ANKIT KOTIA
RAVINDRA KUMAR
and
SUBRATA KUMAR GHOSH

Experimental investigation on effect of aluminium oxide particles on transmission oil SAE-30 of HEMM lubricant

In this study, the effect of Al_2O_3 nano-particles on density and viscosity of transmission oil (SAE-30) used in heavy earth moving machinery (HEMM) is experimentally investigated. In base fluid (transmission oil) different volume fraction of Al_2O_3 (0.01% to 1%) particles are added. Rheological properties have been measured at atmospheric pressure over the temperature ranges of 20°C-50°C. Dynamic light scattering (DLS) technique has been used to obtain the particle size distribution. The present data show that with the increasing temperature the viscosity and density of base fluid and nano-fluid decreases, whereas it increases with increasing particle volume fraction. According to the experimental results of the viscosity, a new correlation for predicting the viscosity of nano-fluid with varying particle volume fraction has been presented.

Keywords: *μ: dynamic viscosity, ϕ: particle volume fraction.*

I. Introduction

The main function of the lubricant is to decrease the wear between the two moving surfaces and also removes excessive generate heat [1]. Poor thermal and rheological behaviour of conventional lubricants, limits their performance. The nano-material dispersion in base fluids for improving their rheological and thermal behaviour was an emerging trend [2]. Nano-lubricant is a suspension of lubricant mixed with nano partials.

P. K. Sharma et al. [3] dispersed TiO_2, and Cu nano-particles in commercial race 4 oil. It was observed that the improvement in break thermal efficiency occurs due to decrease in frictional power loss in the system. M. kole and T. K. Dey [4] used copper oxide nano-particles (40nm) in gear oil and observed that three times increase in viscosity with 0.025 volume fraction of nano-particles. M. A. Kedzierskin [5-6] explored the use of nano-lubricants as a means for improving efficiencies of lubricating oil. Hwang et al [7] studied the effect of the size and morphology of nano-particles suspended in lubricating oils on the lubrication performance. It has been reported that the main mechanism behind friction reduction due to nano-particles can be attributed to rolling/sliding effect, protective film, third-body, and mending effects [8]. It has also been found that different interactions occur when two or more nano-particle additives are added to lubricants, such as adduct effect, synergy and antagonism effects [9].

Messrs. Ankit Kotia, Research Scholar, Ravindra Kumar, M-Tech (Met)and Subrata Kumar Ghosh, Assistant Professor, Department of Mechanical Engg., ISM-Dhanbad, India. E-mails: ankitkotia@gmail.com, ravindra.mech015@gmail.com, subratarec@yahoo.co.in

Nano-lubricant shows relatively more insensitive towards temperature change and also tribo-chemical stable [10]. Another advantage of the addition of nano-particles in lubricant oils is that they can pass through filters [11].

In the present work consists of experimental studies on the influence of aluminum oxide nano-particles as an additive in transmission oil of HEMM (SAE-30). Nano-lubricant is formulated by suspension of Al_2O_3 nano-particles to the transmission oil. Conventional mathematical models available in open literature have been used to compare theoretical and experimental results. A new correlation has been proposed for dynamic viscosity on the basis of experimental data.

II. Experimental procedure

Transmission oil (SAE-30) is designed for efficient power transmission in HEMM and off highway construction machine. It has low viscosity oil with brown in appearance. It is used to transmit heavy load in dusty atmosphere with extreme ambient temperature. The basic properties of transmission oil are shown in Table 1.

TABLE1: PROPERTIES OF TRANSMISSION OIL

Properties	Value
Kinematic viscosity at 100°C	5.7 cSt
Density at 15°C	0.8880 g/cm^3
Viscosity index	105

In present work, aluminium oxide (Al_2O_3) nano-particles with volume fraction ranging (0.01% to 1%) nominal diameter (40 nm) and density 3.965 g/cm^3 are dispersed into measured quantity of base transmission oil. The mass of appropriate volume fraction is being accurately measured by electronic weighing machine with a least count of .001 mg. The required quantity base oil is made in batch of 100 ml at a time. Al_2O_3 particles are non-metallic oxide and hence they would not react with base fluid. After mixing of nano-particles in base lubricant, the suspension is homogenized for 1 hour by magnetic stirrer. the mixture agitated by ultrasonic shaker (Oscar ultrasonic) continuously for 2 hours to ensure uniform dispersion and good suspension stability. Finally batch wise sample is subjected to ultrasonic bath for 30 minute. Nano-lubricant thus prepared do not display any visual sedimentation of Al_2O_3 nano-particles, even after keeping the fluid stationary for more than thirty days. In order to confirm the absence of aggregated Al_2O_3 nano-particles dynamic light scattering (DLS) measurements are performed using the Malven ZS Nano Zeta S analyzer (Ms. Malvern Instrument Inc. Landon, UK). Before testing the properties of nano-lubricants have been subjected to additional 10 minute sonication for homogenising nano-fluid.

A Stabinger-type viscometer (Anton-Parr SVM 3000) was used to measure the dynamic viscosity and density of the nano-lubricant at four different temperatures between approximately 20°C and 50°C. The Stabinger measures viscosity by concentric cylinder method. Rheolab QC (Anton Paar) viscometer was also used to recheck the viscosity measured by Stabinger viscometer, and it was observed that both viscometers gave almost same results. The estimated maximum uncertainty in viscosity measured is within 3%.

III. Results and discussion

Ultraviolet visible spectro-photometer is used for finding out absorption and refractive index of nano-lubricant. Fig.1 shows the variation of absorption of UV light with varying wave length. The peak absorption is 3.233, obtained at 197.50 nm wave length. These parameters like absorption, wave length and refractive index is used in dynamic light scattering (DLS) measurement. DLS technique measures the diffusion of particles moving under Brownian motion and converts this to size distribution using the Stoke-Einstein relationship. DLS display average size of particles in nano-fluid is 219 nm as

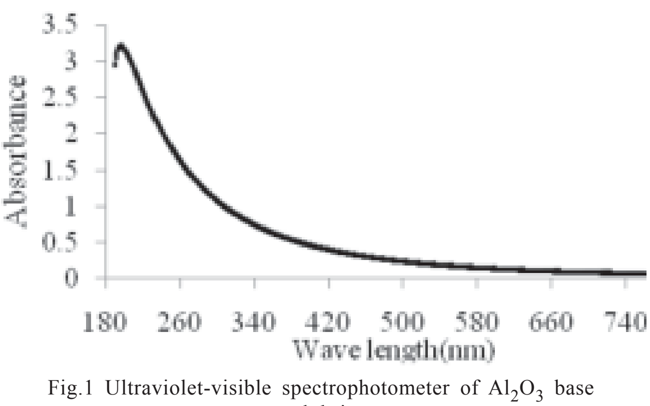

Fig.1 Ultraviolet-visible spectrophotometer of Al_2O_3 base nanolubricant

shown in Fig.2. This increase in particle size from original (40 nm) to 219 nm is due to the formation of agglomeration in the nano-lubricant.

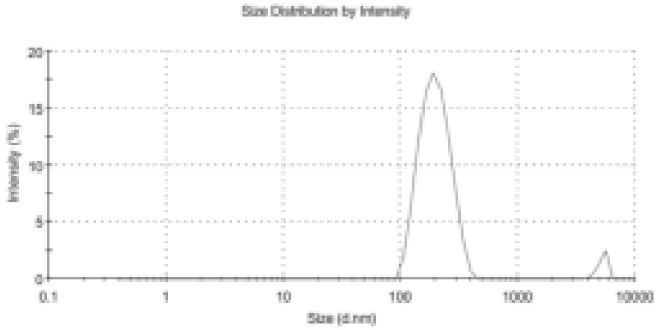

Fig.2 Particle size distribution of Al_2O_3-SAE-30 nanolubricant

A. Density

Fig.3 shows the variation of density of pure transmission oil and nano-lubricant with temperature at atmospheric pressure. It can be observed that the density increases with dispersion of Al_2O_3 particles whereas it decreases with increasing temperature for both pure transmission oil and nano-lubricant.

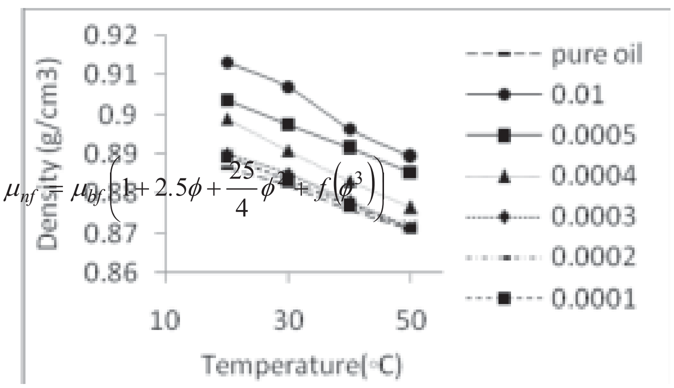

Fig.3 Variation of density of SAE-30 based nano-lubricants at different operating temperature

B. Dynamic viscosity

Dynamic viscosity of nano-fluid is increased with suspension of nano-particles. Many mathematical models are available in open literature to predict viscosity of nano-fluid. In 1972, Lundgren [12] proposed the following equation under the form of a Taylor series, expressed as:

$$\mu_{nf} = \mu_{bf}\left(1 + 2.5\phi + \frac{25}{4}\phi^2 + f\left(\phi^3\right)\right) \quad \text{... ...} \quad (1)$$

Furthermore, the viscosity of the nano-fluids is calculated using Wang's formula [13] which is expressed as:

$$\mu_{nf} = \mu_{bf}\left(1 + 7.3\phi + 123\phi^2\right) \quad \text{... ...} \quad (2)$$

A more appropriate model for predicting viscosity variation was proposed by Krieger and Dougherty [14] and expressed as:

$$\mu_{nf} = \mu_{bf}\left(1-\frac{\phi}{0.5}\left(\frac{a_a}{a}\right)^{1.3}\right)^{-1.25} \quad \text{... ...} \quad (3)$$

where a_a/a is the ratio of effective radii of aggregates (a_a) and primary nano-particle (α).

Fig.4 show that the variation of relative dynamic viscosity and Al_2O_3-SAE 30 based nano-lubricants. It can be easily depicted from Fig.4 that conventional theoretical models are highly inappropriate for predicting viscosity of nano-fluid. A new correlation on the based on experimental data of relative viscosity at 20^{o}C can be expressed as:

$$\frac{\mu_{nf}}{\mu_m} = 7.825\phi^2 + 0.868\phi + 1 \quad \text{... ...} \quad (4)$$

The R-square (randomness error) value is found as 0.9998.

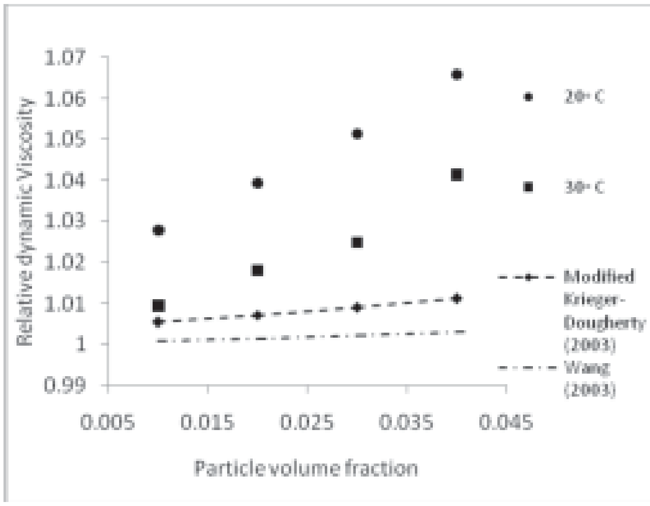

Fig.4 Relative dynamic viscosity variation of Al_2O_3-SAE 30 based nano-lubricants

C. Kinematic viscosity

Fig.5 shows that the variation of kinematic viscosity and Al_2O_3-SAE30 based nano-lubricants with varying temperature.

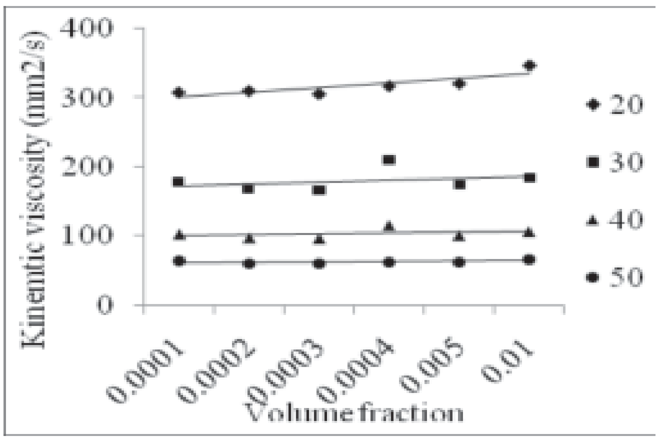

Fig.5 Kinematic viscosity variation of Al_2O_3 SAE-30 based nano-lubricants with varying temperature

It can be depicted from Fig.5 that a very little increment viscosity with the suspension of nano-particles. Also, the viscosity of nano-fluid decrease with increasing temperature because of decrease in intermolecular interaction with rise in temperature.

IV. Conclusion

The variation of viscosity and density with the addition of Al_2O_3 particles is experimentally investigated. The presence of agglomerated particle has been revealed by DLS image. Density and viscosity of nano-lubricant increases with increasing Al_2O_3 particles volume fraction. Classical models for theoretically prediction of viscosity of nano-fluid has found largely inappropriate for prediction of viscosity variation. Hence, a new correlation for variation of dynamic viscosity of transmission oil with the addition Al_2O_3 particles has been proposed.

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