Viscosity and thermal conductivity of copper oxide nanofluid dispersed in ethylene glycol

Kiyuel Kwak and Chongyoup Kim*
Dept. of Chemical and Biological Engineering, Korea University, Anam-dong, Sungbuk-gu, Seoul 136-713, Korea
(Received March 22, 2005; final revision received April 11, 2005)

Abstract

Nanofluid is a novel heat transfer fluid prepared by dispersing nanometer-sized solid particles in traditional heat transfer fluid such as water or ethylene glycol to increase thermal conductivity and heat transfer performance. In this research we have considered the rheological properties of nanofluids made of CuO particles of 10-30 nm in length and ethylene glycol in conjunction with the thermal conductivity enhancement. When examined using TEM, individual CuO particles have the shape of prolate spheroid of the aspect ratio of 3 and most of the particles are under aggregated states even after sonication for a prolonged period. From the rheological property it has been found that the volume fraction at the dilute limit is 0.002, which is much smaller than the value based on the shape and size of individual particles due to aggregation of particles. At the semi-dilute regime, the zero shear viscosity follows the Doi-Edwards theory on rodlike particles. The thermal conductivity measurement shows that substantial enhancement in thermal conductivity with respect to particle concentration is attainable only when particle concentration is below the dilute limit.

Keywords: nanofluid, Brownian motion, thermal conductivity

1. Introduction

Nanofluid is a novel heat transfer fluid prepared by dispersing nanometer-sized solid particles in traditional heat transfer fluid such as water or ethylene glycol to increase thermal conductivity and therefore heat transfer performance. For example, when 0.3 volume percent of copper nano-particles are dispersed in ethylene glycol, one can observe about 40% of increase in thermal conductivity (Eastman and Choi, 1995). Metal oxides such as aluminum oxide or titanium oxide are also feasible even though the amount of heat transfer increase is not as large as metal particles (Masuda et al., 1993). The effectiveness of heat transfer enhancement is known to be dependent on the amount of dispersed particles, material type, particle shape, and so on. It is expected that nanofluid can be utilized in airplanes, cars, micro machines in MEMS, micro reactors among others. Before the introduction of nanofluid, it was expected that heat transfer could be enhanced by dispersing micron-sized particles. But the fluid with micron-sized particles caused problems due to sedimentation and clogging (Xuan and Li, 2000). Most of all, the fluid with micron-sized particles was found to be not efficient enough. Since the concept of nanofluid has been first introduced by Eastman and Choi (1995), there have been many efforts to understand the mechanism of heat transfer enhancement together with experimental measurements of the thermal conductivity of nanofluids and the methods of utilization of nanofluids.

However there has been no established mechanism for the heat transfer enhancement. The reason may arise from the difficulty caused by the fact that the heat-transfer between the base fluid and particles occurs while the particles are in random Brownian motion. Also, depending on the flow condition and chemical nature of particles, dispersion state can be different. Xuan and Roetzel (2000) suggested a mechanism by assuming that nanofluid behaves similarly to common solid suspensions in liquid. Keblinski et al. (2002) argued that the heat transfer increases due to the combined effect of Brownian motion of nano-particles, formation of liquid-solid interface, large conductivity of particle itself and clustering of nano-particles.

There have been some reports on the rheological behavior of suspension of nano-particles. Xiao-Bing et al. (2001) reported the viscosity of nanofluid by using the molecular dynamic simulation and kinetic theory. Zaman et al. (2002) and Zaman (2000) reported on the rheological properties and surface charge of polyethylene-coated silicone oxide particles. Chandrmalar (2000) reported on the rheological properties of aqueous solution of titanium oxide under the