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Experimental Investigation on Dynamic Viscosity and Rheology of Water-Crude Oil Two Phases FlowBehavior at Different Water Volume Fractions

Rasha Mohammed Abd, Abdurhman H. Nour, Ahmad Ziad Sulaiman

Chemical Engineering Program, Faculty of Chemical Engineering & Natural Resources, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, MALAYSIA.

Abstract: - Emulsionconsidered as a ruthless problem within the petroleum industry due to their various costly problems in terms of production loss and transport difficulties. In this study, the dynamic viscosity and rheological properties of water-oil two phase flow were investigated using emulsion and blending with lighter crude oil approaches at different water volume fractions. Water-in-oil emulsion stabilized by (1.5 vol.%) of Cocamide DEA was considered in the study. Two samples of crude oil were used: Heavy crude oil, and heavy-light blended crude oil at (60-40) vol.%. The dynamic viscosity was determined by Brokfeild Rotational Digital Viscometer Model LV/DV-III. Factors that affect the emulsion rheologyical properties: temperature, rotational speed, shear rate, shear stress, and water volume fractionwas inspected.Results showed that the water-in-heavy oil emulsion approach resulted in reducing the viscosity of original crude oil about (14%) and characterized the Non-Newtonian shear thinning "pseudo-plastic" behavior. On the other hand, the second approach of blending with (40 vol.%) of lighter crude oil showed that the viscosity and the density were significantlyreduced to (93.6 %), and (5.7%) at 30 ℃, respectively. However, water-in- blended crude oil emulsion followed the same behavior of the original crude oil emulsion under the same factors and conditions. Finally, the rheology studies of both approaches showed that temperature, shear rate,and water volume fraction have a great impact on the viscosity behavior of water-oil two phase flow.

Keywords: - *Emulsion, Dynamic Viscosity, Rheology, Flow Behavior.*

I. INTRODUCTION

Emulsions are a fine dispersion of two phases (water-in-oil or oil-in-water) with drop sizes usually in the micron range [1], [2], [3]. It has the ability to resist changes in its properties over time, the more stable the emulsion, the more slowly its properties changes [4]. In the petroleum industry, the formation of emulsion plays a significant role as the crude oil is often mixed with water that usually happen at the exit of the well bore. As the oil-water mixture passes over chokes and valves, mechanical input leads to the formation of water-in-oil (w/o) emulsions. This emulsion is considered as a ruthless problem within the petroleum industry due to their various costly problems in terms of production loss and transport difficulties [5]. To minimize the cost of emulsion, it is necessary to separate the produced water that can be settled and separated from the oil by gravity. In fact, natural emulsions are submitted to destabilization processes to separate the two phases to recover pure oil and pure water, while manufactured emulsions tend to stabilize its structure as long as possible [6]. Hence, a good knowledge of crude oil emulsions as well as the availability of methodologies to study emulsion is essential for enhancing the recovery processes at all oil production stages [7], [8], [9].

Since emulsion is a multiphase system, therefore the nature of the emulsion is depending on several factors; lift technique, shear energy, pressure cycle, thermal cycle, chemical demulsifier, and the water cuts during crude oil recovery process [10].Therefore, studying the rheological and physical properties of the emulsion is necessary to identify the factors that affecting the formation of emulsions. In 1977, the rheological properties of emulsions containing different amounts of crude oil at different temperatures were studied by Mao and Marsden [11]. The rheology of both o/w and w/o emulsions between 24°C to 82°C was described adequately by the power-law relationship. It was found that emulsions that having concentrations of the dispersed phase up to 50% by volume behave like Newtonian fluids, whereas those having higher concentrations have flow behavior like Non-Newtonian fluids (pseudoplastic ones). Another rheological study has been done based on light crude oil and tap water emulsion. It was found that the emulsion characterized a Newtonian fluid where some of these emulsions showed the Non-Newtonian behavior if the volume fraction of the dispersed phase is high and near to the inversion point [12].Moreover, a study performed on the water-in-oil (w/o) emulsions that alreadyformed at the exit of the well bore in some heavy crude oil fields.It was found that in the dispersed pattern the viscosity of the mixtureincreases dramatically compared to that of the continuous oilphase, especially at high water volume fractions [13], [14]. The flow behavior of suchmixtures is further complicated by strong non-Newtonian characteristics [15].

This study focused on several points to understand the flow behavior of water-oil two phases in order to enhance the oil recovery at the oil field. The main point of this investigation is to determine the dynamic viscosity of the water-oil two phases, and to inspect their rheological propertiesat different water volume fractions. The study divided into three sections. Firstly, to characterize the crude oil samples. Second, to investigate the dynamic viscosity and the rheological properties of water-in-heavy oil emulsion. The third section is to study the viscosity behavior and the rheological properties of the blended crude oil emulsion to compare its flow ability with the original crude oil emulsion.Indeed, the rheological propertieswill be performed through observing the effects of temperature, shear stress, shear rate, and the water volume fraction data on the apparent dynamic viscosity for theprepared emulsion.

II. MATERIALS AND METHODS

2.1CRUDE OIL SAMPLES

Two types of heavy and light crude oil samples were collected from Petronas Refinery at Melaka, Malaysia for investigation. The heavy crude oil samplewas marked as crude oil A, whereas the sample of (60 vol.%)heavy crude oilblended with (40 vol.%) lighter crude oil was marked as crude oil B. The Physio-chemicalproperties and the chemical fractionation were carried out to identify the behavior of both crude oils before processing as shown in Tables (1) and (2).

2.2 COCAMIDE DEA

The non-ionic surfactant Cocamide Diethanolamine (Cocamide DEA) was used in this study as a natural emulsifying agent to stabilize the crude oil emulsions for the advantage of the recovery in the refinery is much easier compared to other agents. The Cocamide DEA concentration of (1.5 vol. %) was selected based on a previous stability screening studyas it gave a better stability for the prepared emulsion at the room temperature. The concentration (vol.%) is based on the total volume of the prepared emulsion.

2.3 EMULSION PREPARATION AND TESTING

3samples of water-in-crude oil emulsion at three fractions by volume of water and oil phases (50-50, 40-60, and 20-80) vol. % were prepared. In graduated beakers, 300 mL of emulsions was prepared by “agent-in oil method” through mixing the crude oil sample (continues phase) with (1.5 vol. %) of Cocamide DEA (surfactant agent) then the sample was sheared vigorously for 6 minutes. After that, water (dispersed phase) was added gradually and slowly to the mixing phase (oil and surfactant) then agitated for another 4 minutes. The preparation process was achieved using a standard three blade propeller at a range of rotational speeds from (1500- 1800) rpm at 30 ^{o}C. The prepared emulsions were examined by filter paper as well as by test tube methods to identify the type of the emulsion, whether it is a water-in-oil or an oil-in-water. Only w/o emulsion was selected for the study[16].

2.4 SARA METHOD OF ANALYSIS

To identify the crude oil fractions, SARA method of analysis was performed. The fractions that considered in this study include those in the categories of Asphaltenes, Aromatic, Resins, and Saturated compounds. The analytical design of the standardized ASTM (American Society for Testing and Materials) method, ASTM D2007, that employs open-column liquid chromatography [17], [18]was used to separate the crude oil into two major fractions; Asphaltenes and Maltenes(Aromatic, resins, and Saturated) compounds.

2.5 DETERMINATION OF THE APPARENT DYNAMIC VISCOSITY

The dynamic viscosity of the prepared emulsions was examined by Brokfeild Rotational Digital Viscometer Model LV/DV-III with UL adapter and spindle # 31. The Viscometer was connected with a water bath thermostat. Viscosity measurements were performed over a rotational speed range (50,100,150, and 250) rpm and temperatures range (30, 50, 70, and 90) ^{o}C.

2.6 SURFACE AND INTERFACIAL TENSION DETERMINATION

For measurements of the surface and the interfacial tension, a standard test method ASTM(American Society for Testing and Materials) was performed using Du Nouy Interfacial Tensiometer. The tensiometerequipped with 6-cm circumference platinum ring. In this method, the water was placed first in the sample boat for calibration. Then, the oil was added the water to form an emulsion as it's lighter than water. The platinum ring should be inserted in the water layer where the contact of the oil and this ring should be avoided. After 5 minutes, where the interfacial tension reaches to its equilibrium value, measurements were taken.

III. RESULTS AND DISCUSSION

3.1 CRUDE OIL PROPERTIES

Depend on the Physio-chemical propertiesand SARA Fractionation method, it was found that sample A behaves as heavy crude oil, whereas sample B behaves as medium crude oil, as shown in Tables 1, and 2.

Table1: Phsical Properties of The Crude Oil Samples

Crude oil	Crude A	Crude B
Density (g cm^{-3})	0.947	0.893
Viscosity (m·Pas)	298.7	19.1
Surface Tension at 20C (mNm^{-1})	28.98	27.33
Interfacial Tension at 20 °C (mNm^{-1})	25.83	21.07
API Gravity	17.13	26.12

Table II:SARA Fractionations of The Crude Oil Samples

Crude oil samples	Asphaltenes (wt.%)*	Saturated (wt.%)*	Aromatic (wt.%)*	Resins (wt.%)*	R/A ratio
A	12.2	48.7	34.6	4.5	0.37
B	7.6	61.4	27.2	3.8	0.51

* (wt. %) by dry basis

3.2 VISCOSITY BEHAVIOR FOR W/O EMULSION OF HEAVY CRUDE OIL

3.2.1 EFFECTS OF SHEAR RATE AND SHEAR STRESS ON VISCOSITY

The relation between shear rate and shear stress was plotted Fig. 1 to investigate their effects on the flow behavior of the water-in-heavy crude oil emulsion stabilized by (1.5 vol.%) of the Cocamide DEA at different water-oil two phasesratios (50-50, 40-60, and 20-80) vol.%, and temperatures (from 30 to 90) °C. Itcan be observed that the shear stress increased gradually and significantly with the shear rate. Which indicates that all emulsions are following the Non-Newtonian behavior.

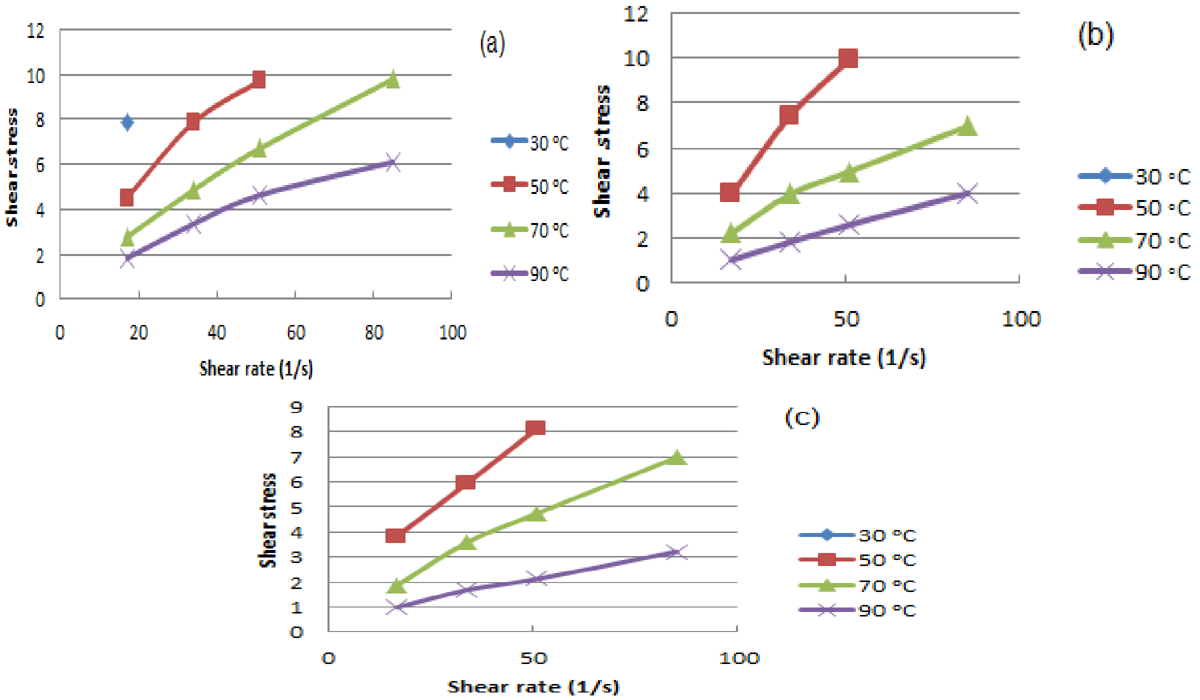


Figure 1: Effects of shear rate and shear stress on viscosity of: a) 50-50 vol.%, b) 40-60 vol.%, and c) 20-80 vol.% of water-in-heavy crude oil emulsion stabilized with (1.5vol.%) of DEA at different temperatures.

3.2.2 EFFECTS OF SHEAR RATE AND TEMPERATURE ON VISCOSITY

The behavior of the apparent viscosity for (50-50,40-60, and 20-80) vol.% of water-in heavy crude oil emulsion stabilized with (1.5 vol.%) of Cocamide DEA were investigated under the effects of shear rate at different temperatures as presented in Fig. 2. In general, over a wide range of shear rate (from 17 to 85) 1/s, the viscosity was significantly decreased as the shear rate increasedwhich means the prepared emulsions are depended on shear rate and following shear-thinning behavior (pseudo-plastic behavior). Thereasonfor this behavior is at the moment of spindle moving,the bonds of aggregated molecules in the sample are starting to destroyand deformed wherethe molecules oriented more parallel to the spindle surface. Thus, the resistance to the spindle rotation (shear rate)is less and therefore viscosity. As the shear rate increased, the aggregates may be more deformed and breaking down into individual flocs thus the viscosity is more reduced.

On the other hand,because temperature is one of the most obvious factors that can affect on the rheological behavior of the materials as some materials are quite sensitive to temperature and a relatively small variation will result in significant change in viscosity. Therefore, the effect of temperature on the w/o emulsion viscosity was investigated as shown in Fig.2. It was found that increase the temperaturegradually (from 30 to 90) ^{o}C resulted in considerable reduction in the dynamic viscosity which indicates that the w/o emulsion viscosity depended on temperature and it is a subject to temperature variations in the processing.

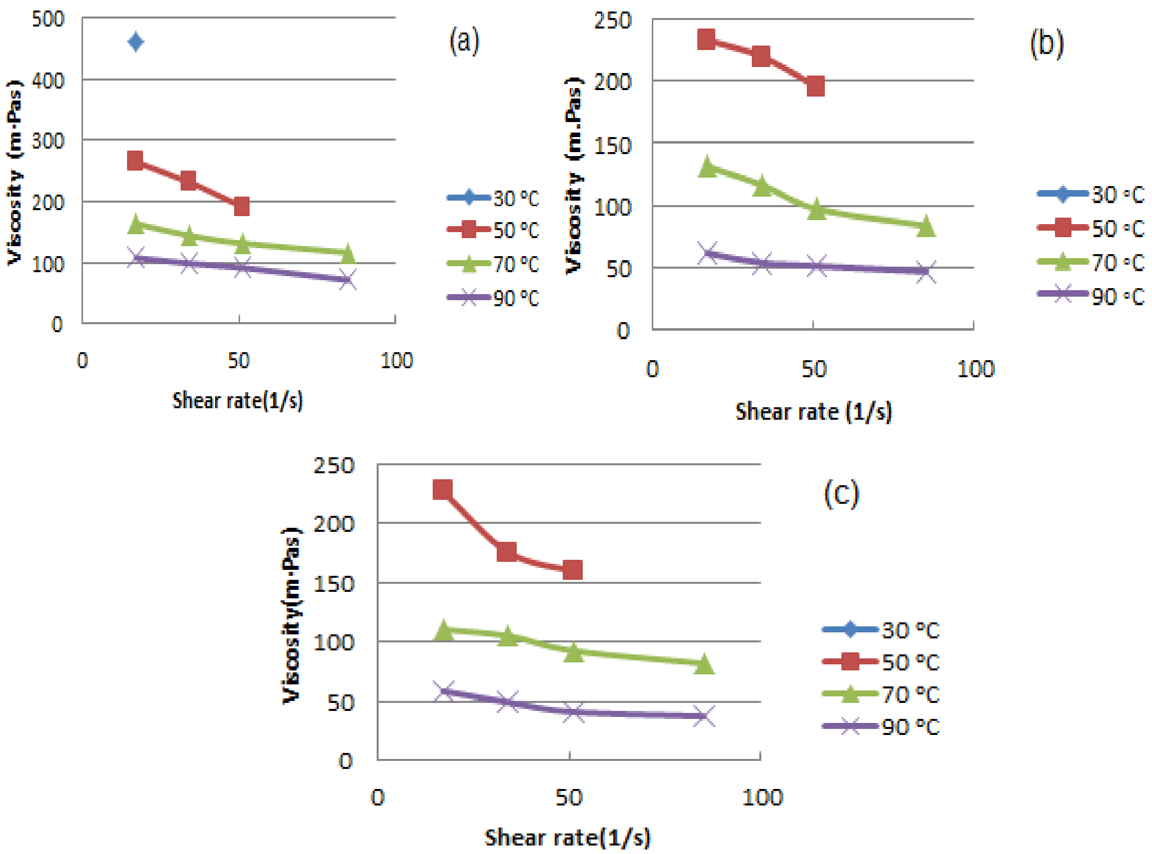


Figure 2: Effects of shear rate on the viscosity of: a) 50-50 vol.%, b) 40-60 vol.%, and c) 20-80 vol.% of water-in-heavy crude oil emulsion stabilized with (1.5 vol.%) of the DEAat different temperatures.

3.2.3 EFFECTS OF WATER VOLUME FRACTION ON VISCOSITY

The volume fraction of water (dispersed phase) found to have a significant effect on the emulsion viscosity behaviorof heavy crude oil emulsion as shown in Fig 3. In theFigure, data of (50-50, 40-60, and 20-80) vol.% w/o emulsion stabilized with (1.5 vol.%) of Cocamide DEA demonstrated the viscosity behavior at different rotational speeds (from 50 to 250) rpm and varied temperatures (from 30-90)^{o}C. It can be noted that reducing the volume fraction of the water (from50 to 40, then to 20)% resulted in significant reduction in the apparent viscosity (from 264.5 to 227.2) m·Pas at 50^{o}C,which is about (14%).Moreover, it can be noted thatemulsion with50 % of the water volume fraction characterize higher elastic behavior andit needs a higher shear rate followed by emulsion with 40%, then 20 %.The reason behind increase the viscosity when thehigh volume fraction of the dispersed phase(water)was used is due to increase the number of the hydrogen bond that leads to increase the hydrodynamic forces and hence the viscosity [3], [16]. Thus,it needs a high shear rate to start the deformation.

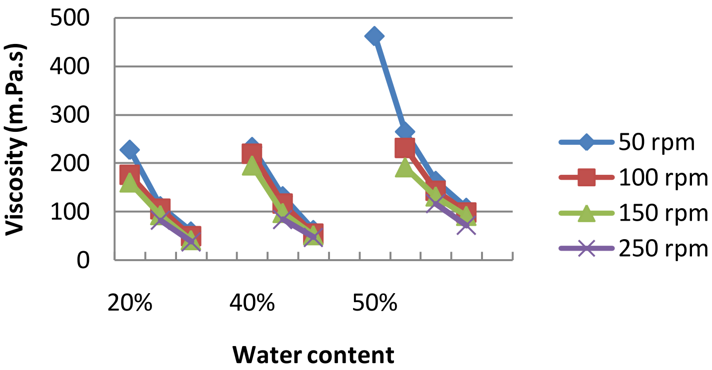


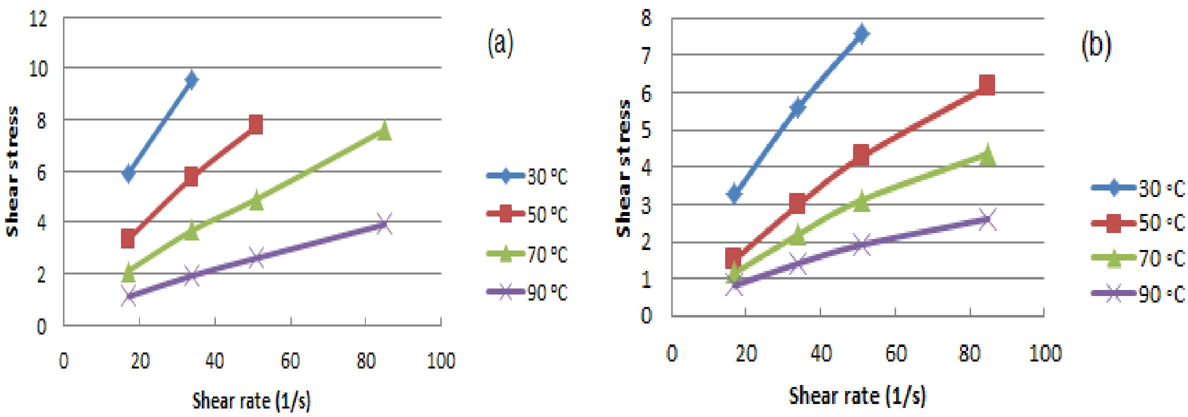
Figure 3: Effects of the water volume fractions on viscosity of heavy crude oil emulsions stabilized with (1.5 vol.%) of DEA at different rpm and temperatures.

3.3 VISCOSITY BEHAVIOR FOR W/O EMULSION OF HEAVY-LIGHT CRUDE OIL

The main task of blending the heavy crude oil with the lighter crude oil is to reduce the viscosity as well as the density and to enhance the flow-ability that could be desirable for the pipeline transportation.Observing the viscosity value for heavy and blended crude oil samples (Table 1), it can be highlighted that blending with (40 vol.%) of a light crude oil resulted in drop theviscosity (from 298.7 to 19.1) m·Pas at 30 ºC, which is almost (93.6%)less than the original viscosity value. Moreover, the density of the original heavy crude oil were reduced (from 0.947 to 0.893) g.m^{-3} at 30 ºC, which is about (5.7 %) less than the original density.For that reason, it is important to investigate the factors that affect thewater- oil two phase flow behavior for the blended crude oil sample to provide a deep understanding of the emulsion system.

3.3.1 EFFECTS OF SHEAR RATE AND SHEAR STRESS ON VISCOSITY

The effects of the shear stress and shear rate data on viscosity of (50-50, 40-60, and 20-80) vol.% of water-in-blended crude oilemulsion using (1.5vol.%) of Cocamide DEA at different testing temperatures (from 30to 90) ºC are shown in Fig. 4. The blended crude oil emulsion was found to follow the Non-Newtonian behavioras the shear stress increased significantly with the shear rate. Similarbehavior was noticed withw/o emulsion of the original crude oil.



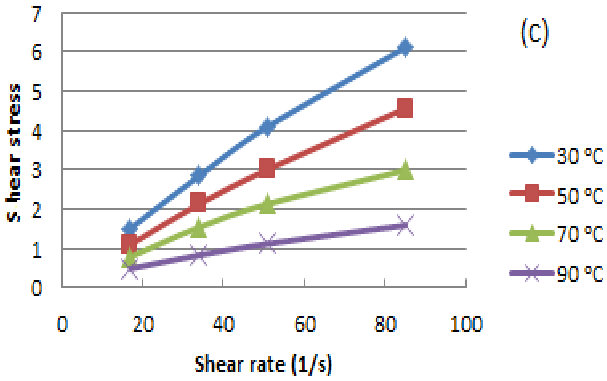


Figure 4: Effects of shear rate and shear stress on the viscosity of: a) 50-50 vol.%,b) 40-60 vol.%, and c) 20-80 vol.% of blended crude oil emulsion stabilized with (1.5 vol.%) DEA at different temperatures.

3.3.2 EFFECTS OF SHEAR RATE AND TEMPERATURE ON VISCOSITY

Fig. 5 represents the relationship between the apparent viscosity of the blend crude oil emulsion and the shear rate at different temperatures (from 30 to 90) °C. It can be noted thatat (50-50 vol. %) of w/o emulsion, the dynamic viscosity of blendedoil emulsionis about (347.9) m.Pas whichis less than the viscosity of the original crude oil emulsion(461.8) m.Pas at 30 °C, which is (24.2%) less than original oil emulsion. However, the viscosity of blended oil taken the same behavior ofthe heavy crude oil emulsionby following shear-thinning (pseudo-plastic) behavior in term of decreasing the emulsion viscosity with increasing the shear rate and the temperature which means the emulsion depended on shear rate and temperature.

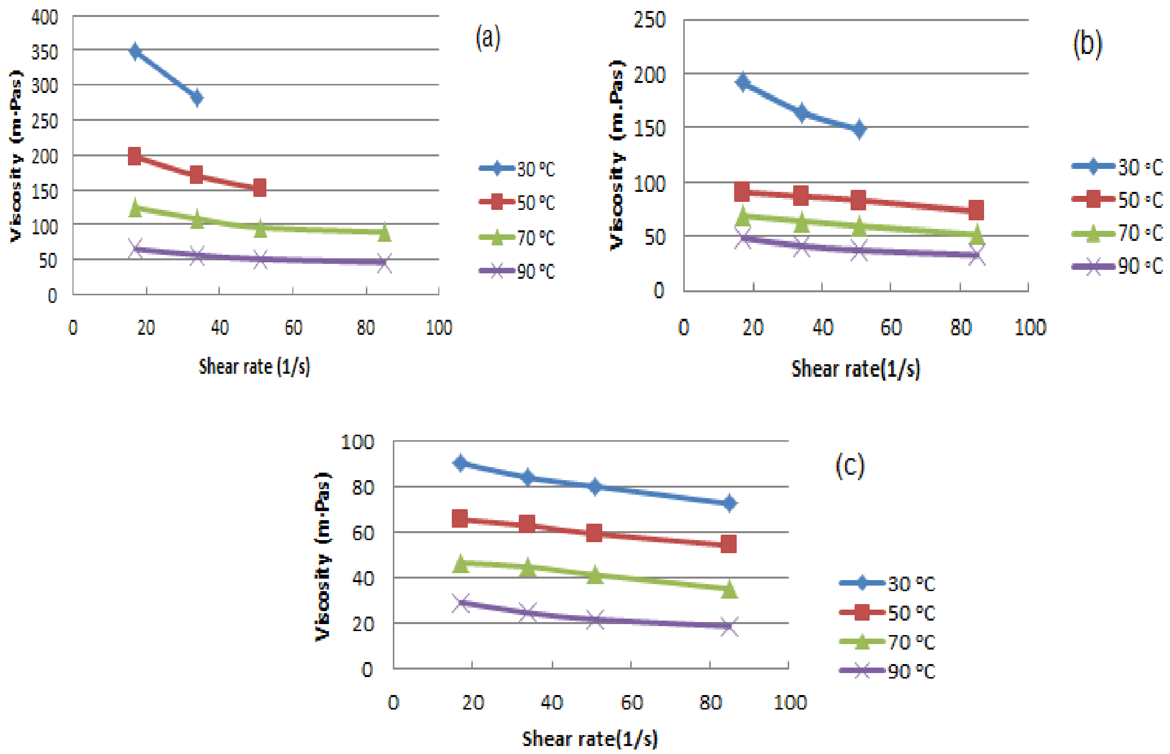


Figure 5: Effects of shear rate and temperature on the viscosity of:a) 50-50 vol.%, b) 40-60 vol.%, and c) 20-80 vol.% of blended crude oil emulsion stabilized with (1.5 vol.%) of DEA.

3.3.3EFFECTS OF WATER VOLUME FRACTION ON VISCOSITY

The effects of the water volume fractions(dispersed phase) on the viscosity of theblended crude oil emulsion stabilized with (1.5 vol.%) of Cocamide DEA over a range of rotational speeds (from 50-250)rpm and temperatures (from 30-90)°C are presented in Fig. 6. It was found that the volume fraction had a significant effect on the rheological properties of the flow behavior of w/o emulsion. This effect appears as the water fraction decreased from 50% to 40% and then to 20%,where the emulsion viscosity was decreased from (347.9,

191.8, to 90) m·Pas at 30 °C, respectively. Thus, emulsion with (50 vol.%) of water needs higher shear rate and characterize higher elastic behavior followed byan emulsion with (40 vol.%)of water, and thenthe emulsion with (20 vol.%) of water as shown in Fig.6 (a), (b), and (c), respectively.This behavior is similar to thebehaviorthat was indicated with the original crude oil emulsions.
Table 3 showed the effects of all approaches used in this study on the dynamic viscosity at low shear rate of 17 (1/s) and different temperatures.

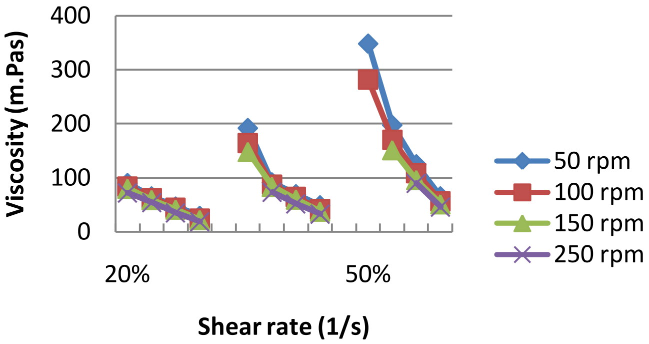


Figure 6: Effect of water volume fractions on the viscosity of the blend crude oil emulsion stabilized with (1.5 vol.%) of DEA at different rpm and temperature

TABLEIII:: VISCOSITY VALUES OF ALL APPROACHES USED IN THIS STUDY AT SHEAR RATE 17 (1/S)

Sample	30 ^{0}C	50 ^{0}C	70 ^{0}C	90 ^{0}C
Pure Heavy oil	298.7			
20-80% w/o emulsion		227.2	110.8	58.8
40-60% w/o emulsion		232.9	131.4	61.8
50-50% w/o emulsion	461.3	264.5	163	107.6
Pure Blended oil	19.1			
20-80% w/o emulsion	90	65.3	46.5	29.2
40-60% w/o emulsion	191.8	91.2	69.3	48.8
50-50% w/o emulsion	347.9	197.3	124.7	65.4

* Viscosity unitesare (m·Pas)

IV. CONCLUSIONS

The present study examinedthe viscosity behavior and the rheology properties of water-oil two phase flow at a different water volume fraction using Malaysian crude oil. Water-in- crude oil emulsion stabilized by (1.5 vol.%) of Cocamide DEA was investigated.A wide range of temperatures (from 30 to 90) °C, rotational speeds (from 50 to 250) rpm, and water volume fractions (20, 40, and 50) % were covered. Using the firstapproachto investigate the viscosity by forming a water-in-heavy crude oil emulsion containing different water volume fraction found that the emulsion flowed a Non-Newtian shear-thinning behavior (pseudo-plastic). Reducing the water volume fraction (from 50 to 20) % resulted in a viscosity reduction about (14%) of original viscosity and the emulsion characterized less elastic behavior that means better flow ability. The second approach of blending with (40 vol.%)lighter crude oil resulted inviscosity and density reduction to about(93.6 %), and (5.7%) at 30 °C, respectively. In addition, forming the water-in-blended crude oil emulsion resulted in more viscosity reduction to about (24.2%) compare to originalw/o emulsion. However, the blended oil emulsion is following the same behavior of the original crude oil emulsion under the same factors and conditions. Finally, the rheological investigation found that temperature, shear rate, and water volume fraction have a great impact on the viscosity behavior of water-oil two phase flow.

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REFERENCES

[1] S. J. Joblom ,*Encyclopedic hand book of emulsion technology*(New York:Marcel Dekker,2001).

[2] J. Bibette,F. Leal- Calderon, V. Schmitte, andP. Pouline,*Introduction in emulsion science-basic principles* (*Springers, 2002).*

[3] L. K. Sunil, Crude oil emulsions,in W. L. Larry and R. F. John (Ed.), *Petroleum Engineering Handbook :General Engineering, 1*(U.S. Texas, 2006)

[4] J. David Julian, and Mc. Clements, *Food emulsions: principles, practices, and techniques, 2nd Ed.*,2 ,2005 , 269.

[5] W. H. Shadi, T. G. Mamdouh, and E. Nabil, Heavy crude oil viscosity reduction and rheology for pipeline transportation, *J. Fuel, 89,* 2010, 1095–1100.

[6] D. Clausse, F. Gomez, C. Dalmazzone, and C. Nick, A method for the characterization of emulsions, thermogranulometry: Application to water-in-crude oil emulsion, *Journal of Colloid and Interface Science*, *287,* 2005, 694–703.

[7] A.Ram, and D. Shah, Emulsion in tertiary oil recovery, in K. J. Lissant (Ed.),*Emulsion and emulsion technology, Surfactant science series, 6* (New York: Marcel Dekker, Inc,1984).

[8] H. K. Abdel-Al, A. Mohamed, and M.A. Fahim, *Petrolum and Gas Field ProcessingHandbook* (NewYork:Marcel Dekker, Inc. Basel, 2003).

[9] D. Langevin, S. Poteau, I. Hénaut, and J.F. Argillier, Crude Oil Emulsion Properties and their Application to Heavy Oil Transportation, *J.Oil & Gas Science and Technology – Rev. IFP*, 59, (5) , 2004, 511-521.

[10] W. S. Gar, and Z. Moshen, Emulsion resolution in electrostaticprocesses, *Energy & Fuels, 14*, 2000, 31-37.

[11] M. L. Mao, and S.S. Marsden, Stability of concentrated crude oil-in-water emulsions as a function of shear rate, temperature and oil concentration,*J. Can. Pet. Tech.* 1977, 54.

[12] D. Dou Dan, and J. Gong , Apparent viscosity prediction of non-Newtonian water-in-crude oil emulsions, *Journal of Petroleum Science and Engineering*, *53*, 2006, 113–122

[13] E.EJohnsen., and H.P Rőnningsen,Viscosity of ‘live’ water-in-crude-oil emulsions: experimental work and validation of correlations, *J. Pet. Sci. Eng., 38,* 2003, 23–36.

[14] M. A.. Farah, R. C.Oliveira, J.N. Caldas, Raand K. jagopal, Viscosity of water-in-oil emulsions: variation with temperature and water volume fraction, *J. Pet. Sci.Eng., 48*, 2005, 169–184.

[15] W. Wei, G. Jing , A. Panagiota,Investigation on heavy crude-water two phase flow and related flow characteristics, *International Journal of Multiphase Flow,37,* 2011, 1156–1164.

[16] A.N.Ilia Anisa, H. N. Abdurhman , and H. N. Azhary, Catastrophic and transitional phase inversion of w/o emulsion for heavy and light crude oil, *J. of Applied Science,10(23),* 2010,2076-3083.

[17] V. C. Laura, and F. Vazquez, Fractionation and Characterization of Mexican Crude Oils, *Energy & Fuels, 23,* 2009, 1603–1609

[18] C. K.Geoffrey, A. M. Annelie, P.R. Ryan, and G. M. Alan, Use of Saturates/Aromatics/Resins/Asphaltenes (SARA) Fractionation To Determine Matrix Effects in Crude Oil Analysis by Electrospray Ionization Fourier Transform Ion Cyclotron Resonance Mass Spectrometry, *J. Energy & Fuels, 20,* 2006, 668-672.