Mytribos Symposium 2 (2017) pp.25-28

Mytribos Symposium
Friction is not a devil

This paper was presented at The 2nd Mytribos Symposium, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor on 8th October 2017

Effect of temperature and shear rate on rheological behavior of contaminated marine hydraulic fluid

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KEYWORDS

Contaminant
Marine hydraulic
Rheology
Shear rate
Temperature

ABSTRACT

Ship uses various types of oil either for fuel, power or lubricity. For lubricity purposes, various types of lubricants are used on board. Since the marine machineries are working in aquatic environment, the lubricating fluid working in each machine is prone to water contamination. In this work, effects temperature, shear rate and contaminant level on rheological behaviors of water contaminated hydraulic fluid were examined. Power law model and Cross-Careau models were applied to the experimental data. The findings show that the contaminated fluid shows some non-Newtonian behavior.

1. Introduction

Ship deck crane and ship steering gear are used to move cargo and maneuver a ship, respectively. Ship machineries can be hydraulic crane, winches, steering gear, rudder and many others. Hydraulic system used to operate the crane and steering gear must meet the required torque, force and speed [1]. As these systems operate in seawater environment, ingression of seawater into the hydraulic system is inevitable. The water content, even in minute quantity can change the oil property, including lubricating property [2]. Operation conditions without enough lubrication will produce higher friction, excessive wear, and severe oxidation [3]. The mechanical components such as valves and actuators can be exposed to the contaminated oil and oxygen. In the long run this will lead to premature failure of the machines. This makes it very important to explore rheological of the oil. Besides that, the oil used must possess enough lubricating properties [4].

Viscosity is one of the most important properties of oil in terms of rheological behavior. Therefore, this paper focused on the study of rheological behavior of contaminated marine hydraulic fluid (CMHF) and emphasizes in the effect of temperature and shear rate.

2. Experimental procedure

Ingression of seawater in lubricating oil was prepared with the ration of 80:20 (oil:water). Viscosity measurement of CMHF was conducted by using Brookfield (Viscometer DV-I+) rotational type viscometer. The viscometer (accuracy ±1% full scale range, repeatability 0.2% full scale range) was calibrated with 4.7 cP Brookfield silicone viscosity standard prior to use. The viscosity of the oils was measured in triplicate at ten different shear rates and different speeds between 3 – 100 rpm. A temperature controller (temperature accuracy ±1°C) was used for temperature study within ranges of temperature from 40 - 100°C. The hydraulic fluid was left 15 minutes until steady state heat transfer was achieved.

The viscosity and percentage of torque were manually recorded when the viscosity reading reached apparent equilibrium (appears relatively constant for reasonable time). The viscosities were calculated at ten different shear rates in mPa and temperature. The shear stress and shear rate were calculated using formulas suggested for non-Newtonian fluid as shown in Equation 1 [5].

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$$\tau = \frac{M}{2\pi R_b^2 h} \qquad (1)$$

where τ is shear stress, M is torque (Nm), R_b is radius of SP18 spindle and h is the height of spindle (m). The shear rate was calculated using Equation 2 [6].

$$\gamma = 1.318 \times N \qquad (2)$$

where N is the speed of spindle (rpm). The experimental data were fitted to two models (Equation 3—4) by using Mathematica software version 7 [7].

$$\eta = K_p \gamma^{n_p - 1} \qquad (3)$$

$$\eta = K_H \gamma^{n_H - 1} + \eta_{\infty,\gamma} \qquad (4)$$

where K_p and K_H are consistency index (pa.s^n), η_p and η_H are flow behavior index (dimensionless), η is dynamic viscosity (Pa. s), $\eta_{\infty,\gamma}$ is viscosity at infinite-shear rate (Pa.s) and γ is shear rate (s^{-1}).

3. Results and discussion

3.1 Test rig

Figure 1 shows the oil flow from hydraulic return line to hydraulic tank. The oil may contain bubbles and water content. In the hydraulic tank, the oil is conditioned before being sucked again through suction pipe. While, Figure 2 shows good oil flowing through a rotater. For Newtonian and fresh oil, the oil is clear and the fluid flow is smooth. And Figure 3 shows the oil when it was contaminated by water (50% by volume). The appearance is milky and the flow is turbulent.

Figure 1: Contaminated marine hydraulic fluid reservoir.

Figure 2: Downstream section of hydraulic rotater.

Figure 3: Contaminated fluid induces turbulent flow in pressurized line.

3.2 Rheology study

Interpretation of how viscous is the fluid is indicated by k. The value of k as tabulated in Table 1 shows a reduction as the temperature increase for both models. This indicates that the CMHF has become less viscous at elevated temperature. Meanwhile, n values indicate the Newtonian level of the fluid. Figure 4 shows the reduction at elevated temperature for Power law model. Herschel-Bulkley model shows a reduction in the value of n from 40 - 60°C and increases afterward. Power model shows a reliable extrapolation due to the significance trend in both parameters [8].

Table 1: Viscous level of viscosity, k and flow behavior index, n fitted with two models at different temperatures (T is temperature, HB is Herschel-Bulkley, PL is Power law).

T (°C)	*k*		*n*	
	HB	PL	HB	PL
40	122854	52	0.99995	0.87691
50	17489	43	0.99979	0.82774
60	44	38	0.26102	0.80426
70	33	32	0.36001	0.80437
100	31	30	0.53011	0.67625

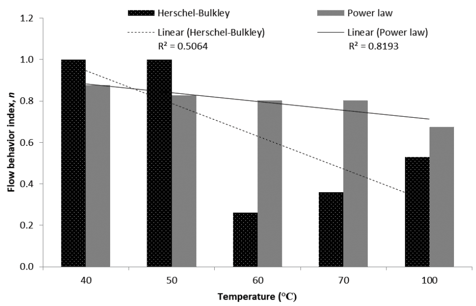

Figure 4: Flow behaviour index, n fitted with two models at different temperatures.

Figure 5 shows the dynamic viscosity as a function of shear rate for experimental data and fitted model. Pseudoplastic behavior is observed for CMHF sample due to the decrease of viscosity with the decreasing shear rate [9]. Both models were found to well fit with the experimental data.

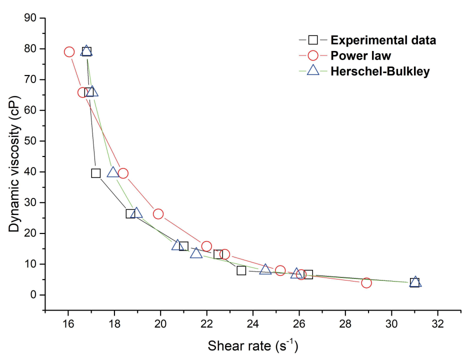

Figure 5: Dynamic viscosity versus shear rate for experimental data and fitted model at 60°C.

Figure 6 shows the dynamic viscosity versus shear rate of CMHF at different temperature. The viscosity reduces as the temperature increase. Higher viscosity value was seen at low shear rate region (16-19s^{-1}) indicating that the rotating component is stalling faster in compared to the high shear rate region. As a result, higher torque is required to start the rotating motion and hence reducing the mechanical efficiency of the system [9].

Increasing in shear rate caused CMHF approximates a levelling off region or also known as Newtonian region. The offset was more apparent starting from 40s-1 onwards. However this trend is less apparent as the temperature increases.

The stability of CMHF relative to the influence of shear rate was determined by calculating the difference between the highest and lowest viscosity values. The difference was 5.7cP, 11.5cP, 14.3cP, 12.1cP and 11.6cP in accordance with the temperature increases. The least difference was at 40°C showing that it has the highest Newtonian level.

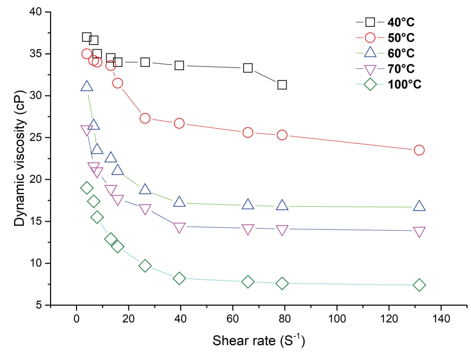

Figure 6: Dynamic viscosity versus shear rate at different temperatures.

4. Conclusion

The elevation of temperature has caused the viscous level of fluid, k reduce indicating that CMHF became less viscous. The viscosity of CMHF also decreases as the temperature increase. The flow behavior index, n shows the highest Newtonian level at 40°C. As shear rate increases, CMHF is approximate the Newtonian region due to least difference in the viscosity value. Power law model has the best fitted data compared to Herschel-Bulkley model.

Acknowledgement

The authors would like to express their deepest gratitude to the staff of fluid and material science lab, especially Pn Siti Zulaikha, Mr Razman, Mr Arif, Mr Yusof for their contribution in laboratory work.

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