International Journal of Heat and Mass Transfer 77 (2014) 765–769

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Effect of temperature and volume fraction on rheology of methanol based nanofluids

R.M. Mostafizur [a], A.R. Abdul Aziz [b], R. Saidur [a,*], M.H.U. Bhuiyan [a], I.M. Mahbubul [a]

[a] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 4 April 2014
Accepted 28 May 2014
Available online 1 July 2014

Keywords:
Nanofluids
Methanol
Viscosity
Rheology
Volume fraction

ABSTRACT

Suspension of selected nanoparticles in a base fluid can generate a nanofluid which is one of the most popular fluids in scientific community that has attractive heat transfer characteristics. Its thermo-physical properties such as viscosity have important effects on fluid flow and heat transfer characteristics as they affect the pumping power and workability of the fluid. In the present work, the rheological behavior (as shear stress and viscosity with respect to shear rate) of Al_2O_3–methanol and TiO_2–methanol were investigated at different volume fractions and temperatures. The results showed that the fluids appeared as a non-Newtonian fluid with shear thickening or dilatant behavior. The work concluded that shear stress and viscosity increased with volume fractions but decreased with temperatures. The increment was higher in TiO_2–methanol compared to Al_2O_3–methanol nanofluid for both shear stress and viscosity.

1. Introduction

Nanofluid is a novel type of heat transfer fluid which is obtained by suspending nanoparticles (nominally 1–100 nm in size) in the conventional base fluids such as water, oils, or glycols [1]. Many studies have elucidated that nanofluid plays an important role in heat transfer. It can effectively improve the heat transfer performance in many heat exchange applications due to its ultrafine sizes, large specific surface area, high thermal conductivity, minimal clogging in flow and stability [2]. Various thermo-physical properties like thermal conductivity, viscosity, density and specific heat have important effects on the flow and heat transfer characteristics. Therefore, previous researchers have focused on nanofluids behavior and found that nanofluids enhance heat transfer [3–8] and mass transfer [9–12].

One of the most crucial factors in heat transfer and flow applications is the fluid viscosity. It measures the interfacial friction, which is the internal resistance of the fluid layers. It is an important parameter for all thermal applications involving fluid flow [13]. The rheological behavior of the fluid flow is needed to obtain the required pumping power. Therefore, a great number of research have been conducted to investigate the viscosity and rheological behavior of different nanofluids. Nanofluids preparation methods [14], particles shapes and sizes [15], particles concentrations, temperatures, surfactants and properties of base fluids affect the rheological behavior of nanofluids. Chen et al. [16] observed the rheological behavior of TiO_2–ethyline glycol and found the fluid behaving like a Newtonian fluid at shear rate of 0.05–104 s^{-1}. They also noticed that temperatures, particle concentrations and aggregation had significant effects on viscosity. Later, Chen et al. [17] reported that particle shape had great impact on viscosity. They also observed that the fluids displayed shear thinning behavior above concentrations of 2 vol%. Similarly, Hojjat et al. [18] observed pseudo plastic (shear thinning) behavior for γ-Al_2O_3, TiO_2 and CuO nanoparticles which were dispersed in a 0.5 wt% aqueous solution of carboxymethyl cellulose (CMC). On the other hand, Tseng and Tzeng [19] observed rheological behavior of indium tin oxide–aqueous solution. Their result showed that the fluids acted as a Newtonian fluid at shear rate of 10–500 s^{-1} where it brought out a shear thinning flow with an increasing shear rates. Moreover, Garg et al. [20] found that MWCNT–water nanofluids showed a shear thinning behavior. Based on the available data from literatures, it is concluded that some nanofluids exhibit Newtonian behavior [16,21–28] while others demonstrate non-Newtonian behavior [18,20,22–38]. Therefore, there is a need for more experimental work on rheological behavior of nanofluids. However, interestingly, Sahoo et al. [28] experimentally found that Al_2O_3 nanofluids behaved like a non-Newtonian fluid at lower temperatures (−35–0 °C) but it displayed Newtonian behavior at

* Corresponding author. Tel.: +60 3 79677611; fax: +60 3 79675317.
E-mail addresses: mostafiz.rahman@live.com (R.M. Mostafizur), azizraman@um.edu.my (A.R. Abdul Aziz), saidur@um.edu.my (R. Saidur), mhub2k2@yahoo.com (M.H.U. Bhuiyan), mahbub_ipe@yahoo.com (I.M. Mahbubul).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.05.055
0017-9310/

higher temperatures (0–90 °C). They tested 1–10% volume concentrations prepared by 53 nm Al_2O_3 nanoparticles dispersed in a base fluid of 60% (by mass) of ethylene glycol and water.

Methanol is used as a working fluid in different types of heat pipes like conventional, vapor-dynamic thermo-syphons, sorption, micro/miniature heat pipes at a temperature range of 200–500 K [39,40]. It is also used in thermosyphons heat exchanger at HAVAC (heating, ventilation, and air conditioning) systems [41]. Methanol based nanofluid can potentially enhance the heat transfer rate of heat exchangers and save energy compared to pure methanol [41]. Therefore, the flow behavior of methanol based nanofluids should be clarified before being applied as a heat transfer fluids. It is also necessary to calculate the required pumping power in heat transfer applications. Based on available literatures, it was found that Pang et al. [42] investigated the thermal conductivity of methanol based nanofluids. Later, Pang et al. [43] investigated the effect of NaCl solution on thermal conductivity enhancement of methanol based nanofluids. Moreover, Lee et al. [44] and Pineda et al. [45] investigated CO_2 bubble absorption enhancement and CO_2 absorption enhancement of methanol based nanofluids. To the best of authors' knowledge, there is no such study on the rheological behavior of methanol based nanofluids. Hence, the present study was conducted to explore the rheological behavior of Al_2O_3–methanol and TiO_2–methanol nanofluids for concentration of 0.01–0.15 vol% and temperature of 1–20 °C to fill the research gap in the literatures.

2. Experimental procedure

2.1. Materials and preparation

Al_2O_3 (13 nm), TiO_2 (21 nm) nanoparticles were suspended in methanol (base fluid) in this investigation. These nanoparticles were chosen because they are produced in large scale in industry and are chemically more stable, easily available and not harmful for human being. The nanoparticles were procured from Sigma Aldrich (Malaysia) and methanol was obtained from R&M chemicals.

The nanoparticle volume fraction was calculated using Eq. (1).

$$\text{Volume concentration, } \phi = \left(\frac{m_{np}/\rho_{np}}{m_{np}/\rho_{np} + m_{bf}/\rho_{bf}} \right) \quad (1)$$

where, ϕ is the nanoparticle volume fraction (%); m_{np} and m_{bf} are the weight of nanoparticles and the base fluids respectively; whereas ρ_{np} and ρ_{bf} are the density of nanoparticles and base fluids respectively.

Then, the two-step method was applied to prepare the methanol-based nanofluids at different volume fractions. Firstly, the nanoparticles were suspended in the base fluid (methanol) followed by shaking in an orbital incubator shaker for 30 min at 150 rpm. The mixture was dispersed later using an ultra-sonication homogenizer so that the nanoparticles are uniformly and evenly

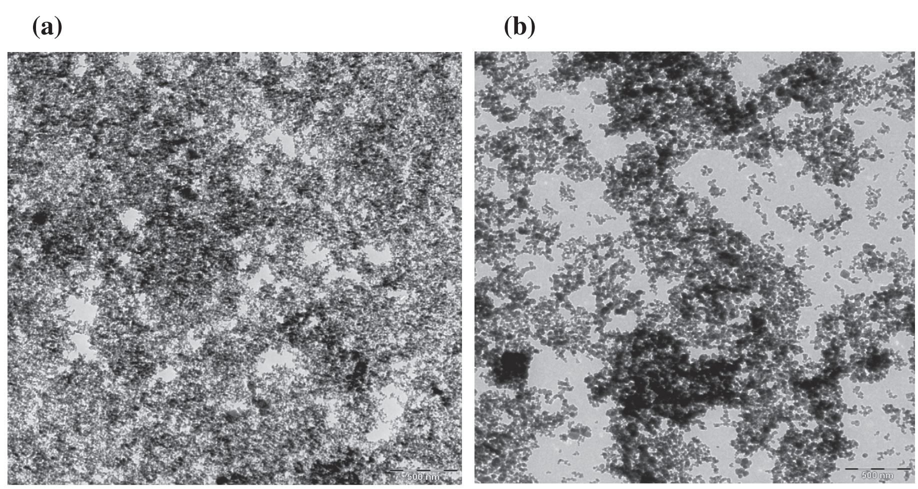

Fig. 1. TEM image of (a) Al_2O_3–methanol and (b) TiO_2–methanol nanofluids.

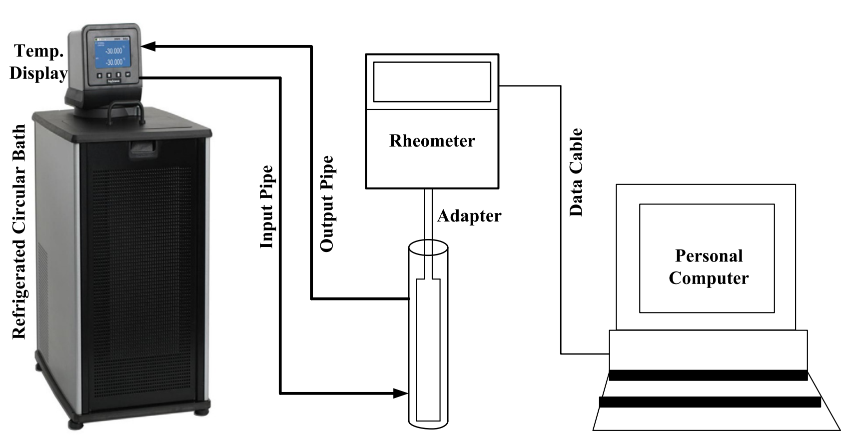

Fig. 2. Schematic setup for the viscosity measurement.