

Tribological Performance of ZnO-Oil Nanofluids at Elevated Temperatures

Ionut C. Harta and Kayla Owens
Oakland University

Steven De Jesús Santiago
Universidad Del Turabo

David Schall, Steven Thrush, Gary Barber and Qian Zou
Oakland University

ABSTRACT

The tribological performance of nanofluids consisting of ZnO nanoparticles dispersed with a stabilizer in an API Group III oil was investigated. Recent research suggests that these fluids may reduce friction and wear compared to the base oil when used as a lubricant in metal-on-metal tests [1]. The effects of nanoparticle concentration and test temperature on friction and wear were studied. Tests were run at 50°C and 100°C to investigate the viability of the fluids at elevated temperatures because possible applications include use as engine lubricants. Nanofluids showed friction reduction of up to 5.2% and reduced wear by up to 82.8% versus oil with only stabilizer at the highest ZnO concentration and the lowest temperature. Stabilizer increased wear at every concentration, but did not affect friction significantly. Fluid viscosity was also investigated. At 30°C, significant shear-thinning behavior was observed for the 2% ZnO solution, and a viscosity versus shear rate curve was found. At higher temperatures and high shear rates, the fluids took on Newtonian characteristics. The transition from non-Newtonian to Newtonian behavior may have important implications in the application of nanoparticle lubricant additives in engine oils.

CITATION: Harta, I., Owens, K., De Jesús Santiago, S., Schall, D. et al., "Tribological Performance of ZnO-Oil Nanofluids at Elevated Temperatures," *SAE Int. J. Fuels Lubr.* 6(1):2013, doi:10.4271/2013-01-1219.

INTRODUCTION

Nanofluids are stable solutions of nanoparticles in a fluid. Nanoparticles are particles sized less than 100nm and can be composed of a wide variety of materials, including metals, metal oxides, and various carbon structures. Water, oil, and ethylene glycol (EG) are just a few of the fluids in which nanoparticles can be dispersed [1, 2, 3].

Most nanofluid research has focused on the enhancement of thermal conductivity due to the addition of nanoparticles to the base fluid. Fluids with nanoparticles dispersed in them show improved heat transfer properties versus the base fluid [4]. The replacement of conventional heat transfer fluids with nanofluids could lead to improved efficiencies in many applications such as engine, transmission, and electronic systems cooling [5]. ZnO nanoparticles have been shown to significantly increase thermal conductivity in oil and in EG [3,6].

Relatively little research has been done on the tribological performance of nanofluids. The available research indicates that metal, metal oxide, and carbon nanoparticles are effective in reducing friction and wear in various metal-on-metal tests versus the pure lubricant when dispersed in the lubricant [2]. Proposed mechanisms of friction and wear modification by nanoparticles include a ball bearing effect, advantageous particle film formation, mending, and polishing of the material surface [7]. Spherical particles may roll between two surfaces, enhancing the load-bearing capacity of the lubricant and reducing friction. Particles may become imbedded in the material surface, which protects against wear and may reduce friction. Particles may also modify the surface of the material by filling in gaps and pits or polishing the surface by removing raised imperfections [7].

The tribological performance of metal oxide nanoparticles as additives in lubricants has recently been studied [1,2]. Nanoparticles such as ZnO, ZrO₂, and CuO have been shown

to reduce friction and wear at low weight concentrations in oil [1]. In water, ZnO and Al₂O₃ nanoparticles both reduce friction, but Al₂O₃ increases wear and ZnO does not affect wear significantly [2]. This investigation considers the friction, wear, and viscosity performance of ZnO nanofluids with low weight concentrations at elevated temperatures with an API Group III base oil as the base fluid.

EXPERIMENTAL DETAILS

Tribometer

Friction testing was carried out with a Bruker UMT-3 tribometer in a rotary ball-on-disk setup with a normal force of 4.448N applied to the steel sample, shown in Figure 1. The linear velocity of the test was kept constant at 115 mm/s because similar experiments have achieved friction and wear reduction near this speed [2].

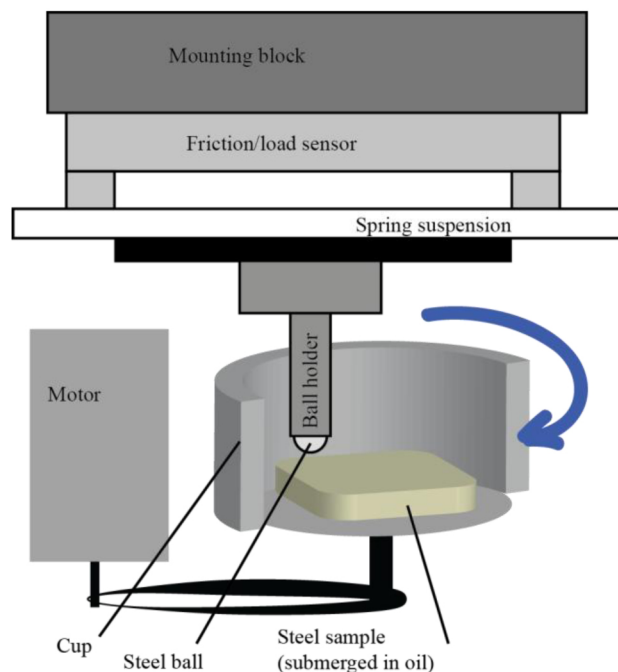


Figure 1. Rotary ball-on-disk tribometer.

Test Materials

4140 steel samples with Brinell hardness of 241-245 were polished to a surface roughness R_a of 60-80 nm. Steel balls were 52100 steel 7.94 mm in diameter with HRC 60-67. The final surface roughness was verified by testing the samples with a mechanical profilometer. Solutions of 0.25%, 0.5%, 1%, and 2% by weight ZnO were mixed. ZnO nanoparticle size ranged between 40-100nm with an irregular morphology. Stabilizer to nanoparticle weight ratio was 1:1, as recommended by the additive manufacturer. Stabilizer is needed to keep the nanoparticles in solution. The stabilizer consisted of 1:10 polyisobutylene succinic anhydride (PSA) to isostearic acid. Control fluids consisted of base oil with

only stabilizer added; the tribological performance of the ZnO fluids were compared to these control fluids. Pure base oil tests were also carried out. The base oil is an API Group III oil. Sample masses of fluid components for the 1% concentration are given in Table 1. All test fluid concentrations were composed of the same mass ratios as in table.

Table 1. Composition of fluids for 1% concentration.

Fluid	Oil (g)	ZnO (g)	Isostearic Acid (g)	PSA (g)
1% ZnO	28.0000	0.2800	0.2545	0.0231
1% Stab.	28.0000	0.0000	0.2545	0.0231

Test Procedures

Fluid preparation

All beakers, scoops, and vials were first cleaned with acetone. ZnO nanoparticles, isostearic acid, PSA, and oil were massed to ± 0.0005 g and added to a clean 40mL vial. After all components were added, the vial was placed into an ultrasonic bath for 30 minutes in order to disperse the ZnO nanoparticles. The fluid was then directly sonicated for 10 minutes at 200W in an Omni Sonic Ruptor 400 in order to further homogenize the solution. If a fluid was allowed to sit for an extended period of time, the sample was again homogenized with the Sonic Ruptor immediately prior to running friction tests. A nanoparticle dispersion study was considered in the development of the fluid preparation procedure [8].

Friction and wear measurement

Polished 4140 steel samples were tested in a rotary ball-on-disk test. Tests were conducted at 50°C and 100°C to investigate the viability of the lubricants at elevated temperatures. Steel samples were completely submerged in the test fluid during tests. Friction data was automatically recorded by the tribometer at a sampling rate of 100 data points per second. One fluid at a given temperature corresponded with one steel sample. Each steel sample was used to repeat the fluid/temperature combination five times—each repetition was conducted at a different test radius on the sample. The average COF of each fluid was found by averaging the individual COF of each of the five radial tests together for a given fluid. The total number of revolutions for a test was kept constant at 1000, rather than the total sliding distance or test time.

The number of revolutions was held constant to ensure that the ball passed each point on the sample exactly 1000 times, which made comparison of the cross-sectional area of the wear tracks possible between different radii of any given part. If total sliding distance were held constant, the cross-sectional wear area of the tracks could only be compared at radii of equal size because the ball would complete varying amounts of rotations at each radius. Time constraints made it impractical to hold the sliding distance constant. The balls