Int. J. Chem. Sci.: 14(3), 2016, 1367-1375
ISSN 0972-768X
www.sadgurupublications.com

SYNTHESIS AND GRAVITY DRIVEN SEDIMENTATION STUDY ON ZnS-GEAR LUBRICANT OIL NANOFLUIDS FOR GEAR LUBRICANT APPLICATIONS

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ABSTRACT

Nanofluid is a kind of new engineering fluid consisting of solid nanoparticles with sizes typically of 1-100 nm homogeneously dispersed in base fluids. In this study, spherical shaped zinc sulphide (ZnS) nanoparticles are prepared by chemical precipitation method. The synthesised nanoparticles are ultrasonically suspended in gear lubricant oil and its suspension stability is evaluated by gravity driven sedimentation test for different gear lubricant applications. Further, the effect of molecular interaction and separation distance of dispersed additives on the sedimentation velocity is discussed through Lennard-Jones potential equation.

Key words: Nanofluid, chemical precipitation method, Suspension stability, Sedimentation velocity.

INTRODUCTION

In recent years, nanosized functional materials have attracted more research intension due to their smaller size dependent physical, chemical, optical, and tribological properties. The nanometer sized metallic or non-metallic particles are called as additives when they are homogeneously dispersed in liquid or semisolid mediums and the resultant fluid is called as nanofluids.

Many researchers reported that the dispersed additive enhances the properties of base fluid, which leads to apply in different applications. Heat dissipation of electronic components is more difficult due to the reduction of available surface area for heat removal. Nguyen et al.[1] homogeneously dispersed various concentrations Al_2O_3 nanoparticles in

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distilled water and measured their heat transfer behavior for the liquid cooling system used in electronic microchips. The additive improved the convective heat transfer coefficient of distilled water and the junction temperature of heated component is reduced 23% than that of additive free distilled water. Kole et al.[2] studied the thermal conductivity and viscosity of car engine coolant by suspending Al_2O_3 nanoparticles and their results shows that 3.5% volume fraction of Al_2O_3 nanoparticles displayed that the maximum thermal conductivity enhancement of about 10.41% at room temperature. This enhanced cooling ability can reduce the weight and complexity of thermal management systems. Masuda et al.[3] experimentally measured the thermal conductivity of water based TiO_2 and Al_2O_3 nanofluids using transient hot-wire method. Their results reported that the additives significantly improved the thermal conductivity of base fluid. The thermal conductivity of Al_2O_3-water nanofluids and TiO_2-water nanofluids at 4.3 vol.% were 32% and 11% greater than that of base liquid, respectively.

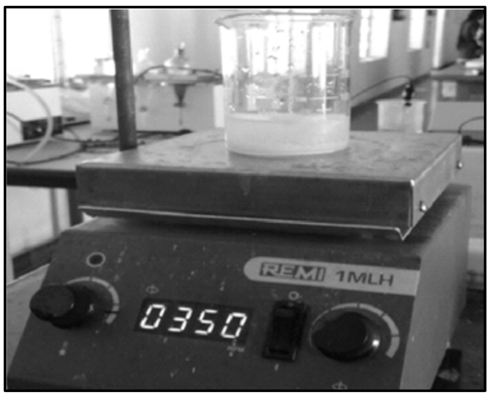
The lubricant oil used in industrial engineering components are expected to avoid direct metal-metal interaction by maintaining a stable layer of oil film between the metal interfaces. The conventional lubricants are failed to develop oil film between the rubbing surfaces at higher contact pressure and temperature, which increases the friction and wear. The suspension of nanoscale additives enhances the tribological behavior lubricant oil like anti wear and friction reduction. Dwyer-Joyce et al.[4] investigated the mechanism of closed three-body abrasive wear of diamond-lubricant oil nanofluids using optical elastohydrodynamic lubrication rig. They showed that the suspended diamond additives embedded in the softer rubbing surface and tumbled through the contact, which produces ball bearing effect and reduces the friction between them.

Some of the transition metal oxides like ZnO, TiO_2 and Fe_3O_4 etc. proved as a potential candidate for different applications. In the same way zinc sulphide (ZnS) is also one of the useful metal oxides, which has so many applications in various fields as a semiconductor. ZnS is the II-VI compound semiconductor materials for various applications, including light-emitting diodes (LEDs), sensors, lasers, electroluminescence, flat panel displays, infrared windows and bio devices. The surface state of ZnS can be increased by bonding of capping agents like poly vinyl alcohol (PVA). In this work, ZnS nanoparticles are prepared by chemical precipitation technique and poly vinyl alcohol is used as capping agent to modify the surface of nanoparticles and prevents the growth of the particle to larger size. The synthesised nanoparticles are ultrasonically dispersed in the conventional gear lubricant oil and their suspension stability is evaluated by gravity driven sedimentation test for gear lubricant applications. The size, shape and elements of nanoparticles are determined by scanning electron microscope (SEM) equipped with energy dispersive spectra (EDS).

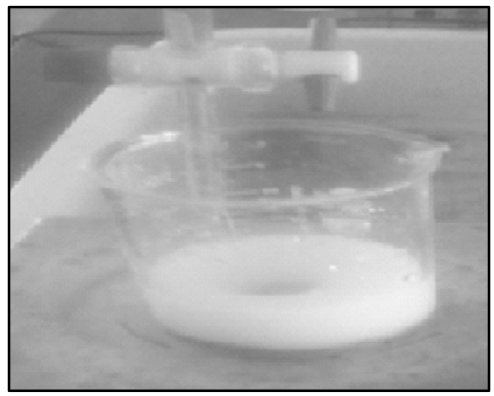
EXPERIMENTAL

Preparation of ZnS nanoparticles

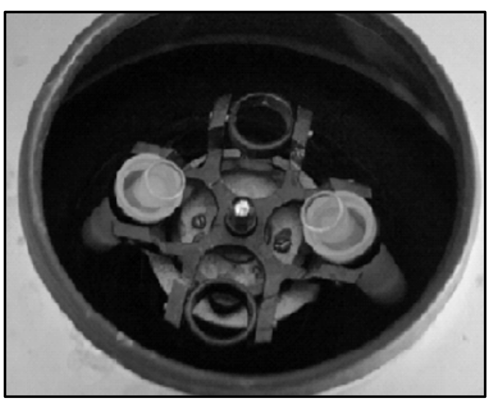
ZnS Nanoparticles were synthesized using poly vinyl alcohol capping agent by simple chemical precipitation technique and the Fig. 1 demonstrates the preparation steps of ZnS Nanoparticles. 0.5 M aqueous solution of zinc acetate dihydrate (molecular weight is 219) and 0.5 M aqueous solution of sodium sulfide (molecular weight is 78.04) were stirred for 20 and 10 min, respectively by using a magnetic stir for preparing 250 mL of sample and then it is mixed with the poly vinyl alcohol capping agent solution (Step 1). Then the 15 mL of sodium sulphide solution is taken in burette and mixed with zinc acetate and PVA mixer and vigorously stirred for 90 min (Step 2).



Step 1: Stirring of zinc acetate mixer and PVA



Step 2: Addition of sodium sulphide



Step 3: Centrifugation of white precipitate

Step 4: Powder sample

Fig. 1: Preparation steps of ZnS nanoparticles by chemical precipitation technique

A white colour precipitate was obtained and it is separated by centrifugation process and washed ten times with double distilled water and again it is washed ten times with ethanol (Step 3). The washing of the white colour precipitate with ethanol is used to obtain pure ZnS. Finally, the white precipitate was dried in oven at 80^{o}C for 4 hrs to get powder sample.

Characterisation of ZnS nanoparticles

The SEM analysis is used to study the size and shape of the synthesised ZnS nanoparticles. The Fig. 2 shows the SEM image of ZnS nanoparticles prepared by precipitation technique where the particles are strongly agglomerated due to the high surface energy between them.

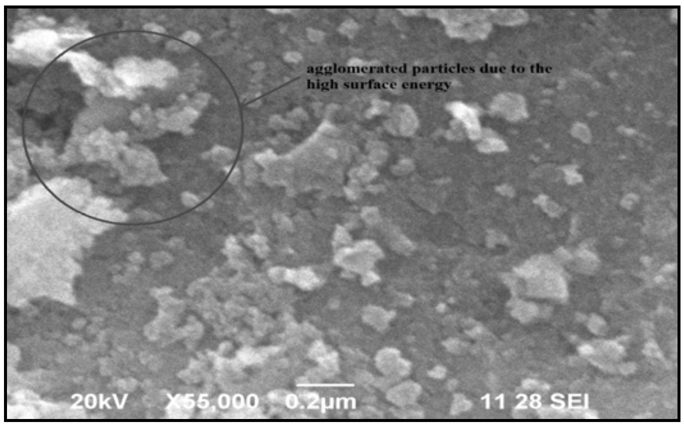


Fig. 2: SEM image of ZnS nanoparticles

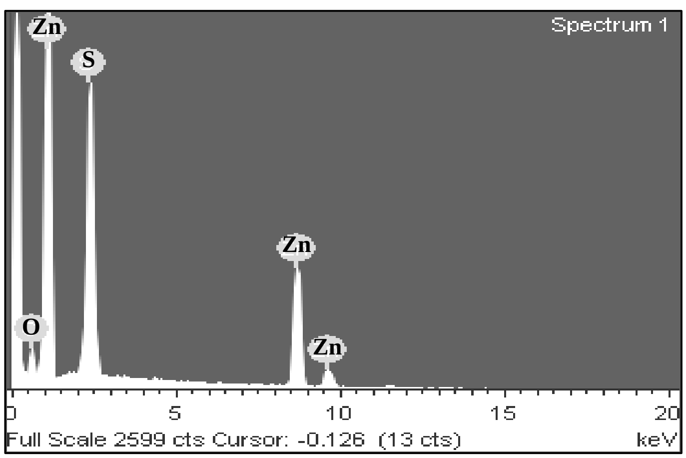


Fig. 3: EDS analysis of ZnS nanoparticles

The SEM image shows that the particles are having the average size of 50 nm and spherical in shape. It also shows that the size and shape of nanoparticles are uniform. The Fig. 3 shows the EDS estimation of synthesised nanoparticles, which conforms the existing of Zn and sulphur compounds.

Preparation of ZnS-gear oil nanofluids

Gear oil is a lubricant in various gear trains, which creates a lubricant oil film between the gear teeth and reduces the direct metal-metal interaction. The thickness of oil film thickness is depends upon the contact pressure and operating temperature. At higher contact pressure and temperature the conventional gear lubricant oil fails to maintain the lubricant film between the teeth, which leads to gear teeth wear[5]. For this reason, the conventional gear lubricant is mixed with 0.2 wt%, 0.4 wt% and 0.6 wt% of weighed quantity of ZnS nanoparticles. Then the mixture is sonicated for 15 min by using a probe sonicator (Sonics, USA)[6]. The sonication separates the agglomerated ZnS nanoparticles and used to prepare the homogeneous ZnS-gear oil nanofluids and thus the Zns-gear lubricant oil nanofluids with different concentrations are prepared. The Fig. 4 shows the prepared ZnS-gear oil nanofluids with 0.2 wt%, 0.4 wt% and 0.6 wt% of ZnS nanoparticles.

Fig. 4: Ultrasonically prepared ZnS-gear lubricant oil nanofluids

Suspension stability of ZnS nanoparticles in gear lubricant oil

The investigation on suspension stability of dispersed ZnS nanoparticles in gear lubricant oil matrix is a key issue that influences the properties of nanofluids for different applications; and it is also necessary to study the influencing factors to the dispersion stability of nanofluids. The smaller size of additives has greater surface energy, which leads to rapid aggregation of particles can lead to 'caking'. This process increases the size of particles and leads to sedimentation, making it impossible to resuspend. Different concentrations of ZnS containing gear lubricant oil is taken in glassy containers and isolated in a vibration free environment for its suspension stability analysis. Fig. 5 shows the photograph of 0.2 wt%, 0.4 wt% and 0.6 wt% concentrations of ZnS additives in gear lubricant oil after 10 days. The colour difference observation between the prepared nanofluids (Fig. 4) and prepared nanofluids after 10 days is less. Fig. 6 shows the photograph of 0.2 wt%, 0.4 wt% and 0.6 wt% concentrations of ZnS additives in gear lubricant oil after 18 days and it is observed that the dispersion of ZnS nano particles in the gear lubricating oil forms a colloidal solution and according to the concentration; some of the particles tend to recombine or agglomerate and begins to settle.

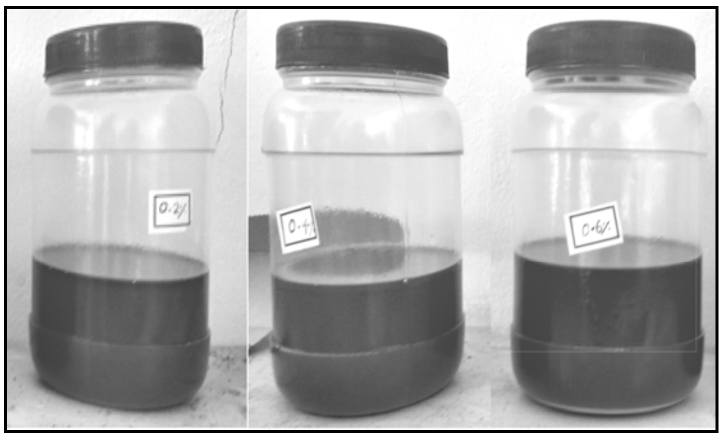


Fig. 5: Photograph of different concentrations of nanofluids after 10 days

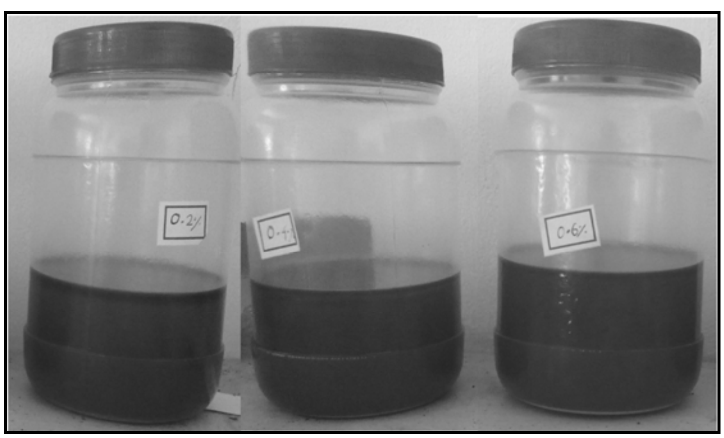


Fig. 6: Photograph of different concentrations of nanofluids after 18 days

It is observed that the recombination of the particles increases the sizes and velocity of particles, which increases the rate of Brownian motion[7] and this, is the cause of sedimentation of dispersed ZnS particles in the prepared nanofluids. But, it is inferred that the dispersion stability of the ZnS-gear lubricant oil nanofluid is acceptable and can be stored and used for 15 days and its settling velocity is calculated by the following formula.

$$\text{Sedimentation velocity} = \frac{\text{Original height of nanofluids} - \text{Height after 288 hrs}}{\text{Time taken}}$$

Generally, intermolecular interactions of the particles under suspension are described by Lennard–Jones forces. Lennard-Jones potential describes the potential energy of interaction between two non-bonding atoms or molecules based on their distance of separation and it is a function of the distance between the centres of two dispersed additives. Also, Lennard-Jones potential approximates the interaction between two particles, which repulse at short distances and attract at large. It is given in the equation (1):

$$U(r) = 4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6}\right] \quad \ldots(1)$$

Where, r is the distance between the centres of the particles, ε is the depth of the potential well, σ is the distance at which energy interaction becomes zero. The suspension stability of dispersed particles in the colloidal solution is a function of the Lennard-Jones separation distance. As the separation distance decreases below equilibrium, the potential energy becomes increasingly positive, indicating a repulsive force and at long separation distances, the potential energy is negative indicating an attractive force. This indicates that at long-range distances, the pair of atoms or molecules experiences a small stabilizing force. Lastly, as the separation between the two particles reaches a distance slightly greater than σ, the potential energy reaches a minimum value indicating zero force. At this point, the pair of particles is most stable and will remain in that orientation until an external force is exerted upon it. Further, in the colloidal solution, there are three forces acting on each nanoparticle namely, the force due to gravity (FG), force due to buoyancy (FB) and force due to viscous drag (FD). Assuming, the nano particles are approximated to sphere of diameter 'd' due to this dimension,

$$FG = (\pi\, d^3\, \rho_p\, g)/6 \quad \ldots(2)$$

$$FB = (\pi\, d^3\, \rho_{bf}\, g)/6 \quad \ldots(3)$$

$$FD = 3\, \pi\, \mu_{bf}\, v \quad \ldots(4)$$

Where, d is the diameter of the particle (m), ρ_p is the density of the particle (Kg m^{-3}), g is the acceleration due to gravity (m. sec^{-2}), ρ_{bf} is the density of the base fluid, μ_{bf} is the viscosity of the base fluid and v is the sedimentation velocity of the particle in suspension. By equating equations 2, 3 and 4 the sedimentation velocity can be estimated by the equation (5).

$$v = [d^2 (\rho_p - \rho_{bf}) g]/(18 \mu_{bf}) \quad \ldots(5)$$

From the above expression, the theoretical sedimentation velocity of the particle the particle in suspension can be calculated and by assuming 'L' as a depth of sedimentation in 'm' and the time taken to settle the dispersed additives can be estimated by the equation (6).

$$\text{Time taken 't'} = (18 L \mu_{bf}) / [d^2 (\rho_p - \rho_{bf}) g] \quad \ldots(6)$$

CONCLUSION

Spherical shaped ZnS nanoparticles with larger surface energy have been synthesized by chemical precipitation method and it is suspended in gear lubricant oil by ultrasonication. The gravity driven sedimentation results shows that the ZnS-gear lubricant oil nanofluids can be stored for 15 days. Further, the theoretical correlations to estimate the sedimentation velocity and time required to settle dispersed additives in fluid medium is derived through Lennard-Jones potential approximation.

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Accepted : 15.05.2016