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Procedia Engineering 148 (2016) 1149 – 1155

Procedia Engineering

www.elsevier.com/locate/procedia

4th International Conference on Process Engineering and Advanced Materials

# The Rheology of Light Crude Oil and Water-In-Oil-Emulsion

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**Abstract**

Research on rheological behavior of crude oil emulsion is vital due to complex behavior of crude oil. Usually, crude oil emulsion is found in mixed state with solid particles, organic additives and emulsifying agents. Crude oil emulsion can be encountered during oil production, transporting or processing. The production of emulsion is a costly problem both in terms of chemicals usage to overcome the problem and production loses. In order to get a better understanding on rheological behaviour of crude oil emulsion, the rheological study of water in oil emulsion was investigated. The present paper deals with the rheological study of light crude oil from Bintulu, Sarawak and its mixture with water. This rheological study includes viscosity dependence vs. shear rate, temperature and volume water ratio. Water in oil emulsions were prepared by mixing light crude oil with different water volume fractions (20%, 30% and 40%). Rheological measurements were carried out by Antoon Paar MCR 301 rheometer operated at pressure of 2.5 bar. The results showed that emulsion exhibit non-Newtonian flow behavior at low shear rate and Newtonian flow behaviour at high shear rate. Besides that, viscosity of water in oil emulsion was strongly augmented by increasing volume of water and decreased the temperature. It was noted that a large discontinuity in the viscosity occurs at volume water ratio of 30 to 40%. In the case of 100% light crude oil, the study demonstrated Newtonian behavior. However, for emulsion with different volume water ratios, the rheological studies follow non-Newtonian shear thinning behavior and were described in better way by Ostwald de Waele and Herschel-Bulkley models. As a conclusion, rheological study shows that temperature, shear rate and volume water ratio have great impacts on the viscosity of water in oil emulsion and it is important to understand these factors to avoid various costly problems.


Peer-review under responsibility of the organizing committee of ICPEAM 2016

*Keywords:*Rheology; viscosity; water-in-crude oil emulsion

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Peer-review under responsibility of the organizing committee of ICPEAM 2016
doi:10.1016/j.proeng.2016.06.614

## 1. Introduction

Emulsion system is encountered in everyday life as cosmetics, foods, pharmaceutics, biological systems, petroleum processing and etc. Emulsion can be defined as a disperse system consists of droplets of liquid. Oilfield emulsion generally occurs as water droplets dispersed in oil (W/O) and occasionally as oil droplets in water (O/W)[1] . During oil production, water is commingle together with crude oil due to pressure gradients over chokes and valves[2]. High mechanical forces in the chokes and valves will disperse water as droplets in the oil phase and form an emulsion. Basically, during secondary phase of oilproduction, the emulsion will stabilized by natural surfactant such as asphaltenes and resins. This emulsion consists of crude oil as disperse medium and brine as disperse phase. Production of emulsion causes lots of problems during crude oil separation and must be treated. As the oil reservoir become older, the percentage of crude requiring treatment increases. In petroleum industry, treating and removing of water is essential to avoid fouling of equipment and to meet the sellable crude oil specification. Basic sediment and water (BS&W) is one of the crude oil specifications that must be complied in order to determine the quality of the sellable crude oil where BS&W content should not exceed 0.5%[3].

In order to treat emulsion efficiently, rheological behaviours of emulsion have been investigated[4-5]. Rheological deals with the flow of fluid and deformation of solid under various kinds of strain and stress. Rheological properties of emulsion can be determined by measuring the relationship between stress, strain, temperature and time. Besides, rheological properties of emulsion can be described by several behaviours such as dilatant, Newtonian, psuedoplastic, and Bingham.

Water-in-crude oil emulsion exhibit non-Newtonian behavior[6]. Non-Newtonian can be described by studying the viscosity of emulsion as a function of shear rate. When the viscosity decreases at high shear rate, this phenomenon is called as shear thinning effects. Viscosity of emulsion depends on some factors such as shear rate, temperature, water volume fraction, amount of solid present and etc. Knowledge on viscosity of emulsion is important as the assessment of production strategies[7].

Viscosity of emulsion is significantly influence by shear rate. The effect of shear rate towards viscosity is attributed by concentration of dispersed phase. This behaviour is a result of droplets crowding or structural viscosity.Water volume fraction of the dispersed phase also has an important effect on the viscosity of emulsion. Viscosity of emulsion increases with increasing water volume fraction. The volume water fraction is mainly influenced by number of hydrogen bonds as well as hydrodynamic forces.

The main objective of this research is to study rheological behavior of water in oil emulsion. In this study, variations of viscometry study as a function of shear rate, temperature and volume water fraction are performed. The results from this study provide better understandings on demulsification process of crude oil emulsion.

**Nomenclature**

| | | |
|---|---|---|
| $\tau$ | applied shear stress | [Pa] |
| $\gamma$ | shear rate | [$s^{-1}$] |
| k | consistency index | [$Pa.s^n$] |
| n | flow behaviour index | |
| $\tau_0$ | apparent yield stress | [Pa] |

## 2. Experimental procedure

Light crude oil from Bintulu, Sarawak was used in this study for the preparation of emulsion. Emulsions were prepared with different volume fraction of water (i.e. 20%, 30%, and 40%). In order to prepare samples of water in oil emulsions, water was added gradually to the oil placed in 250 ml beaker. Emulsions were homogenized with 10 000 rpm in 15 minutes. Emulsions were left in order to settle for a period of 24 hours in vials after homogenized. Rheological behaviors of the emulsions were analyzed by Antoon Paar MCR 301 rheometer which operates at pressure of 2.5 bar. The rheological test were conducted withintemperature range 20 – 90°C and shear rate varied from 0.1 – 1000 $s^{-1}$. Light crude oil used in the experiment has physical properties as given in Table 1.

Table 1.Properties of light crude oil

| Analysis | Light crude oil |
|---|---|
| Physical State | liquid |
| Specific Gravity | 0.83 |
| API gravity | 38.98 °API |
| Pour Point °C | - 20 |

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## 3. Experimental results

### *3.1. Modelling analysis*

Modelling analysis was carried out to identify the best fit model for the experimental data. There were two models involved in this study, which are Ostwald de Waele and Herschel-Bulky as given in Equation 1 and 2 respectively. These two models are the best in explaining the colloidal suspension of emulsion. Flow behaviors of emulsion were described by fitting the experimentally measured shear stress-shear rate data to the model. According to Majdidet. al,[8] by using these modelling, emulsion with different volume water fraction can be characterize by the calculation of model parameter, (behavior index, n and consistency factor, k). The results of the modelling analysis were presented in Table 2.

$$\tau = k(\gamma)^n \tag{1}$$

$$\tau = \tau_0 + k(\gamma)^n \tag{2}$$

Table 2.Modelling analysis of experimental data

| Composition of the emulsion | Ostwald de Waele | | | Herschel - Bulkley | | | |
|---|---|---|---|---|---|---|---|
| | n | *k* | $R^2$ | $\tau_0$ | *k* | n | $R^2$ |
| 20% | 1.1316 | 0.7033 | 0.9983 | 0.07614 | 0.00523 | 1.1989 | 0.99853 |
| 30% | 0.9331 | 1.4370 | 0.9957 | 0.11147 | 0.00464 | 1.2627 | 0.99592 |
| 40% | 0.2068 | 0.5914 | 0.9474 | 0.35681 | 0.23306 | 0.67904 | 0.99965 |

Table 2 shows the highest regression correlation coefficient, $R^2$, of 0.99853 for the Herschel –Bulky model. It can be concluded that Herschel –Bulky model was the best model to describe the experimental data over the tested range of shear rate.

### *3.2. Effect of shear rate and shear stress on viscosity*

*3.3.* The relationship between shear rate and shear stress at different temperature was plotted in Figure 1. The measurement was conducted at 40% volume water fraction and temperature range (20°C – 90°C). Upon analyzing Figure 1, it can be observed where shear stress increased significantly with shear rate, which follow non-Newtonian shear thinning behavior.

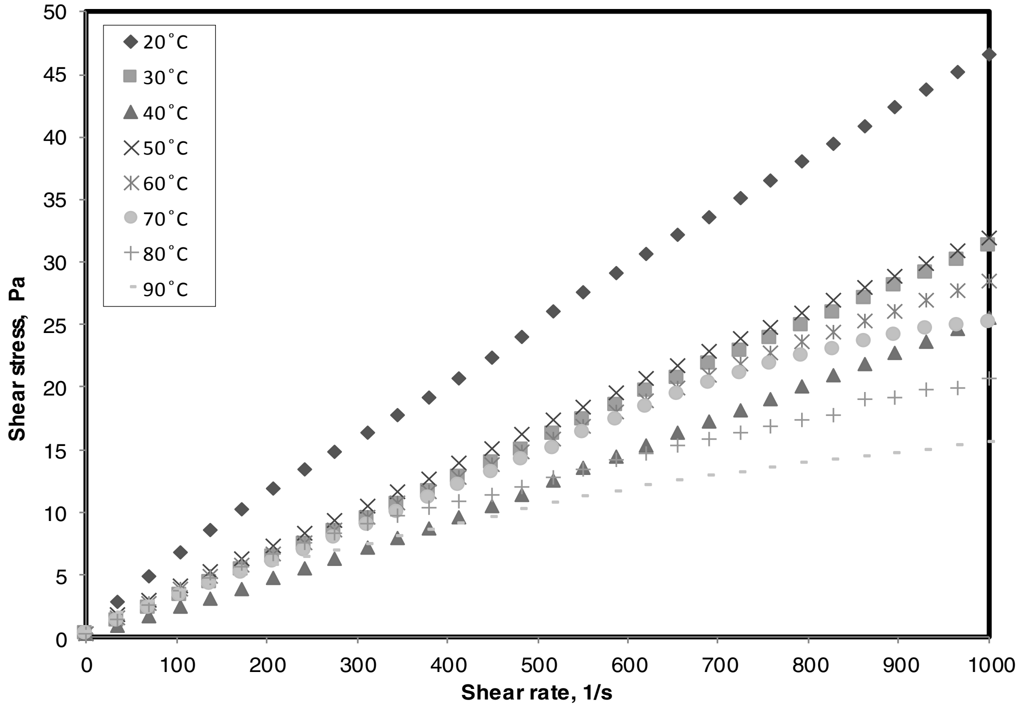


Fig. 1.Shear stress versus shear rate at 40% volume water fraction

### 3.4. Effect of shear rate and temperature on emulsion viscosity

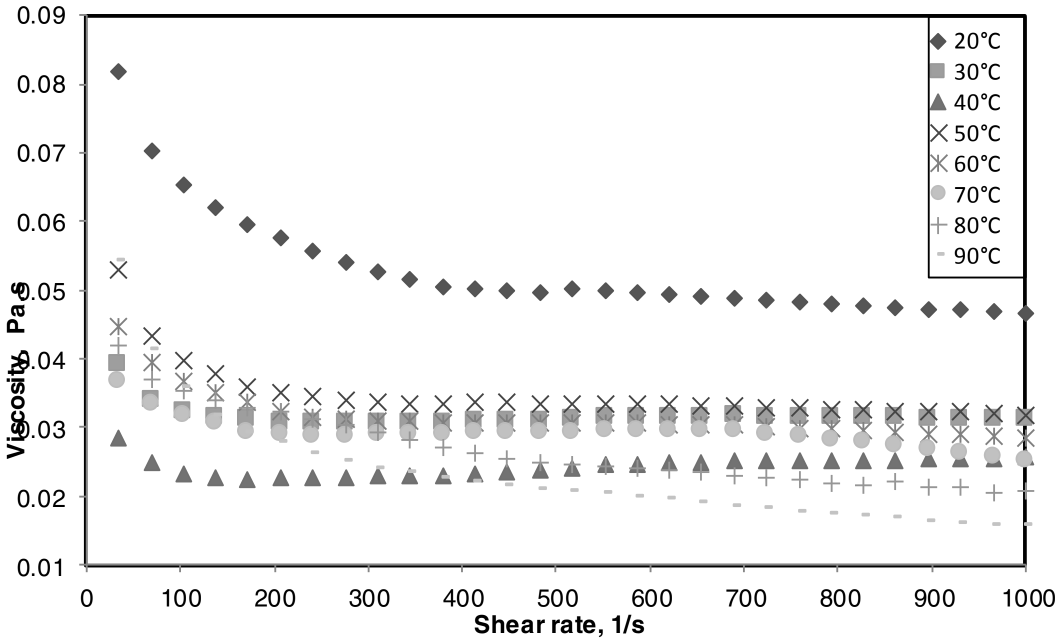


Fig. 2.Effect of temperature on viscosity at 40% water fraction

Figure 2 above shows viscosity behavior of light crude oil emulsion versus shear rate at different temperatures. Viscosities of the light crude oil emulsion were examined over shear rate ranging from 0.1 – 1000 $s^{-1}$ and temperature ranging from 20°C – 90°C. Increase in temperature of light crude oil emulsion results in significant decrease of viscosity. The effect of temperature on emulsion can be explained according to its surface tension and viscosity of dispersed phase. Increase in temperature reduces emulsion formation which will results in increase in burst of cavities. Although number of transient cavities increases as temperature increases, the factor does not give impact towards the emulsion viscosity.

Moreover, the curves also indicate that an increase in shear rate, resulting in decrease in viscosity. The viscosity reaches low values at high shear rate because the flow encountered less resistance. At the moment of spindle rotations, the bonds of aggregated molecules start to destroy due to the energy exerted by shear is dissipated in the light crude oil emulsion. As the shear rate increase, the molecules tend to break down into individual flocs, thus, resistance to spindle rotation is less and eventually reducing the emulsion viscosity. This phenomenon's also known as non-Newtonian shear thinning behaviour where it is similar to that of light crude oil emulsion reported by Majdid et al. [9] and M. Mekkaoui[10]. It is also proven from the graphical that the effects of viscosity differences are larger at low shear rate than at high shear rate. The graph shows two different behaviors within the experimental shear rate ranges. At lower shear rate region up to 200 $s^{-1}$ emulsion exhibits non-Newtonian shear thinning behavior, where the viscosity is higher. However, at higher shear rate region, viscosity decreases and exhibit Newtonian profile. This occurs because with increasing shear rate, the molecules start to untangle from each other and starts to align in the direction of flow. From the observation, the viscosity of emulsion is strongly affected by the temperature and it is subject to temperature variation in the separation processes.

*3.4. Effect Water Volume Fraction on Viscosity*

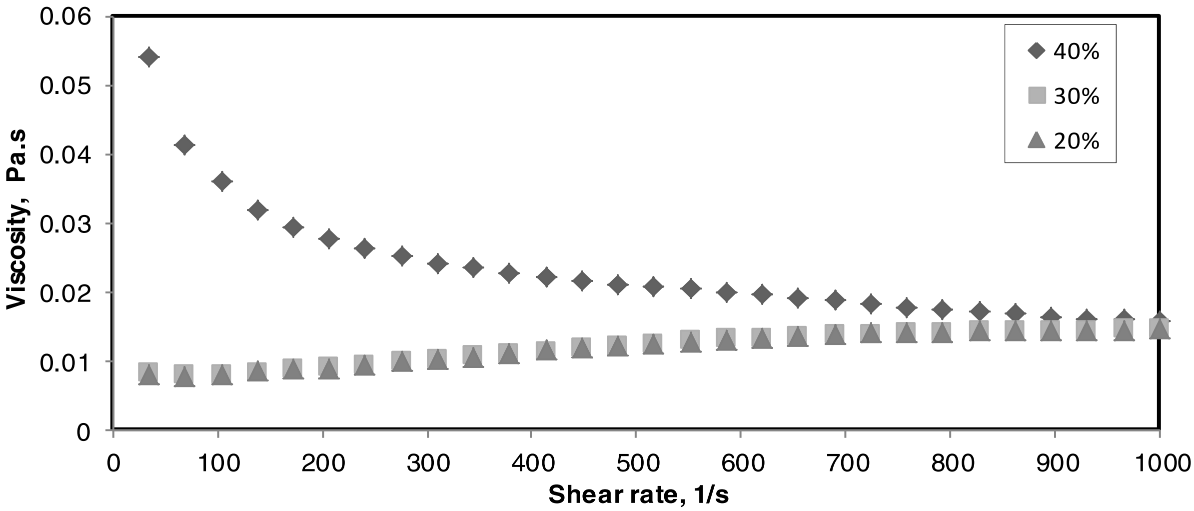


Fig. 3.Effect of water volume fraction on viscosity at 90°C

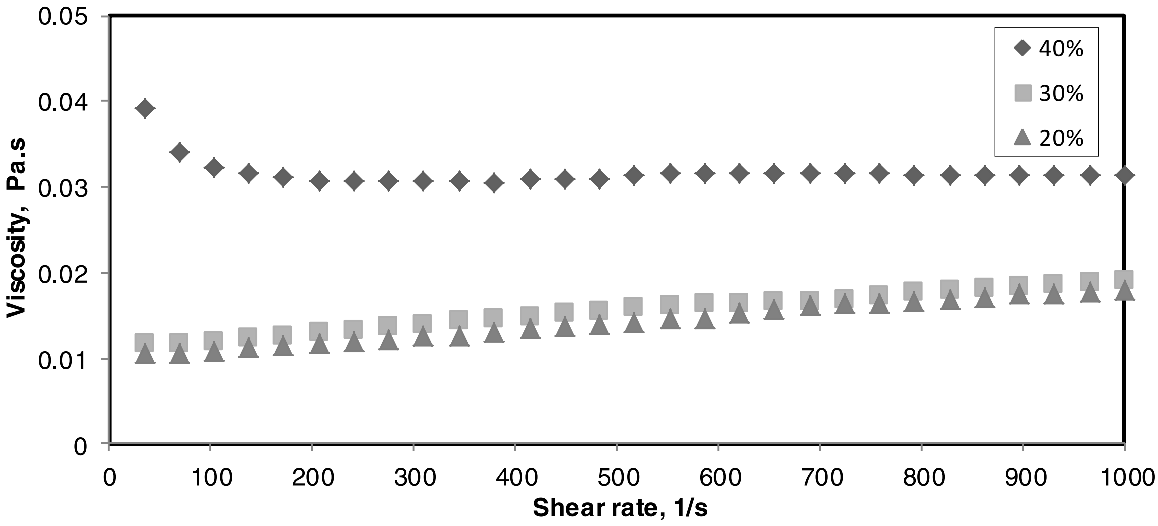


Fig. 4.Effect of water volume fraction on viscosity at 30°C

The effect of volume water fraction was studied and depicted in Figure 3 and 4. In these figures, the emulsion was tested over the range of 0.1 – 1000 $s^{-1}$ and 20% – 40% of volume water fraction. Figure 3 and figure 4 are tested at different temperature, 90°C and 30°C respectively. Generally, the viscosity of emulsion changes as the volume water fraction is varied. Results showed that the viscosities noticeably increase with the water content. At high volume fraction, emulsion will have higher number of water droplet as well as hydrogen bond. Thus, lead to increase in hydrodynamic forces due to interaction between droplets. As the volume water fraction increase, emulsion show remarkable elasticity behavior resulting from the interfacial energy associated with deformation of liquid films which eventually lead to increase in viscosity. It can be noted that both figure had larger reduction in viscosity between 30% and 40%. However, there was slightly different in viscosity between 30% and 20%. This phenomenon happened due to frequently of droplet interaction and increase friction between oil and water. This was mainly due to increase of water content in the emulsion which leads to increase number and volume of dispersed water droplets in the continuous phase (oil). Emulsion with 20% of water fraction demonstrated the lowest viscosity and characterizing less elastic behavior compared with 40% volume water fraction. In figure 3 found that the curve approaches each other at highest shear rate, which means that the viscosity becomes independent on the shear rate and temperature [11]. Meanwhile, Figure 4 shows almost Newtonian flow behavior for 20% – 40% volume water fraction.

## 4. Conclusion

This study investigates the rheological behavior of light crude oil emulsion particularly in viscosity behavior. The experimental results indicate that emulsion exhibits non-Newtonian shear thinning behavior which can be best presented by Herschel-Bulkley model. Temperatures ranging from 20°C – 90°C were examined to study the effect of temperature toward viscosity. Viscosity of emulsion decreases from 0.819 to 0.0466 Pa.s as temperature increases. Besides, increasing volume water fraction from 20% – 40% results in higher viscosity and characterized higher elasticity. It was found that viscosities of emulsion were significantly influenced by shear rate, temperature and water contents.

## Acknowledgements

The authors would like to thank to Ministry of Higher Education (MOHE) and UniversitiTeknolgi MARA (UiTM) for the financial support given through the Research Acculturation Grant Scheme (RAGS), 600-RMI/RAGS 5/3 (74/2013).

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