle-phase microemulsion (Winsor type III) for solutions D and E, which is considered the best type of emulsion for mobilizing oil trapped in the fine pores of the reservoir through the formation of microemulsions. The volume of emulsion formed was observed to decrease over time before finally tending to reach a stable condition after 48 hours as shown in Figures 7 and Figure 8 respectively for solutions D and E. The decrease in stability and volume of the emulsion phase was caused by a combination of physical and chemical factors, such as coalescence (merging of emulsion droplets), Ostwald ripening, as well as separation due to gravitational forces in the form of creaming or sedimentation.

Evaluation of two types of solutions showed that the emulsion volume for the surfactant solution with a concentration of 1.25% (solution D) was 3.00% higher compared to that for the surfactant solution with a concentration of 1.50% (solution E) which was only 1.75%. This indicates that there was an optimum concentration for a salinity of 12,000 ppm of MES surfactant that could form a middle phase microemulsion with light crude oil.

Interfacial tension measurement (IFT)

Based on the phase behavior study, a surfactant solution with a concentration of 1.25% (solution D) was selected for the IFT test. The test was conducted for 84 days (12 weeks) in an oven at 60° C. The test results are shown in Table 4. The IFT measurement result for the solution with crude oil was 0.521 mN/m. This result does not meet the

Table 3. Phase behavior test. Only solutions D and E produced a middle phase microemulsion.

Solution	Emulsion volume, %	Phase emulsion type
A	1.25	Upper
B	1.25	Upper
C	7.00	Upper
D	3.00	Middle
E	1.75	Middle
F	2.00	Upper
G	1.75	Upper

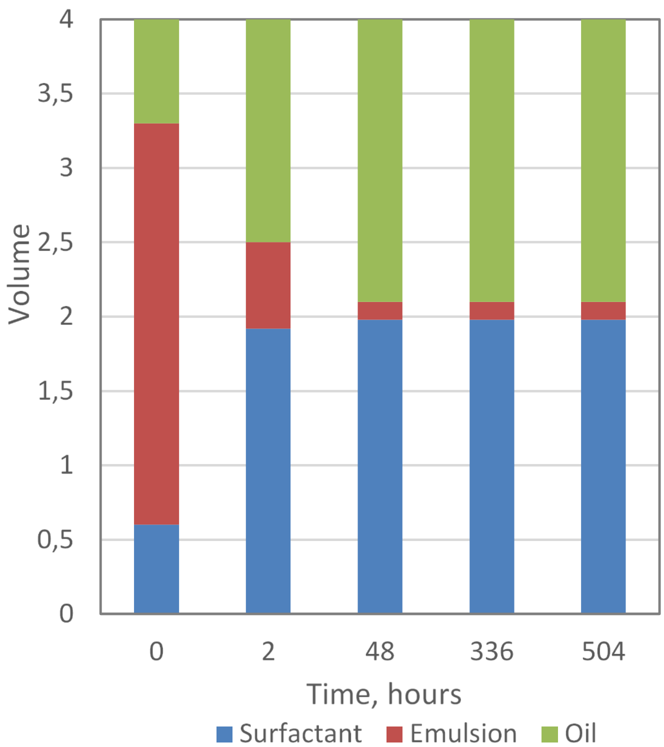
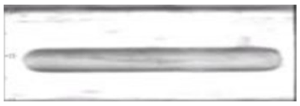


Figure 7. The results of phase behavior testing of the 1.25% MES-ethanol composite surfactant system at a salinity of 12,000 ppm; demonstrating the formation of an optimal Winsor Type III middle-phase microemulsion after 504 hours of observation, achieving a peak emulsion volume of 3.00%, which represents the highest performance among all tested formulations.

Table 4. Experimental Results and Visualization of 1.25% MES Surfactant IFT Testing.

Property	Value
MES Surfactant concentration, %	1.25
Observation Time, hours	504
Emulsion volume percentage, %	3.0
IFT (nm/m)	0.52
Visualization on the tool	

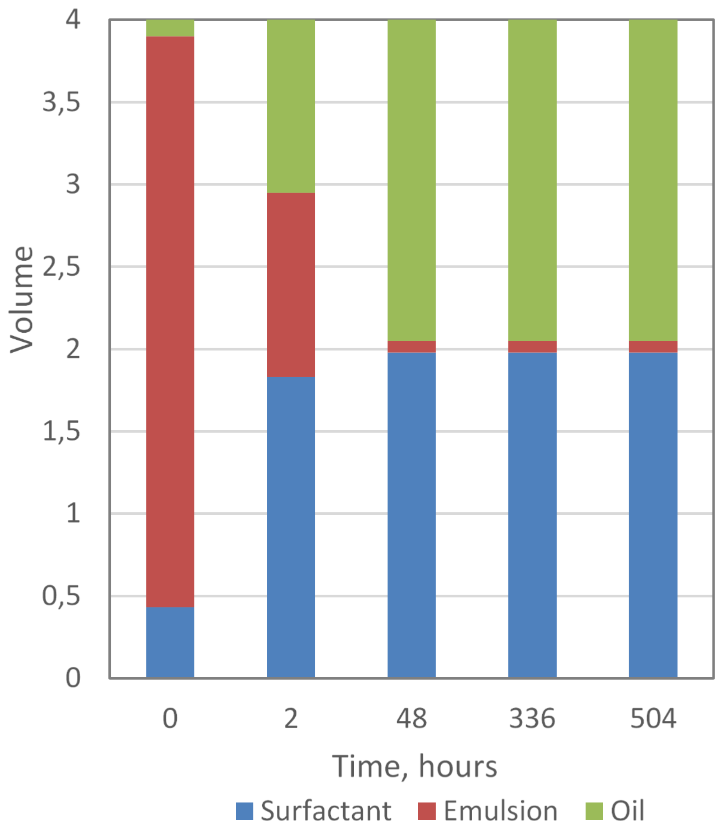


Figure 8. Phase behavior testing of the 1.5% MES-ethanol composite surfactant system at 12,000 ppm salinity revealed that an optimal Winsor Type III middle-phase microemulsion was established after 504 hours, yielding an emulsion volume of 1.75%.

ultra-low IFT target (1×10^{-3} mN/m) (Rosen et al., 2005). However, the MES surfactant with the addition of 96% (v/v) ethanol was able to significantly reduce the interfacial tension of brine and crude oil from approximately 42 mN/m to almost 54 mN/m (Zhang et al., 2022).

Coreflooding test

Coreflooding testing was conducted to assess Coreflooding testing was conducted to assess its effectiveness in increasing oil recovery. The injection fluid consisted of brine with a salinity of 12,000 ppm for waterflooding and a composite solution of MES surfactant and 96% (v/v) ethanol at a concentration of 1.25% for surfactant flooding. Prior to injection, the rock sample was characterized, resulting in a bulk volume of 13.75 cm^3. The rock was then saturated with brine for 24 hours, resulting in a pore volume (PV) of 2.022 cm^3, calculated based on the difference between wet and dry weights and a brine density of 1.009 g/cm³. The rock was then saturated with crude oil (36°API) at 2.4 PV, resulting in an initial oil volume (OOIP) of 1.20 cm³ with an oil saturation (Soi) of 59.34% and a water saturation (SWI) of 40.66%.

The next stage was waterflooding. During this stage, brine with a salinity of 12,000 ppm was injected. Oil production increased progressively in proportion to the volume of water injected. However, after water breakthrough, the increase in oil recovery decreased, indicating that most of the readily mobile oil had been produced as illustrated in Figure 9. Although water injection continued to 2 PV, no substantial additional oil production was observed, indicating that the remaining oil was largely trapped by capillary forces and could no longer be effectively mobilized by water alone. This situation emphasized the limitations of conventional waterflooding and highlighted the need for chemical injection to reduce capillary entrapment and mobilize the remaining oil. This waterflooding stage produced 0.35 cm³ of oil, with a recovery factor (RF) of 29.24%, and a remaining oil volume of 0.85 cm³.

The final stage was the injection of a 1.25% MES surfactant solution at 2 PV. This stage resulted in an additional oil recovery of 0.20 cm³. This resulted in a total oil recovery of 0.55 cm³ with a recovery factor (RF) of 45.90%. The final remaining oil volume was 0.65 cm³. The additional oil recovery observed during surfactant injection can be explained by the ability of the MES–ethanol system to modify the interfacial and capillary conditions within the pore network. Reducing the interfacial tension to 0.521 mN/m weakened the capillary forces that previously trapped the residual oil after water injection. Furthermore, the formation of a mid-phase microemulsion at 1.25% MES demonstrated the surfactant's ability to bind oil and water, increasing the recoverable oil volume.

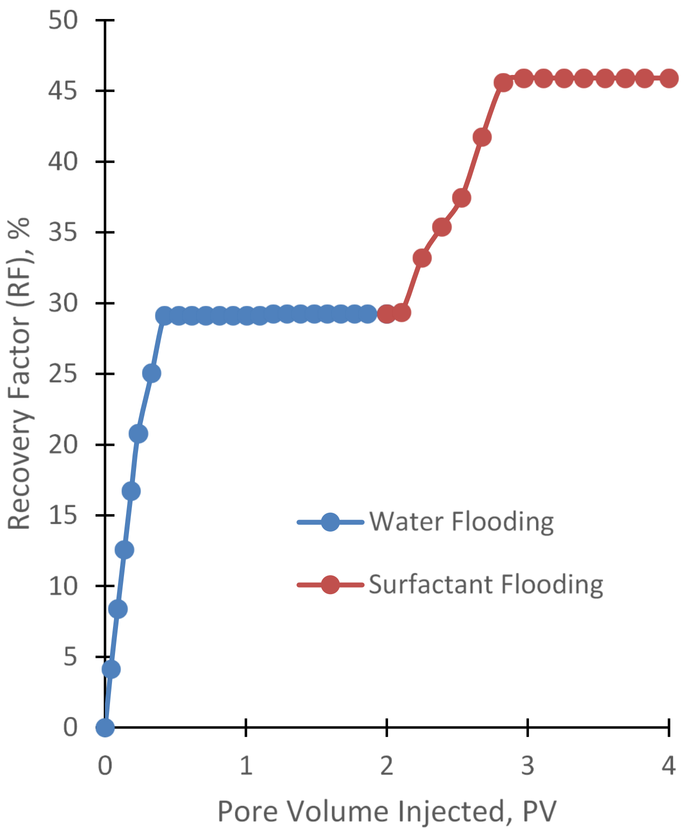


Figure 9. Recovery factor caused by water flooding (blue curve) and surfactant flooding (red curve), respectively provides incremental recovery of 29.17% and 16.66%.

This mechanism is consistent with the significant decrease in residual oil saturation (Sor) from 42.04% after waterflooding to 24.73% after surfactant injection. The reduction in Sor indicates that the surfactant formulation was able to access pore spaces previously bypassed by water, particularly smaller pores where capillary forces dominate. Although the measured IFT has not reached ultra-low levels, the 29.16% recovery improvement obtained in this study indicates that the MES–ethanol formulation has practical potential for chemical EOR applications. These results indicate that effective oil mobilization can still be achieved through a combination of moderate IFT reduction, microemulsion formation, and increased displacement efficiency. Further optimization of salinity, ethanol ratio, or injection strategy could potentially improve performance toward higher recoveries, making this formulation a promising and environmentally friendly alternative for field-scale implementation.

CONCLUSION

The addition of 96% ethanol successfully acts as a co-solvent to counteract the salting-out effect and micelle aggregation of palm oil-based methyl ester sulfonate (MES) surfactant in a 12,000 ppm brine environment, ensuring optimal thermal stability and clarity of all formulations at 60°C. Furthermore, while the solution viscosity increases proportionally with higher surfactant concentrations due to denser micellar association, it consistently declines as the temperature rises from 30°C to 60°C because heightened kinetic energy weakens the internal intermolecular structures.

Formulation optimization demonstrates that the optimum concentration is achieved at 1.25% MES combined with 1.25% ethanol, which yields the largest middle-phase microemulsion (Winsor Type III) volume of 3.00%. This specific formulation successfully reduces the interfacial tension (IFT) between the brine and 36 °API crude oil to 0.521 mN/m at 60°C; although this result does not yet meet the strict ultra-low IFT target of 1×10^{-3} mN/m, the ethanol co-surfactant proves highly effective in significantly lowering the fluid system's IFT from its initial baseline.

Coreflooding performance confirms that injecting the 1.25% MES–ethanol formulation delivers a substantial incremental oil recovery factor of 29.24% over conventional waterflooding, achieving a total cumulative recovery factor of 45.90% and drastically dropping the residual oil saturation (Sor) from 42.00% to 32.11%. The practical and scientific implication of these findings highlights that effective oil mobilization within reservoir pore networks can still be achieved through a combination of moderate IFT reduction and stable microemulsion formation, establishing this biodegradable, locally sourced surfactant system as a technically feasible and environmentally friendly alternative for field-scale chemical EOR applications.

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DECLARATION

Author contribution

Mulia Ginting: conceptualization, methodology, investigation, data curation, formal analysis; writing original draft, review & editing. Muhammad Taufiq Fathaddin: Supervision (Primary), conceptualization, methodology, Validation. Puri Wijayanti conceptualization, methodology, Validation, Apriandi Rizkina Rangga Wastu conceptualization, methodology, Validation, Zakia Azzahra conceptualization , review & editing. Eleonora Anselina Desi Letor review & editing. Ryan Gilberth de Fretes review & editing.

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The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Competing interest

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The use of AI or AI-assisted technologies

The author(s) used Deepseek Copilot to assist. After using this tool, the authors review and edit the content as needed and take full responsibility for the publication's content.

GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
EOR	Enhanced oil recovery	
IFT	Interfacial tension	dyne/cm
MES	Methyl ester Sulfonate	
mD	Millidarcy	mD
NaCl	Sodium chloride	
ppm	parts per million	ppm
DMA	Digital density Meter	g/cm3
RF	Recovery factor	%
OOIP	Original oil in place	mL
PV	Pore volume	mL
SOI	Initial oil saturation	fraction
SWI	Initial water saturation	fraction
ROIP	Remaining oil in place	mL
SOR	Residual oil saturation	fraction

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