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Investigation of tribological characteristics of Polyol Ester – Copper Oxide nanolubricant

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Abstract : Friction characteristics are significant for any lubricants since it optimizes the energy consumption in any dynamic systems and in the present work, the influence of CuO nanoparticles on the tribological characteristics of Polyol ester (PoE) oil is experimentally investigated, due to its wide usage in refrigeration systems. CuO nanoparticles have been experimentally used along with many refrigerants and found compatible for present generation refrigeration systems by many research studies. PoE oil is checked for enhanced friction characteristics which could possibly minimize the power consumption of the refrigeration systems with reciprocating compressors. Experiments were conducted on PoE/CuO nanofluids prepared at three different concentrations of CuO nanoparticles in the base oil, viz. 0.025, 0.05 and 0.10 % by mass using an ultrasonic oscillator. Surface roughness studies were conducted on Pin-on Disc wear testing machine and viscosity studies at different operating temperature were measured by Redwood viscometer for all the samples. Significant results were reported in friction characteristics and viscosity aspects for the nanolubricants compared with the pure lubricant.
Keywords : Lubricant; nanofluids; tribology; friction coefficient; viscosity.

Introduction

The widespread use of nanotechnology has made remarkable changes in day to day applications, the ability to construct items from bottom up, using techniques and tools being developed to make complete, high performance products. Any material in its bulk form possessesits own physical properties, which when sliced down to the size in the order of nano meter, will never be reproduced since the effective surface area increases substantially as the particles size decreases to nano scale. Copper nanoparticles smaller than 50 nm are considered super hard materials that do not exhibit the same malleability and ductility as bulk copper. Due to its enormous surface free energy, nanoparticles – fluids surface interactions are found to be sizeable enough to nullify the density difference effects, which usually would make the particles either sink or float in the base fluid.Solid particlesof engineering materials whose size in the order of 0 – 100 nm whendispersed in conventional fluids are called nanofluids and these fluids are reportedly observed with enhancedthermo-physical propertiesthan their base fluids by many research studies[3,21]. Similar to their potential to enhance the properties of conventional base fluids, nanoparticles are remarkablyfound to have good potential in improving the thermal properties of refrigerants and its compatibility with lubricants[12, 16, 10].More specifically the nanoparticles can be synthesized either by one step chemical processes or by two step mechanical methods. The nanoparticles can be suitably characterized for their average size distributions, chemical contents, mechanical and electronics properties, stability nature in suspension using various developed techniques[9, 11].

. Detailed review of literature shows that copper oxide nanoparticles were studied for enhanced thermo-physical properties and heat transfer properties of various fluids[19, 20, 4, 5]. Another researcher[8], reported that 5 %

by volume of CuO nanoparticles in ethylene glycol resulted with22.4 % enhancement in its thermal conductivity. In a different study[7], they claimed that addition of 0.1 vol. % of fullerene nanoparticles in mineral oil reduced its friction coefficient to an extent of 90%, which remarkably concludes that nanoparticles can be utilized in improving the compressor efficiency. The research of nanoparticles on refrigerants is also an essential part of nanofluids study and to carry them forward, the particles can be studied adding either directly in to the refrigerants[2, 4, 5], or in to the lubricants[22, 17], which will then mix with the refrigerant in its operation. In the present research, CuO nanoparticles are elucidated for its influence on Polyol ester, the lubricant oil whose usage is very extensive in refrigeration systems. Also, PoE is compatible with wide variety of refrigerants like R134a, R410A and other HC refrigerants. The attempt has been made in a view to ascertain the direct and indirect benefits in energy consumption which could be obtained from the enhancement of lubricant property in any refrigeration systems fit with hermetic compressors.

Preparation of Nanofluids

The nanofluid preparation process is considered to be significant since it controls the stable suspension of the nanoparticles in the base fluid for a prolonged duration. As suggested from the literatures, the nanofluids of different concentrations in the present work too are prepared using an Ultra sonic oscillator. The Ultrasonication processes have been carried out for sufficient period to avoid agglomeration of the nanoparticles in the PoE oil and furthermore no surfactants are involved in the studies for this reason. Three different mass fractions of nanoparticles as mentioned in Table 1 are dispersed with 50 ml of PoE oil individually, while it is under sonication process. Each sample is kept under ultrasonic agitation process for 60 minutes. After this process, it is visibly observed that the nanoparticles are in good dispersion with the PoE oil, which is shown in Figure 1. The same dispersion level is observable from the samples even after 12 hours starting from preparation.

Table 1: Properties of CuO nanoparticles

SlNo.	Description	Values
1	Density	6.30 g.cm^{-3}
2	Average size	50 nm
3	Melting point	1326 °C
4	Mass fractions used	0.025, 0.05, 0.10 (%)

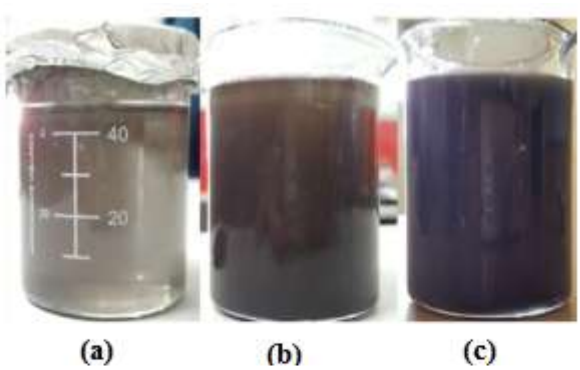

Figure 1: PoE oil with CuO nanoparticles of different mass fractions; (a) 0.025% (b) 0.05% (c) 0.10%

Experiments

Viscosity

At first, the viscosity measurements have been carried out for both of the pure PoE oil and the PoE oil mixed with CuO nanoparticles. Viscosity is one of the essential physical properties of lubricants, which is directly related to the power consumption in a system and henceforth it is considered to examine the viscosity variation of the nanolubricant from that of the pure lubricant oil. Some researchers[15],reported that addition of additives such as polyisobutylene and polybutadiene rubber in mineral base oil improved its Viscosity Index to industry standards. The viscosity measurements are conducted in Redwood viscometer [IS 1448 (P: 25) -1976]. The time takenfor pure PoE oil to pass through a standard orifice and get collected in a 50 cc flask is noted down for each trial. In the same way the time is noted varying theoil temperatureranging from 40^o C to 90^o C. This complete procedure is repeated for nanoparticles added PoE oil at the specified temperature range. The kinematic viscosity ($mm^2.s^{-1}$) of the lubricant oil can be estimated using equation (1).

$$\mu = At - \frac{B}{t} \quad (1)$$

A = 0.26; B = 171.5; t - Redwood seconds.

Friction coefficient

Friction coefficient is a significant tribologicalproperty for any lubricants since it controls the energy consumption in the applied system. Also, it can easily be measured and considered to be criteria to justify two different lubricants based on its power consumption aspects. Another researchers[13],claimed that addition of optimum amount of TiO_2 nanoparticles in mineral oil increased the COP of a R12 refrigerant system to a maximum of 17%. The authors could observe significant improvement in the lubricant property of the mineral oil when TiO_2 nanoparticles were dispersed in it. In the present work, to compare the tribological nature of CuO nanoparticles added PoE oil with that of the pure PoE oil, wear test has been performed with both types of oils in a Pin-on Disc testing machine (TR – 20LE), shown in Figure 2. The experimental parameters on Pin-on Disc machine are listed in Table 2.

Figure 2: Pin on Disc Tribometer

Table 2 : Tribometer specifications for the wear test

Pin material	Aluminium 6061
Disc material	Cast iron
Disc diameter	116 mm
Disc rotation speed	500 rpm
Test duration for each trial	135 s

The wear test machine used in our work has loading capacity of 200N and it is suitable for both dry and wet test conditions. The sliding distance calculation is performed using equations (2) & (3) as shown below,

$$\text{Sliding speed} = \frac{\pi * D * N}{60000} \ m.s^{-1} \quad (2)$$

$$\text{Sliding distance} = \left[\left(\frac{\pi * D * N}{60000}\right) * t\right] m. \quad (3)$$

Where,

D – Diameter of the rotational disc (mm)
N – Rotational speed of the disc (rpm)
t – Rotational duration of the disc (s)

Results and Discussions

Effect of Temperature

The effect of temperature on the viscosity of CuO nanoparticles suspended PoE oil has been studied for three different mass concentrations, viz. 0.025, 0.05 and 0.10 %. The viscosity values for the nano lubricants as well as pure lubricant against each temperature as measured in Table 3 using equation (1) are plotted in Figure 3. The trend in viscosity variation with temperature for the pure lubricant is also observed for the nano lubricants. As the temperature increases from 40 °C to 90 °C, the viscosity of pure PoE oil decreases from 98.34cStto 17.31cSt ($mm^2.s^{-1}$) and its value decreases from 108.80 $mm^2.s^{-1}$ to 18.08 $mm^2.s^{-1}$ for 0.025% CuO added PoE oil for the same temperature increment. This nature of variation of viscosity in liquids is possible due to intensified Brownian motion as the temperature increases[6].Furthermore, the viscosity of the lubricant upon addition of nanoparticles varied from the pure lubricant viscosity and the variation is proportional to the mass fraction of nanoparticles added in it. At 40 °C, the viscosity of pure PoE oil is 98.34$mm^2.s^{-1}$ which increases to 108.80 $mm^2.s^{-1}$, 124.70 $mm^2.s^{-1}$ and 151.30 $mm^2.s^{-1}$with the addition of 0.025%, 0.05% and 0.1% CuO nanoparticles respectively as plotted in Figure 3.In general, as the mass fraction increases the mean free path of the nanoparticles travel reduces and also the viscosity of the base fluid increases. More and more increment in viscosity is not advisable since it affects the power consumption in a system. Hence, the addition of nanoparticles exclusively in a lubricant is to be optimized to acquire an optimal power utilized system. The optimal quantity of nanoparticles to disperse in PoE oil can be found with the help of friction coefficient test, additionally.

Table 3: Kinematic viscosity of pure and nano added PoE oil at different temperatures

Kinematic viscosity (cSt)				
Temperature (°C)	Percentage by mass of nanoparticles (%)			
	0	0.025	0.05	0.10
40	**98.34**	108.80	124.70	151.30
50	**56.94**	69.04	76.12	98.87
60	**48.50**	53.78	59.32	72.71
70	**36.24**	40.79	45.58	52.20
80	**22.33**	24.01	25.94	29.23
90	**17.21**	18.08	18.94	20.93
Bold value implies for pure PoE oil				

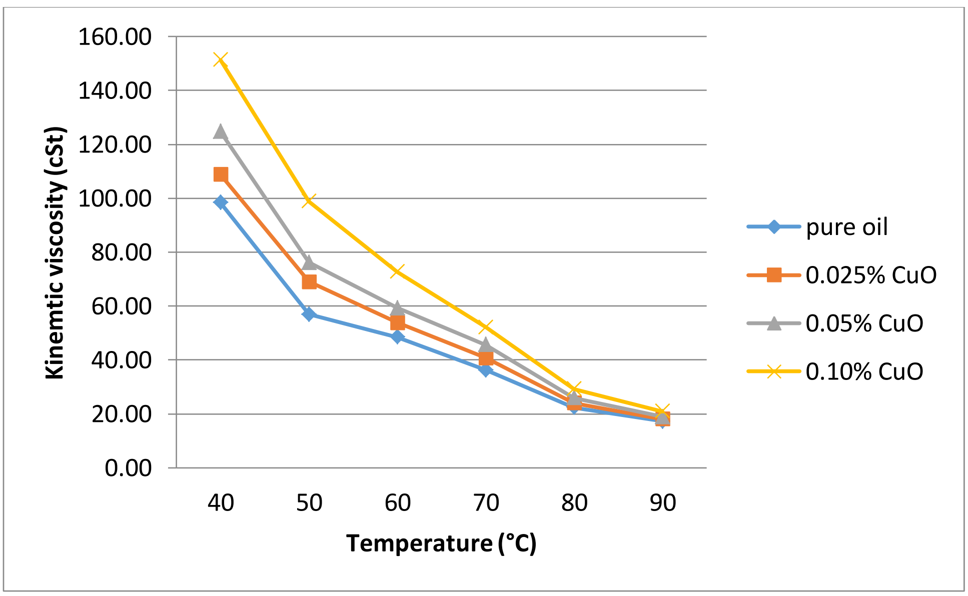

Figure 3: Kinematic viscosity of PoE oil against various temperatures

Effect of mass fraction

The wear test has been carried on with a Pin-on Disc testing machine. Addition of nanoparticles would increase the viscosity of the base fluid and modifies its friction characteristics. In case of lubricants (PoE oil) the friction coefficient is also an essential criterion to decide the optimal amount of nanoparticles which would contribute to minimum friction when added to the pure lubricant[13]. Figure 4, shows the down fall of friction coefficient values for the standard test specimen in the machine as the mass fraction of CuO nanoparticles increased in the PoE oil. The experiments on friction coefficient for pure and nano lubricants are conducted keeping the parameters as specified in Table 2 remains invariable, for enough trails. Table 4 lists out the average friction coefficient values taken from large no of experiments for various concentrations of nano lubricants. It is evident from the plot shown in Figure 4 that the slope of friction coefficient against the nano lubricant concentration is negative which is advantageous for any lubricants due to the fact that it will eventually optimizes the power consumption in a system when loaded with nanoparticles. The possible reason for this nature could be put down to the deposition of small particles in the grooves of the sliding test specimen which eventually minimizes the crest and valley differences in it. The reduction in the friction coefficient from the pure lubricant to a maximum of 66.7% for a 0.1% CuO added lubricant could be a leveraging factor to suggest the nanoparticles for these applications.

Table 4: Friction coefficient for nanofluids at different volume fractions

SlNo.	Percentage by mass of nanoparticles (%)	Friction Coefficient value
1	**0**	**0.18**
2	0.025	0.13
3	0.05	0.09
4	0.10	0.06
Bold value implies for pure PoE oil		

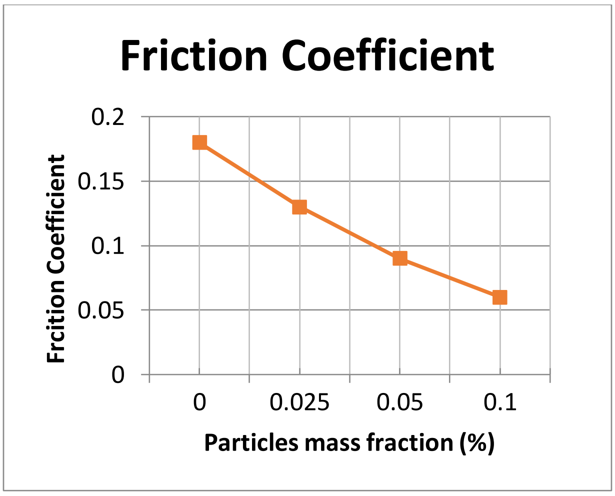

Figure 4: Variation of friction coefficient for different mass fraction of nanoparticles

Annual consumption cost

The coefficient of performance (COP) of refrigeration systems depends on the compressor work input.Furthermore, compressor performance is influenced by mechanical losses such as viscosity of lubricant, friction in bearings, loads, temperature and materials of the bearing and piston[1]. The present work demonstrated the potential of nanolubricants in reducing the friction coefficient compare to that of the pure lubricant when tested in qualitatively similar set up. Henceforth, it is considered to be reasonable to establish procedure for finding the cost difference involved when nanolubricant is utilized replacing the pure lubricant in refrigeration compressors. The COP of the refrigeration system is defined by the equation (4) which relates the refrigeration effect in the evaporator region with the compressor work utilized to achieve the specified refrigeration effect.

COP = Refrigeration effect / Compressor work (4)

The electrical work given to the compressor is to pressurize the vapour refrigerant from evaporator pressure to condenser pressure. Furthermore the electrical input supplied to the compressor is not the actual work input taking for COP estimation of the refrigerator since frictional power loss involves in compressor bearings as well as in between the piston-cylinder assembly. The friction losses decrease the compressor work which in further affects the desired refrigeration effect in a refrigerator and the COP will be altered. Hence, in a refrigerator, to achieve a desired value of COP, additional power is to be supplied to the compressor more than the actual power estimated.

Available compressor work = efficiency of compressor x input power (5)

The annual electricity cost incurred in running the refrigerator with hermetic compressor is given by equation (6).

Annual electricity cost for running the compressor

= (input power to compressor x hours of operation/year x electricity unit cost) (6)

It is well known that the efficiency of the hermetic compressor depends on the friction coefficient associated to the compression and expansion process in the hermetic compressor. In further anysignificant increase in the efficiency of the compressor due to the reduction in the friction coefficient will reduce the input power requirement to run the refrigeration system without affecting the COP. Positively, the level of reduction in the input power to the compressor depends on the capacity of the specific system and which paves way to cut the annual running cost significantly as discussed using the above mentioned correlations.

Conclusions

The present experimental workis focussed on investigating the optimum amount of CuO nanoparticles which could result in constructive performance when dispersed in PoE oil. The following observations are made;

1. Three samples of CuO added PoE oil, made with mass fractions of CuO nanoparticles as 0.025%, 0.05% and 0.10% are found stable even after 4 hours of their preparation by Ultrasonication method.
2. Kinematic viscosity of the pure PoE oil and that of the CuO added PoE oil are determined using Redwood viscometer and found that the viscosity of nano added PoE oil is more than that of the pure oil. Also, the viscosity variation with the temperature agrees with the trend of the pure oil.
3. The wear test is conducted in Pin-on Disc machine to evaluate the friction characteristics of the PoE oil. The results from wear tests show that addition of CuO nanoparticles even up to 0.10% by mass of PoE oil reduced the friction coefficient of the test specimen, note worthily.
4. Based on the results, it is found that the process of addition of nanoparticles in lubricant oil used for refrigeration compressors has positive potential in reducing the annual electricity cost.

Similar test sets can be conducted for various types of nanoparticles with different lubricants and the optimum amount can be identified which will minimize the power consumption for the systems.

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