RHEOLOGICAL PROPERTIES OF CRUDE OIL EMULSION

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Abstract

Emulsion either water-in-oil or oil-in-water emulsion can be important in almost all stages of upstream activities in petroleum industry such as drilling, completion, production, transportation and separation of emulsified crude oil. For instances heavy crude oil have become increasingly important sources of hydrocarbons in many part of the world which transportation of these heavy crude to the refinery can be a problem, and the formation of crude oil emulsion due to high paraffinic compound existed in the crude causes problem in dewatering stage of the crude emulsion. Production of stable emulsion at high temperature and pressure has lead to the design of many new fracturing fluid systems and new drilling fluid systems. The inversion of the type of emulsion at higher concentrations of the dispersed phase has been utilised as a helpful process for transporting crude oil for long distances through pipeline. Therefore, a knowledge of the rheological behaviour of these emulsions, under both laboratory and field conditions, is important to choose the right approach in designing the required facilities. In order to get better understanding the effect of various influencing parameters on rheological properties of crude oil emulsion, the synthetic crude oil emulsion prepared by using a crude oil sample and Triton X-100 was studied at various temperature and water concentration. Brookfield Digital Rheometer was used to measure the rheology of the emulsion. The results showed that at low water concentration the emulsion behaves as a Newtonian fluid, however, at high water concentration it behaves as a non-Newtonian fluid. It was also observed that the viscosity decreases with temperature and the highest viscosity was observed at the point close to phase inversion.

Introduction

Emulsion is a common phenomena in the oil industry because about two third of the crude oil production of the world can be associated with emulsion. In oil industry, a water-in-oil emulsion is considered as normal emulsion while a oil-in-water emulsion as reverse emulsion. The rheological properties and characteristics of the emulsion is very important for it has wide application in the oil industry, for example to increase oil recovery and to ease oil transportation. The specific objectives of this study are to determine the rheological model which suits the water-in-oil emulsion of the synthetic Semangkok-A emulsion system, to demonstrate that the emulsion is shear rate dependent where Newtonian or non-Newtonian fluid are applied at certain range of shear rates, and to study the effect of shear rate, water concentration and temperature on emulsion viscosity.

Material, Apparatus and Experimental Procedure

Materials

The crude oil used in this study was Semangkok-A Crude Oil from oil field's offshore Trengganu. The crude oil was a clean crude oil where the water had been separated from the oil. The Semangkok-A Crude Oil had a bad history of emulsion problem the opposite was observed, only free water forms at the bottom and a creamy layer at the top. Upon introducing heat, all the emulsion systems were demulsified into water and oil. The low content of natural emulsifiers of asphalt and BS&W (see Table 1) in the produced water are believed to be the reason for instability of the emulsions. At any water content, the excess oil or/and water portions will easily coalesce between their phases to form free oil or/and free water. Since the emulsion is unstable, no further rheological measurements and analyses were carried out.

Water-in-Oil Emulsion of Crude Oil-Tap Water-Triton X-100 System

We had successfully determined the effects of temperature and water concentration on the rheological properties of the Semangkok-A emulsions (Rosli, 1996 and Lim, 1997). The rheological data are presented in a plot as apparent viscosity versus shear rate in Fig. 1 to Fig. 6, apparent viscosity versus water concentration in Fig 7, apparent viscosity versus temperature in Fig. 8 and log-log plot of shear stress versus shear rate in Fig. 9 to Fig. 14. The followings are the results and discussion of this particularly stable water-in-Oil emulsion system.

Effect of Shear Rate

The emulsion system behaves as a shear thinning (pseudoplastic) fluid. This is shown in Fig 1 to Fig. 6, where the apparent viscosity decreases with increasing shear rate. The emulsions also display an increasing pseudoplastic behaviour of apparent viscosity decrease with shear rate as the concentration of the disperse phase (water) is increased. Fig. 9 to Fig. 14 shows the characteristics of the log-log plot of shear stress versus shear rate at various water concentration. From the analysis of the plots, the power law flow index, n, is about 0.96 and the confidence of fitting to power law model is very close to 98%. The consistency index is increasing as the water concentration increases. See Table 2 to Table 4 (Lim, 1997). These fitted data implied that the emulsion is a non-Newtonian fluid with pseudoplastic behaviour. However, at very low water concentration and low shear rate the emulsion behave as a Newtonian fluid. It was also observed that at high shear rate (above 200 sec^{-1}) the emulsion will behave as a shear thickening fluid.

Effect of Temperature

The temperature effect the viscosity of the continuos phase. As temperature increases, the continuos phase's viscosity decreases. The decrease of continuos phase's viscosity will decrease the overall emulsion system viscosity. The viscosity data of water-in-oil emulsion is very temperature-dependent as shown in Fig. 8 with a bigger percent decreases of viscosity is prevailed for high water content.

Effect of Water Concentration

From Fig. 7, it shows that the rheology of emulsion is affected by the amount of water in the system (Woelflin, 1942). The viscosity will increase drastically to a maximum as become nearer to the inversion point and will decrease sharply after passing that point. Before the inversion of emulsion from water-oil to oil-water emulsion, increase of water content will facilitate the dense aggregation and flocculation of the disperse phase (oil). A very close packed of disperse phase will reduce the mobility of disperse phase and will increase the interfacial viscosity of disperse phase droplets which in turn will increase the viscosity of the emulsion system. However, after the inversion point, the continuos phase will be water which the viscosity of the emulsion will gradually decrease to the viscosity of water as water concentration increase.

where it formed a very stable emulsion at the surface. This crude oil had an API gravity of 40.2 degree and density of 824.1 kg/m^3 at 15^{o}C. The kinematic viscosity and surface tension of the crude oil at room temperature of 26.5^{o}C were about 5.251 cSt and 34.22 mN/m, respectively. The API gravity and density values were determined by hydrometer method of ASTM D1298. The kinematic viscosity was measured by viscometer tube of ASTM D445 and the surface tension by KRUSS Digital Tensiometer (ring type). A complete physical and chemical characteristics of the Semangkok-A crude oil, produced formation water and tap water are given in Table 1 (Mohd. Yusof, 1997). The produced water has the following ionic concentrations: anions - F (4 ppm), Cl (707 ppm), PO_4 (8 ppm), NO_3 (0 ppm) and SO_4 (45 ppm), and cations - Ca (5695 ppm), K (391 ppm) and Na (3 ppm) (Mohd. Yusof, 1997).

Emulsifier

The commercially available Triton X-100 was used to emulsified the emulsion in this study. Triton X-100 is a non-ionic water soluble molecule. It has a density of 1065 kg/m^3 and a viscosity of 240 cP at 25^{o}C. Its surface tension is about 3100 dyne/m.

Emulsification Method

In this study two types of emulsion were prepared. The first type was an emulsion constructed with crude oil, tap water and Triton X-100, and the second one was an emulsion prepared with crude oil and produced formation water of Semangkok Oil Field.

The preparation technique of the emulsion was similar to the method used by Steinborn and Flock (1983). A 500 ml biker and a hot plate equipped with a variable RPM, heater and magnetic stirrer was used to mix the water-oil emulsion. For crude oil-tap water-Triton X-100 emulsion system, a 1 ml Triton X-100 was (in excess of the minimum amount required to obtain a stable emulsion) premixed with a 90 ml crude oil. Only the amount of water was varied depending on the percentage of water needed in the emulsion system. In all cases, the water-in-crude oil emulsions were prepared by first preheating the crude oil to about 60^{o}C and then gradually adding the appropriate amount of water to the oil while mixing at slow speed for 8 minutes, followed by a rigorous stirring at high speed for 30 minutes. The emulsion was allowed to stand for 15 minutes before the rheological measurements were taken.

Viscosity Measurement

The viscosity was measured with a Brookfield Digital Rheometer. Spindle type ULA was used for all viscosity measurements The rheometer was capable of providing the shear stress and apparent viscosity data against shear rate from each viscosity determination.

Before taking the viscosity measurements, the rheometer was checked with a calibration fluid (Brookfield Standard Fluid, 48 cP at 25^{o}C). The rheometer was thoroughly cleaned between measurement of different emulsion samples.

Results and Discussion

Water-in-Oil Emulsion of Crude Oil-Produced Water System

The emulsion prepared with crude oil and produced water is not a stable emulsion. At low produced water concentration below 50%, the emulsion separated into a free crude and formed a creamy layer at the bottom within 15 minutes of standing time. However, at water concentration between 60 % to 70 %, a free crude oil forms at top, a gel liked layer at the middle and a free water at the bottom. The semi-solid gel liked layer which dominated almost 90% of the total volume was expected to has a very high viscosity that the rheometer fail to measure its viscosity. At 80% or more of water concentration,

Conclusion

From the results of this study, we can conclude that the Semangkok-A emulsions has the following rheological properties:

1. The viscosity of a water-in-oil emulsion is largely dependent on the amount of water in the emulsion. A general curve to show the change of viscosity of an emulsion from 0 percent to 50 percent water reveals that the crude oil emulsion should be pumped with either a low water concentration or an extremely high water concentration as to maintain low pumping pressure. The maximum viscosity was observed near the inversion point where the emulsion system changes from water-in-oil emulsion to oil-in-water emulsion at about 40 to 50 % water concentration.

2. The rheology of Semangkok-A emulsion is shear rate and temperature dependent.

Acknowledgement

The authors feel grateful to the Research & Consultation Unit, Universiti Teknologi Malaysia for financial support of the project. A token of appreciation is also due to Petronas E&P East Coast and EPMI for supplying Semangkok-A crude oil. The author wishes to acknowledge the help given them by students, Rosli,.L.J.Ming, S.K. Khong and Mohd Yusof, who made most of the tests under the direction of M.A.Manan and Dr. H.B. Mat.

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Table 1 : Physical and chemical properties of Semangkok-A Crude Oil, Produced Formation Water and Tap Water.

Parameter	Semangkok-A Crude Oil	Semangkok-A Produced Water	Tap Water
Interfacial Tension (between crude oil-water), mN/m	-	7.27	15.1
API gravity	40.2	7.6	9.4
Density, kg/m^3	824.1	1016.6	
Kinematic Viscosity at 60°C, cSt	2.306	0.7452	0.7191
Dynamic Viscosity at 60°C, cP	1.8134	0.7519	0.7161
pH at 27.3°C	-	8.9	-
Asphalt Content, %	0.39	-	-
BS&W Content, %	< 0.05	-	-

Table 2 : Power Law's Data Analysis for Semangkok-A Water-Crude Oil Emulsions at 28°C.

Power Law Plot's Criteria	Water Concentration in Emulsion					
	0 %	10 %	20 %	30 %	40 %	50%
Power Law Index, n	0.961	0.996	0.942	0.914	-	0.769
Consistency Coefficient, k	5.29	6.49	8.58	18.4	-	51.9
Degree of Fitting to Power Law, %	98.4	99.1	99.6	99.2	-	99.8

Table 3 : Power Law's Data Analysis for Semangkok-A Water-Crude Oil Emulsions at 50°C.

Power Law Plot's Criteria	Water Concentration in Emulsion					
	0 %	10 %	20 %	30 %	40 %	50%
Power Law Index, n	0.859	0.906	0.937	0.869	0.800	0.798
Consistency Coefficient, k	5.07	5.79	5.42	16.3	95.2	33.0
Degree of Fitting to Power Law, %	96.3	99.1	98.8	98.9	100.0	99.0

Table 4 : Power Law's Data Analysis for Semangkok-A Water-Crude Oil Emulsions at 80°C.

Power Law Plot's Criteria	Water Concentration in Emulsion					
	0 %	10 %	20 %	30 %	40 %	50%
Power Law Index, n	0.875	0.929	0.885	0.837	0.857	0.890
Consistency Coefficient, k	3.66	3.63	4.26	15.1	38.7	15.8
Degree of Fitting to Power Law, %	98.6	99.3	98.1	98.7	99.5	99.3

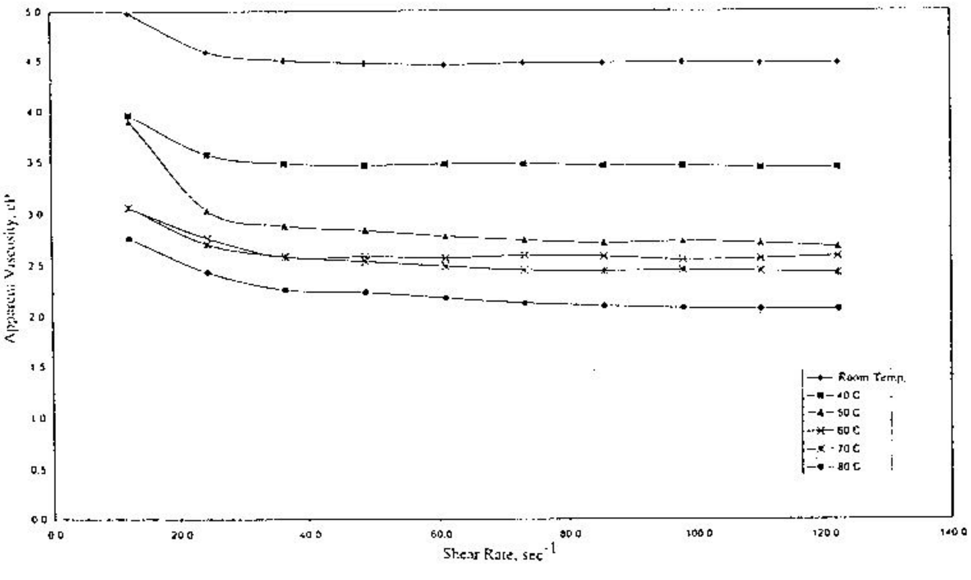

Fig. 1: Apparent viscosity versus shear rate for clean Semangkok-A crude oil

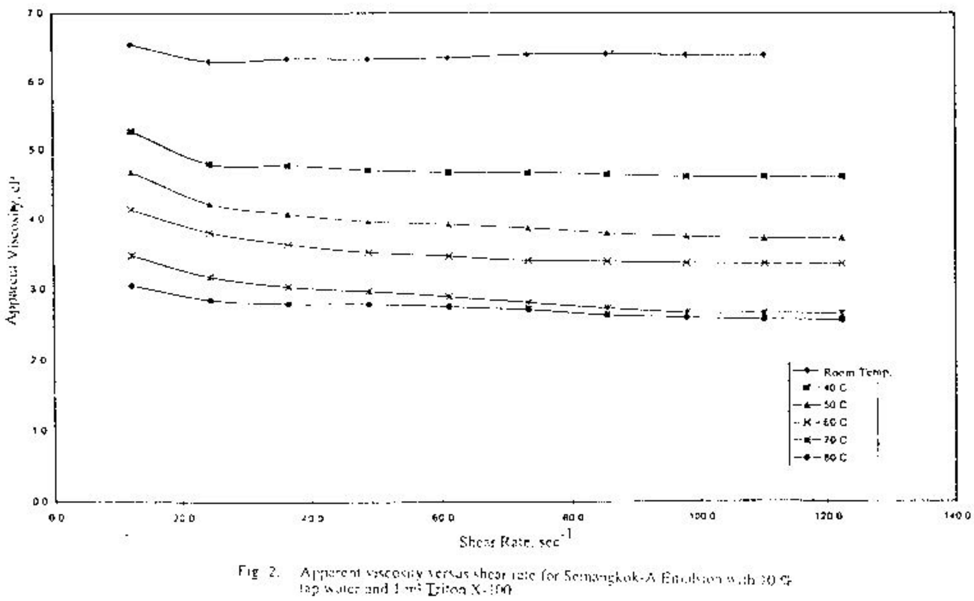

Fig. 2: Apparent viscosity versus shear rate for Semangkok-A Emulsion with 30 % tap water and 1 % Triton X-100

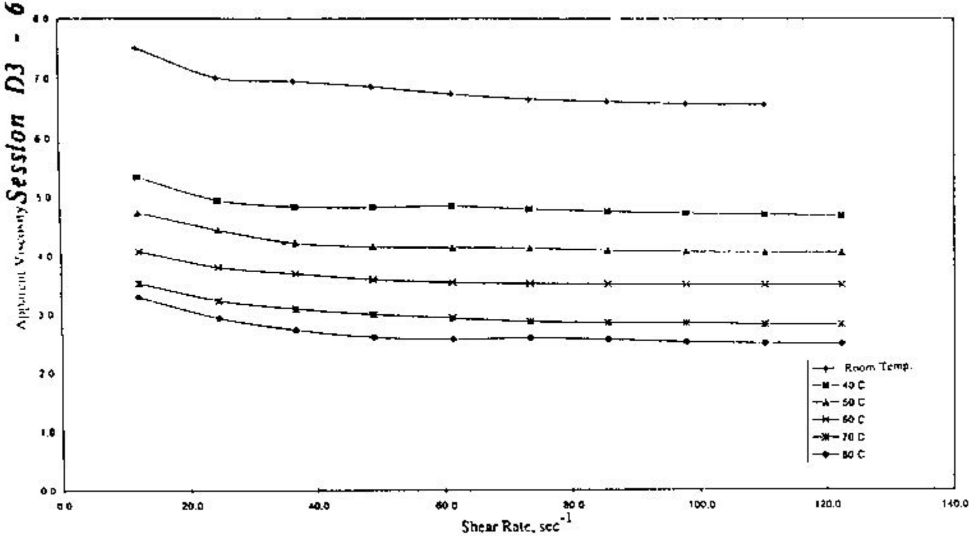

Fig. 3: Apparent viscosity versus shear rate for Semangkok-A Emulsion with 20 % tap water and 1 ml Triton X-100

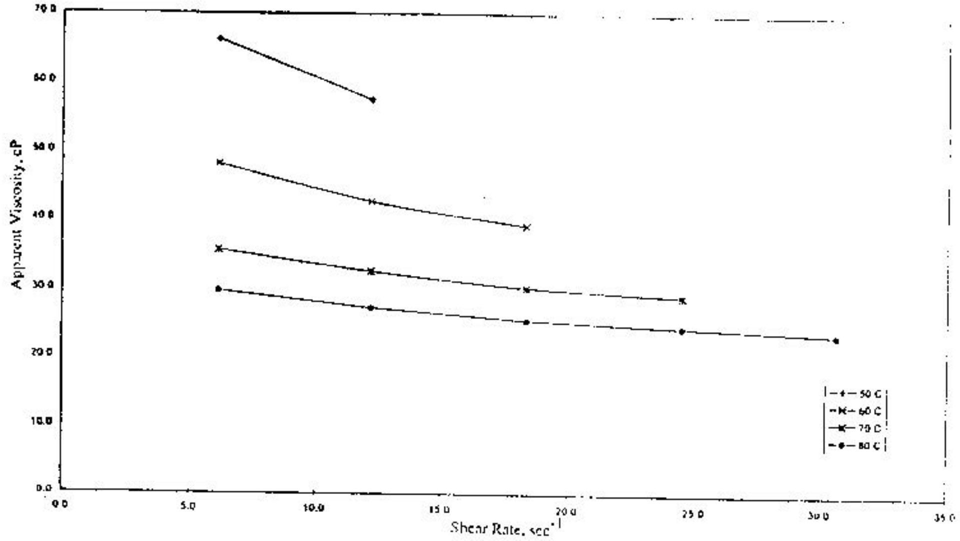

Fig. 5: Apparent viscosity versus shear rate for Semangkok-A Emulsion with 40 % tap water and 1 ml Triton X-100

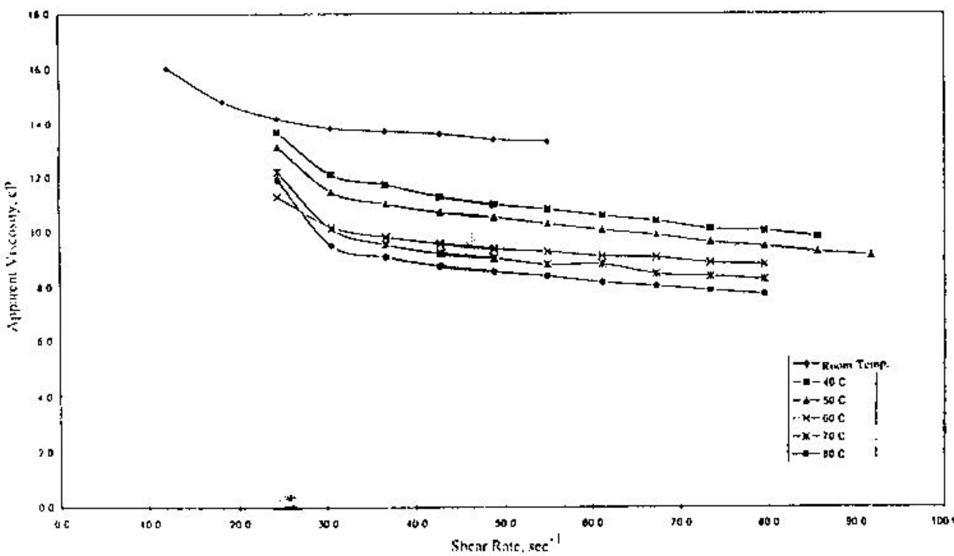

Fig. 4: Apparent viscosity versus shear rate for Semangkok-A Emulsion with 30 % tap water and 1 ml Triton X-100

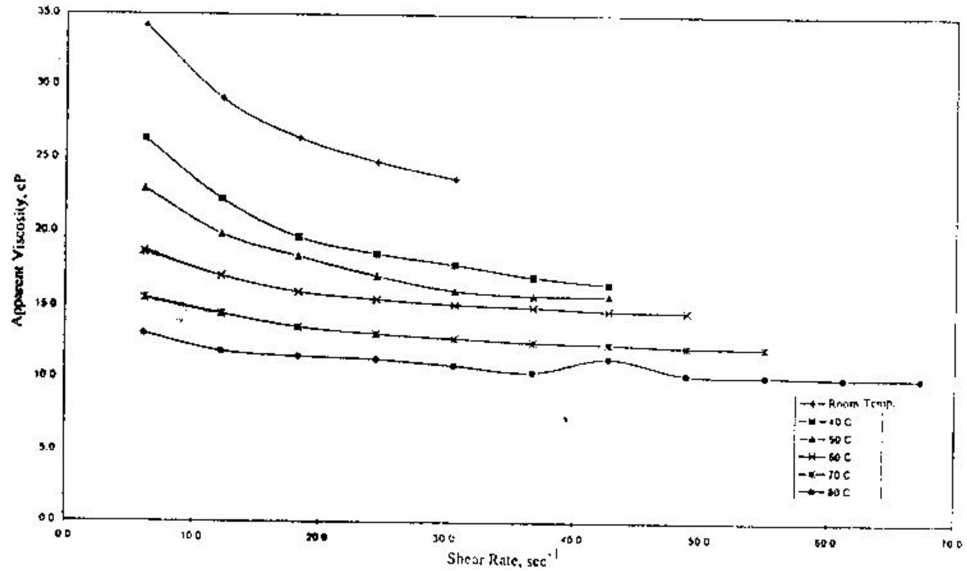

Fig. 6: Apparent viscosity versus shear rate for Semangkok-A Emulsion with 50 % tap water and 1 ml Triton X-100

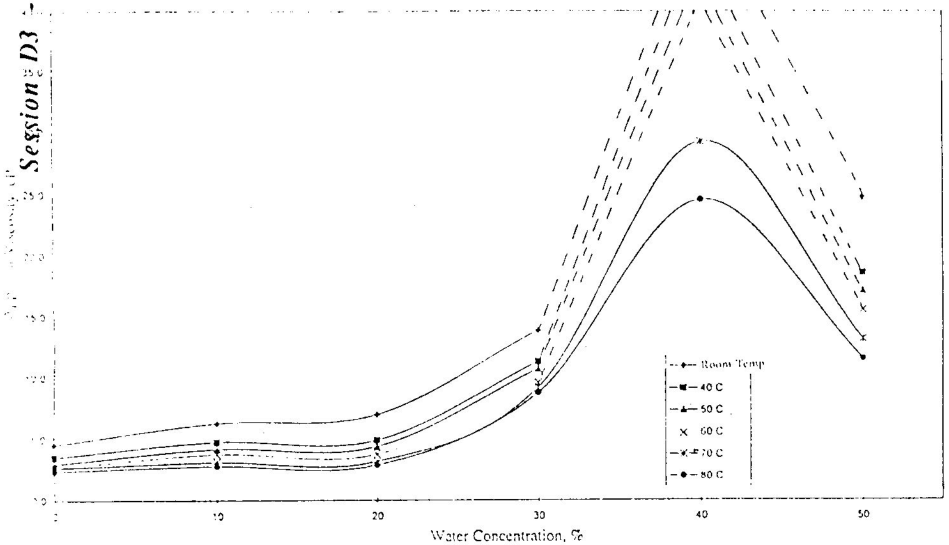

Fig. 7: Apparent viscosity versus water concentration at shear rate of 24.5 sec^{-1}

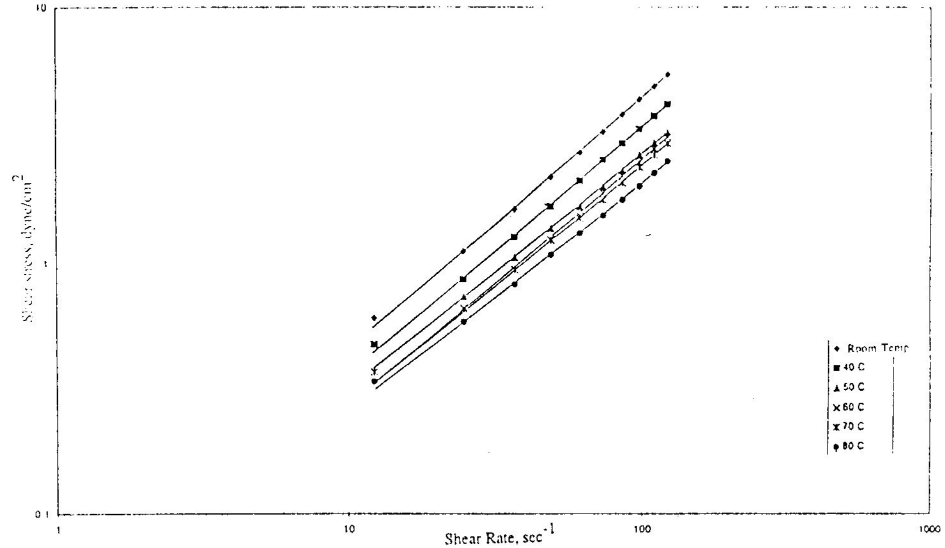

Fig. 9: Shear stress versus shear ate for clean Semangkok-A crude oil

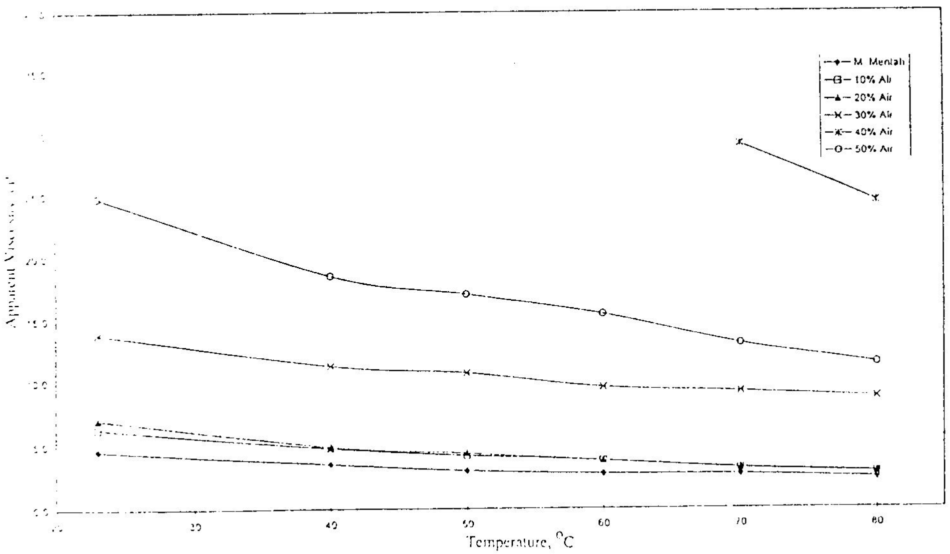

Fig. 8: Apparent viscosity versus temperature at shear rate of 24.5 sec^{-1}

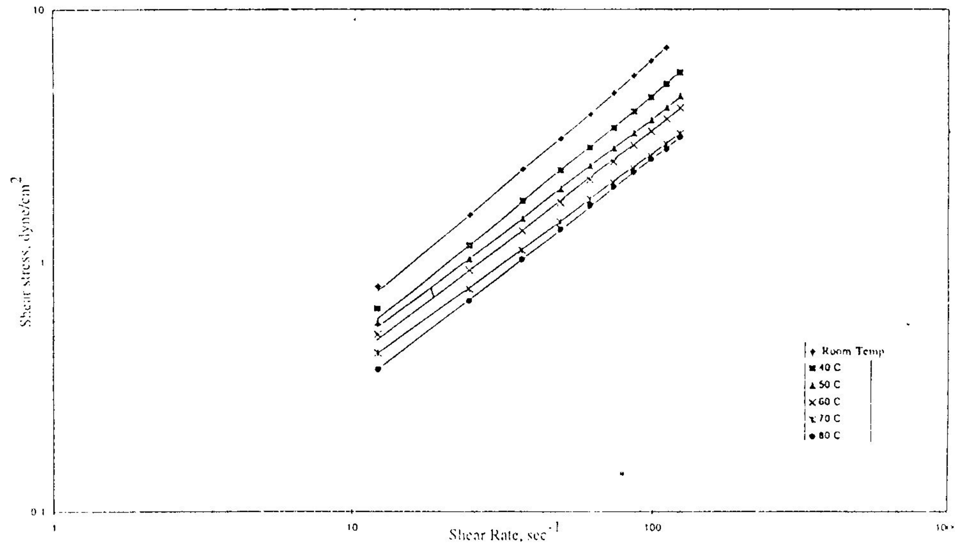

Fig. 10: Shear stress versus shear rate for emulsion with 10 % tap water and 1 ml Triton X-100

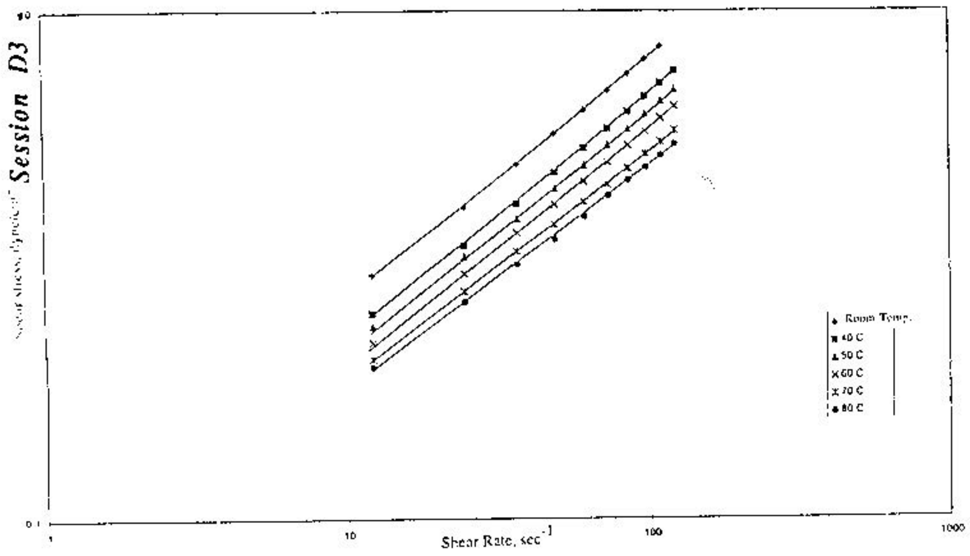

Fig. 11: Shear stress versus shear rate for emulsion with 20 % tap water and 1 ml Triton X-100

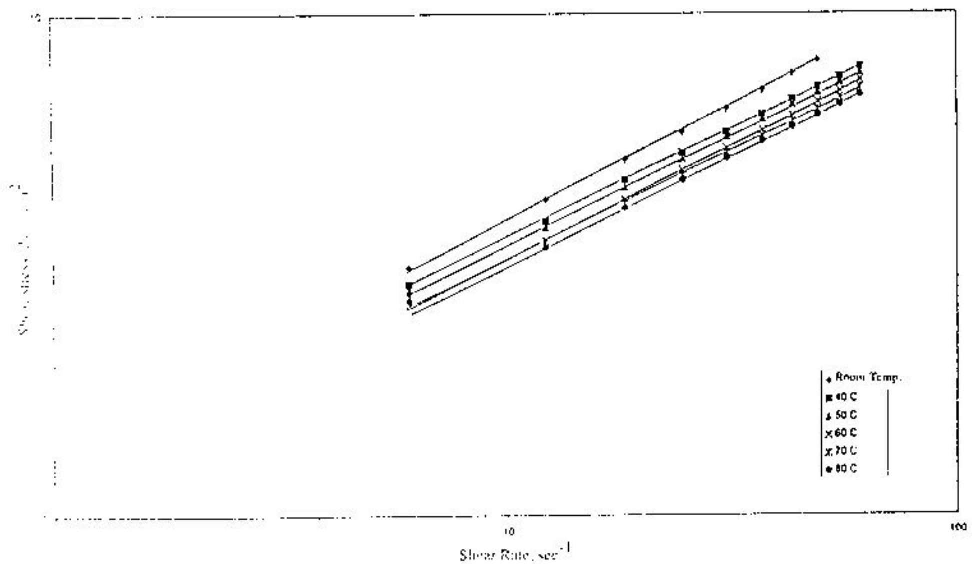

Fig. 12: Shear stress versus shear rate for emulsion with 30 % tap water and 1 ml

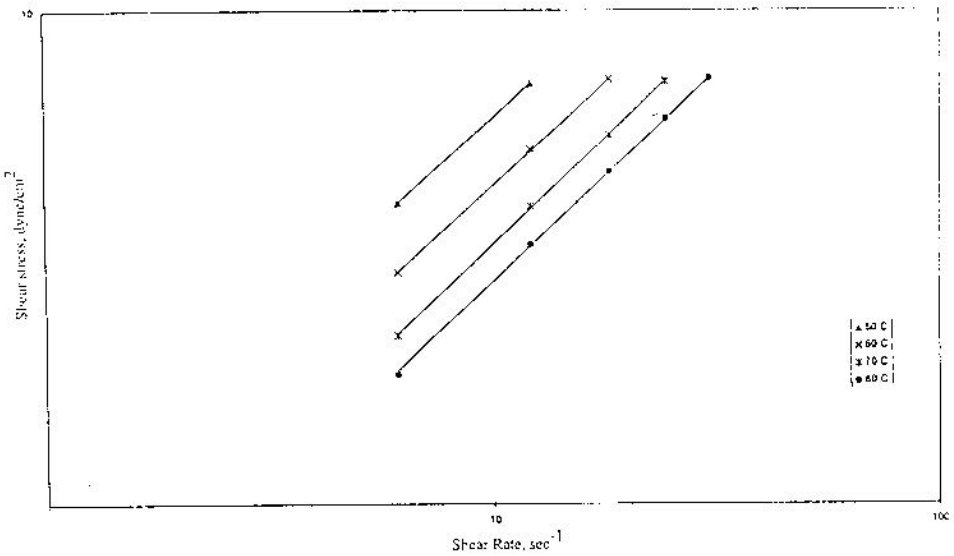

Fig. 13: Shear stress versus shear rate for emulsion with 40 % tap water and 1 ml Triton X-100

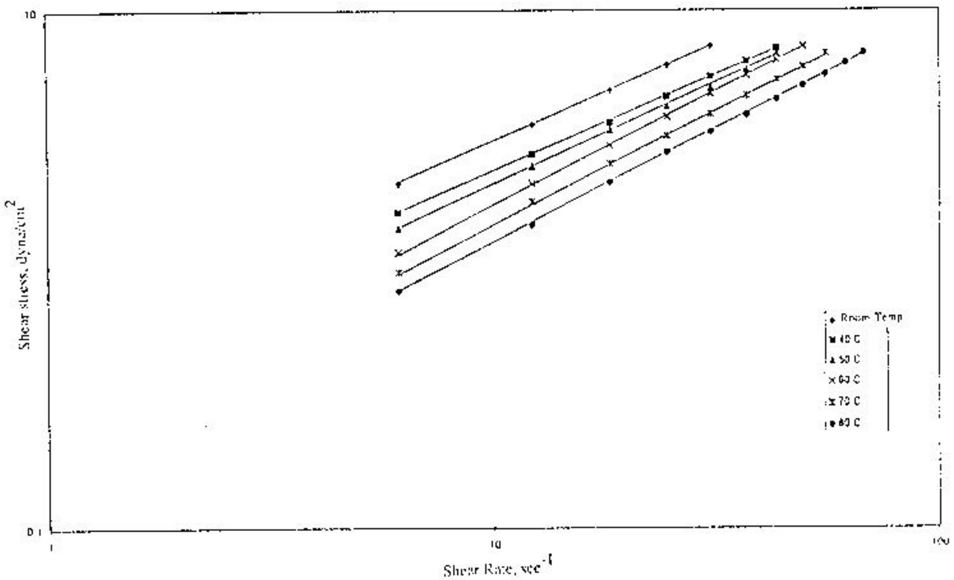

Fig. 14: Shear stress versus shear rate for emulsion with 50 % tap water and 1 ml