Scientific Contributions Oil & Gas, Vol. 48. No. 4, December: 105 - 116

SCIENTIFIC CONTRIBUTIONS OIL AND GAS

Testing Center for Oil and Gas
LEMIGAS

Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

Utilizing Used Lubricants to Enhance Intermediate Crude Oil Recovery Through Water-in-Oil Emulsions

Mukhlis Noor Alfatih[1], Dwi Atty Mardiana[1], Shabrina Sri Riswati[1], and Changhyup Park[2]

[1]Petroleum Engineering Department, Universitas Trisakti
Kyai Tapa Street No. 1, Grogol, Jakarta, Indonesia

[2]Department of Energy and Resources Engineering, Kangwon National University
Chuncheon, Republic of Korea

Corresponding author: Dwi Atty Mardiana (atty@trisakti.ac.id)

Manuscript received: October 17th, 2025; Revised: November 04th, 2025
Approved: December 04th, 2025; Available online: December 15th, 2025; Published: December 15th, 2025.

ABSTRACT - This study experimentally analyzes the impacts of water-in-oil (W/O) emulsion derived from used lubricants on enhanced intermediate-crude-oil recovery. The objective is to identify a viable and economically efficient method to enhance the extraction of intermediate crude oil. Typically, W/O emulsions have been employed as displacing fluids in heavy oil reservoirs. According to the results, there have been challenges experienced in the selection of an affordable petroleum-based product and ensuring its availability for emulsion preparation. Used lubricants can be incorporated as a component in the formulation of an emulsion solution by mixing them with brine. The physical and chemical properties of these used lubricants are evaluated to determine their suitability as a displacing agent. Subsequently, several concentrations of the emulsion were prepared, ranging from 5% to 60% (vol/vol), to effectively evaluate their suitability as a displacing fluid. The experimental workflow covered viscosity testing, mobility ratio measurement, IFT evaluation, emulsion stability checks, adsorption analysis, and thermal stability assessment. Core-flooding is performed to determine the recovery factor. A 5% W/O emulsion is found to be an effective displacing fluid for intermediate crude oil. The core-flooding results showes about a 27% increase in recovery when using the conventional flooding emulsion. Overall, the findings indicate that adding used lubricants to W/O emulsions improves intermediate oil recovery due to their favorable viscosity and stability.

Keywords: enhanced oil recovery, water in oil emulsion, used lubricants, intermediate oil, recovery factor.

How to cite this article:

Mukhlis Noor Alfatih, Dwi Atty Mardiana, Shabrina Sri Riswati, and Changhyup Park, 2025, Utilizing Used Lubricants to Enhance Intermediate Crude Oil Recovery through Water-in-Oil Emulsions, Scientific Contributions Oil and Gas, 48 (4) pp. 105-116. DOI org/10.29017/scog.v48i4.1924.

INTRODUCTION

Enhanced oil recovery (EOR) plays a crucial role in improving oil production from depleted and mature reservoirs. Chemical EOR involves the introduction of chemical agents into the injected water to improve sweep efficiency and reduce the residual oil remaining in the reservoir, thereby increasing overall oil recovery. The chemical injection often involves the utilization of three distinct categories of chemicals: alkaline, surfactant, and polymer (Erfando et al., 2019). The alkaline would reduce surfactant adsorption (Gregersen et al., 2013; Riswati et al, 2019). Surfactants are known to contribute to the reduction of interfacial tension (IFT) between oil and water (Sainuka et al., 2021; Alfatih et al., 2022; Maulida 2024). The polymer contributes to the modification of the mobility ratio, resulting in the mitigation of viscous fingering phenomena and an increase in sweep efficiency (Frigrina et al., 2017; Vilanti et al., 2017; Fathaddin 2025). The mixture of surfactant and polymer into water-in-oil (W/O) emulsion would control the mobility ratio between the displacing fluid and oil, while also providing stability to IFT during the emulsification and entrapment stages of heavy oil.

Water in used lubricants results in the formation of W/O emulsions. Lubricants are composed of hydrocarbons, which can produce a stable emulsion with water due to the presence of detergent additives (Pawlak 2003). From a chemical standpoint, used lubricants share similar characteristics with surfactants. These lubricants typically contain soot particles and exhibit a significant level of acidity. Moreover, they naturally exist in the form of nanoparticles, which can contribute to the reduction of IFT (Arab et al., 2018; Kaito et al., 2022; Pei et al., 2015). At room temperature, lubricant viscosities typically fall in the range of 30 to 100 centipoise. In order to reduce the quantity of oil utilized in the production of high-viscose W/O emulsions, there is a need for an increase in the amount of water that is emulsified into lubricants (Allenson et al., 2011; Aminzadeh et al., 2016; Ghloum et al., 2015). Acquiring used lubricants is a relatively straightforward and cost-effective process, largely because they are discarded byproducts from both motor vehicles and industrial operations. Moreover, these lubricants are readily available in substantial volumes. To prevent environmental harm, it is imperative that the trash undergoes recycling prior to its disposal. The purpose of this study is to optimize the utilization of petroleum waste as a chemical injection agent in order to enhance oil production, particularly in intermediate oil reservoirs.

W/O emulsions are considered effective for boosting oil recovery in heavy oil reservoirs because they improve fluid mobility and oil displacement. They form easily during waterflooding, with stability strengthened by the natural lipophilic surfactants in heavy oil. Displacement efficiency largely depends on emulsion properties such as viscosity, stability, droplet size distribution, and rheology (Neto et al., 2019). Silva (2018) focused on the homogeneity and stability of W/O emulsions, as well as analyzing the rate of condensation and the impact of various salinity conditions. Emulsions lacking an emulsifying agent exhibit enhanced stability when subjected to lower ionic concentrations and thereby highlighting the significance of the composition of the aqueous phase in maintaining emulsion stability (Moradi et al., 2011). In-situ W/O emulsions with higher viscosity can better control fluid mobility, slowing water-cut increase and improving sweep efficiency, which in turn enhances heavy-oil output during waterflooding (Pang et al., 2019).

Studies by Rousseau et al. (2022) show that ex-situ W/O and O/W emulsions, prepared at the surface and injected, can outperform in-situ W/O systems. Controlling the process with specific chemicals improves the emulsification of field crude oil. Other studies have evaluated the performance and compatibility of these injected emulsions using oil from the field (Ghloum et al., 2015; Barnes et al., 2012; Li et al., 2018; Bryan & Kantzas 2007). Fu & Mamora (2010) conducted an experiment wherein they substituted crude oil with used lubricants in the W/O emulsion process. Used lubricants were employed as an injection fluid on heavy oil fields located in Canada and Venezuela, with a concentration ranging from 40% to 70% (vol/vol).

Despite these advancements, most studies on lubricant-based emulsions focus on heavy-oil reservoirs. Intermediate oil reservoirs, which are common in Indonesia, remain underexplored, even though their lower viscosity profile may require different mobility and IFT strategies. Used lubricants offer a cost-effective option for enhancing W/O emulsions and improving economic performance, yet their compatibility, optimum dosage, and displacement behavior in intermediate systems have not been systematically evaluated.

Therefore, this study evaluates the feasibility of incorporating used lubricants as an EOR agent for intermediate oil reservoirs. The work characterizes the physicochemical properties of used lubricants, examines their effects on emulsion behavior and IFT stability, and tests their performance through core-flooding experiments. The outcomes establish whether low-concentration lubricant additives can improve mobility control and oil recovery, providing a cost-efficient alternative for chemical EOR applications.

METHODOLOGY

This study is conducted through a series of systematic laboratory experiments designed to evaluate the performance of W/O emulsions formulated using recycled lubricants for EOR applications. The laboratory work is conducted at the petroleum engineering facilities of Universitas Trisakti in Jakarta and the applied testing laboratories of the Shell LOBP Marunda. The experimental procedures are divided into four main phases: (1) characterization of used lubricants; (2) characterization of crude oil and rock samples; (3) emulsion compatibility testing; and (4) core-flooding and oil recovery evaluation.

The first phase focuses on determining the physicochemical characteristics of used lubricants to assess their potential as an EOR agent. The analyses include viscosity measurement, determination of metal and wear metal content using inductively coupled plasma–optical emission spectroscopy (ICP-OES) in accordance with ASTM D5185, and evaluation of emulsion stability using (fourier transform infrared spectroscopy) overlay to observe the effects of nanoparticle dispersion and surfactant behavior. The acidity level of lubricants is also measured to determine oxidation tendency and chemical stability.

The second phase involves the characterization of the intermediate crude oil and rock samples used in this study. This step aims to ensure compatibility between the emulsion and reservoir materials. The fluids used in this study consist of a brine solution and intermediate crude oil. A 30,000-ppm brine is selected based on EOR polymer screening results, ensuring emulsion stability under low-salinity conditions. The brine and crude oil have densities of 0.9977 and 0.8967 g/cc, specific gravities of 1.0071 and 0.9062, and crude oil viscosity of 85 cP, respectively. Berea sandstone cores are used to represent the reservoir rock. This synthetic sandstone consists mainly of silica (61–100%) with minor oxides such as TiO_2, Al_2O_3, Fe_2O_3, MgO, and CaO. The core sample measures 2.58 cm in diameter and 3.59 cm in length, with a dry weight of 37.23 g, porosity of 26.78%, permeability of 521.57 mD, and bulk volume of 18.78 cc. Due to their high silica content and chemically inert nature, Berea sandstone prevents reactions with detergent additives and the aqueous components of W/O emulsion, making it suitable for compatibility assessments and flooding experiments.

In the third phase, W/O emulsions are formulated using various lubricant-to-water ratios ranging from 5% to 60% (vol/vol) and a brine solution containing 30,000 ppm salinity. The compatibility and performance of these emulsions are then evaluated through several key tests, including viscosity analysis, IFT measurement using a Lauda TD3 tensiometer according to ASTM D971, emulsion stability testing, adsorption analysis using a spectrophotometer, and thermal stability assessment at 90°C for 4 days. These evaluations are carried out to select the most stable and effective emulsion formulation for injection purposes.

The fourth phase consists of a core-flooding experiment, which aims to assess the displacement efficiency of the selected emulsion. Core-flooding process is performed after the initial water flooding, enabling a direct comparison between baseline recovery and emulsion-enhanced oil recovery. The produced oil samples are subsequently analyzed using FTIR to determine their composition and to assess the quantity of emulsion generated during the flooding process. The recovery factor is then calculated based on the produced oil volume to quantify the improvement in recovery performance resulting from emulsion injection.

RESULT AND DISCUSSION

Characteristics of used lubricants

Total acid number (TAN) of used lubricants in this study was about 3.65 mgKOH/g, larger than that of the new lubricants, 3.5 mgKOH/g (see Table 1). TAN increment represented the oxidation in the utilized lubricating substance. The oxidation in the nanoparticle form might have the benefit of ensuring the stability of emulsion materials, as they exhibited resistance to degradation and could withstand the temperature conditions of the reservoir while functioning as a displacing fluid.

The viscosity of used lubricants, based on the Brookfield method, yielded 60 cp (centipoise), which is 9% higher than that of the new one. This viscosity increment meant that lubricants effectively operate in the combustion chamber, facilitating the removal and dispersion of combustion residue (Pawlak 2003). The advantageous characteristics of the displacing fluid are attributed to the polymeric features of the lubricants that have been employed.

Table 1. Characteristics of new and used lubricants.

Item test		New lubricant	Used lubricant
Total Acid Number (ASTM D664), mgKOH/g		3.50	3.65
Dynamic Viscosity by Brookfield, mPa.s		55	60
Wear Metal Content (ASTM D5185), ppm	Al	1	11
	Cr	1	1
	Cu	1	1
	Fe	1	11
	Pb	1	1
	Na	1	1
	Si	1	12
	Ca	2420	2127
	P	840	756
	Zn	950	691
	Mg	20	6

Table 1 summarizes wear metal contents and compares them between two kinds of lubricants, i.e., used and new ones. The concentrations of some metals, such as aluminium (Al), iron (Fe), and silicon (Si), increased significantly compared with the new lubricants, a reason would be from engine components, e.g., the piston ring and the camshaft (Pawlak 2003). The augmentation in the concentration of these metallic salts conferred the advantages to the characteristics of nanoparticles, enabling them to effectively stabilize the creation of emulsion solutions. Arab et al. (2018) showed that nanoparticles produced from wear metal salt can stabilize emulsions during the emulsification process. These nanoparticles function as catalysts to maintain the stability of the emulsion solution, thereby preventing its degradation, ensuring resistance to temperature fluctuations, and preserving the integrity of the O/W interface.

Several wear metals, such as calcium (Ca), phosphorus (P), zinc (Zn), and magnesium (Mg), decreased in concentration, yet their presence still indicated residual detergent additives in used lubricating oil. These additives function as surfactants that reduce IFT, facilitating the detachment of adhered oil from rock surfaces and shifting reservoir wettability from oil-wet to water-wet. The transition ultimately enhances displacement efficiency (Babu et al., 2015).

Figure 1 compares FTIR spectra of the new (purple) and used (red) lubricants. In used lubricants, stronger absorption appears around 1700 cm^{-1} and 1100 cm^{-1}, which are associated with carbonyl (C=O) and sulfate (SO_x) functional groups. These changes indicate that oxidation and sulfation processes occurred during lubricant operation. The slight increase in absorbance intensity, ranging from 0.1 to 0.2 %T/cm, suggests the presence of oxidized and sulfated nanoparticles, which contribute to the surfactant-like behavior of used lubricants. These properties are beneficial for stabilizing W/O emulsions and improving the interfacial behavior when applied as an injection fluid in EOR applications. Table 1 and Figure 1 show that the used lubricants maintained stable viscosity and nanoparticle composition with active surfactant characteristics. These results indicate that the used lubricants fulfill the essential criteria of a polymeric surfactant, making them suitable for use as a displacing agent in intermediate crude oil recovery.

Emulsion compatibility test

W/O emulsions synthesized from used lubricants and brine with volume fractions of 5%, 10%, 20%, 40%, 50% and 60% exhibited a color change from dark brown to light brown as the brine content increased (Figure 2). All emulsions appeared milky, homogeneous, and showed no visible phase separation even at higher brine concentrations, indicating that used lubricants have an inherent ability to form stable W/O emulsions. Figure 3 shows the trajectories of mobility ratio and viscosity as a function of W/O emulsion concentrations. The stable flow would be made because the mobility ratio is maintained below 1. The ratio between the mobility value of the 5% emulsion and the viscosity value (μw) of 115 cP, and the viscosity of the sample crude oil (μo) was 0.74. In a solution characterized by a higher concentration of brine, the mobility ratio decreased when the concentration ranged from 10% to 60%.

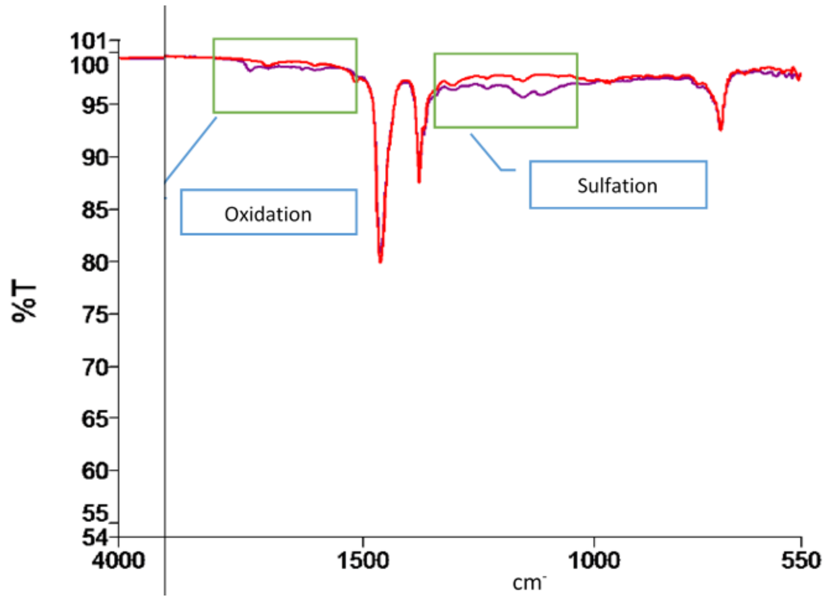


Figure 1. FTIR overlay of new and used lubricants showing key functional groups associated with oxidation (≈1700 cm^{-1}) and sulfation (≈1150–1250 cm^{-1}). The preserved peaks in the used lubricant indicate the presence of polar compounds and surfactant-like functional groups, which contribute to emulsion stability and IFT reduction

Figure 2. Photographs of W/O emulsions prepared from used lubricants and brine at water fractions of 5–60 vol%. Increasing the water fraction changes the emulsion colour from dark to light brown, while all samples remain visually homogeneous and show no macroscopic phase separation

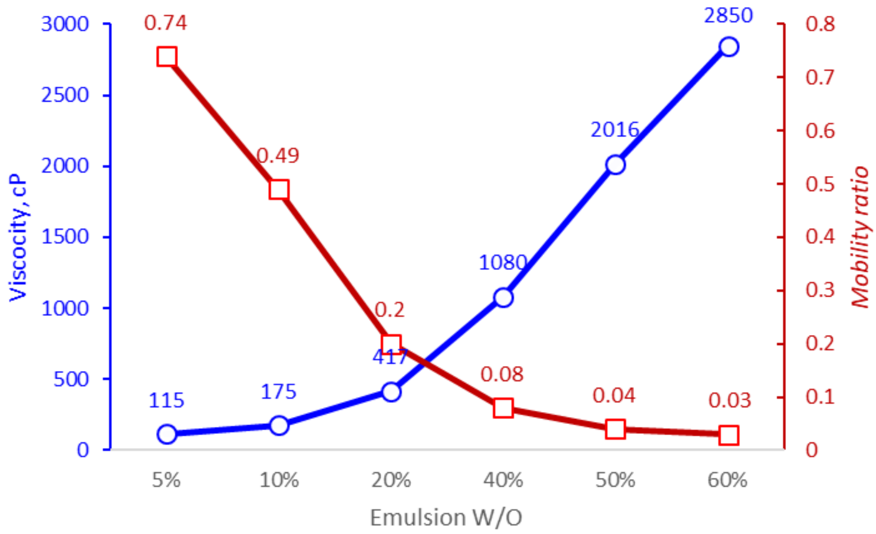


Figure 3. Viscosity and mobility ratio as the concentration of W/O emulsion.

Table 2. Adsorption test results

Variation Emulsion	Emulsion-to-solid weight ratio (We/Ws)	Initial concentration (ppm)	Final concentration (ppm)	Adsorp-tion (µg/g)
5%	0.044	50	49.890	4.8
10%	0.044	100	99.886	5.0
20%	0.045	200	198.765	55.3
40%	0.046	400	397.623	109.6
50%	0.047	500	495.782	197.2
60%	0.047	600	595.942	192.3

IFT tests indicated a noticeable reduction in emulsion for emulsion concentrations of 5%, 10%, 20%, and 40%, as shown in Figure 4. This reduction is observed in comparison to the IFT values of crude oil and brine. This study aims to analyze the reduction in IFT of new lubricants, specifically comparing IFT values of 40 dyne/cm and 8.6 dyne/cm in a 5% emulsion. The observed percentage difference between these two IFT values is calculated to be 78.5%. Figure 3 confirmed that the used lubricants in W/O emulsion were more effective in reducing IFT than the new product. A lower IFT value increases the capillary number, thereby enhancing the displacement of trapped oil and improving overall oil recovery (Eni 2017). The stable solution exhibits a low adsorption magnitude due to its resistance to the surface absorption phenomena on the rock (Moradi 2011). Table 2 shows the adsorption tests as the variations of W/O emulsions. Notably, no discernible reduction in concentrations was observed following the adsorption test, indicating the stability of the emulsion. At lower concentrations, 5% and 10%, the adsorption values were below 10 µg/g, indicating the emulsions remained stable with negligible polymer loss to the rock surface. However, it was observed that the concentrations of the emulsion at 20%, 40%, 50%, and 60% exhibited a decline, which may be attributed to the presence of a significantly elevated brine concentration. Table 3 shows the results of the thermal test conducted at 90^{0}C. It revealed that the emulsion solution with a concentration of 5% exhibited the highest degree of stability. Only 5% cases did not show the degradation, and thereby 5% W/O emulsion was the most attractive solution from the viewpoints of viscosity changes and degradation. The result is attributed to the elevated quantity of lubricants present in the solution, which effectively augmented the strength of the hydrophilic link in the emulsifying solution by 5%.

Table 3. Thermal test result

Parameter	Thermal test at 90 °C					
Variations of W/O emulsion	5%	10%	20%	40%	50%	60%
D-1 visc. cP	115	175	417	1080	2016	2860
D-2 visc. cP	115	175	405	907	1527	1778
D-3 visc. cP	115	173	380	690	1018	1426
D-4 visc. cP	114	171	375	689	1012	1422
Percentage diff., %	0.8	2.3	10.1	36.2	49.8	50.3
Degradation	X	V	V	V	V	V

Note:
D-1, D-2, D-3, and D-4 represent viscosity measurements taken after Day 1, Day 2, Day 3, and Day 4.
X: No degradation observed
V: Degradation is observed

Consequently, this led to the formation of emulsions that exhibited enhanced stability when compared to solutions with concentrations of 10%, 20%, 40%, 50%, and 60%. No discernible deterioration in the process of separation and notable alterations in viscosity were seen in the course of time for the emulsification with a concentration of 5%.

Core-flooding

Based on all results examined from the experiments of W/O emulsion, which consisted of various parameters such as viscosity, mobility ratio, IFT, stability, adsorption, and thermal properties, 5% W/O emulsion was stable. Consequently, this particular emulsion solution is deemed suitable for further investigation in the core flood test, specifically for intermediate crude oil. In comparison to emulsions with concentrations of 10%, 20%, 40%, 50%, and 60%, the 5% emulsion solution possesses a distinct advantage in terms of its mobility ratio, which is lower than 1 (specifically, 0.74). Additionally, it exhibits comparable IFT along with favorable adsorption behavior and stability under varying temperature conditions. These characteristics collectively contribute to improved sweep efficiency and displacement efficiency. Figure 5 shows the recovery factor as a result of core-flooding tests. During the injection of 5% emulsions with a salinity of 30,000 ppm, the resulting total oil volume retrieved was determined to be 0.658 ml, which corresponds to 27.42% of the initial oil volume present in the core. Figure 5 shows that during the initial stages of the flooding process, there was a notable enhancement in the recovery factor by 25.83%. This improvement can be attributed to the introduction of emulsion injection, which resulted in a more favorable mobility ratio. Consequently, sweep efficiency increased due to the emulsion's desirable viscosity and its significant reduction of IFT.

Visual observations of flooding experiments are presented in Figure 6, which illustrates the oil displacement behavior during waterflooding and emulsion flooding. The figures clearly illustrate the progression of oil displacement along the core. The high viscosity of the emulsion and its ability to reduce IFT helped mobilize the oil that remained trapped after the waterflooding stage. However, only a slight additional recovery of 1.58% was observed in the subsequent injection, as most of the movable oil had already been displaced during the early phase of emulsion flooding. In general, both waterflooding and emulsion injection improved oil recovery, achieving the highest total recovery factor of 61.78%.

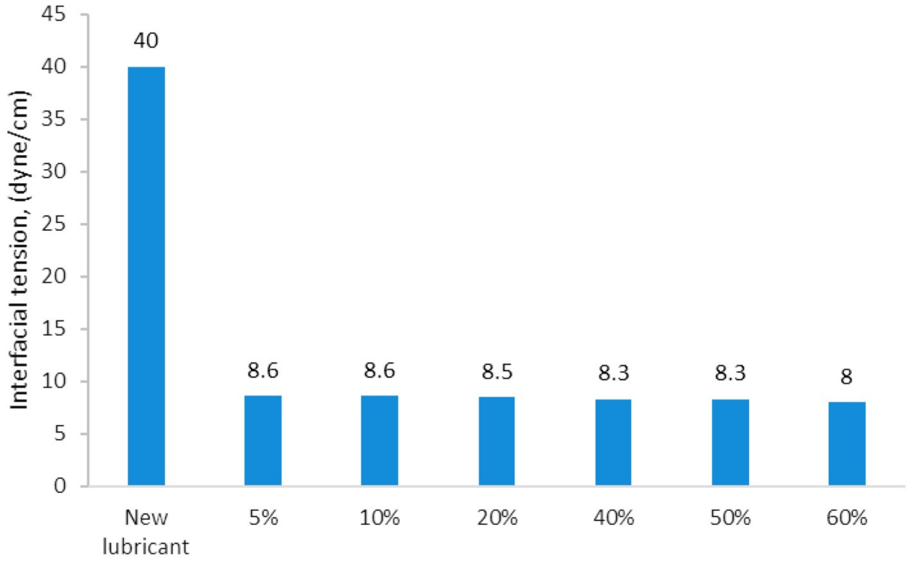


Figure 4. Interfacial tension between crude oil and brine in the presence of new lubricant and W/O emulsions with 5–60 vol% water. The IFT drops from 40 dyne/cm for the new lubricant to about 8–8.6 dyne/cm for all emulsion formulations, indicating a ~78% reduction.

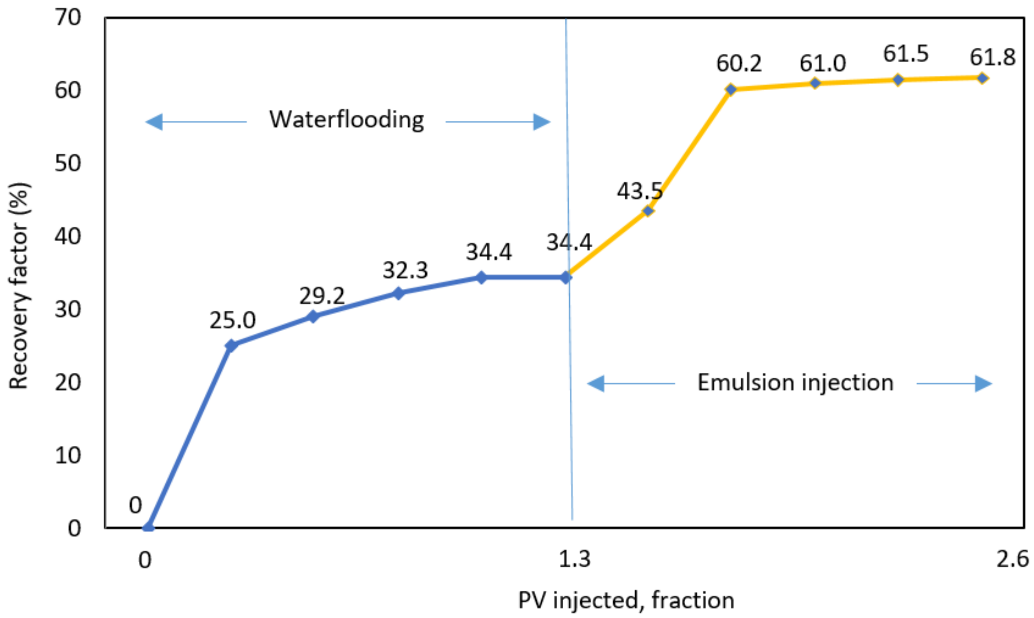
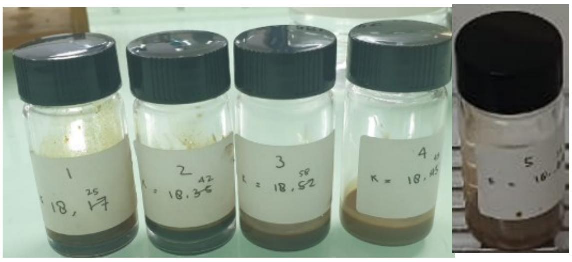


Figure 5. Recovery factor versus injected pore volume for a sandstone core during waterflooding followed by 5 vol% W/O emulsion injection. Waterflooding recovers about 34.4% OOIP at 1.3 PV, while subsequent emulsion injection increases the total recovery to 61.8% OOIP

(a)



(b)

Figure 6. Visual observation of oil displacement during waterflooding (a) and emulsion flooding (b)

CONCLUSION

In conclusion, the development of stable emulsions as nanoparticles is significantly influenced by the outcomes of physical chemistry analysis conducted on used lubricants. These analyses include viscosity testing, acid number determination, measurement of calcium, magnesium, phosphorus, and zinc metal content, assessment of oxidation levels, and evaluation of increased wear metal content such as iron, silicate, and aluminium. The compatibility test yielded a result indicating that the viscosity of the 5% emulsion solution composition, which is the most accurate and stable, is slightly higher than the viscosity of the oil. This result is desirable as it ensures a good mobility ratio of 0.74, a comparable IFT, and stability at high temperatures. Consequently, the emulsion solution can effectively enhance sweep efficiency and displacement efficiency. During the core-flooding experiment, a constant salinity emulsion of used lubricants was injected into the Berea core. The outcome of this experiment showed a significant increase in the recovery factor, with a value of 27.42%. Furthermore, the total oil recovery reached 61.8% when a 5% emulsion was utilized.

ACKNOWLEDGEMENT

The authors are grateful for the research funding provided by the Directorate of Research and Technology of the Ministry of Education and Culture in accordance with the Research contract between Region III Higher Education Service Institution (LLDIKTI REGION III) and Trisakti University Number 1440/LL3/AL.04/2023.

GLOSSARY OF TERMS

Symbol	Definition	Unit
FTIR (Fourier Transform Infrared Spectroscopy)	An analytical method to identify chemical bonds and functional groups within samples.	
IFT (Interfacial Tension)	The force per unit length acting at the interface between two immiscible fluids	mN/m
O/W (Oil-in-Water) emulsion	oil droplets are dispersed within a continuous water phase	
OOIP	Original Oil in Place	
PV	Pore Volume	
TAN (Total Acid Number)	A measure of the acidity of oil or lubricant, indicating oxidation or degradation level.	mgKOH/g

W/O (Water-in-Oil) emulsion	Water droplets are dispersed within a continuous oil phase	
μ	Viscosity	cP (centipoise)

REFERENCES

Allenson, S.J., Yen, A.T., Lang, F. 2011, 'Application of emulsion viscosity reducers to lower produced fluid viscosity', OTC Brasil Conference, Paper OTC 22443. https://doi.org/10.4043/22443-MS.

Alfatih, M.N., Setiati, S., Mardiana, D.A., Fathaddin, M.T. & Rakhmanto, P.A. 2022, 'Analysis of water-in-oil emulsions effect from used engine lubricant oil potential material for EOR heavy crude oil', Proceedings of the 2022 International Conference on Engineering and Information Technology for Sustainable Industry. https://doi.org/10.1145/3557738.3557882.

Aminzadeh, B., Hoang, V., Inouye, A., Izgec, O. 2016, 'Improving recovery of a viscous oil using optimized emulsion viscosity', SPE Improved Oil Recovery Symposium, Paper SPE -179698-MS. DOI:10.2118/179698-MS.

Arab, D., Kantzas, A., Bryant, S.L. 2018, 'Nanoparticle-fortified emulsification of heavy oil', SPE EOR Conference at Oil and Gas West Asia, Paper SPE-190377-MS. https://doi.org/10.2118/190377-MS.

Babu, K., Pal, N., Bera, A., Saxena, V.K., Mandal, A. 2015, 'Studies on interfacial tension and contact angle of synthesized surfactant and polymeric from castor oil for enhanced oil recovery', Applied Surface Science, 353, 1126-1136. DOI:10.1016/j.apsusc.2015.06.196.

Barnes, J.R., Groen, K., Dubey, S., Reznik, C., Buijse, M.A., Shepherd, A.G. 2012, 'Controlled Hydrophobe Branching to Match Surfactant to Crude Oil Composition for Chemical EOR', Paper presented at the SPE Improved Oil Recovery Symposium, https://doi.org/10.2118/154084-MS.

Bryan, J., Kantzas, A. 2007, 'Potential for alkali-surfactant flooding in heavy oil reservoirs through oil-in-water emulsification', Petroleum Society of Canada International Petroleum Conference, Paper 2007-134. https://doi.org/10.2118/2007-134.

Demikhova, I.I., Likhanova, N.V., Hernandez, J., Lopez-Faicon, D.A. 2016, 'Emulsion flooding for enhanced oil recovery: filtration model and numerical simulation', Journal of Petroleum Science and Engineering, 143, pp. 235–244. https://doi.org/10.1016/j.petrol.2016.02.018.

Eni, H., Sutriah, K., Muljani, S. 2017, 'Surfaktan berbasis minyak sawit untuk aplikasi EOR pada Lapangan minyak intermediet', Lembaran Publikasi Minyak dan Gas Bumi, 51 (1), pp.13-21.https://journal.lemigas.esdm.go.id/index.php/LPMGB/article/view/10

Erfando, T., Rita, N. & Ramadhan, R. 2019, 'The key parameter effect analysis of polymer flooding on oil recovery using reservoir simulation', Journal of Geoscience, Engineering, Environment, and Technology, 4 (1), pp. 49–55. https://doi.org/10.25299/jgeet.2019.4.1.2107.

Fathaddin, M.T., Prapansya, O.R., Rakhmanto, P.A., Mardiana, D.A., Wydhea, Irawan, S., Abdillah, R. 2025, 'The Effect of TiO2 Nanoparticles on The Performance of Kappaphycus Alvarezii Biopolymer for Enhanced Oil Recovery', Scientific Contributions Oil and Gas, 48 (3) pp. 367-382. DOI org/10.29017/scog.v48i3.1909.

Frigrina, L., Kasmungin, S. & Mardiana, D.A. 2017, 'Studi polimer gel dengan crosslinker mengenai pengaruh variasi konsentrasi polymer, salinitas, dan suhu terhadap gelation time dan resistance factor', Prosiding Seminar Nasional Cendekiawan, pp. 139–144.

Fu, X., Mamora, D. 2010, 'Enhanced oil recovery of viscous oil by injection of water-in-oil emulsion made with used engine oil', SPE Improved Oil Recovery Symposium, Paper SPE -129902-MS. https://doi.org/10.2118/129902-MS.

Ghloum, E., Rashed, A., Al-Jasmi, A., Al-Ali, A., Mali, P., Sanyal, A. 2015, 'Selection of suitable viscosity reducer to facilitate test production of heavy oil and deep reservoir', SPE Kuwait Oil and Gas Show, Paper SPE-175312-MS. https://doi.org/10.2118/175312-MS.

Gregersen, C.S., Kazempour, M., Alvarado, V. 2013, 'ASP design for the Minnelusa formation under low–salinity conditions: impacts of anhydrite on ASP performance', Fuel, 105 (2013), pp. 368-382. https://doi.org/10.1016/j.fuel.2012.06.051.

Haishun, F., Kang, W., Zhang, L., Chen, J. 2018, 'Experimental study on a fine emulsion flooding system to enhance oil recovery for low permeability reservoirs', Journal of Petroleum Science and Engineering, 171, pp. 974–981. https://doi.org/10.1016/j.petrol.2018.08.011.

Kaito, Y., Goto, A., Ito, D., Murakami, S., Kitagawa, H., Ohori, T. 2022, 'First nanoparticle-based EOR Nano-EOR project in Japan: laboratory experiments for a field pilot test', Proceedings of the SPE Symposium on Improved Oil Recovery. https://doi.org/10.2118/209467-MS.

Li, Z., Lu, Y., Wu, H., Yang, M., Feng, H., Xu, D., Hou, J., Kang, W., Yang, H., Zhao, Y., Bai, B. 2018, 'A novel ultra-low IFT spontaneous emulsification system for enhanced oil recovery in low permeability reservoirs', SPE EOR Conference at Oil and Gas West Asia, Paper SPE-190406-MS. https://doi.org/10.2118/190406-MS.

Maulida, F., Sutiadi, A., Fathaddin, M.T., Mardiana, D.A., Setiati, R., Rakhmanto, P.A., Ristawati, A., Irawan, S., Arkaan, M.D. 2024, 'The Characteristics of Sapindus Rarak Green Surfactant Injection to Enhance Oil Recovery', Scientific Contributions Oil and Gas, 47 (3) pp. 277-289. DOI.org/10.29017/SCOG.47.3.1637.

Moradi, M., Alvarado, V., Huzurbazar, S. 2011, 'Effect of salinity on water-in-crude oil emulsion: evaluation through drop-size distribution proxy', Energy & Fuels, 25(1), pp. 260–268. DOI:10.1021/ef101236h.

Neto, D.M.C., Sad, C.M.S., Silva, M., Santos, F.D., Pereira, L.B., Corona, R.R.B., Silva, S.R.C., Bassane, J.F.P., Castro, E.V.R., Filgueiras, P.R., Romão, W., Lacerda, V. 2019, 'Rheological study of the behavior of water-in-oil emulsions of heavy oils', Journal of Petroleum Science and Engineering, 173, pp. 1323–1331. https://doi.org/10.1016/j.petrol.2018.10.016.

Sainuka, N.J., Kasmungin, S., & Mardiana, D.A. 2021, 'The effect of non-ionic surfactant in gravity drainage processes in the reservoir to increase oil production at a laboratory scale', Journal of Earth Energy Science, Engineering, and Technology, 4(1). https://doi.org/10.25105/jeeset.v4i1.9061.

Pang, S., Pu, W., Xie, J., Chu, Y. 2019, 'Investigation into the properties of water-in-heavy oil emulsion and its role in enhanced oil recovery during water flooding', Journal of Petroleum Science and Engineering, 177, pp. 798–807. https://doi.org/10.1016/j.petrol.2019.03.004.

Pawlak, Z. 2003, Tribochemistry of Lubricant Oils. Elsevier, University of Technology and Agriculture, Bydgoszcz, Poland.

Pei, H.H., Zhang, G.C., Ge, J.J., Zhang, J., Zhang, G., Fu, L.P. 2015, 'Investigation of nanoparticle and surfactant stabilized emulsion to enhance oil recovery in waterflooded heavy oil reservoirs', SPE Canada Heavy Oil Conference, Paper SPE-174488-MS. https://doi.org/10.2118/174488-MS.

Rousseau, D., Gallo, C. le, Wartenberg, N., Courtaud, T. 2022, 'Mobility of microemulsions: a new method to improve understanding and performances of surfactant EOR', Proceedings of the SPE Symposium on Improved Oil Recovery. https://doi.org/10.2118/209414-MS.

Riswati, S.A., Bae, W., Park, C., Permadi, A.K., Efriza, I., Min, B. 2019, 'Experimental analysis to design optimum phase type and salinity gradient of Alkaline Surfactant Polymer flooding at low saline reservoir', Journal of Petroleum Science and Engineering, 173, pp.

1005-1019. https://doi.org/10.1016/j.petrol.2018.09.087.

Silva, M.D., Sad, C.M.S., Pereira, L.B., Corona, R.R.B., Bassane, J.F.P., Santos, F.D., Neto, D.M.C., Silva, S.R.C., Castro, E.V.R., Filgueiras, P.R. 2018, 'Study of the stability and homogeneity of water-in-oil emulsions of heavy oil', Journal of Petroleum Science and Engineering, 226, pp. 278–285. https://doi.org/10.1016/j.fuel.2018.04.011.

Vilanti, A., Kasmungin, S., Mardiana, D.A. 2017, 'Pengaruh permeabilitas dan konsentrasi polimer terhadap saturasi minyak sisa pada injeksi polimer', Jurnal Teknik Mesin dan Mekatronika, 2(01). DOI:10.33021/jmem.v2i01.321.