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Experimental Investigation of Aluminum Oxide and Cerium Oxide (Ce (IV)) Nanoparticle as Additives of HEMM Gear Oil

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Abstract—*Lubricants are basically materials used for excessive heat rejection & control friction and wear. Instead of traditional materials, new nanomaterials and nanoparticles have been recently under investigation as lubricants or lubricant additives because of their potentially interesting tribological properties. The suspension of nanosized metallic or oxide particles in base lubricant, known as nanolubricants, is used to enhance the thermo physical and rheological properties of base fluid. In present study synthesis and testing of Al_2O_3-gear oil and Ce (IV) - gear oil nanolubricants have been performed. Al_2O_3 and Ce (IV) nanoparticles have been dispersed in the range of 0.01% to 1% in gear oil used in Heavy Earth Moving Machinery (HEMM). Nan particle characterization has been performed by Field Emission Scanning Electron Microscope (FE-SEM) test. Rheological properties have been experimentally tested and the results compared with theoretically existing models available in open literature.*

1. INTRODUCTION

In recent years, various environmental issues such as reduction of environmental pollution, enhancing quality of life and elimination of impurities is of high importance in developed countries. Meanwhile, recent studies on lubricants with additives such as nano-particles have attracted the interest of many researchers. Nanomaterials have attracted considerable attention because of their unique properties and tremendous application potentials in a wide range of areas. Experiments showed that with the addition of nanomaterials in the lubricating oil, the anti-wear and anti-friction properties could be obviously improved [1-2]. These base fluids suspended with nanometer sized particles referred to as nanolubricant, improves lubrication performance by averting contact between metal surfaces. Currently, more and more researchers have been devoted to enhancing the lubricant properties by using nanoparticles as lubricant additives. It has been observed that the suspended nanoparticle in base oil leads to agglomeration after some period of time. Thus, it is necessary to study and analyze the influencing factors to the dispersion stability of nanofluids. When appropriate nanoparticles are added, the lubrication properties can be better than those of traditional solid lubricant additives. Therefore nanoparticles become promising new lubricating materials, which have an important economic value on the friction-energy consumption. Most of the previous research in this field is confined with base fluid as water, ethylene glycol, transformer oil, etc. Recently, new base fluid like gear oil of HEMM has been used as a base fluid with Al_2O_3 nanoparticles to improve thermal and wear performance [3].

In the present study the effect of Al_2O_3 and Ce(IV) nanoparticles on the thermo physical properties of gear oil used as a lubricant in heavy earth moving machinery (HEMM). The measurement of thermo physical properties has been performed varying nanoparticle volume fraction and temperature. Experimental results have been compared with the mathematical models available in the open literature for viscosity and density.

2. EXPERIMENTAL ANALYSIS

In the present work, aluminum oxide (Al_2O_3) nano particles and Ce (IV) nano particles with volume fraction ranging (0.01% to 1%) has been used. Al_2O_3 nano particles have nominal diameter (40 nm) and density 3.965 g/cm3 where as Ce (IV) nano particles with volume fraction ranging (0.01% to 1%) have nominal diameter (1530nm) and density 7.132 g/cm^3. The base fluid is commercial gear oil. Measured quantities of nanoparticles are dispersed into base gear oil. The mass of the appropriate volume fraction is being accurately measured by electronic weighing machine with a least count of 0.001 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. The final batch wise sample is subjected to an ultrasonic bath for 30 minutes. Nanolubricant thus prepared do not display any visual sedimentation of Al_2O_3 and Ce(IV) nanoparticles, even after keeping the fluid stationary for more than thirty days. Morphology of nanofluids are tested using FESEM test. Before testing, the properties of nano-lubricants have been subjected to additional 10 minute sonication for homogenizing nanofluid.

3. RESULT AND DISCUSSION

Fig. 1 demonstrates the morphologies of Al_2O_3 nanoparticle in pure and dispersed state using FESEM test. It can be observed that Al_2O_3 nanoparticle have spherical morphology. It can be observed that Al_2O_3 nanoparticles retain their spherical morphology even after the dispersion in engine oil base lubricant.

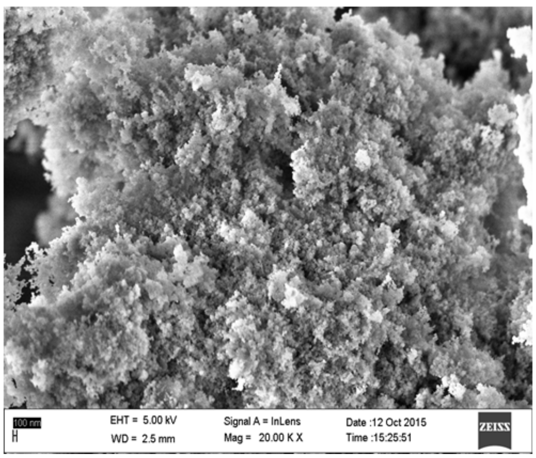

Fig. 1: Morphology of Al_2O_3 particles in Al_2O_3-gear oil nanolubricant

Fig. 2 demonstrates the morphologies of Ce(IV) nanoparticle in pure and dispersed state using FESEM test. It can be observed that Ce (IV) nanoparticle have plate type morphology. It can be observed that Ce (IV) nanoparticles retain their plate shape morphology even after the dispersion in engine oil base lubricant.

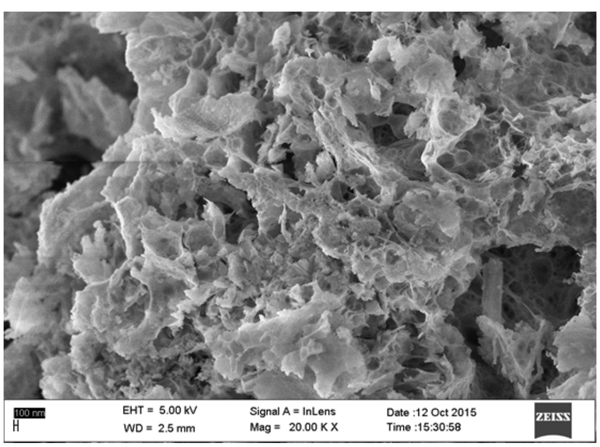

Fig. 2: Morphology of Ce(IV) particles in Ce(IV) -gear oil nanolubricant

Fig. 3 shows variation of density of Al_2O_3-gear oil nanolubricant with temperature at different volume fraction it can be observed that density is high at less temperature and at higher volume fraction as the temperature increases density decreases .But then also nanofluid with higher volume fraction posses higher density at the given temperature range. Volume fraction 0.01% shows increment of 1.27% to1.09% of density when compared to volume fraction 0.05%.

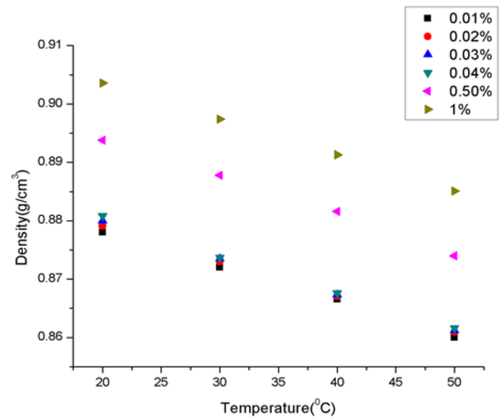

Fig. 3: Variation of density of Al_2O_3-gear oil nanolubricant with temperature at different volume fraction

Fig. 4 variation of density of Ce (IV)-gear oil nanolubricant with temperature at different volume fraction it can be observed that density is high at less temperature and at higher volume fraction as the temperature increases density decreases .But then also nanofluid with higher volume fraction posses higher density at the given temperature range. 0.2% volume fraction shows highest density and it is 1.02% to 0.77% more than 0.04% which means density hugely depends on volume fraction.

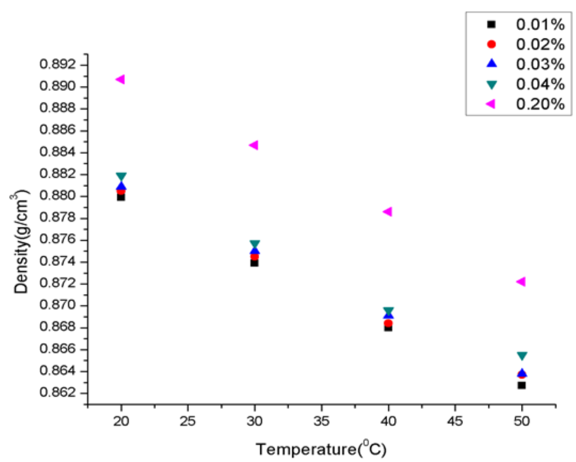

Fig. 4: Variation of density of Ce(IV)-gear oil nanolubricant with temperature at different volume fraction

The viscosity of nanofluid increases with increasing particle volume concentration [4-8]. Table 1 shows the prominent mathematical models for prediction of relative viscosity of nanolubricants with a variation of particle volume fraction.

Table 1: Mathematical models for viscosity of nanofluid

Authors	Mathematical models
Einstein model [4]	$\mu_{nf} = \mu_{bf}(1+2.5\phi)$ Valid for spherical particles of low particle volume fraction $\phi \leq 0.02$.
Brinkman model [5]	$\mu_{nf} = \mu_{bf}\dfrac{1}{(1-\phi)^{2.5}}$ Formulated by two corrections of Einstein's model.
Lundgren model [6]	$\mu_{nf} = \mu_{bf}\left(1+2.5\phi+\dfrac{25}{4}\phi^2+f(\phi^3)\right)$ Formulated from the Taylor Series. Reduction of Einstein model.
Wang et.al [7] model	$\mu_{nf} = \mu_{bf}(1+7.3\phi+123\phi^2)$ Showed the particle volume fraction is the key factor for improved viscosity.
Batchelor model [8]	$\mu_{nf} = \mu_{bf}(1+2.5\phi+6.5\phi^2)$ Considered the effect of Brownian motion. Extension of Einstein model
Chen et al.[9] model	$\mu_{nf} = \mu_{bf}(1+10.6\phi+10.6\phi^2)$

Fig. 5 shows a variation of kinematic viscosity at different volume fraction of nanofluid. There are very slight increases in kinematic viscosity as the volume fraction increases but it drastically decreases with increase in temperature for all used particle volume fraction. Kinematic viscosity at 20 C is approximately 85% more than the value of kinematic viscosity at 30 C. This shows the effect of temperature on kinematic viscosity of nanofluid.

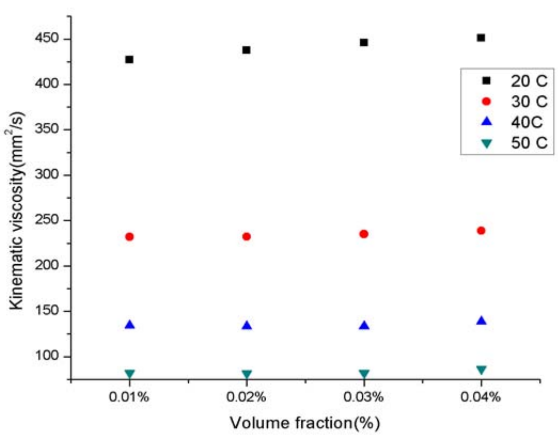

Fig. 5: Variation of kinematic viscosity of Al_2O_3-gear oil nanolubricant with particle volume fraction

Fig. 6 represents a variation of relative dynamic viscosity of gear oil with Al_2O_3 nanoparticles volume fraction. It can be observed that relative dynamic viscosity increases with increasing Al_2O_3 particle volume fraction. Mathematical models under predicted viscosity value and their predictions are highly inappropriate than experimental results. When temperature is taken 40 degree C there is highest increment in relative dynamic viscosity although different models taken into consideration are showing near about similar increment this shows viscosity depends on temperature.

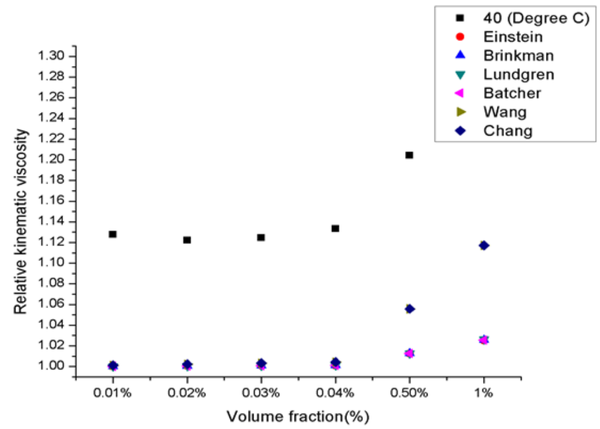

Fig. 6: Variation of dynamic viscosity of Al_2O_3-gear oil nanolubricant with particle volume fraction

Fig. 7 shows a variation of kinemetic viscosity at different volume fraction of nanofluid ,there is very slight increases in kinematic viscosity as the volume fraction increases but as temperature increases kinematic viscosity decrases at all volume fraction. Kinematic viscosity at 20 C is approximately 85% to87% more than the value of kinematic viscosity at 30 C means kinematic viscosity depends on temperature.

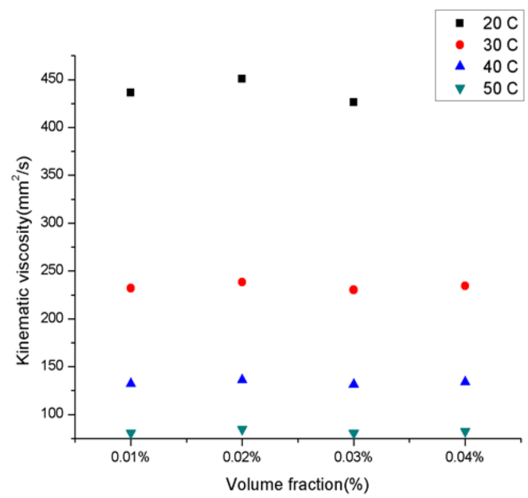

Fig. 7: Variation of kinematic viscosity of Ce (IV) -gear oil nanolubricant with particle volume fraction

Fig. 8 shows a variation of relative dynamic viscosity of gear oil with Ce (IV) nanoparticles volume fraction. It can be observed that unsymmetrical behavior with different temperature as volume fractions of nanofluid is varied and different models are showing similar trends with each other and less increment in relative dynamic viscosity

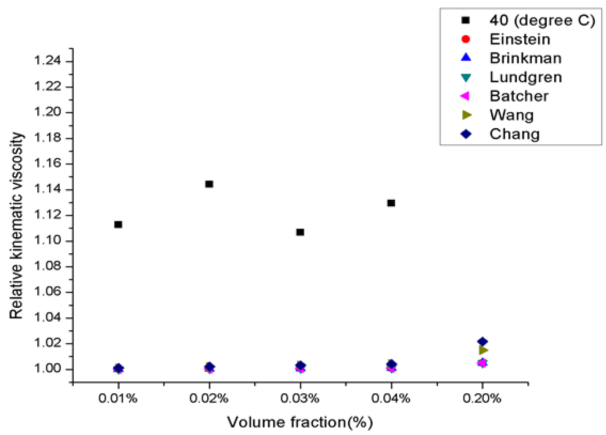

Fig. 8: Variation of dynamic viscosity of Ce (IV) -gear oil nanolubricant with particle volume fraction

4. CONCLUSION

An experimental investigation has been performed for the study of variation of thermo physical properties of HEMM gear oil with the dispersion of Al_2O_3 and Ce (IV) nanoparticles. The following conclusions can be made:

- Density and viscosity of base lubricants increases with dispersion of nanoparticles.
- Morphology of nanoparticles remains unaltered in dispersed stage.
- Viscosity of Al_2O_3-gear oil and Ce(IV)- gear oil decreases with increase temperature.
- Experimental results of Al_2O_3-gear oil and Ce(IV)- gear oil nanolubricants does not follows predictions of theoretical results of viscosity.

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