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Performance of Electrostatic Field in Continuous Demulsification of Simulated Crude Oil Emulsion

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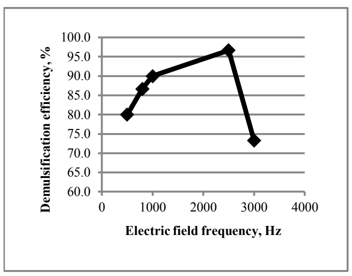
Graphical abstract



Abstract

Water-in-oil (W/O) emulsion is always formed in crude oil production. In most cases, the presence of water droplets in crude oil is undesirable because they can cause several problems such as corrosion of process equipment and a decrease in crude oil quality, as well as its market price. In this research, a simulated W/O emulsion that consists of kerosene as a continuous oil phase, water as a dispersed phase and SPAN 80 as an emulsifier has been formulated. The feasibility of using Span 80 for W/O emulsion formation and emulsion stability has been investigated. Stability test proved that the emulsions with 2 w/v % of Span 80 were stable and no separation was observed for the first 48 hours of gravitational settling. Besides, this research also aimed to study the effects of several parameters such as frequency, emulsion flow rate, voltage, water content in emulsion, and emulsifier concentration on the demulsification performance under high voltage electric field. The results showed that the best demulsification performance was 90% using electrical method at 1000 Hz of frequency, 10kV of voltage, 0.4 mL/s of emulsion flow rate, 2 w/v % of emulsifier, and 30 % of water portion of simulated crude oil.

Keywords: Emulsion; crude oil; demulsification; electrical field

1.0 INTRODUCTION

Petroleum is a naturally occurring fuel that is composed of organic chemicals. Petroleum can be in gas and liquid phases when its chemical mixture is composed of smaller and larger molecules respectively [1]. The gas phase of petroleum is known as natural gas. Meanwhile, the liquid phase of petroleum is known as crude oil, which contains thousands of distinct chemical compounds [1-2]. Crude oil can be extracted from the ground and it is usually a greenish-brown liquid with a strong odor [3]. Some are like tar and they are black, heavy and thick. In general, crude oil from different petroleum reservoirs has different characteristics [1]. Crude oil, once refined, yields the raw material for 3000 different products [3]. Over 100 years, the products from crude oil or petroleum served as important fuels to industries and customers [4].

Crude oil is rarely produced alone but it is often in the form of water-in-oil (W/O) emulsion [5-6]. This undesired water content in crude oil can cause several problems to the petroleum industry. For instance, the presence of impurities such as water containing salt in crude oil can cause serious corrosion and fouling in heat exchanger and distillation equipment if the water content is not removed [2, 7]. Besides, the increase of water content in crude oil increases the viscosity and ^{o}API gravity value of crude oil. The higher value of viscosity and ^{o}API gravity value of crude oil will decrease the selling price of crude oil [2]. Moreover, a sellable crude oil must meet the crude specifications that are stated by the purchasers. The amount of basic sediment and water (BS&W) of a sellable crude oil should meet the limit, and its limit is normally varied from 0.1 wt. % to 3 wt. % [2, 6].

In the petroleum industry, untreated crude oil may content the amount of water that varies from 1 wt. % to over 90 wt. % [6]. Thus, the separation of water from crude oil is needed due to the above reasons. The treating process of crude oil can be done by demulsification or water breaking process. In the petroleum industry, the demulsification process can be achieved by several chemical and physical methods [8]. Each method has its advantages and disadvantages, but all methods have the same purpose of minimizing water content to its limit. Chemical methods involve the use of chemical demulsifiers with the presence of bases or acids [2, 5, 6]. However, these methods are not preferable because the chemicals used can cause contaminations [8] and produce new emulsions that are more difficult to demulsify when overdosing [2].

However, physical methods involve the use of heat, electric field and gravity [2, 5, 6]. Thermal and gravitational treatments seldom resolve the emulsion matter alone [5, 6]. On the other hand, electrical treatment can resolve the emulsion problem on its own [9]. Besides, electrical treatment can also minimize the use of heat and skips the utilization of chemical demulsifiers, which makes this method more environmentally friendly [10]. Moreover, electrical treatment can be applied not only in oil and petroleum industries, but also in edible oil industries such as palm oil, sunflower oil and vegetable oil processing [9]. Thus, electrical treatment is a preferable method of breaking emulsion into water and oil. It has been successfully studied for removal and recovery of various solutes from wastewater including organic compounds such as lignin [11], dyes [12], and metal ions such as palladium [13], and silver [14].

In this research, a continuous demulsification of simulated W/O emulsion using an electric field was conducted. The objectives are to measure the stability of the prepared emulsion and to investigate the effects of several parameters such as electric field frequency, emulsion flow rate, voltage, water content in emulsion and emulsifier concentration on the demulsification of W/O emulsions.

2.0 EXPERIMENTAL

2.1 Materials

All the chemicals described here were used without any further purification. Kerosene and SPAN 80 or sorbitan oleate or sorbitan (Z)-mono-9-octadecenoate as a continuous phase were received from Sigma-Aldrich Co., USA. Besides, piped water was used as a dispersed phase.

2.2 Experimental Procedures

2.2.1 Preparation of Continuous Oil and Dispersed Water Phases

In the preparation of continuous oil phase, SPAN 80 was measured by an electronic balance and added to a beaker containing kerosene. The mixture was then stirred with a stirrer to dissolve SPAN 80 in the oil phase. The required amount of SPAN 80 was calculated based on the volume of kerosene. For instance, to prepare 45 mL of oil phase with 2 w/v % SPAN 80, the mass of SPAN 80 needed was 0.90 g. Meanwhile, piped water was used alone as a dispersed phase.

2.2.2 Preparation of Simulated W/O Emulsion

A 50 mL of simulated W/O emulsion was prepared by mixing the continuous oil (kerosene with 2 % (w/v) Span 80) and dispersed water phases. A homogenizer (Heidolph, model: SilentCrusher M) was used to homogenize the mixture for 5 minutes at 5000 rpm of agitation speed.

2.2.3 Stability Test

Stability test was conducted to measure the stability of the prepared emulsion. In this stability test, 2 w/v % of SPAN 80 was used to produce simulated W/O emulsions. The prepared emulsions were put in graduated cylinder and left to demulsify naturally under the influence of gravitational for one week. The volume of water separated was recorded from time to time.

2.2.4 Continuous Demulsification Experiment

After determining the optimum condition of stable emulsion, continuous demulsification of W/O emulsions was carried out by exposing W/O emulsions to electric field using a continuous high voltage coalescer (ISO-TECH ISR622 Oscilloscope) for 5 minutes. Several parameters such as frequency, emulsion flow rate, voltage, water content in emulsion and emulsifier concentration were varied during the continuous demulsification experiments. After that, each sample was collected in a measuring cylinder and left for 30 minutes of settling. The volume of water layer for each sample was then recorded. Lastly, the effect of each parameter was evaluated based on demulsification efficiency as shown by equation 1.

$$\text{Percentage of breakage (\%)} = (V_f / V_i) \times 100\% \quad (1)$$

where,
V_i is the initial volume of water, mL; and
V_f is the final volume of water, mL.

3.0 RESULTS AND DISCUSSION

3.1 W/O Emulsion Stability and Characterization

Table 1 shows the result for the stability test. The result shows that 2% (w/v) of Span 80 produced a stable emulsion. No breakage was observed within more than 48 hours. Besides, there were only 10 % (Sample A) and 6.7 % (Sample B) of emulsion breakage after 80 and 66 hours, respectively. Moreover, both samples achieved only 70 % of breakage after 140 hours of gravitational settling.

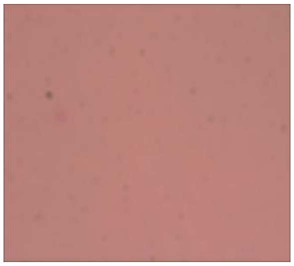
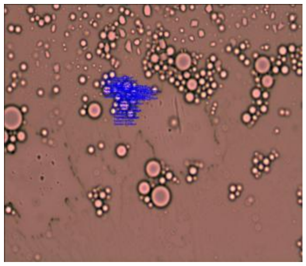
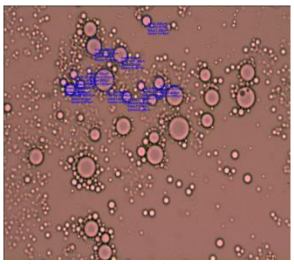
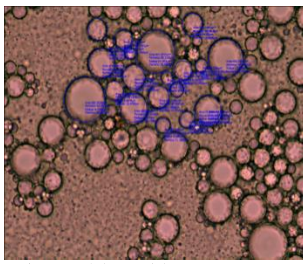
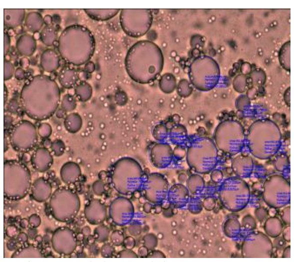
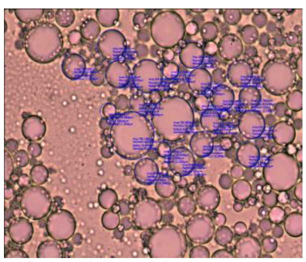
Table 1 Stability test by gravitational settling

Time, hr	Sample A 20% H_2O		Sample B 30% H_2O	
	Water layer, mL	Breakage, %	Water layer, mL	Breakage, %
1	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0
48	0.0	0.0	0.0	0.0
66	0.0	0.0	0.2	6.7
80	0.2	10.0	1.0	33.3
100	0.6	30.0	1.6	53.3
120	1.0	50.0	2.0	66.7
140	1.4	70.0	2.2	73.3

Table 2 shows the optical pictures of internal water droplets in W/O emulsions at different water portions (i.e. 0 %, 10 %, 15 %, 20 %, 25 % and 30 %). From Table 2, no water droplets were observed in the continuous phase. Besides, the number of bigger water droplets increases as the water portion in the emulsions increases. This means that the emulsion is less viscous and the formation of w/o emulsion is bigger.

Moreover, the average diameter of water droplets in W/O emulsions at different water portions is shown in Table 3. The diameters of the water droplets are in the unit of micrometer (μm). In general, the average diameter of water droplets increases with water portion. However, the average diameter of water droplets saturates at about 17 μm when the water portion increases from 25 % to 30 %. It is expected that there is small and significant change in the viscosity of emulsion.

Table 2 Internal water droplets in W/O emulsions at different water portions

 Continuous phase (kerosene with SPAN 80) with 0 % H_2O.	 W/O emulsion with 10 % H_2O.
 W/O emulsion with 15 % H_2O.	 W/O emulsion with 20 % H_2O.
 W/O emulsion with 25 % H_2O.	 W/O emulsion with 30 % H_2O.

3.3 Parameter Study on Demulsification Performance

3.3.1 Effect of Electric Field Frequency

Figure 1 shows that the percentage of emulsion breakage increases from 80 % to 97 % when the frequency increases from 500 Hz to 2500 Hz. According to Eow and Ghadiri [15], water droplets vibrate with the applied electric frequency and then undergo coalescence process. Therefore, water droplets vibrate faster at higher frequency (2500 Hz), causing the increase of water separation and also the percentage of emulsion breakage. However, emulsion breakage decreases sharply to 77 % when the frequency reaches 3000 Hz. According to Lesaint *et al.* [10], there is an upper limit for the applied frequency in terms of emulsion destabilization. It means that the demulsification rate decreases when the applied frequency is beyond the optimum frequency. This is because the coalescence rate of water droplets decreases at the upper limit of frequency. From the observation, the cloudiness of the top layer decreases when the emulsion breakage increases. This is because large amount of water volume was separated from the continuous oil phase when the frequency increases and resulted in less amount of emulsion layer.

Table 3 Average diameter of water droplets in W/O emulsions at different water portions

Water portion, % H_2O	Average diameter of water droplet, µm
10	3.932
15	7.479
20	15.802
25	17.678
30	17.728

Thus, in general, the percentage of emulsion breakage increases with frequency, but it decreases above 2500 Hz of frequency. However, the optimum frequency for this parameter is 1000 Hz instead of 2500 Hz due to a safety issue due as continuous hissing sound is produced from higher frequency.

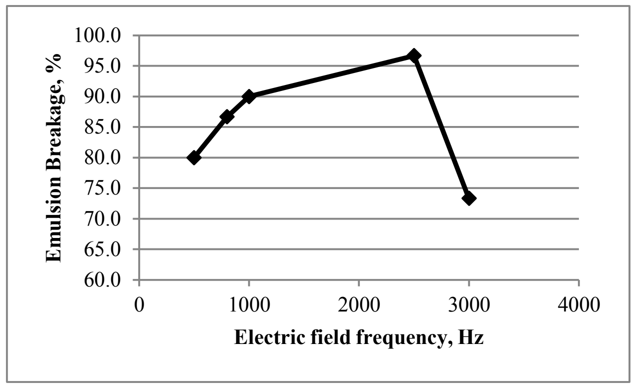


Figure 1 Effect of electric field frequency on demulsification of W/O emulsions (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 35 mL of kerosene with 2 w/v % of SPAN 80, dispersed phase = 30 % or 15 mL, flow rate = 0.4 mL/s, frequency = 500 Hz – 3000 Hz and voltage = 10 kV)

3.3.2 Effect of Emulsion Flow Rate

Figure 2 shows that the percentage of emulsion breakage increases initially from 83.3 % to 90.0 % when the emulsion flow rate increases from 0.2 mL/s to 0.4 mL/s, then it decreases to 80 % when the emulsion flow rate increases to 0.6 mL/s. From the observation, the increase of emulsion breakage is because the emulsion with flow rate of 0.4 mL/s is more frequently exposed to the electric field compared to the emulsion with lower flow rate. Besides, both emulsions have enough residence time to coalescence. Thus, emulsion breakage of emulsion with flow rate of 0.4 mL/s is slightly higher than the emulsion with lower flow rate. However, the decrease of emulsion breakage from 90 % to 80 % is due to the decrease of contact time of the emulsion with an electric field. From the observation, the emulsion with flow rate of 0.6 mL/s moved very fast and did not have enough time to coalesce in the coalescer. This proves that the residence time is inverse to emulsion velocity [16]. Thus, there is lower chance for droplets with higher velocity to coalesce and cause less emulsion breakage.

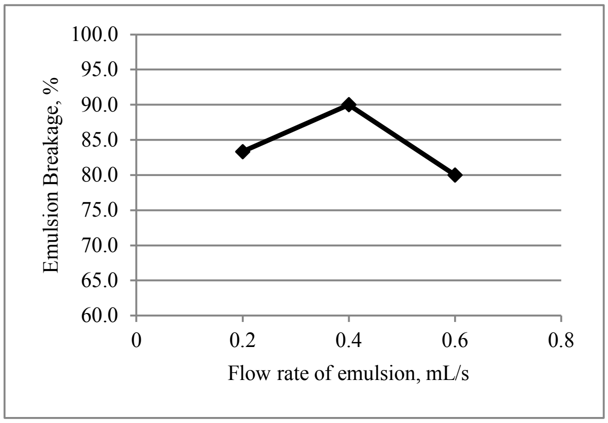


Figure 2 Effect of emulsion flow rate on demulsification of W/O emulsions (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 35 mL of kerosene with 2 w/v % of SPAN 80, dispersed phase = 30 % or 15 mL, flow rate = 0.2 mL/s – 0.6 mL/s, frequency = 1000 Hz and voltage = 10 kV)

3.3.3 Effect of Electric Field Voltage

Figure 3 shows that the percentage of demulsification increases from 66.7 % to 93.3 % when the electric voltage increases from 2 kV to 10 kV. According to Noik *et al.* [17], an effective voltage to be applied should be within the minimum voltage (related to threshold voltage) and the maximum voltage (related to critical voltage). This is because only reversible flocculation takes place with no coalescence of water molecules when the applied voltage is under the threshold voltage [10]. However, irreversible coalescence occurs when the applied voltage is above the critical voltage [18]. In this study, it is obviously shown that the applied electric fields (2 kV to 10 kV) are within the minimum and maximum voltages because the percentage of emulsion breakage increases linearly with voltage and saturates at 93.3 %. In the electro-coalescence process, water droplets gain energy from electric field to overcome the interfacial tension and promote coalescence. At higher voltage, the number of small droplets formed to develop sufficient forces increases and subsequently coalescence followed by the increase of emulsion breakage [17]. Therefore, it can be concluded that the percentage of emulsion breakage (66.7 % to 93.3 %) increases with electric voltage (2 kV to 10 kV), and the optimum voltage is 10 kV.

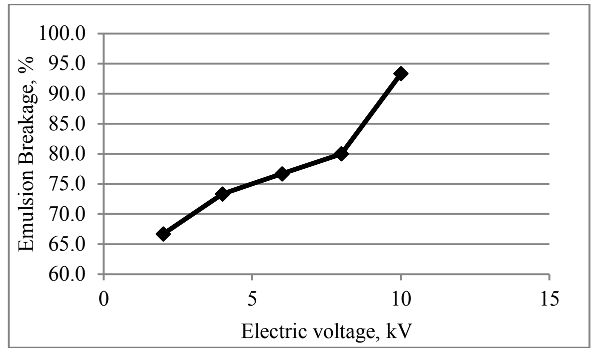


Figure 3 Effect of voltage on demulsification of W/O emulsions (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 35 mL of kerosene with 2 w/v % of SPAN 80, dispersed phase = 30 % or 15 mL, flow rate = 0.4 mL/s, frequency = 1000 Hz and voltage = 2kV – 10 kV)

3.3.4 Effect of Water Portion

Figure 4 shows that the percentage of the demulsification increases from 50 % to 93.3 % when the water portion increases from 10 % to 30 %. According to Anisa and Nour [15], the increase of water content tends to increase the water droplets size, and this statement can be explained from Figure 5. Figure 5 shows that the average diameter of water droplet increases (from 3.932 µm to 17.728 µm) with the water content in W/O emulsion. The increased water content tends to increase the ability of water droplets to aggregate and eliminate rigid film surrounding the droplets, causing the droplets to coalesce by forming single and larger unit of droplets. Besides, the number of hydrogen bonds are also increased in higher water content and causing the decrease of the droplets distance [19]. Thus, higher numbers of bigger size water droplets are formed and they tend to promote faster sedimentation, and this causes the increase of separation efficiency [10].

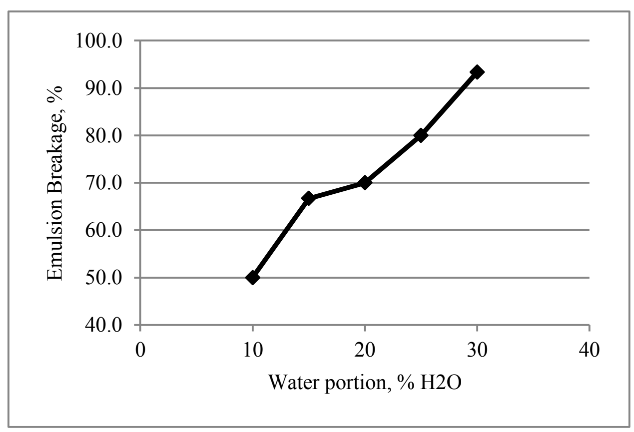


Figure 4 Effect of water portion on demulsification of W/O emulsions (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 45 mL – 35 mL of kerosene with 2 w/v % of SPAN 80, dispersed phase = 10 % - 30 % or 5 mL – 15 mL, flow rate = 0.4 mL/s, frequency = 1000 Hz and voltage = 10 kV)

However, from Figure 4 and Figure 5, emulsion breakage increases greatly in the range of 25 % to 30 % of water content in emulsion, whereas the droplet size is saturated at around 17 µm. When water content increases from 25 % to 30 %, the number of water molecules increases and they are filled in a packed order in a continuous phase as shown in Table 2. Therefore, the chance for bigger number and packed molecules to coalesce is higher and leading to the increase of emulsion breakage. Lastly, it can be concluded that the optimum portion of water is 30 %.

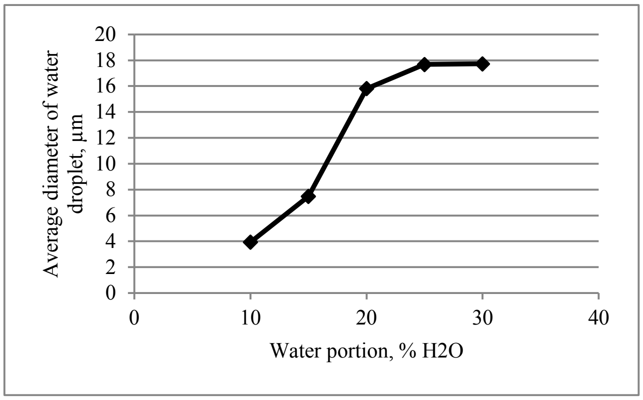


Figure 5 Average diameter of water droplets at different water portion (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 7 mL – 9 mL of kerosene with 2 w/v % of SPAN 80 and dispersed phase = 10 % - 30 % or 1 mL – 3 mL)

3.3.5 Effect of Emulsifier Concentration

Figure 6 shows that the percentage of emulsion breakage decreases from 90 % to 33.3 % when the emulsifier (SPAN 80) concentration increases from 2 w/v % to 10 w/v %. According to Troy *et al.* [20], dispersion of water molecules into a continuous oil phase is due to the presence of emulsifier that has hydrophilic (oil soluble) and lipophilic (water soluble) properties. When the emulsifier concentration increases, this hinders the formation of bigger droplet during coalescence, causing the decrease of water separation. Thus, a more stable W/O emulsion is formed with higher concentration of SPAN 80.

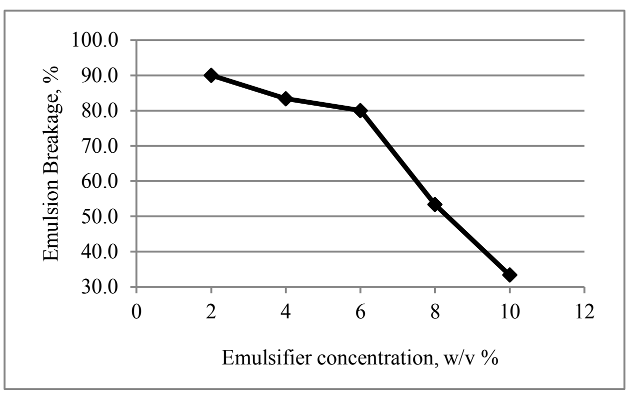


Figure 6 Effect of emulsifier concentration on demulsification of W/O emulsions (Homogenizer speed = 5000 rpm, homogenized duration = 5 minutes, continuous phase = 35 mL of kerosene with 2 w/v % - 10 w/v % of SPAN 80, dispersed phase = 30 % or 15 mL, flow rate = 0.4 mL/s, frequency = 1000 Hz and voltage = 10 kV)

4.0 CONCLUSION

The stability test proved that emulsions with 2 w/v % of SPAN 80 were stable and no separation was observed for the first 48 hours of gravitational settling. The results also showed that the best demulsification performance for W/O emulsion contained 30% portion of piped water and 2% (w/v) emulsion above 90 % of demulsification efficiency, with 1000 Hz of frequency, 0.4 mL/s of emulsion flow rate and 10 kV of voltage.

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