

Nonionic Demulsifier for Smart Demulsification of Crude Oil Emulsion at Room and Moderate Temperatures

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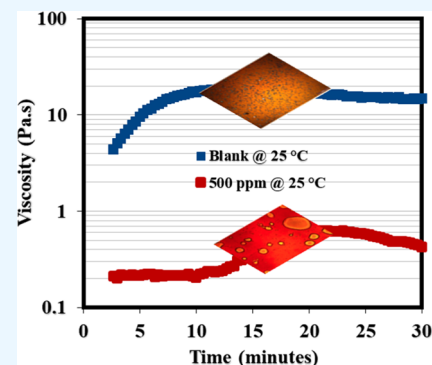
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ABSTRACT: This study reports the demulsification activity of a newly developed nonionic demulsifier (NID) via the condensation of glycolic acid ethoxylate lauryl ether with amine. The demulsification performance of the developed NID was assessed under room and moderate temperatures (25 and 60 °C), while the concentrations of NID were varied from 100 to 700 ppm at both temperatures in order to observe their oil–water separation efficiency. The demulsification mechanism was expatiated by determining the viscosity and elastic modulus of emulsion in the presence and absence of the NID. Adsorption at the oil and water interface was analyzed through a series of interfacial tension measurements. Accordingly, under the aforementioned temperatures, the optimal demulsification efficiency of the NID was 95% (25 °C) and 99% (60 °C) at 500 ppm. Viscosity determination at both temperatures revealed a drastic reduction in emulsion viscosity in the presence of NID, and the viscosity drop was of high magnitude at moderate temperatures (60 °C). Likewise, the elastic modulus measurements in bulk rheology revealed that the presence of NID in the emulsion weakened the elastic strength. Again, the interfacial modulus test exhibited the percolation of NID at the oil–water interface and the displacement of asphaltenes. Interfacial tension (IFT) measurements of the oil–water system at different NID concentrations showed that the particles were adsorbed at the oil–water interface. The IFT values of the oil–water system in the presence of NID ranged from 1.84 to 3.02 mN/m as compared to that of the NID-free oil–water system recorded as 16.11 mN/m. It is envisaged that this new nonionic demulsifier would be very useful in oilfields and petrochemical industries.



1. INTRODUCTION

Crude oil emulsions are inevitably a serious challenge in the petroleum industry, especially during hydrocarbon exploitation and processing. Owing to the presence of solid particles, resins, asphaltenes, and other natural substances in crude oil, the formation of oil emulsions becomes feasible in the course of mining, processing, and transportation.¹ However, the corrosive implications of emulsions on equipment, pipeline damage, and increased operational cost necessitate the need to separate water at upstream prior to the conveyance of crude oil to the refining plant for further processing.²

Demulsification in the petroleum industry refers to the means or technique applied to effectively separate water and crude oil from the produced oil emulsion, such that the crude oil transported through pipelines to the refinery contains a minimal amount of water. The notable applied demulsification techniques are primarily physical, biological, and chemical.^{3–5} Physical demulsification techniques include microwave irradiation,^{6,7} gravitational settling,⁸ membrane separation,^{9–11} filtration,¹² and ultrasonic method.^{13–15} Biological demulsification involves the use of bacteria to demulsify oil emulsions aided by bacteria cells or extracellular compounds.¹⁶ Chemical demulsification is one of the techniques employed in the petroleum and petrochemical industries to break crude

emulsions and emulsified oil–water mixtures, and this method is known to be efficient for lowering the emulsion stability and enhancing the film-thinning by using chemicals called demulsifiers. These chemical demulsifiers are amphiphilic and neutralize the emulsion stability by absorbing at the oil–water interface and modifying the interfacial properties.¹⁷ Chemical demulsification is composed of two mechanisms: the demulsifier demonstrates a high interfacial activity and migrates to the oil–water interface, and the demulsifier displaces the interfacial films and promotes film drainage by lowering the tension gradient.¹⁷ Eventually, oil–water separation takes place via coalescence or flocculation.

Numerous research activities have been conducted by many researchers to develop varieties of chemical demulsifiers.^{18–24} Among the notable chemical demulsifiers in the petroleum and petrochemical industries are ionic liquids.^{25–35} In a demulsi-

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fication study by Qu et al.,² two unique ionic liquids (PPBD and PPBH) with four ionic centers and four hydrophobic branches were synthesized for oil–water emulsion separation at a low demulsification temperature (40 °C). The outcome of their work showed that the addition of 250 mg/L of PPBH and PPBD in separate emulsions resulted in 96.34 and 95.23% demulsification efficiency (DE), respectively, at 40 °C. In another investigation by Lei and his colleagues,³⁶ a Gemini ionic liquid (PGE-TFA) with interfacial activity was synthesized for breaking crude oil emulsions. The 500 mg/L PGE-TGA achieved about 95.53% oil–water separation within 90 min at 40 °C. At elevated demulsification temperature (70 °C), they reported that 500 mg/L PGE-TGA could only achieve a slight increase in demulsification efficiency (97.72%). Also, ethylene oxide,^{22,23,32,37,38} propylene oxide,^{22,23,30,37,39–41} and their derivatives are very prominent among other ionic liquid demulsifiers. Several literature studies have assessed the demulsification performances of these ionic liquids in the presence of different water types,^{42–44} at various temperatures,^{2,22,23,45} in the presence of salts,^{45–48} and the impact of acidic and alkaline conditions^{23,36,45,49,50} on the activity of these demulsifiers. However, one of the key salient issues with some, if not many, ionic liquids is their poor demulsification activity at room temperature (e.g., 20–25 °C) and temperatures within 60 °C.²² Besides, the cost implication and toxicity concerns of ionic liquids are becoming a high priority in oilfields coupled with their tedious and hazardous preparation steps. Owing to these alarming factors, researchers are intensifying tremendous efforts to design new and efficient chemical demulsifiers that would be cost-effective, eco-friendly, and efficiently separate oil and water at low and moderate temperatures.

In this study, a nonionic demulsifier (NID) was developed by condensation of glycolic acid ethoxylate lauryl ether with amine. The use of such nonionic demulsifiers has not been extensively studied in the demulsification of crude oil emulsions. In demulsification research that was carried out by Zhang et al.,¹ an oxygen-enriched nonionic demulsifier was developed, and the authors claimed this nonionic demulsifier achieved 100% dehydration in less than 25 min. Thus, the present study reports the demulsification performance of an in-house developed nonionic chemical demulsifier. The synthetic route and chemical structure characterization of this demulsifier have already been reported in our preceding report.⁵¹ This demulsifier has not been reported in the literature for demulsification application, and this is the first report on the use of this chemical as a demulsifier of crude oil emulsion. In addition, this laboratory-grown nonionic demulsifier is eco-friendly, less toxic, and inexpensive, and its oil–water efficiencies are comparable to many other chemical demulsifiers.^{22,24,49,50,52,53} In this work, stable emulsions were produced from crude oil and laboratory-synthesized seawater, and the demulsification performance of this new chemical demulsifier was tested at various concentrations and at room and moderate temperatures (25 and 60 °C). The demulsification mechanism of this nonionic demulsifier was studied via rheological means under the aforementioned temperatures by measuring the rheological properties of the produced emulsions in the presence and absence of the synthesized demulsifier. By doing so, the rheological measurements shed light on how this new demulsifier was able to diffuse and displace the emulsifiers at the interface of oil and water. Likewise, the interfacial tension (IFT) measurements were

performed at various concentrations of this nonionic demulsifier (NID) in order to assess its migration and aggregation at the oil–water interface. It is envisaged that this NID would be very useful in the treatment of emulsions in the petroleum and petrochemical industries.

2. EXPERIMENTAL SECTION

2.1. Materials. At 15 °C, the oil possesses an API gravity of 32.5 and viscosity of 10.9 mPa.s. The oil contains saturates (36.2%), asphaltenes (2.8%), resins (11%), and aromatics (50%). This crude oil is obtained from one of the oilfields in Saudi Arabia. The laboratory-produced seawater was prepared from the following salts: Na₂SO₄, NaCl, MgCl₂, NaHCO₃, and CaCl₂, with a total of 57,700 mg/L salinity (Table 1). This

Table 1. Ions in the Laboratory-Synthesized Seawater

ions	concentration (mg/L)
Na ⁺	18,300
Ca ²⁺	700
Mg ²⁺	2100
SO ₄ ²⁻	4300
Cl ⁻	32,200
HCO ₃ ⁻	100
total	57,700

particular seawater concentration was used because oilfields have high salinity during crude oil processing. So, this concentration was used to mimic the oilfields scenario. The precursor chemicals and reagents used in the synthesis of the nonionic demulsifier (NID) were supplied by Sigma-Aldrich. The precursor chemicals and reagents used in the synthesis of the nonionic demulsifier (NID) such as glycolic acid ethoxylate lauryl ether (CAS 220622-96-8) were supplied by Sigma-Aldrich.

2.2. Emulsification and Demulsification Methods. To produce a stable crude oil emulsion, seawater was added systematically inside a beaker filled with a determined amount of crude oil. A 30 mL portion of water was added gradually into 20 mL of crude oil and agitated under a constant speed of 1100 ppm. Prior to mixing, formation water in crude oil was removed using the centrifuge. The mixing proceeded until a single phase was detected after 1 h. The produced emulsion was examined under ambient conditions for 6 weeks to ensure that there was no phase separation. After 6 weeks of preparation, there was no noticeable oil/water separation. A bottle test procedure was utilized to investigate the demulsification activity of the synthesized NID. Then, six g (6 g) of NID was dissolved in a 50 mL bottle containing 14 g (14 g) of 2-propanol, making the bulk demulsifier solution 30 wt %. Afterward, various concentrations of the NID ranging from 100, 300, 500, and 700 ppm were formulated and injected into vials containing the produced emulsions and tightly covered. The demulsification performance was thereafter studied at room temperature (25 °C) and inside the oven at moderate temperature (60 °C). Besides, a blank emulsion sample without the NID was prepared as a control sample. All samples were hand shaken for 10 s, and oil/water separation was monitored periodically. The demulsification efficiency of NID at various concentrations was evaluated using the formula⁵⁴ shown in eq 1. The demulsification rate describing the extent of water removal from emulsion with respect to time was determined by eq 2.

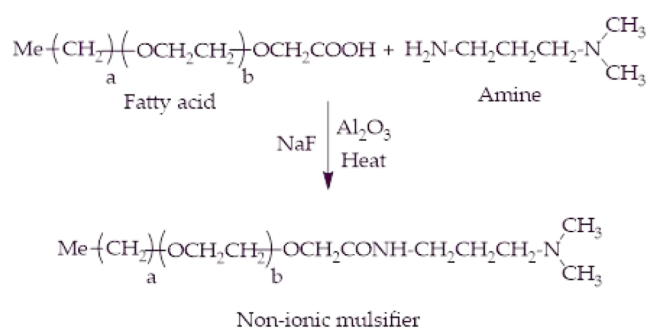
$$\text{demulsification efficiency (\%)} = \frac{V}{V_0} \times 100 \quad (1)$$

$$\text{demulsification rate} = \frac{V}{t} \quad (2)$$

where V is the volume of separated water, V_0 is the volume of initial water in the produced emulsion, and t is the periodic settling time (min) of the separated water.

2.3. Synthesis of Nonionic Demulsifier (NID). A round-bottom flask fitted with a condenser was placed on a magnetic stirrer and filled with a 1:1.5:0.1 ratio of glycolic acid ethoxylate lauryl ether, amine, and sodium fluoride, respectively. The reaction progressed for 12 h at 160 °C with a continuous flow of argon. Eventually, the extra amine was evaporated by reduced pressure, and sodium fluoride was removed by filtration to obtain the nonionic demulsifier (NID), as shown in Scheme 1. The Fourier transform infrared

Scheme 1. Synthetic Route of the Developed Nonionic Demulsifier (NID)



(FTIR) spectrum (Figure 1a) of NID revealed an adsorption band at 3412 cm^{-1} that corresponds to the N–H stretching vibration. The resonating peak that appeared at 1658 cm^{-1} was mainly due to the stretching vibration of the amide group. Moreover, the CH_2 bending vibration was observed at 1460 cm^{-1} . Two distinguished signals were noticed at 2921 and 2855 cm^{-1} and assigned to the asymmetric and symmetric stretching vibrations of the C–H bond in the aliphatic tail. The prominent sharp peak at 1097 cm^{-1} is connected to the ether (C–O–C) group. Represented in Figure 1b is the thermal analysis of NID, as determined by the thermogravimetric analysis (TGA). The initial weight losses at temperatures less than 100 °C are invariably due to the evaporation of residual moisture, while the sharp weight loss at 298 °C above exhibited the temperature effect on the structural degradation of NID. Since the demulsification activities in several oilfields are carried out at 50–100 °C, NID would withstand these temperatures without quick degradation. Regarding the ^1H NMR of NID (Figure 1c), the signals at δ 0.88 ppm are the single methyl group at one end, and the peak at δ 2.33 ppm is the two methyl groups at the second end attached to tertiary nitrogen. The signals of multiple $-\text{CH}_2-$ groups of the lipophilic tail were detected at δ 1.25 ppm. The prominent large peak at δ 3.67 ppm was connected to the ethoxy ($-\text{C}-\text{C}-\text{O}-$) groups, and the proton of the amide group was observed at δ 7.56 ppm. Represented in Figure 1d is the ^{13}C NMR of NID in which the peak at δ 14.0 ppm is the methyl group at one end, and the peak at δ 45.3 ppm is the two methyl groups at the second end attached to tertiary nitrogen. The repeating $-\text{CH}_2-$ units were resonated at δ 29.4 ppm, and the

repeating ethoxy groups were observed at δ 70.4 ppm. The carbonyl carbon of amide groups was detected at δ 169.8 ppm. According to the electrospray ionization mass spectrometry (ESI-MS) data of NID (Figure 1e), the base peak at m/z 813.6 seems to agree with the chief component being NID where $a = 11$ and $b = 11$. The following peaks before and after the base peak were the distribution of the ethoxy groups having a mass difference of (m/z 44), which is the mass of one ethoxy group.

Figure 2a shows the surface tension of the NID aqueous solution measured at various concentrations. The data plot revealed a reduction in surface tension with the increasing concentration of NID until the critical micelle concentration (cmc) is reached at 0.068 wt % (680 ppm). Following the cmc point, the air/water interface would be surrounded by NID molecules, and a further increase in the NID concentration would therefore not have any effect on the surface tension. Figure 2b presents the turbidity of the NID aqueous solution at varying concentrations under different temperatures. The NID turbidity level at 0.25 wt % was nearly constant until 324 K, and a fair increment in turbidity was then experienced up to 342 K. At 0.5 wt % NID, the turbidity was almost constant throughout the entire temperature; however, the turbidity level of NID at 0.5 wt % was higher than that of 0.25 wt %, suggesting enhanced solubility of NID at 0.5 wt % and the formation of micelles.¹ However, a reduction in the turbidity set in as the NID concentration was increased to 0.75 wt %, and this reduction intensified at 1 wt % NID across all of the temperatures. This observation suggests a decrease in the solubility of NID molecules in water since 0.75 wt % and above already surpassed the cmc⁵⁵ of the developed NID in aqueous solution.

2.4. Characterizations. The investigation of emulsion morphology was performed using a Leica DM2000 microscope to ensure accurate analysis. The chemical composition of the NID was elucidated through Fourier transform infrared (FTIR) spectroscopy. The thermal resilience of the chemical demulsifier was determined by employing a thermogravimetric analyzer (TGA) from TA Instruments.

Bulk rheology of produced emulsions and oil–water interfacial modulus measurements were carried out using a TA rheometer (DHR-3). For emulsion viscosity determinations, a fixed shear rate of 0.01 s^{-1} was applied, while storage modulus measurements were conducted at a 5% strain, depicting the region of linear viscoelasticity. The concentric cylinder geometry was used during bulk rheology tests, while double wall ring (DWR) interface geometry was employed for oil–water interfacial modulus measurements.

To evaluate the NID adsorption at the interface of oil and water, the surface activity described as the surface tension and interfacial tension (IFT) was performed at room temperature (25 °C) by using the Biolin Scientific machine. The interfacial tension (IFT) values were also determined for the oil–water system without a NID (blank sample). The turbidity measurement of NID aqueous solution at various concentrations was determined using the Data Physics Multi Scan 20 stability analysis system. A vial filled with NID aqueous solution was placed in the scan tower of the system. The turbidity was calculated from the obtained transmission and backscattering intensity at the specified temperatures (300 to 343 K). The unit of turbidity was recorded as the nephelometric turbidity unit (NTU).

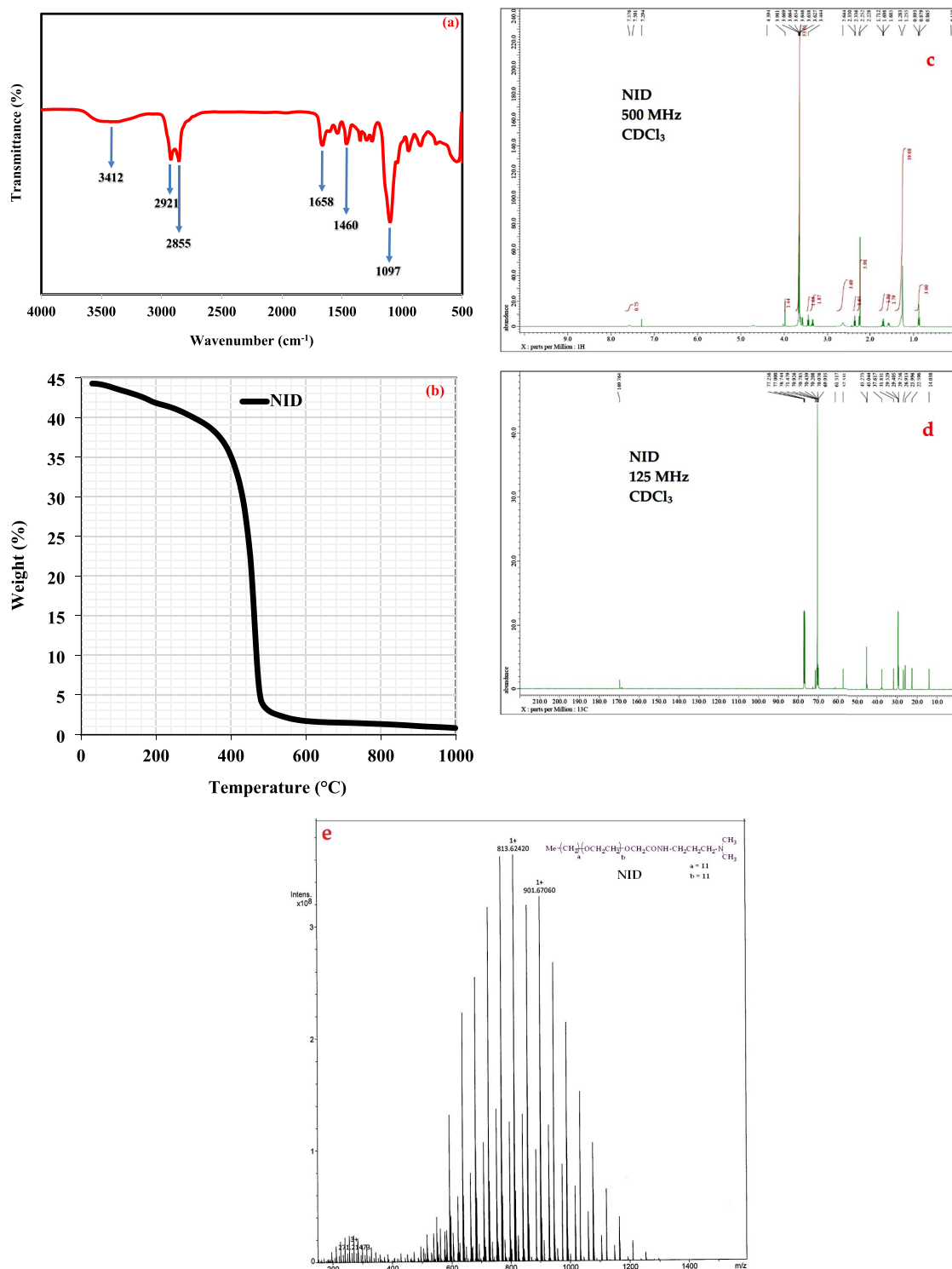


Figure 1. (a) FTIR spectrum, (b) TGA curve, (c) ^1H NMR spectra, (d) ^{13}C NMR spectra, and (e) ESI-MS analysis of the NID developed.

3. RESULTS AND DISCUSSION

3.2. Characterization of the Produced Emulsion.

Emulsions reported in this study were produced by the rigorous agitation of crude oil from an oilfield and laboratory-formulated seawater. After proper preparation, the stability of the formed emulsion was monitored for 8 weeks without any visual separation of the phases. Figure 3a shows the optical microscopic image of the formed emulsion in which the droplets analyzed under the microscope possessed average

sizes in the range of 0.1–17 μm . By observation, water droplets were dispersed in the crude oil, indicating that the produced emulsion was water-in-oil (W/O), and this was also confirmed by checking the emulsion conductivity, which is close to being zero. Figure 3b relates the viscosity and stress behavior of this emulsion as a function of the shear rate from 0.1 to 1000 s^{-1} . The emulsion viscosity was observed to be declining as the shear rate increased. This is expected due to the aggregation of molecules in the emulsion sample.⁴² The stress behavior of this

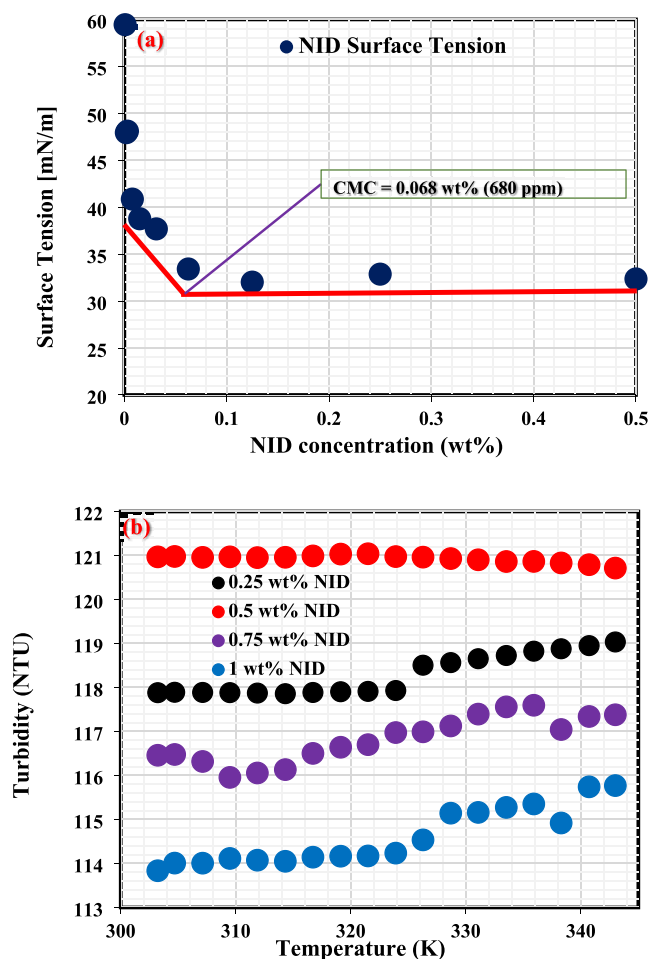


Figure 2. (a) Surface tension of NID aqueous solution measured at room temperature (25 °C). (b) Turbidity curves of NID aqueous solution at different concentrations and temperatures.

emulsion was observed to have increased as shear rate values increased, indicating shear thinning characteristics.⁴²

3.3. Demulsification Performance of NID. This section reports the demulsification performance of NID at room and moderate temperatures (25 and 60 °C). Varying NID concentrations from 100, 300, 500, and 700 ppm were tested to assess their potential to break the produced crude oil emulsions and effectively separate crude oil and water into clear phases under the aforementioned demulsification temperatures. Figure 4a reflects the demulsification efficiencies at various NID concentrations (100–700 ppm) under room temperature (25 °C). As can be seen in this figure, the blank emulsion remained unchanged (no separation) for 12 h of monitoring; however, oil/water separation was noticed to have increased with the increasing NID concentration for 12 h demulsification duration. After 12 h of demulsification activity at room temperature, the demulsification efficiencies of NID at 100, 300, 500, and 700 ppm were evaluated to be 45, 68, 95, and 93%, respectively. Following this, the demulsification activity of NID was tested inside the oven at a moderate temperature (60 °C) because many chemical demulsifiers could work better for demulsification at elevated temperatures, hence among the key reasons for conducting the current demulsification study at room and moderate temperatures. Shown in Figure 4b is the demulsification activity of various concentrations of NID at 60 °C. Just like the demulsification

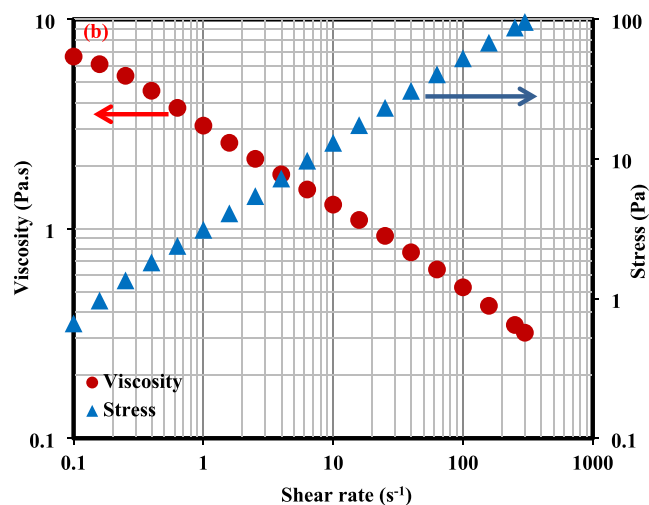


Figure 3. (a) Optical image of the produced crude oil emulsion. (b) Viscosity behavior and stress of the produced emulsion.

condition of the blank emulsion under room temperature, the blank sample again did not reveal any observable oil/water separation during the entire 120 min (2 h) demulsification duration at 60 °C. However, under this demulsification temperature (60 °C), oil/water separation was observed to be rapid at different NID concentrations. The demulsification efficiency of NID at 100, 300, 500, and 700 ppm after 2 h of demulsification activity was estimated to be 75, 88, 99, and 96%, respectively. It is necessary to note that the demulsification activity and the demulsification duration were shorter at moderate temperature (60 °C) compared with the demulsification activity under room temperature (25 °C) conditions. This scenario is expected because increasing the demulsification temperature would generally contribute to the instability of emulsion, and this would favor a swift oil/water separation.⁴² The demulsification efficiency (DE) of NID at 25 and 60 °C is obviously considerable, and its performance is compared with some notable chemical demulsifiers, as shown in Table 2. As can be seen from this table, NID would be a promising demulsifier that can compete favorably with the existing chemical demulsifiers employed for the separation of oil–water mixtures in the petroleum industry. Further, Figure 5a,b relates the demulsification rate at both temperatures (25 and 60 °C), describing the extent to which every tested concentration of NID was able to dispel water under a specified period during the demulsification activity. Generally, the demulsification activity of the NID proceeded at a faster

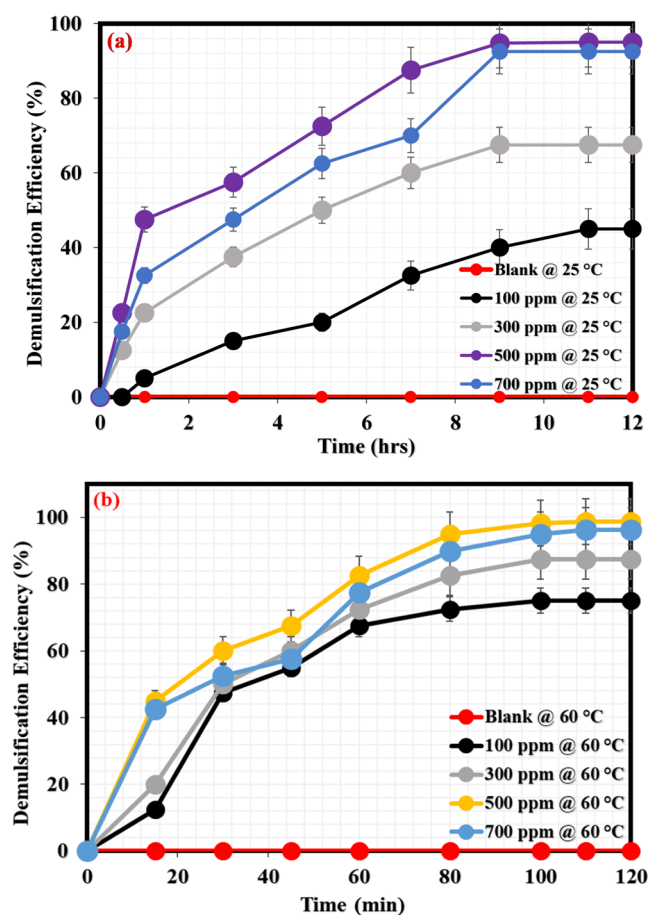


Figure 4. (a) Demulsification efficiency at different NID concentrations (25 °C); (b) demulsification efficiency at different NID concentrations (60 °C).

Table 2. Demulsification Efficiency (DE) of NID in Relation to Some Existing Chemical Demulsifiers

chemical demulsifier	concentration (ppm)	temperature (°C)	DE (%)	reference
poly(amido amine) demulsifier	50	ambient	91.5	Kuang et al. ⁵⁶
gemiini ionic liquid demulsifier (Y12)	400	50	100	Ding et al. ²³
low-temperature ionic liquid demulsifier (EBTA)	250	40	95.36	Tang et al. ²¹
ionic liquid PPBH	250	40	96.34	Qu et al. ²
ionic liquid PPBD	250	40	95.23	Qu et al. ²
nonionic demulsifier	500	25	95	this work
nonionic demulsifier	500	60	99	this work

rate under moderate temperature as compared to the demulsification activity experienced under room temperature.

3.4. Viscosity and Elastic Modulus Measurements.

This section presents the application of rheology to shed more light on the demulsification mechanism of the synthesized NID. The demulsification of emulsions via the bottle test is a simple physical technique that is practically not adequate to establish the working mechanism of a typical chemical demulsifier. Rheology is another reliable method among other methods that could be applied to assess the workability of a chemical demulsifier upon its injection into the produced

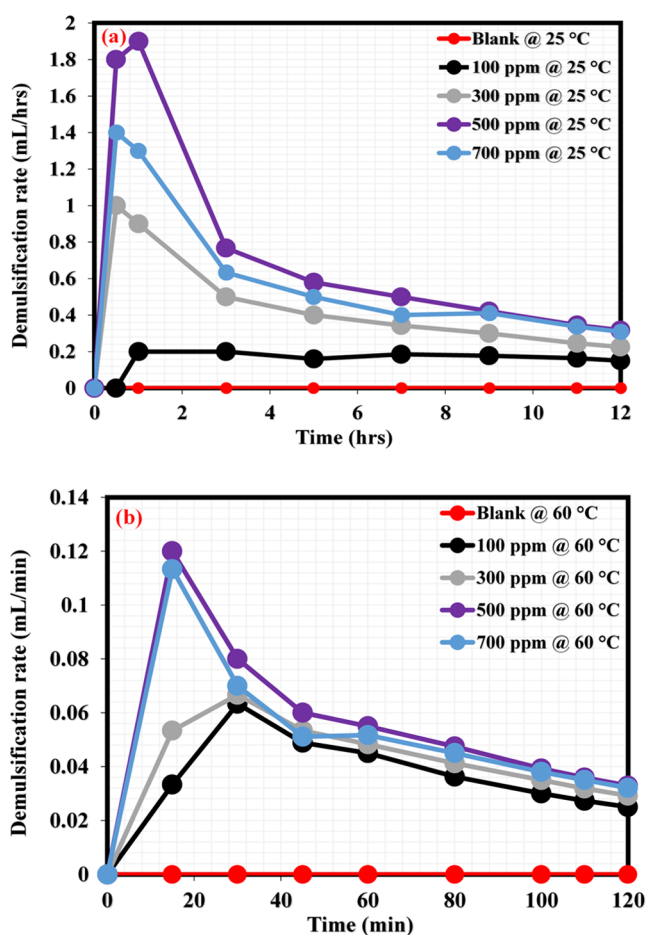


Figure 5. (a) Demulsification rate of various NID concentrations at room temperature (25 °C); (b) demulsification rate of various NID concentrations at moderate temperature (60 °C).

emulsion. The bulk rheology test of produced crude oil emulsion before and after the addition of NID is among the reliable means of establishing the efficacy of an actively working demulsifier.^{37,58} This technique is reasonable and well adopted by the researchers because the crude oil exploration comes out of oil wells to the subsurface in the form of real emulsion before it is conveyed to the separator tank for separation. It is expected that the viscosity of the emulsion should differ before and after demulsifier injection. Usually, the emulsion viscosity drops in the presence of an active demulsifier. This means that an excellent demulsifier would penetrate and adsorb at the oil/water interface and subsequently rupture the interfacial films^{22,44,49,59} that are bonding the oil–water molecules. Likewise, the interfacial films of emulsion possess a sort of mechanical strength^{22,60,61} enabling the oil–water interface to remain intact, and as far as the current study is concerned, the NID developed was not added to the crude oil directly; rather, it was incorporated into the formed emulsion in order to examine the weakening of oil–water bonding molecules at the interface, which would definitely lead to emulsion viscosity reduction. Represented in Figure 6a,b is the viscosity profile of the produced emulsion before and after the injection of 500 ppm of NID at 25 and 60 °C. As can be noticed at both temperatures, the viscosity of the emulsion infused with 500 ppm of NID dropped considerably as compared to that of the blank sample. The viscosity reduction at both temperatures is an indication of the

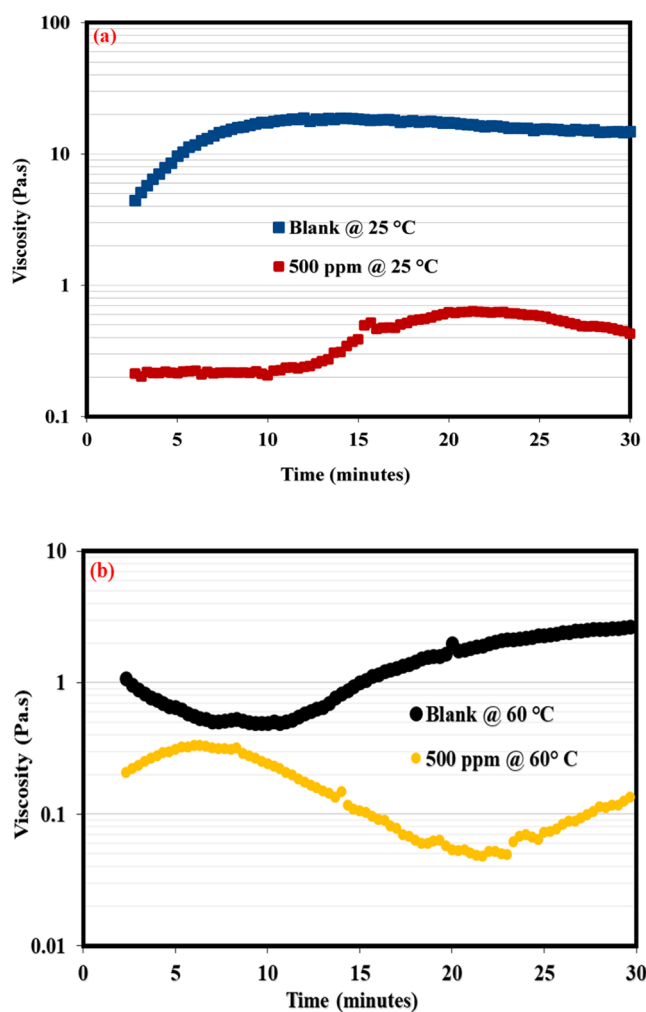


Figure 6. Viscosity profile of the produced emulsion with and without NID at ambient temperature: (a) 25 and (b) 60 °C.

adsorption of NID at the oil/water interface and the systematic rupture of emulsifiers binding the oil/water molecules together at the interface. Hence, a working and active chemical demulsifier incorporated inside the emulsion would diminish the emulsion viscosity, and the viscosity decrease becomes intense as temperature advances. Likewise, the interfacial films at the oil–water interface exhibit a sort of elastic strength owing to the buildup and influx of emulsifiers at the oil/water interface. Ideally, a working and active chemical demulsifier would destabilize the emulsifying substances at the interface, enabling the stability of the emulsion. Hence, elastic modulus measurement can therefore be used to reveal the elastic strength of the produced emulsion prior to and after the injection of a working demulsifier. Displayed in Figure 7a,b are the elastic modulus curves of blank emulsion and emulsion injected with 500 ppm of NID. It was obvious in these plots that the elastic modulus of emulsion incorporated with the NID retarded across the tested frequencies as compared to that of the blank sample. The decrease in the elastic modulus of emulsion injected with the NID was, however, more glaring under low frequencies in the range of 0.1–10 rad/s. Generally, the elastic modulus of the emulsion filled with the NID diminished across the entire frequency as compared to the blank sample because the presence of the NID weakened the elastic strength at the oil–water interface. Furthermore, the

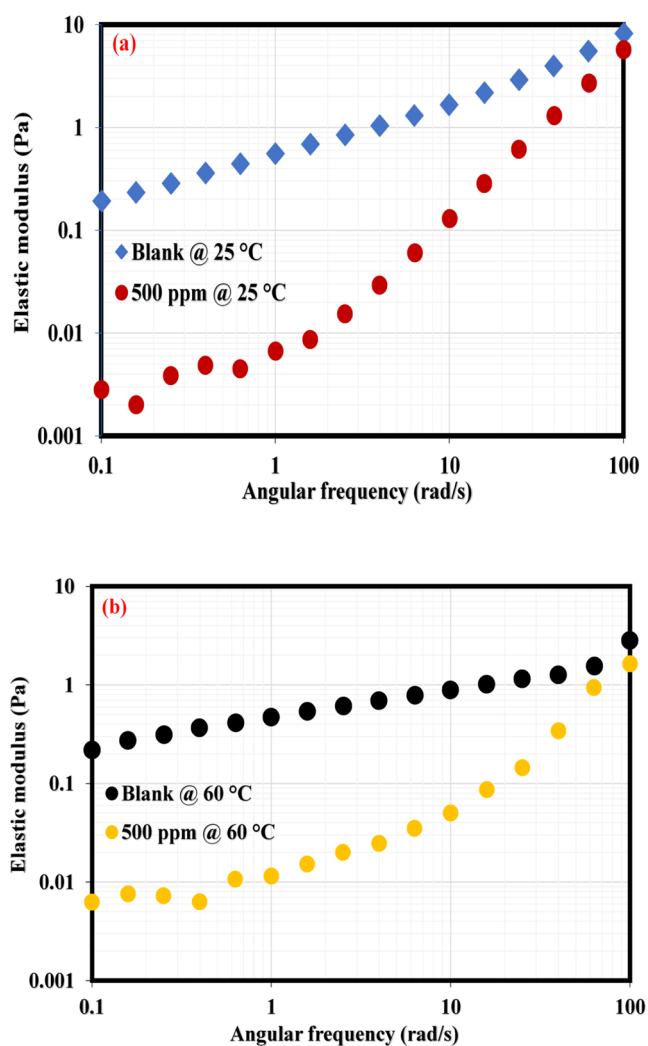


Figure 7. Elastic modulus measurements of the produced emulsion with and without NID: (a) 25 and (b) 60 °C.

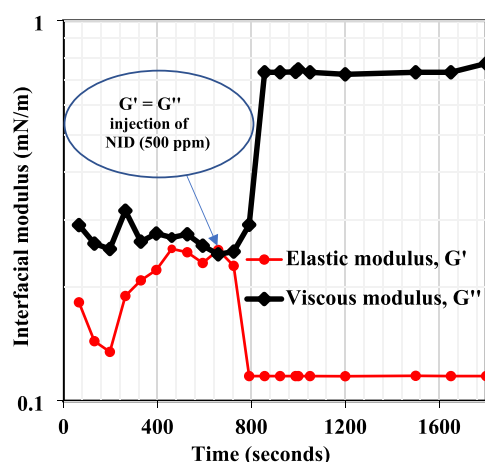


Figure 8. Oil–water interfacial modulus measurements in the presence of an NID.

oil–water interfacial modulus measurement shown in Figure 8 gave another insight into the activity of the NID demulsifier. The asphaltene aggregates were building up at the oil–water interface until the elastic modulus (G') intercepted the viscous modulus (G'') at about 750 s during measurement, indicating

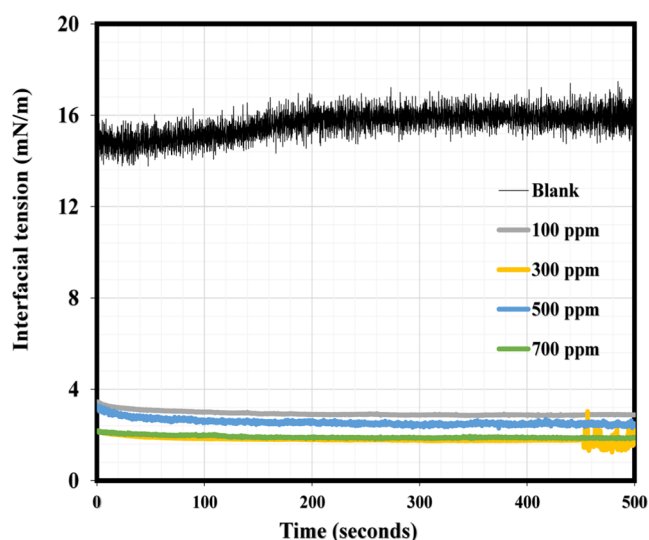


Figure 9. Oil–water dynamic IFT measurements at various concentrations of NID.

asphaltene accumulation at the oil–water interface was acting like rigid elastic films that were holding oil–water molecules intact. At this juncture of similar viscoelasticity ($G' = G''$) behavior, 500 ppm of NID was carefully injected, and this led to a sharp reduction in G' and an increase in G'' at about 800 s during the test. The sharp reduction in G' and sudden increase in G'' signified the rupture of asphaltenes molecules at the oil–water interface, and G' and G'' remained unchanged until 1800 s, which probably indicated complete dissociation of emulsifying materials at the oil–water interface.

3.5. Interfacial Tension Measurements. Interfacial tension (IFT) measurement is very key in describing the stability of emulsion and the penetration of demulsifier at the interface of oil/water as well as the adsorption mechanism of

the interfacial films. Figure 9 illustrates the IFT measurements revealing the adsorption of different NID dosages behavior at the oil/water interface and the oil–water interfacial behavior in the absence of NID. As can be seen in these plots, oil–water IFT values at 100, 300, 500, and 700 ppm of NID concentrations after 500 s of dynamic measurements were found to be 3.02, 1.84, 2.41, and 1.84 mN/m, respectively, while the IFT value of the oil–water system without the NID was recorded to be 16.11 mN/m under the same duration. It should be noted that the higher IFT values recorded at 500 ppm of NID could be attributed to the uneven and inconsistent migration of NID to the oil–water interface, and similar results have been reported.^{2,62} The inference from these IFT results is that the produced NID was able to migrate to the oil–water interface, and its gradual adsorption of the interfacial films was manifested by a sharp decrease in the IFT in the presence of its various concentrations as compared to the IFT value of the blank sample. The outcomes of the IFT measurements are in good agreement with past studies reported in the literature.^{2,23} A simple demulsification mechanism elucidating how the demulsifier displaces the oil–water interfacial film is displayed in Figure 10, elucidating the breaking of the produced emulsion by NID, followed by the aggregation of water droplets, resulting in coalescence and gradual oil/water separation.

4. CONCLUSIONS

The current study investigates the demulsification activity of a newly developed nonionic demulsifier (NID). Emulsions produced from crude oil and seawater were destabilized by the NID of varying concentrations at room and moderate temperatures (25 and 60 °C). The outcomes of demulsification tests showed that about 95 and 99% water removal was achieved at 25 and 60 °C, respectively. The rigid interfacial films triggering the stability of emulsion at the interface of oil and water were broken by subjecting the produced emulsion to

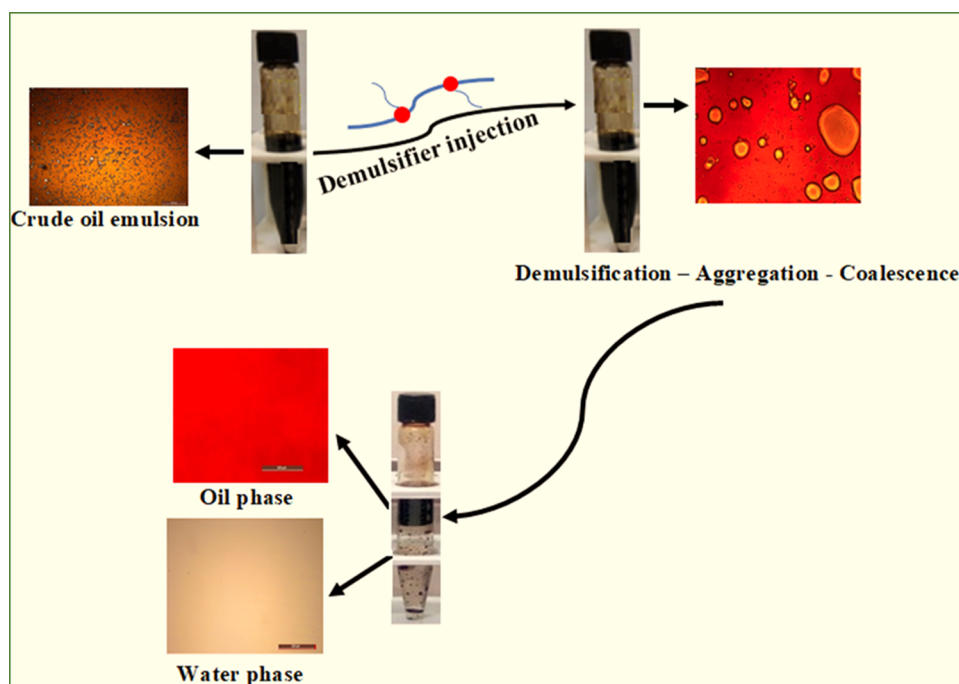


Figure 10. Proposed demulsification mechanism for the NID demulsifier.

viscosity and elastic modulus tests at both temperatures in the presence of the NID. The viscosity behavior and elastic modulus of the produced emulsion were observed to have dropped owing to the displacement of the natural emulsifiers resting at the oil/water interface. Besides, the interfacial tension (IFT) measurements established the penetration and adsorption of the NID at the oil/water interface. Accordingly, the IFT values of oil–water at varying NID concentrations were evaluated to be within 1.84–3.02 mN/m, and that of the NID-free oil–water system was estimated to be 16.11 mN/m.

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