FACTORS AFFECTING THE VISCOSITY OF NANOLUBRICANTS: A REVIEW

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Abstract: During the past decade, nanotechnology with its brisk development has seized the attention of scholars, scientists and engineers. Nanolubricants are one of the astonishing outcomes of nanotechnology which could remarkably enhance the effectiveness of lubricating systems. In this study, an attempt has been made to cover the factors affecting the viscosity of nanolubricants. Through the available literature, the effects of volume fraction, temperature, particle size and shape on the viscosity of nanolubricants are discussed.

Index Terms -Nanolubricants; viscosity; lubricating systems; volume fraction; temperature

1 INTRODUCTION

A lubricant is a substance introduced to reduce friction and wear of interacting surfaces in mutual contacts. It ultimately reduces the heat generation, carry away the foreign particles/debris and reduce the friction by transmitting the frictional forces and heat. The property of diminishing the frictional forces is referred as lubricity. Generally, mineral based lubricants contain 90% base oil (petroleum fractions/mineral oils) and less than 10% of homogeneously dispersed nano additives. Vegetable oils/synthetic liquids such as hydrogenated polyolefins, silicones, esters, fluorocarbons etc. are also used as base lubricant oils in different applications.

The lubricating performance is enhanced by dispersing nano scale additives into conventional lubricating oils which delivers increased viscosity, reduced friction and wear, resistance to oxidation and corrosion, aging/contamination, etc. The lubricating oil containing well dispersed nanoparticles is called as nanolubricants which have emerged as a novel class of nanotechnology-based lubricating fluids/oils and have grown significantly in the past years. The lubricant oil containing well dispersed nanoparticles is illustrated in the Figure 1.

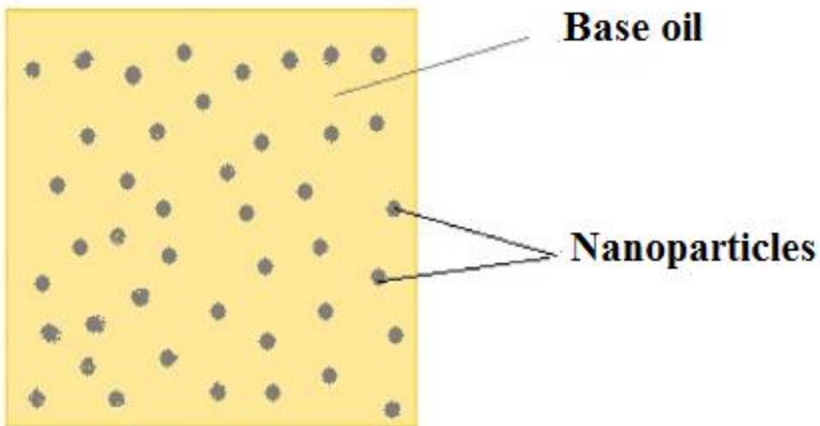

Figure 1 Nanoparticles dispersed in lubricant oil

A large number of nano scale additives are utilized to promulgate performance characteristics to lubricant oils. The nanoparticles could be metal particles like Al, Cu and Ni; oxides like TiO_2, Al_2O_3, SiO_2, Fe_2O_3, CuO and Fe_3O_4; and compound materials like SiC, AlN and graphene [1]. The main families of nano scale additives are: pour point depressants for preventing crystallization of waxes, anti-foaming agents (silicone compounds) for lowering surface tension, viscosity index improvers (polyacrylates and butadiene) for maintaining viscous at higher temperatures, anti-oxidants (hindered phenols, butylated hydroxytoluene, dithiophosphates) to suppress the rate of oxidative degradation of hydrocarbon molecules, detergents to ensure the cleanliness by preventing the formation of deposits at high temperatures, corrosion/rust inhibitors (alkaline materials like alkylsulfonate salts) to absorb acids that has corrosive nature, anti-wear additives (phosphate esters and zinc dithiophosphates) to form protective tribofilms on interacting metal parts in mutual contacts, extreme pressure/anti-scuffing additives (sulfur compounds like dithiophosphates) to form protective films on relatively moving/sliding metal parts and friction modifiers [2-3].

Before designing a mechanical tribo-system in which a nanolubricant is the working fluid, it is necessary to know their paramount thermophysical properties like viscosity, thermal conductivity, specific heat capacity and density. Among these, viscosity is a vital property which indicates the resistance of fluids. Nanolubricants exhibit remarkably higher viscosity compared to their base oils. It further increases with increasing nanoparticle concentration [4]. Many parameters affect the viscosity of nanolubricants including base fluid type, preparation method, particle size, temperature, particle shape, volume acidity (pH value), concentration, surfactants, shear rate and particle aggregation [5]. This study reveals the comprehensive review various factors affecting the viscosity enhancement of nanolubricants.

2 VISCOSITY MEASUREMENT METHODS

In general, either the object is stationary and the fluid moves past it/the fluid remains stationary and an object moves through it which is caused by relative motion of fluid and a surface is a measure of viscosity. A viscometer/viscosimeter is an instrument used for estimating the viscosity of a fluid medium. Viscometer measures the viscosity under constant flow condition whereas rheometer estimates viscosities with varying flow conditions. The viscosity measuring instruments are designed to calculate the resistance to flow fluid in which the geometry of instrument calibrates the strain rates and the corresponding stresses which is the measure of resistance to flow. The viscosity measuring principles of various viscometers are summarized below:

- Concentric Cylinders Viscometer: The torque needed to move the cylinder at constant angular velocity is equal to the total torque exerted by the viscosity of the fluid.
- Cone-and-Plate Viscometers: The resistance to the rotation of cone produces a torque that is proportional to the shear stress of fluid which is then converted into absolute centipoise units.
- Parallel Disks Viscometer: The shear stress varies across the radius for a parallel plate which is then converted into absolute centipoise units.
- Capillary Viscometers: The time of liquid takes to flow between two level marks is measured. A minimum flow time is defined for capillary viscometers to ensure that the flow conditions inside the capillary allow for laminar flow.
- Falling sphere viscometers: Stokes' law is the basis of the falling sphere viscometer, in which the fluid is stationary in a vertical glass tube. A sphere of known size and density is allowed to descend through the test liquid. It reaches terminal velocity, which can be measured by the time it takes to pass two marks on the tube which is then converted into absolute centipoise units.
- Falling cylinder viscometers: The piston and cylinder assembly is held up for a few seconds, then allowed to fall by gravity, creating a shearing effect on the measured liquid. The time of fall is a measure of viscosity with the clearance between the piston and inside of the cylinder forming the measuring orifice.
- Oscillating piston viscometer: The sample is first introduced into the thermally controlled measurement chamber where the piston resides. The oscillatory motion of piston within the measurement chamber with a controlled magnetic field imposes shear stress on the liquid and the viscosity is determined by measuring the travel time of the piston according to Newton's Law of Viscosity.
- Vibrational viscometers: The measurement of the damping of an oscillating electromechanical resonator immersed in a fluid whose viscosity is to be determined. The higher the viscosity, the larger the damping imposed on the resonator.
- Bubble viscometer: The time required for an air bubble to rise is directly proportional to the viscosity of the liquid, the faster the bubble raises, the lower the viscosity.
- Rectangular-slit viscometer: The slit viscometer/rheometer is based on the principle that a viscous liquid resists flow, exhibiting a decreasing pressure along the length of the slit.

3 CHARACTERIZATION TECHNIQUES OF NANOPARTICLES

The characterization methods of the structural properties of nanoparticles such as particle size, chemical nature, morphology and size of agglomerations are referred as characterization techniques. Here are all usable methods in most of the studies are scanning electron microscopy (SEM), transmission electron microscopy (TEM), vibration sample magnetometer (VSM), energy-dispersive x-ray spectroscopy (EDX), x-ray diffraction (XRD), thermal analysis TG-DTA-DSC, Fourier transform infrared spectroscopy (FTIR), infrared absorption spectroscopy, UV–Vis spectroscopy and inductively coupled plasma–optical emission spectroscopy (ICP-OES).

4 FACTORS AFFECTING THE VISCOSITY OF NANOLUBRICANTS

Viscosity is the internal resistance force of fluid and hence it is a paramount parameter for all heat transfer and lubricating applications. Viscosity of nanolubricants depends on many factors (Fig. 2) like volume concentration, temperature, particle size, shear rate, morphology and density.

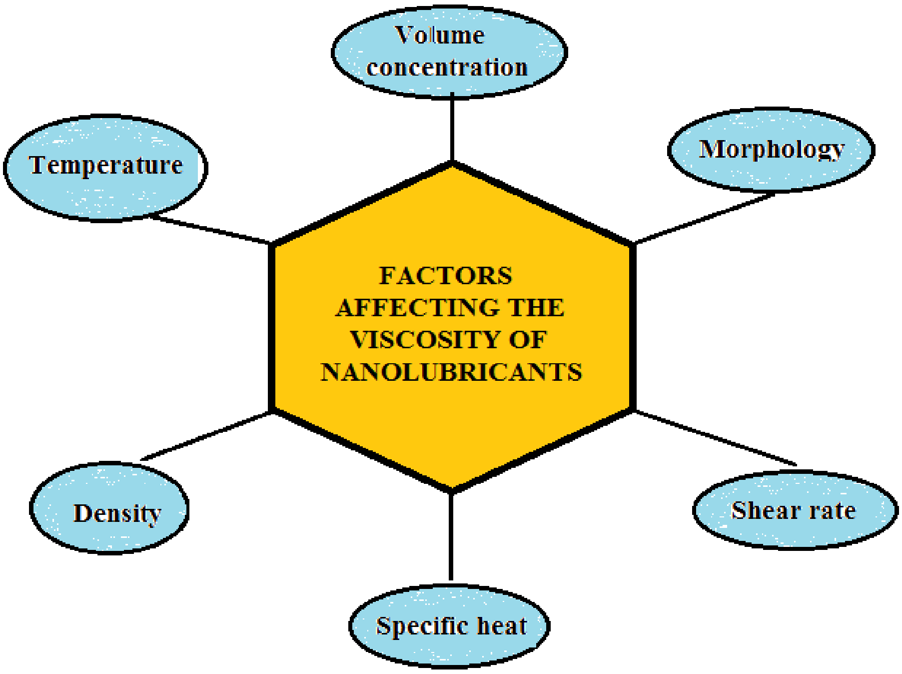

Figure 2 Factors affecting the viscosity of nanolubricants

4.1 Volume concentration/weight fraction

Volume concentration/weight fraction of nanolubricants is the most important factor which directly affects the viscosity of nanolubricants. Many researchers have shown that, viscosity of nanolubricants effect due to the volume concentration/weight fraction of nanoparticles [6]. Saeedinia et al. examined the temperature dependent viscosity of CuO-nanolubricants with different particle weight fractions of 0.2–2% which shown Newtonian behavior for all weight fractions and temperatures [7]. Katiyar et al dispersed Fe-Ni nanoparticles (≤15 nm) into paraffin oil and studied of their magneto-rheological behavior. Their results showed the big influence of nanoparticle concentration on the viscosity and yield stress by reporting approximately 24 times enhancement in Bingham property for nanofluid containing 10 wt% of Fe-Ni nanoparticles [8]. Yang et al. Investigated the effect of multi-walled carbon nanotubes dispersion, surfactant concentration and steady shear viscosity of oil (PAO6) nanofluids and reported that viscosity of nanofluids was found to increase with increasing MWCNT concentration [9]. The addition of hexamethyldisiloxane (HMDS) dispersant into silicone oil can decrease its viscosity which was found to be of the Newtonian nature [10]. Singh et al. investigated the viscosity of ethylene glycol-CNT nanofluids and reported that the viscosity was found to increase and decrease with increasing of CNT concentration and temperature, respectively [11]. Kotia et al. dispersed Al_2O_3 nanoparticles in gear lubricant oil and found 10.5 % increment in viscosity with 0.5 % nanoparticle volume fraction [12]. Nezhaada et al. measured the viscosity of SWCNT dispersions in lubricating oil at different temperatures. They reported a maximum of 33% increase in viscosity at SWCNT concentration of 0.2 wt% [12]. Zhou et al. is also observed similar increase in viscosity of Al_2O_3/PAO nanofluids. [13].

4.2 Morphology

Morphology of nanoparticles, both size and shape can influence on the viscosity of cooling system. Murshed et al. was augmented that larger particles yield larger weight percentage of agglomeration compared to the smaller nanoparticles in base fluids leading to greater viscosity enhancement of their suspensions [14]. Yiamsawas et al. investigated the viscosity of Water/EG (80:20) mixture nanofluid by dispersing 120 nm size Al_2O_3 nanoparticle and found approximately 2.23 times larger viscosity than base fluid at 4 vol% [15]. Sharifpur et al. dispersed 19 nm, 139 nm and 160 nm sized Al_2O_3 nanoparticles into glycerol and measured their viscosity. They reported that higher viscosity for smaller sized nanoparticles and the difference in viscosity was more significant at higher nanoparticle volume concentrations [16]. Nguyen et al. reported that the viscosity of 36 nm sized Al_2O_3 nanofluids is lower than that of 47 nm A_2O_3 particles dispersed nanofluids [17]. Abdelhalim et al. reported that the large size (50 nm) nanoparticle dispersion exhibits higher viscosity than the smaller nanoparticles dispersions (10 nm and 20 nm) [18].

The shape of the dispersed nanoparticles was also studied to be an influencing property for an increase in viscosity. Timofeeva et al. reported higher viscosity of platelets shape Al_2O_3 nanoparticles compared to brick shape nanoparticles [19]. It is found that the reasons for the opposite effect of nanoparticles size and shape on viscosity variations are not yet well understood and need further analyses and studies to investigate the real mechanisms.

4.3 Shear rate

Variations in the rheological behavior of nanolubricants have also been reported to vary according to the type of base fluid and their preparation method. He et al. reported a shear thinning behavior TiO_2 nanofluid and observed rapid decrease in the shear viscosity due to increasing shear rate [20]. Phuoc et al. examined the rheological nature of Fe_2O_3 nanofluids and they reported that Fe_2O_3 nanofluids exhibits shear-thinning behavior beyond a particular nanoparticle concentration [21]. Yang et al. reported that viscosity of Cu nanofluids increase moderately with the concentration of nanoparticlesat due to the shear-thinning nature of nanofluids at low shear rate [22]. Kotia et al. found that CuO nanolubricants exhibit non-Newtonian behaviors with increasing volume fraction of nanoparticles [23]. Rashin and Hemalatha investigated the viscosity of CuO nanolubricant by varying the shear rate and found non-Newtonian fluid behaviour due to the pseudoplastico properties of nanolubricants [24].

4.4 Temperature

Temperature is one of the most important parameters affecting the viscosity of nanolubricants [25]. Singh et al. investigated the viscosity of ethylene glycol-CNT nanofluids and reported that the viscosity decrease with increasing temperature [11]. Nezhaada et al. measured the viscosity of SWCNT suspensions in lubricating oil at different temperatures ranging from 25 to 100 °C. They found that the viscosity of nanofluids decreased with increasing [26]. Thottackkad et al. obtained increase in viscosity of CuO nanolubricants with increase in nanoparticle volume fraction up to 60 °C [27]. Sanukrishna et al investigated the rheological nature of TiO_2 -PAG nanolubricant for 0.07 to 0.8% volume concentrations at the temperature range from 20 °C and 90 °C and reported that viscosity of nanolubricant increase with increase in nanoparticle concentration and decrease with increase in temperature [28].

4.5 Density

Density is an important thermophysical property of nanolubricants for evaluating the heat transfer and lubricating performances of nanolubricants which directly affects the Reynolds number, pressure loss, friction factor and Nusselt number. Maheswaran et al. dispersed garnet nanoparticles into lubricating oil and reported that density of nanolubricants increases with the increase in nanoparticle concentration [29]. Talib et al. determined the density crude jatropha oil, synthetic ester and modified jatropha oil by the ratio of weight over volume of oil using a pycnometer at 15oC. They observed that, the synthetic ester exhibited higher density compared to crude jatropha oil and modified jatropha oils. The density of modified jatropha oil samples increased linearly as a function of the additive concentrations and molar ratio [30].

V Conclusions

The viscous behavior of nanolubricants and factors affecting them has been reviewed. Nanofluids and nanolubricants exhibit significantly greater viscosity compared to the base fluids which increases with increasing nanoparticles concentration. Many influencing factors are to be improved before used for commercial applications which should be optimized with respect to temperature, particle size, material, dispersion stability, size distribution, and shape. Presently nanofluid developing technology is in a developing phase; however, the available results are enough to spot the influencing factors of viscosity enhancement whereas the reasons for the opposite effect of nanoparticles size on viscosity variations are not yet well understood and need further analyses and studies to investigate the real mechanisms. Further, more research inputs are needed to spot new theoretical models/ correlations, which can predict the viscosity with more accuracy.

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