International Communications in Heat and Mass Transfer 38 (2011) 144–148

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Rheological characteristics of non-Newtonian nanofluids: Experimental investigation ☆

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ARTICLE INFO

Available online 4 December 2010

Keyword:
Nanofluid
Non-Newtonian
Power law
Consistency index
Rheological behavior

ABSTRACT

γ-Al_2O_3, TiO_2 and CuO nanoparticles were dispersed in a 0.5 wt.%. aqueous solution of carboxymethyl cellulose (CMC) to prepare three types of non-Newtonian nanofluids. Rheological characteristics of the base fluid and nanofluids with various nanoparticle concentrations at different temperatures were measured. Results show that all nanofluids as well as the base fluid exhibit pseudoplastic (shear thinning) behavior. The rheological characteristics of nanofluids and those of the base fluid are functions of temperature and particle concentrations.

1. Introduction

Numerous high-tech industries such as microelectronics, transportation, manufacturing, and metallurgy are often faced with the technical challenges of having higher cooling performance. Conventional methods leading to increased heat transfer rates such as extended surfaces and micro-channels, have the disadvantage to increase the required pumping power of the cooling fluid. The development of advanced fluids with improved flow and thermal characteristics are of paramount importance to achieve higher heat flux densities. Thermal conductivities of solids may be orders of magnitude greater than that of fluids and it is therefore expected that dispersion of solid particles will significantly improve the thermal behavior of fluids. Well dispersed and stable suspensions of nanoparticles in conventional heat transfer fluids were named nanofluids [1]. Many investigators have studied the various characteristics of fluid flow and heat transfer behavior of nanofluids over the past 15 years [2–4] and found that enhanced heat transfer coefficients were obtained with nanofluids. However, it is important that the enhanced heat characteristics of these new fluids are not counteracted by additional pumping power to circulate these fluids in the process. It is therefore necessary to also examine the rheological behavior of these fluids.

Rheological behavior is an important parameter in systems involving fluid flow. For calculating the required pumping power, the rheological behavior of flowing fluid is needed. Numerous investigations have been carried out on viscosity and rheological characteristics of various nanofluids [5–37]. All of these studies showed that viscosity of nanofluids was larger than that of the base fluid and increased with an increase in the nanoparticle concentration. For all these investigations, different types of base fluids were used but they were all Newtonian fluids. Based on the available data in the literature, the resulting dispersion of nanoparticles in Newtonian base fluids resulted in nanofluids exhibited Newtonian behavior [7,16,19,20,28], while many other nanofluids exhibited non-Newtonian, mainly shear-thinning, behavior [7–11,17,21,27,29–31,33]. The viscosity of nanofluids decreased with an increase in the nanoparticle size [12,14,34]. The effect of the temperature on the viscosity of nanofluids was also investigated. Results showed that, as most other fluids, the viscosity of nanofluids decreased with an increase in temperature [17–19,23,27,29,31,35,36,38]. Xinfang et al. [38] have studied the viscosity of Cu/water nanofluids, and their results showed that viscosity of nanofluids is independent of nanoparticle concentration. Tseng and Tzeng [15] have shown that aqueous nanofluids containing indium tin oxide nanoparticles over shear rate range of 10 to ~500 s^{-1} exhibited Newtonian behavior, but as shear rate increased their rheological behavior change into shear-thinning flow. Similar results were obtained by Alphonse et al. [39]. Some investigations showed that nanofluids with low nanoparticle concentrations exhibited Newtonian behavior, but at higher nanoparticle concentrations exhibited shear-thinning behavior [25,40]. Garg et al. [30] have reported the experimental results of a study on rheological behavior of MWCNT/water nanofluids. Their results clearly showed that nanofluids exhibited shear-thinning behavior.

The rheological behavior of nanofluids has often been modeled using the power law model with its two fitting parameters: the power law index and the consistency index. The power law index of nanofluids normally increases with an increase in temperature whereas the consistency index of nanofluids decreases with temperature. In this paper, the rheological behavior of suspensions of

☆ Communicated by W.J. Minkowycz.

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0735-1933/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2010.11.019