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Viscosity and density of aluminum oxide nanolubricant

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ABSTRACT

This paper presents liquid kinematic viscosity and density measurements of a synthetic polyolester-based aluminum oxide (Al_2O_3) nanoparticle dispersion (nanolubricant) at atmospheric pressure over the temperature range 288 K–318 K. Two Al_2O_3 particles diameters were investigated: approximately 60 nm and 10 nm. A good dispersion of the spherical nanoparticles in the lubricant was maintained with a surfactant. Viscosity and density measurements were made for the neat lubricant along with twelve nanolubricants with differing nanoparticle and surfactant mass fractions. A new model was developed to predict the kinematic viscosity of the nanolubricant by summing the viscosities of the nanoparticle, the surfactant and the base lubricant. The resulting correlated model for the liquid kinematic viscosity was a function of temperature, nanoparticle mass fraction, surfactant mass fraction, and nanoparticle diameter. The measurements are important for the design of nanolubricants for heat transfer and flow applications.

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Viscosité et masse volumique d'un nanolubrifiant à base d'oxyde d'aluminium

Mots clés : suspension colloïdale ; masse volumique ; lubrifiant ; viscosité ; refroidisseur d'eau

1. Introduction

Recent studies by Henderson et al. (2010), Bi et al. (2007), and Kedzierski (2008) have explored the use of nanolubricants (lubricants with dispersed nanoparticles) as a means for improving efficiencies of air-conditioning and refrigeration equipment. For low flow qualities, Henderson et al. (2010) have shown that CuO nanoparticles can improve the flow boiling heat transfer of refrigerant/lubricant mixtures by as much as 76% and that the lubricant can act as a necessary dispersant. Bi et al. (2007) showed that TiO_2 nanolubricants produced energy savings of more than 25% in domestic refrigerators. Copper-oxide nanoparticles have also been shown to improve refrigerant/lubricant pool boiling by as much as 245% (Kedzierski and Gong, 2009). Aluminum-oxide nanoparticles have produced similar enhancements for refrigerant/lubricant boiling (Kedzierski, 2011a, 2012).

Considering the potential of nanolubricants for improving the efficiency of air-conditioning and refrigeration equipment, viscosity and density measurements of potential

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Nomenclature

English Symbols

A_n	constants in Table 2 $n = 0,1,2,3$
B_n	constants in Table 1 $n = 0,1$
D_p	nanoparticle diameter [m]
T	absolute fluid temperature [K]
T_r	T/273.15 K [–]
U_ρ	expanded uncertainty of density [kg m^{-3}]
U_ν	expanded uncertainty of viscosity [mm^2 s^{-1}]
x	mass fraction

Greek symbols

ρ	liquid density [kg m^{-3}]
ν	liquid kinematic viscosity [mm^2 s^{-1}]
ν_o	unity viscosity = 1 [mm^2 s^{-1}]

Subscripts

L	pure lubricant
m	mixture, measured
np	Al_2O_3 nanoparticle
p	predicted
s	surfactant

nanolubricants will benefit both fundamental research and design considerations. For example, Kedzierski (2001) has shown that the lubricant viscosity and density influence the performance of boiling refrigerant/nanolubricant mixtures and are required parameters for its prediction (Kedzierski, 2012). Because of works like Eastman et al. (2001), nanofluids immediately bring to mind the benefits of increased thermal conductivity as induced by the nanoparticles. However, when considering refrigerant/nanolubricant boiling, the improvement associated with increased thermal conductivity is generally less than 20% of the total boiling enhancement (Kedzierski, 2008). Most of the enhancement is caused by an exchange of momentum between the nanoparticles and the bubbles (Kedzierski, 2011a, 2012). As a result, the viscosity is probably a more crucial property to measure than the thermal conductivity, for this application, given that the lubricant viscosity is also a key determinant for proper operation of the compressor.

Compressors in refrigerators and chillers have specific requirements for lubricant viscosity. Although there is reason to believe that most of the nanoparticles will remain in the evaporator, thus, limiting the nanoparticle mass fraction in the compressor, the effect of nanolubricants in the compressor must be considered. This may require either redesign of the compressor or the nanolubricant to ensure proper lubrication. For this reason, knowledge of the viscosity and the density of a nanolubricant are essential for its application to equipment.

Both the size of the nanoparticle and the amount of surfactant used in the manufacture of a nanolubricant are important in determining the quality of the dispersion. A high quality dispersion, one where the nanoparticles remain suspended without agglomeration, is essential for the reliable operation of refrigeration and air-conditioning equipment. Nanoparticles that agglomerate have the potential for clogging filters and lodging in other system components. In addition, the quality of a dispersion determines the potential for refrigerant boiling enhancement (Kedzierski, 2011b) and the thermophysical properties of the nanolubricant. For this reason, the focus of the present study is to investigate the influence of nanoparticle size and the dispersant (surfactant) mass fraction on the viscosity and the density of selected aluminum oxide-based nanolubricants.

2. Test liquids

A manufacturer used a proprietary, polymeric surfactant[1] along with a commercial polyolester lubricant (RL68H),[2] commonly used with R134a chillers, with a nominal liquid kinematic viscosity of 72.3 mm^2 s^{-1} at 313.15 K, to make twelve different nanolubricants of varying surfactant and nanoparticle mass fractions for two different aluminum oxide (Al_2O_3) nanoparticle diameters (D_p): one with nominally 60 nm, and the other with 10 nm. In addition, the viscosity and the density of the neat RL68H and a 50/50 by mass mixture of RL68H and the surfactant were measured. All of the test liquids were ultrasonically mixed for approximately 24 h prior to measurement.

The size of the Al_2O_3 nanoparticles in the nanolubricant was measured with a Dynamic Light Scattering (DLS) technique using a 633 nm wavelength laser and a sieving technique using a syringe filter. An index of refraction of 1.67 for Al_2O_3 was used in the Brownian motion-based calculation that was done internally by the DLS instrument for the particle size. The uncertainty of the packaged DLS instrumentation was confirmed with a NIST-traceable 60 nm ± 2.7 nm nanofluid standard. The measured diameter of the standard with the DLS system was 64 nm ± 5 nm, which coincides with the range of uncertainty of the standard. The DLS measurements showed that the nanoparticles were well dispersed in the nanolubricant with mostly discrete, nominally 10 nm and 60 nm diameter nanoparticles on a number-weighted basis[3] for the two different nanolubricants. Fig. 1 shows a Transmission Electron Microscopy (TEM) image of the 10 nm

[1] Due to the proprietary nature of the surfactant (Nanophase Technologies R&D product code R1103RL68H), no property information can be provided here.

[2] Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

[3] The manufacturer reports these same nanoparticles as having surface-area weighted nanoparticle sizes of 20 nm and 40 nm, which are derived from specific surface area measurements (Sarkas, 2009).