Study on the effect of ultrasonic wave amplitude on de-emulsification of crude oil to enhance production process

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Abstract. One of the most challenging issue faced by the oil and gas industry is the formation of crude oil emulsion. The emulsion formation will lead to inconsistency in the production performance, which directly affects the economic growth of the industry. Current, conventional de-emulsification methods such as thermal, demulsifiers, and electrical methods are found ineffective in solving crude oil emulsion problem relativity to expected settling time. Therefore, this research aims to propose ultrasonic wave application method for better separation rate to solve crude oil emulsion problem. The effects of ultrasonic waves are investigated by designed experiment under different operating temperature. The optimum operating conditions are investigated and identified through optimization methods in Design Expert Software. The goals of this research are to achieve maximum water and oil separation and minimize the rag layer thickness. Based on the experiments and results, the best operating condition is at operating temperature of 60 °C at 40 μm of ultrasonic frequency of 20 kHz. These parameters were able to provide 73.3% of water separation rate and 20% volume fraction of oil layer after eight hours of bottle test.

1. Introduction
Crude oil emulsions can be technically defined as heterogeneous liquids system that consists of two immiscible liquids that came into contact and did not dissolve with each other [1]. An undisclosed oilfield in the South China Sea is facing emulsion problem as excess water is injected to the well for the enhanced oil recovery purpose [2, 3]. Besides, the neighbouring oilfields operated by a different company are also facing the same problem [4]. Emulsion is formed when oil and water are mixed vigorously in the process of entering perforation in the casing with the presence of huge different in pressure between the reservoir and well head [1]. Akpabio and Ekott [5] claimed that emulsion were naturally formed at the well head, chokes and valves section due to the action of the shear stress and the pressure drop in the system. Ultrasonic wave is a mechanical wave that require medium to propagated [6]. In the application of ultrasonic, amplitude are the contributing factor to the separation of crude oil emulsion [7-9]. A certain value of amplitude (P_a) pass through a medium at hydrostatic pressure (P_h) can caused oscillation to the molecules as shown in figure 1 [6]. During the oscillation cycle, the pressure is positive and the distance between the molecules decrease in compression cycle, whereas it is vice versa in rarefaction cycle. Thus, its yield can be represented by P_c = P_h - P_a [6]. At certain amplitude, the average distance between molecules exceeds the critical distance and it will form a void and induce cavitation bubble in it as the droplets are not intact with each other [6]. Therefore, a higher amplitude of ultrasonic will result in a large formation of bubbles known as cavitation effect [7]. The objective of this
research is to obtain the separation between water and oil at maximum value and minimize the rag layer thickness.

![Figure 1. Relation of local pressure with cavitation [6].](image)

2. Methodology and experimental design

The crude oil emulsion was prepared by mixing crude oil and formation water. The crude oil used in this study was obtain from crude oil terminal that served the oilfield. The crude oil was shaken well before mixed with formation water. One litre of formation water was prepared to represent the oil field environment. Firstly, seven chemical components were measured in g/L and pour into one litre beaker. Table 1 shows the chemical components used during the preparation of water formation. One litre of ultra-pure water, which was obtained from Elga PURELAB Flex 3 Water Purification System, was added gradually to the beaker. The mixture was agitated vigorously using IKA R 1389 three blade propeller at the speed of 400 rpm and ambient temperature of 23 °C for a duration of one hour.

| Chemical Substance             | Concentration (g/L) |
|--------------------------------|---------------------|
| Sodium Bicarbonate             | 5.1260              |
| Potassium Chloride             | 0.2646              |
| Sodium Chloride                | 6.0114              |
| Barium Chloride Dihydrate      | 0.0067              |
| Strontium Chloride Hexahydrate | 0.0141              |
| Magnesium Chloride Hexahydrate | 0.0750              |
| Calcium Chloride Dihydrate     | 0.2344              |

Water in oil (w/o) emulsion was prepared in 100 ml beaker in the ratio of 30:70 of water and oil. About 50 ml was prepared for each crude oil emulsion study. Firstly, the oil and water were mixed together and heated up to 60 °C. Once the temperature reached 60 °C, the mixture was stirred with IKA T25 DS2 stirrer at 12,000 rpm for duration of 15 minutes at mixing temperature of 60 °C. The stable emulsion is formed and underwent ultrasonic irradiation treatment instantly to prevent the break change of crude oil emulsion stated.

3. Results and discussion

The crude oil emulsion stability of base sample was determined through eight hours of bottle test. No ultrasonic wave application was conducted on the base sample. The volume fraction of oil and rag layer was recorded and is presented in figure 2. The volume fraction was calculated from the volume of each layer divided by the total volume. Rapid oil separation occurred after 60 minutes of bottle test based on gravity settling. The best separation achieved in base sample was after six hours with 20% volume
fraction of crude oil layer and 80% volume fraction of rag layer. The base sample took six hours to reach stability. However, it was an ineffective separation as there was no water layer formation.

Figure 3(a) shows the lowest operating temperature of 30 °C. The expected increase in oil layer is observed on the volume fraction with respect to the time. At the first hour, the oil layer increases equally and it start to behave differently after first hour. Samples A1 and A3 crude oil layer reached it stability after 6 hours of bottle test. However, Sample A2 that underwent ultrasonic intensity of 60% did not achieve stability. Water-in-oil emulsion Sample A1 underwent 40% of ultrasonic irradiation showed the highest oil layer volume fraction of 16% compared to other ultrasonic intensity. Nevertheless, it is considered ineffective as the volume fraction of oil in base sample is 20%. Figure 4(b) shows the results at heating temperature of 45 °C. Based on the graph, the volume fraction of oil layer increases gradually with respect to the time. After 8 hours of bottle test, oil layer thickness did not achieve stability and increased exponentially. This indicates that coalescence and flocculation process were in progress. Sample B1, B2 and B3 clearly showed that oil layer thickness was inversely proportional to the ultrasonic intensity. Hence, B1 showed the highest oil layer thickness whereas B3 have the lowest oil layer thickness were expected due to the differential in amplitude. Nevertheless, volume fraction of oil layer in Sample B1 (16%) had not surpassed base sample (20%).

In figure 3(b), the oil layer formation for three samples are valid and in-line with the experiments of Gaikwad and Pandit [9] experimental result stating that the increase of the pressure amplitude of the ultrasonic prompted more cavitation effect. As a result, the formation of bubble and busting process increased aggressively and caused the w/o emulsion to breakup and enhance emulsification instead of de-emulsification process. Therefore, lower ultrasonic amplitude is desirable to provide sufficient energy for the new interface formation [9]. Figure 3(c) illustrates the change of oil layer and water layer volume fraction of Samples C1, C2 and C3 over period of 8 hours at operating temperature of 60 °C. The formation of oil layer was increased rapidly after five minutes of bottle test in Samples C1 to C3. Samples C3 have the highest oil layer volume fraction of 24% which higher than base sample by 4%. Besides, Samples C1 have the same oil layer volume fraction with base sample and it is expected to increase after eight hours of bottle test. The water layer formation was showed in Samples C1 and C2. Sample C3 does not exhibit any sign of water formation during 8 hours of bottle test. Water layer can be observed after 15 minutes of bottle test with a volume fraction of 22% in sample C1 as compared to sample C2 which formed after 30 minutes with a volume fraction of 12% at the end of bottle test. The results show significant improvement compared to no water separation in the base sample.
This phenomena was proven true by Kokal [10], Smith and Arnold [11]. They state that high temperature increases the collision rate between droplets by reducing the interfacial viscosity and enhanced coalescence rate. Sample C3 show no water layer formation due to high ultrasonic amplitude. These occurrence due to the increasing in the intensity of shock wave and caused the emulsion to breaking up and reduced coalescence rate [8, 9]. It can be deduced that ultrasonic is able to accelerate the separation rate of crude oil emulsion at heating temperature of 60 °C at 40% of ultrasonic amplitude.

Figure 4 shows the change of volume fraction of oil layer at different heating temperature at threshold amplitude of 40%. The threshold amplitude was focused because it gave the highest cavitation rate compared to other amplitude level. Based on figure 4, Sample C1 shows the highest volume fraction of oil layer. The trend was proven by Kokal [10] finding that increase in temperature enhanced the separation rate of crude oil. As the temperature increases, crude oil particles will absorb the energy and converts to kinetic energy. It allowed crude oil to vibrate and move due to differential in density of crude oil and water. In molecular structure of view, increased temperature resulting in destabilization of
interfacial film and allowed coalescence process to occur [10]. Hence, coalescence rate increase at high thermal energy. In short, heat accelerated the de-emulsification process.

![Graph showing volume fraction of oil layer at threshold amplitude of 40% and at different heating temperature.](image)

**Figure 4.** Volume fraction (%) of oil layer at threshold amplitude of 40% and at different heating temperature.

Based on the pattern, it clearly showed that higher temperature will increase the oil layer separation rate as it can be seen at high operating temperature of 60 °C, the volume fraction of oil layer is approximately 20%. As the temperature increase, the viscosity decreased and the hydrodynamic force big enough to enhance the separation rate. Figure 5 shows the distribution of water droplets in crude oil emulsion before and after bottle in Sample C1 which under operating temperature of 60 °C at 40% ultrasonic amplitude. After eight hours of bottle test, the water droplets size have increased from 5.22 μm to 18.32 μm and formed more uniform structure.

![Water droplets in rag layer for Sample C1 for (a) before bottle test and (b) after eight hours of bottle test.](image)

**Figure 5.** Water droplets in rag layer for Sample C1 for (a) before bottle test and (b) after eight hours of bottle test.

The reason for this was due to the effect of temperature and the irradiation of ultrasonic. Under the heating effect, the water and oil droplets gain kinetic energy to vibrate and move vigorously in the system. Increase of operating temperature, caused interfacial tension between the particle and viscosity of oil to decrease, which increased the ease of dispersion of one phase into others. With all the experimental data, the optimum operating conditions for the ultrasonic wave amplitude de-emulsification process was analysed by using Design Expert software. Based on the optimization analysis, interaction effect between operating temperature and ultrasonic amplitude collated with crude oil, water and rag layers were identified. The models yield an empirical equation that valid in the range of operating temperature at 30 °C to 60 °C and ultrasonic wave amplitude of 40% to 80%. Where OL is the volume fraction of oil layer, WL is the volume fraction of water layer, RL is the volume fraction of rag layer, A is the operating temperature (°C) and B is the ultrasonic wave amplitude (%).
4. Conclusion
The optimum parameter for ultrasonic de-emulsification is at heating temperature of 60 °C at 40% of ultrasonic amplitude. At 40 μm of ultrasonic amplitude give the best sinusoidal wave to the crude oil emulsion. This statement is justified and proven by past researchers that the threshold amplitude and temperature are the key factors in affecting the quality of separation rate of crude oil emulsion. There was no water separation in crude oil emulsion after 8 hours of bottle test under ultrasonic irradiation treatment in Samples A and B which were conducted in heating temperature of 30 °C and 45 °C. Based on the experimental result and design expert optimization, Water formation in crude oil emulsion is strongly affected by the change of amplitude whereas oil layer formation is affected by the change of crude oil temperature.

References
[1] Udonne, J., Chemical treatment of emulsion problem in crude oil production. Journal of Petroleum and Gas Engineering Vol, 2012. 3(7): p. 135-141.
[2] Vai Yee, H., et al., Managing Chemical Flooding, and By-Products with Produced Water Re-Injection (PWRI) System in Offshore Environment, in SPE Enhanced Oil Recovery Conference. 2013, Society of Petroleum Engineers: Kuala Lumpur, Malaysia.
[3] Najamudin, K.E., et al., Chemical EOR Produced Water Management at Malay Basin Field, in Offshore Technology Conference-Asia. 2014, Offshore Technology Conference: Kuala Lumpur, Malaysia.
[4] Mat, H., et al., Study on demulsifier formulation for treating Malaysian crude oil emulsion, in Department of Chemical Engineering. 2006, Universiti Teknologi Malaysia: Malaysia.
[5] Akpabio, E.J. and E.J. Ekott, Application of Physico-Technological Principles in Demulsification of Water-In-Crude Oil System. Indian Journal of Science and Technology, 2013. 6(1): p. 3898-3902.
[6] Sauter, C., et al., Influence of hydrostatic pressure and sound amplitude on the ultrasound induced dispersion and de-agglomeration of nanoparticles. Ultrasochemistry, 2008. 15(4): p. 517-523.
[7] Hielshcer, T., Ultrasonic production of nano-size dispersions and emulsions. Dans European Nano Systems Workshop - ENS 2005, Paris : France, 2007.
[8] Behrend, O. and H. Schubert, Influence of hydrostatic pressure and gas content on continuous ultrasonic emulsification. Ultrasochemistry, 2001. 8(3): p. 271-276.
[9] Gaikwad, S.G. and A.B. Pandit, Ultrasound emulsification: effect of ultrasonic and physicochemical properties on dispersed phase volume and droplet size. Ultrasochemistry, 2008. 15(4): p. 554-563.
[10] Kokal, S.L., Crude oil emulsions: A state-of-the-art review. SPE Production & Facilities, 2005. 20(01): p. 5-13.
[11] Smith, H.V. and K.E. Arnold, Crude oil emulsions. Petroleum Engineering Handbook. 3rd ed., Social of Petroleum Engineers, 1987: p. 19.1-19.34.