

Research Article

Novel Local Demulsifiers for Crude Oil Emulsion Treatment in Oil and Gas Industry

Emuchuo Chukwudi, Osokogwu Uche* 

Department of Petroleum and Gas Engineering, Faculty of Engineering, University of Port Harcourt, Port Harcourt, Nigeria

Abstract

Emulsion is the mixture of two immiscible liquid (water and oil) that found themselves together under agitation and turbulence in the presence of emulsifying agents like resins, fines, paraffins, sand etc. Crude oil emulsion is one of the major challenges in petroleum production and processing operations in the oil and gas industry. Several methods like chemical, thermal, and electrical or combination have been adopted to surmount these production challenges in the industry. In this study, the focus is on the chemical method (demulsifier) hence it is the most widely used method in Nigeria. The aim of this study is to develop a novel local demulsifier to address and avoid the formation of crude oil emulsions in the oil and gas sector while the objectives are to design novel demulsifiers from a local source, treat crude oil emulsion at various bottle test ratios and to determine the percentage of basic sediments and water (BS&W) left in the treated crude emulsion. An emulsion sample of crude oil was obtained and treated with three reagents. The analysis of the three reagents revealed that the treated crude substance formed an emulsion. The LD2 reagent demonstrated the most effective treatment in the confirmatory test, resulting in 86% oil, 12% sludge, and 2% water at a ratio of 0.2. Servo and LD1 both confirmed that the substance is composed of 90% oil and 10% contaminants, with a ratio of 0.6. LD1 outperformed Servo in the following ratios. Locally sourced demulsifiers demonstrate a high capacity to resolve emulsion challenges in the oil and gas sector and can serve as a cost-effective alternative to foreign demulsifiers, given their biodegradable nature.

Keywords

Local Demulsifier, Crude Oil, Emulsion, Treatment, Water

1. Introduction

An emulsion is a dispersion (droplets) of one liquid in another immiscible liquid. The phase that is present in the form of droplets is the dispersed or internal phase, and the phase in which the droplets are suspended is called the continuous or exterior phase. For created oilfield emulsions, one of the liquids is aqueous and the other is crude oil. The amount of water that emulsifies with crude oil varies greatly from facil-

ity to facility. It can be less than 1% and occasionally larger than 80%. Crude oil is discovered in combination with gas and saline formation water. As the reservoir becomes low, water is coproduced with oil and the number of wells producing water with crude oil is rapidly growing. These immiscible fluids are quickly emulsified by the combined action of shear and pressure drop at the wellhead, chokes and valves

*Corresponding author: oxgood79@gmail.com (Osokogwu Uche)

Received: 24 June 2025; Accepted: 7 July 2025; Published: 28 July 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

[10] as mentioned in [17]. When at least two immiscible phases are present in a system, they are called dispersion. The creation of a dispersed system involves a dispersed phase and a continuous flow [5]. Emulsion is a two-phase system composed of two liquids not forming homogeneous when mixed, one is (dispersed phase) constantly dispersed as globules in the second phase (continuous phase) [9]. During the extraction and transportation of crude oil, the production of an emulsion is evident. The formation happens once the heterogeneous mixture flows in the piping valves and porous rocks and endures turbulence at high temperature or high pressure. The key causes that facilitated the emulsion formation include the existence of surface-active substances, ionic compositions and pH of the water [19] as mentioned in [17].

The treatment of emulsion is highly significant as it is always been met in the production stage of oil. In addition, the dehydration of crude oil is a crucial stage in oil treatment because it will not be sold until the market specification is met. This study work focused on the application of local demulsifier for the treatment of the crude oil emulsion in the oil and gas industry. This research effort will also optimize Nigeria crude oil production as it will be substituted for the extravagant cost of the foreign demulsifiers in the oil and gas business.

The aim of this research is to design model novel demulsifiers for crude oil emulsion treatment in the oil and gas industry with the following objectives: to design novel demulsifiers from a local source, treat crude oil emulsion at various bottle test ratios, determine the percentage of basic sediments and water (BS&W) left in the treated crude emulsion.

2. Literature Review

Although the density difference between the water and oil crude assuring that the water is separated generally below the oil level, due to constant production [4], the amount of water and salts in the created crude oil, rises. Emulsions are formed as a result of mixing and agitation in the oil production system. Both crude oil and water migrate through the wellbore through porous rock, then to the top of the well tubes, the wellhead choke valve, and eventually to the surface separators via the manifold. Due to the turbulent flow, the crude oil and water are subjected to churning and turbulence during this transition, leading the water to form water droplets in the crude oil. The existence of two liquids that do not dissolve but rather disperse in each other and the degree of stability of the emulsion is governed by the nature of the mixture, the chemical composition, the viscosity of the two liquids, temperature, the availability of emulsifying reagents, as well as enough mixing time for the discontinuous phase to permeate into the continuous phase, all affect emulsion stability. In addition to the solid elements scattered in crude oil such as sand, charcoal, calcium, silica, iron, zinc, and aluminum sulfate, natural emulsifying agents in crude oil include paraffins, asphaltene, resinous compounds, and soluble organic acids.

Emulsions are generated owing to turbulence in the production equipment, beginning with the well, where oil and water flow via the choke valve, where the fluids are subjected to agitation due to the turbulence of the flow, resulting in the leaking of water droplets into the crude oil. The proportion of water emulsified with crude oil varies widely from one emulsion to another, some emulsions having water percentages as low as 1% and others having water percentages as high as 80%. The measurement of droplets in the continuous phase of two types of emulsions can be used to categorize them. Droplets higher than 0.1 Mm can be observed in huge emulsions and this type is usually insecure thermodynamically. Micro-emulsions are thermodynamically stable and have extremely small droplets (less than 10nm). The nature and quantity of the emulsified substance, as well as temperature, mixing, and the qualities of both the water and the crude oil, all influence the distribution of droplets in an emulsion [4].

2.1. Types of Emulsion

Produced oilfield emulsions can be categorized into three basic groups: water-in-oil, oil-in-water, and numerous or complex emulsions. Water-in-oil emulsions consist of water droplets in a continuous oil phase, whereas oil-in-water emulsions consist of oil droplets in a water-continuous phase. figures 1 and 2 depict the two basic (water-in-oil and oil-in-water) forms of emulsions. In the oil business, water-in-oil emulsions are more common (most generated oilfield emulsions are of this form); hence, the oil-in-water emulsions are sometimes referred to as “reverse” emulsions [20].

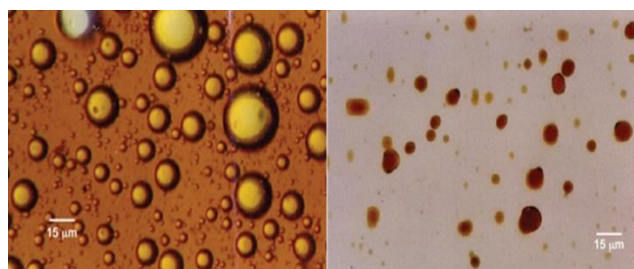


Figure 1. Photomicrograph of a water-in-oil emulsion and Photomicrograph of an oil-in-water emulsion [11].

Multiple emulsions are more complicated and comprise of tiny droplets suspended in bigger droplets that are suspended in a continuous phase. For example, a water-in-oil-in-water emulsion consists of water droplets suspended in bigger oil droplets that, in turn, are suspended in a continuous water phase. Figure 2. displays an example of a multiple emulsion [20].

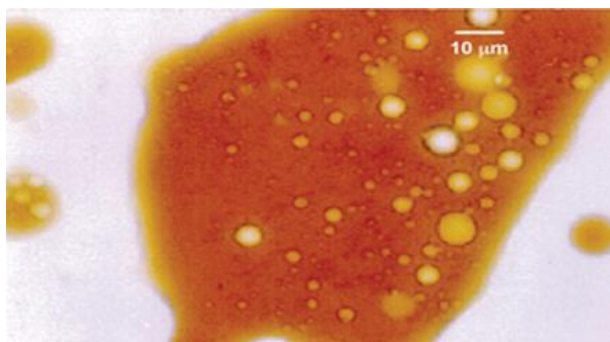


Figure 2. Photomicrograph of a water-in-oil-in-water emulsion [11].

Given the oil and water phases, the sort of emulsion created relies on numerous parameters. As a rule of thumb, when the volume percentage of one phase is very little compared with the other, the phase that has the smaller proportion is the dispersed phase and the other is the continuous phase. When the volume-phase ratio is near to 1 (a 50: 50 ratio), then additional factors govern the type of emulsion created [20].

Emulsions are also distinguished by the size of the droplets in the continuous phase. When the dispersed droplets are larger than 0.1 μm, the emulsion is a macroemulsion [20]. Emulsions of this sort are often thermodynamically unstable (i.e., the two phases will separate over time due of a tendency for the emulsion to reduce its interfacial energy by coalescence and separation). However, droplet coalescence can be minimized or even abolished employing a stabilization mechanism. Most oilfield emulsions fit in this group. In contrast to macroemulsions, there is a second type of emulsions known as microemulsions. These emulsions form spontaneously when two immiscible phases are brought together because of their very low interfacial energy. Microemulsions have very small droplet sizes, less than 10 nm, and are considered thermodynamically stable. Microemulsions are significantly different from macroemulsions in their formation and stability [20].

2.2. Crude Oil Demulsification (Emulsion Breaker)

Demulsification is the separation of a crude oil emulsion into oil and water phases. From a process point of view, the oil producer is concerned in three aspects of demulsification: rate or the pace at which this separation takes place, amount of water left in the crude oil after separation and quality of separated water for disposal.

A fast rate of separation, a low value of residual water in the crude oil, and a low value of oil in the waste water are obviously desirable. Produced oil normally has to meet company and pipeline criteria. For example, the oil delivered from wet-crude processing facilities must not contain more than 0.2% basic sediment and water (BS&W) and 10 pounds of salt per thousand barrels of crude oil. This standard relies on corporate

and pipeline characteristics. The salt is insoluble in oil and related with residual water in the processed crude. Low BS&W and salt concentration is essential to reduce corrosion and deposition of salts. The fundamental goal in refineries is to remove inorganic salts from the crude oil before they produce corrosion or other harmful consequences in refinery equipment. The salts are removed by washing or desalting the crude oil with relatively fresh water.

2.3. Methods of Emulsion Breaking (Demulsification)

These days, a variety of demulsification techniques—including thermal (heating and microwave irradiation), mechanical (settling under gravity, centrifugation, filtration, membrane, ultrasound treatment), chemical, biological, electrical, and magnetic methods—are employed to separate crude oil emulsions, [24] as cited by [14]. Recently, there have been several review papers describing these techniques in oil dewatering [2, 3, 8, 15, 18, 21-24] as cited by [14] with their associated advantages and disadvantages.

For example, chemical demulsification is one of the frequently employed and adaptable methods of demulsification of different types of emulsions, nonetheless, this process often contaminates the separated products and is not always economically feasible for all oil emulsions demulsification. Another very new developed technology of crude oil emulsion separation is a biological process. Despite its more eco-friendly and cost-effective nature, this method is time-consuming and very sensitive to operational conditions [16] as cited by [14] and therefore biodemulsification of crude oils is not considered in this review, since its effect is based on the action of demulsifier producing bacteria and, consequently, the formation of biosurfactants requires special attention to the consideration of properties of the isolated bacteria which are deemed to be out of the scope of this review.

Membrane separation is one of the effective and relatively new methods used for the separation of oil and water emulsions, which does not require large energy and thermal expenditure. However, the technique is vulnerable to fouling with the requirement for frequent cleaning, additionally relatively low permeate flux may be viewed as a constraint and a disadvantage of this technology [15, 24] as stated by [14]. Today membrane technology has been used more for the separation of oil-in-water emulsions or direct emulsions, such as industrial wastewater polluted with hydrocarbons [6] as quoted by [14].

Finally, electrical separation and microwave irradiation techniques might be used as a solution to the complex situations due to their relatively low cost and absence of extra contaminations, while low separation efficiency is the only noticeable drawback of these methods [24] as cited by [14].

There are many of study works focusing largely on the chemical and heat treatment of oil emulsions in Kazakhstan [1, 12, 13] as quoted by [14]. However, there are not enough

studies on integrating different effective and comparatively cost-efficient approaches and innovations on the demulsification of very stable heavy oil emulsions. Complex approaches may incorporate many modes of dewatering, for instance, chemical separation supported by microwave irradiation, membrane separation, or ultrasound treatment [3, 7], as referenced by [14]. Despite the previous critical evaluations [2, 18] of the current status of demulsification methods utilized in the oil sector, the selection of successful combination dewatering methods is still relevant.

3. Materials and Method

The following are the materials and the equipment used in carrying out the experimental work: Crude oil emulsion sample, Servo demulsifier, LD1 (mixture of Camphor, Hydraulic oil, Detergent, Alum), LD2 (mixture of Camphor, Lime oil, Hydraulic oil, Alum, Detergent), Weighing balance, Electric Magnetic heater stirrer, Beaker, Spatula, Mortar and piston, Blender, Thermostatic water bath.

3.1. Method

The methods in achieving the research are here below: Preparation of the local demulsifier LD1 and LD2.

LD1 composition:

Camphor 15g, Detergent 15ml, Hydraulic oil 50ml and Alum 5g while

LD2 composition:

Camphor 15g, Lime oil 15m, Hydraulic oil 50ml, Alum 5g and Detergent 50ml.

Procedure

- 1) The camphor and the alum were grinded into powder form using the blender
- 2) 15g of the camphor was measured and poured into beaker
- 3) 5g of alum was measured and poured into the beaker
- 4) 50ml of hydraulic oil was measured and was poured into the beaker
- 5) 15ml of detergent were measured and poured into the beaker

The resulted mixture in the beaker was put into the electric magnetic heater with stirrer for homogenous mixture. The stirrer was connected to the power source and was switched ON. It was heated for about ten (10)minutes and the composition changed to light gel-like structure. The end product was LD1. 10g of lime oil was added to the composition in LD1 above and the resulted product was the LD2.

3.2. Treatment of the Crude Oil Emulsion

The emulsion was treated using the three demulsifiers, (Servo, and the local LD1 and LD2).

Procedure

- 1) The crude oil emulsion was measured into six (6) pre-

scription bottles into three places for servo, LD1, and LD2 respectively.

- 2) Each of the demulsifiers was extracted at the ratio of 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 into each prescription bottle
- 3) The demulsifier with the emulsion was shaken for homogeneous mixture
- 4) The thermostatic water bath was plugged to power source, switched ON and was set at 60 °C
- 5) The prepared crude oil emulsion was put into the thermostatic water bath and was allowed to be heated for two (2) hours at 60 °C
- 6) After the two hours, the bottles were removed from the water bath and the reading at the zerominute and every 30minutes interval were taken and recorded

3.3. Confirmation Method of the Emulsion Treatment

This was done to confirm the percentage of water present in the crude oil after treatment. The method used to achieve this is the centrifuge method with the following equipment and procedures; crude oil sample, centrifuge machine and timer with the following procedures used;

- 1) The centrifuge machine was connected to power source
- 2) The crude oil sample was poured into the centrifuge tube to 10ml
- 3) The centrifuge tube with the oil was inserted into the jacket
- 4) The jacket was inserted into the machine
- 5) The machine was set at 5000rpm for fiveminutes
- 6) The machine was allowed to stop after the fiveminutes and the sample was brought out for separation analysis.

The result was taken and recorded

Calculation:

The percentage BS & W is calculated as below

$$\% \text{ BS \& W} = (X/10 \times 100)$$

Where X is the ratio of separation.

The result and all the findings are recorded in chapter four above.

4. Results and Discussion

From the graph of Figure 3 above at 0min, the components did not show any separation in ratio 0.2, 0.4, and 1.2. These three ratios were 100% oil but ratio 0.6, 0.8, and 1.0 shows little deflection pf water 2% without sludge. At 30min there was a little deflection in all the ratios showing 98% oil, 0% sludge, and 2% water but only ratio 0.6 difference of 95% oil and 5% water without sludge. At 60min they all shoe the same result of the 30min above. At 90min there was a consistent result of the previous time. In confirmation test there was a reasonable amount of separation of three components in the treated emulsion. All the ratios apart from 0.6 show 95% oil, 3% sludge, and 2% water. While that of ratio 0.6 shoes 90% oil, 8% sludge and 2% water. Un all the ratios with time dependent

and preference to confirmation test, ratio 0.6 performed the best while others follow regular pattern in servo.

While the graph below shows the detail representation of

the reactant LD1 in the component's separation at various ratios with respect to time and confirmation test in the treated crude oil emulsion.

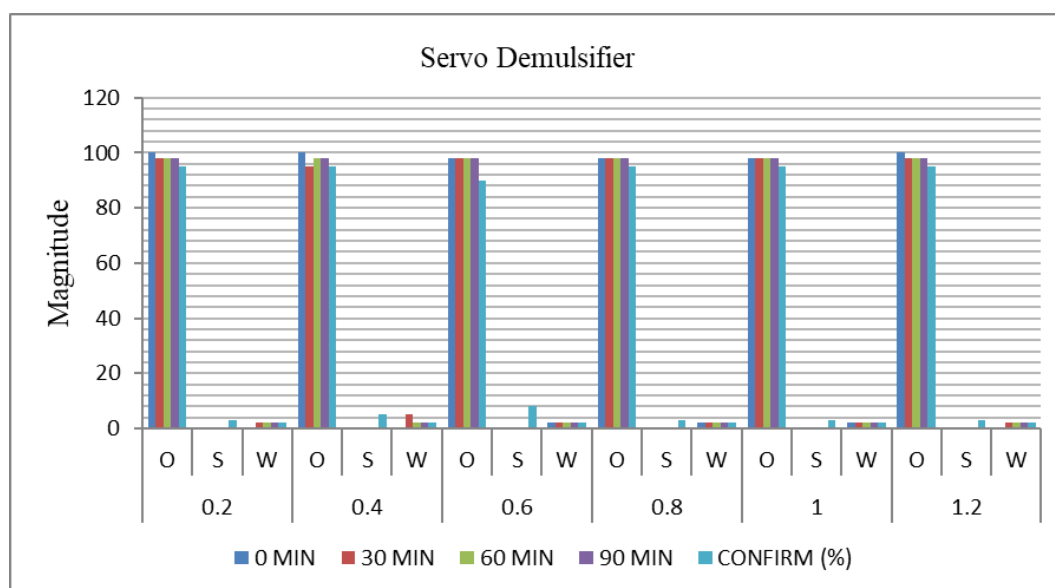


Figure 3. Result of servo in the crude oil emulsion treatment.

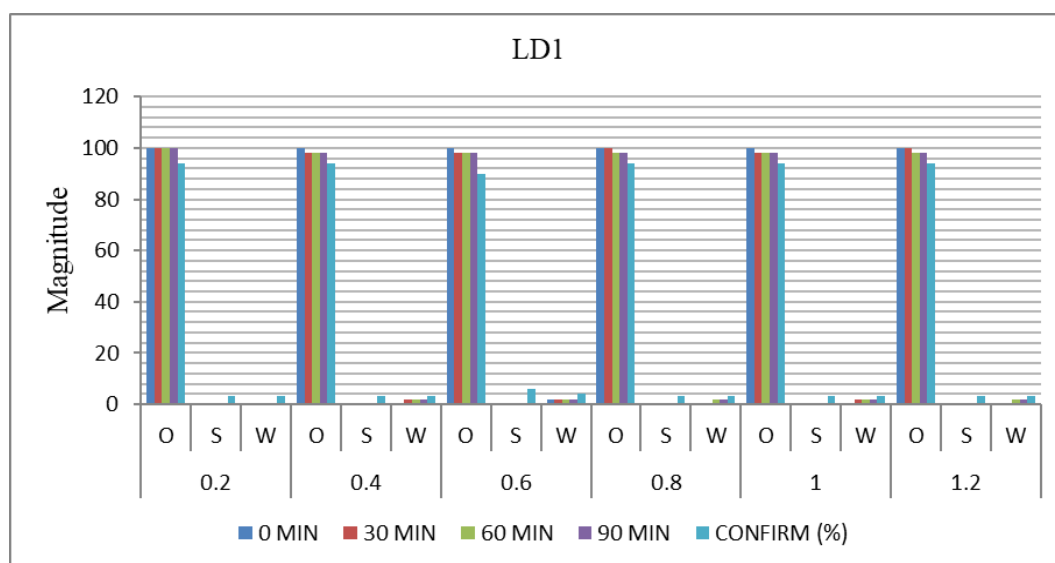


Figure 4. Result of LD1 in the crude oil emulsion treatment.

From Figure 4 which is the graph of reactant LD1, all the ratios were 100% oil without sludge and water at the 0min meaning there was no separation. At 30min there was a variation in ratios 0.4, 0.6, and 1.0 in the deflection of 98% oil, 2% water without sludge. There was no variation in 0.2, 0.8, and 1.2 which were still 100% oil without sludge and water. At 60min, ratio 0.2 still did not show any variation while all other ratios were 98% oil and 2% water without sludge. At 90min, there was a consistence of the previous reading at 60min. In confirmation test, there was a vivid separation in all with clear

water interface. Ratio 0.6 confirmed 90% oil, 6% sludge and 4% water. All other ratios confirmed 94% oil, 3% sludge and 3% water respectively. In reactant LD1, the ratio 0.6 performed least of oil recovery in the confirmatory test while every other ratio has the same variation as a regular pattern of 94% oil, 3% sludge, and 3% water.

And lastly, the LD2 Result Analysis on the graph below shows the detail representation of the reactant LD2 in the component's separation at various ratios with respect to time and confirmation test in the treated crude oil emulsion.

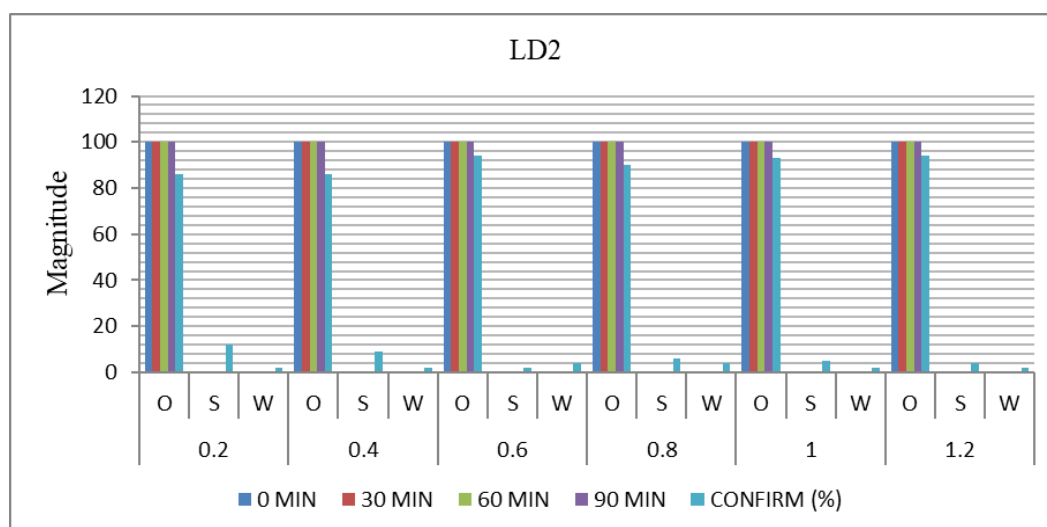


Figure 5. Result of LD2 in the crude oil emulsion treatment.

From Figure 5 above, the reactant LD2 shows no reaction with respect to time in the composition of the emulsion at various ratios. This implies the reactant LD2 was unable to break the emulsion with the effect of the applied heat.

There was a rigorous change in confirmation test. A vivid water interface with high level of sludge was observed. Ratio 0.6 and 1.2 performed the best in oil recovery of 94% and 6% for sludge and water. Others are 0.8, 1.0, 0.4, and 0.2 in the order of their percentage hierarchy of oil recovery in the confirmation test.

In the LD2, the reactant was unable to break the emulsion but only confirmation test did. That is to say that the LD2 reactant is not a good designed demulsifier for the emulsion breaker.

5. Conclusion

In the three reagents used for the treatment, LD2 performed the best treatment in confirmatory test at ratio 0.2 to be 86% oil, 12% sludge, and 2% water. But Servo and LD1 confirmed the same as 90% oil, with 10% impurities at the same ratio of 0.6 respectively. LD1 performed better than Servo in the subsequent ratios. It is therefore concluded that the processed crude was an emulsion and that the three reagents used for the treatment separated the emulsion into three components of oil, sludge, and water. The purpose of the project is achieved as the formulated demulsifiers, LD1 and LD2 were able to produce perfect desirable result of breaking the emulsion into its components of oil, sludge, and water.

Abbreviations

BS&W	Basic Sediment and Water
LD1	Local Demulsifier 1
LD2	Local Demulsifier 2
OSW	Oil, Sediment (Sludge), Water

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Adilbekova, A. O, Omarova, K. O, Karakulova, A, Musabekov, K. B (2015), Nonionic surfactants based on polyoxyalkylated copolymers used as demulsifying agents, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Volume 480, 5 September 2015, Pages 433-438, <https://doi.org/10.1016/j.colsurfa.2014.11.004>
- [2] Abdulredha Murtada Mohammed, Siti Aslina Hussain, Luqman Chuah Abdullah, (2020): Optimization of the demulsification of water in oil emulsion via non-ionic surfactant by the response surface methods, *Journal of Petroleum Science and Engineering*, Volume 184, 106463, ISSN 0920-4105, <https://doi.org/10.1016/j.petrol.2019.106463>
- [3] Abed S M, N H Abdurahman, R M Yunus, H A Abdulbari and S Akbari, (2019): Oil emulsions and the different recent demulsification techniques in the petroleum industry - A review. <https://doi.org/10.1088/1757-899X/702/1/012060>
- [4] Ahmed Abdulrazzaq Hadi, Ali Abdulkhabeer Ali, Mohammed Turki khathi, (2021): A review Of Emulsification Types, Formation Factors, And Current Treatment Methods, <http://dx.doi.org/10.1016/j.matpr.2022.01.091>
- [5] Goodarzi F, Zendehboudi S, (2019). A comprehensive review on emulsions and emulsion stability in chemical and energy industries. *Can J ChemEng* 97(1): 281–309.
- [6] Kim, Y, Kim, H. W, and Park, H. J (2021), Effect of pea protein isolate incorporation on 3D printing performance and tailing effect of banana paste, *LWT*, Volume 150, October 2021, 111916, <https://doi.org/10.1016/j.lwt.2021.111916>

- [7] Kang, W, Yin, X, Yang, H, Zhao, Y, Huang, Z, Hou, X, Sarsenbekuly, B, Zhu, Z, Wang, P, Zhang, X, Geng, J, Aidarova, S, (2018), Demulsification performance, behavior and mechanism of different demulsifiers on the light crude oil emulsions, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, Volume 545, 20 May 2018, Pages 197-204, <https://doi.org/10.1016/j.colsurfa.2018.02.055>
- [8] Lim, J. S, Wong, S. F, Law, M. C, Samyudia, Y, Dol, S. S, (2015), A review on the effects of emulsions on flow behaviors and common factors affecting the stability of emulsions, *J. Appl. Sci.*, 15(2015), pp. 167-172, <https://doi.org/10.3923/jas.2015.167.172>
- [9] Mohyaldinn ME, Hassan AM, Ayoub MA (2018). Application of emulsions and microemulsions in enhanced oil recovery and well stimulation. *Intech Open*, (tourism), p 13.
- [10] Matijasevic B, Banhart J (2006) Improvement of aluminium foam technology by tailoring of blowing agent. *Scripta Mater* 54(4): 503–508. <https://doi.org/10.1016/j.scriptamat.2005.10.045>
- [11] Petrowiki, (2015): Oil emulsion – Petrowiki – Society of Petroleum Engineers. https://petrowiki.spe.org/Oil_emulsions
- [12] Orazbekuly, Y, Galina I. Boiko, Nina P. Lubchenko, Sergey A. Dergunov (2014), Novel high-molecular multifunctional reagent for the improvement of crude oil properties, *Fuel Processing Technology*, Volume 128, December 2014, Pages 349-353, <https://doi.org/10.1016/j.fuproc.2014.07.039>
- [13] Otarbaev, N. S, Kapustin, V. M, Nadirov, K. S, Bimbetova, G. Z, Zhantasov, M. K, and Nadirov, R. K. (2019), New Potential Demulsifiers Obtained by Processing Gossypol Resin, *Indones. J. Chem.*, 2019, 19(4), 959 – 966.
- [14] Saidulla Faizullayev, Akbota Adilbekova, Wojciech Kujawski, Mojtaba Mirzaeian, (2022): Recent demulsification methods of crude oil emulsions – Brief review, *Journal of Petroleum Science and Engineering*, Volume 215, Part B, 110643, <https://doi.org/10.1016/j.petrol.2022.110643>
- [15] Saad, M. A., Kamil, M., Abdurahman, N. H., Yunus, R. M., & Awad, O. I. (2019). An overview of recent advances in state-of-the-art techniques in the demulsification of crude oil emulsions. *Processes*, 7(7), 470.
- [16] Sabati, H., and Motamedi, H. (2018), Investigation of the relationship between cell surface hydrophobicity and demulsifying capability of biodemulsifier-producing bacteria. *Front. Biol.* 13, 358–365 (2018). <https://doi.org/10.1007/s11515-018-1514-2>
- [17] Sofiah Atirah Raya, Ismail Mohd Saaid, Abdelazim Abbas Ahmed, Abubakar Abubakar Umar, (2020). A critical review of development and demulsification mechanisms of crude oil emulsion in the petroleum industry. *Journal of Petroleum Exploration and Production Technology* <https://link.springer.com/journal/13202>
- [18] Sousa, A. M, Pereiram M. J, Matos, H. A (2022), Oil-in-water and water-in-oil emulsions formation and demulsification, *Journal of Petroleum Science and Engineering*, Volume 210, March 2022, 110041, <https://doi.org/10.1016/j.petrol.2021.110041>
- [19] Sjöblom J (2001) *Encyclopedic Handbook of Emulsion Technology*. Crc Press, Hoboken.
- [20] Sunil L. Kokai, Saudi Aramco, (2017): Crude oil Emulsion, *Petroleum Engineering Handbook* page 533-570. https://petrowiki.spe.org/PEH:Crude_Oil_Emulsions
- [21] Umar, A. A, Ismail Bin Mohd Saaid, Aliyu Adebayo Sulaimon, Rashidah Bint Mohd Pilus (2018), A review of petroleum emulsions and recent progress on water-in-crude oil emulsions stabilized by natural surfactants and solids, *Journal of Petroleum Science and Engineering* Volume 165, June 2018, Pages 673-690, <https://doi.org/10.1016/j.petrol.2018.03.014>
- [22] Wong, S. F, Lim, J. S, Dol, S. S (2015), Crude oil emulsion: A review on formation, classification and stability of water-in-oil emulsions, *Journal of Petroleum Science and Engineering*, Volume 135, November 2015, Pages 498-504, <https://doi.org/10.1016/j.petrol.2015.10.006>
- [23] Zadymova, N. M, Skvortsova, Z. N, Traskin, V. Y, Yampol'skaya, G. P, Mironova, M. V, Frenkin, E. I, Kulichikhin, V. G & Malkin, A. Y. (2016), Heavy oil as an Emulsion: Composition, Structure, and Rheological Properties, *Colloid J* 78, 735–746 (2016). <https://doi.org/10.1134/S1061933X16060211>
- [24] Zolfaghari R, Fakhru'l-Razi A, Abdullah LC, Elnashaie SSEH, Pendashteh A (2016) Demulsification techniques of water-in-oil and oil-in-water emulsions in petroleum industry. *Separation Purification Technology* 170: 377–407. <https://doi.org/10.1016/j.seppur.2016.06.026>