



Experimental study on thermal conductivity of stabilized Al_2O_3 and SiO_2 nanofluids and their hybrid

Georgiana Madalina Moldoveanu^a, Gabriela Huminic^b, Alina Adriana Minea^{a,*}, Angel Huminic^b

^a Technical University “Gheorghe Asachi” of Iasi, Faculty of Materials Science and Engineering, Iasi, Romania

^b University Transilvania of Brasov, Faculty of Mechanical Engineering, Brasov, Romania

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ABSTRACT

This paper shows an experimental study on thermal conductivity of hybrid nanofluids made of Al_2O_3 – SiO_2 suspended in pure water. Also, simple nanofluid samples, with various volume fractions of Al_2O_3 and SiO_2 were prepared and used for comparison. Analysis clearly outlined the influence of volume fraction on thermal conductivity and few correlations were proposed based on experimental results. Furthermore, an in-depth 3-dimensional analysis was performed and results are in accordance with state of the art. In regard to temperature influence, authors noticed a linear increase of thermal conductivity while temperature is rising and regression equations were determined.

A regression analysis was also completed in order to connect the experimental results with volume fractions of both nanofluids and hybrid nanofluids and few correlations were proposed.

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1. Introduction

Nanofluids are suspensions which consist from a base fluid (such as water, ethylene glycol, and engine oil) and solid particles with a diameter of less than 100 nm. Due to higher thermal conductivity of solid particles compared to liquids, it may be obtained working fluids with significant enhanced thermal conductivities that can be used in thermal devices [1–17]. Realizing the unique properties of nanofluids and their potential, in last years, a novel class of nanofluids, which consist from two or three solid particles suspended in the base fluid, called hybrid nanofluids, was developed. These novel hybrid nanofluids showed a great promise as next-generation heat transfer fluids for heat transfer applications.

Numerous studies have been conducted to investigate the thermal-physical properties of nanofluids and hybrid nanofluids, but most studies are focused on to evaluation of thermal conductivity [3–14,18–29], especially of alumina nanofluids [30–36]. Recent reviews on the thermo-physical properties of nanofluids or hybrid nanofluids have been presented by Yang et al. [37], Jabbari et al. [38], Kumar and Arasu [39], Huminic and Huminic [40] and Hamzah et al. [41].

If the studies on the thermal conductivity of alumina nanofluids can be easily found in the current literature, regarding the silica nanofluids, only few studies on thermal conductivity are reported

in literature, although these types of nanoparticles are low cost, and therefore, can be purchased more easily.

Kang et al. [42] experimental investigated the thermal conductivity of diamond (UDD), Ag and SiO_2 nanofluids using the transient hot-wire method. The results indicated an enhancement in thermal conductivity of nanofluids compared to the base fluid, the increase in thermal conductivity being also reported.

Experiments regarding thermal conductivity of SiO_2 /water nanofluids were performed by Jahanshahi et al. [43]. The thermal conductivity was measured within the range of the volume fractions of nanoparticles of 1 to 4% and the results showed an enhancement in thermal conductivity up to 24% at a nanoparticles volume fraction of 4.0%.

Xie et al. [44] experimental investigated the thermal conductivities of Al_2O_3 , MgO, TiO_2 , ZnO, and SiO_2 with the nanoparticle size of 20 nm dispersed in ethylene glycol. They founded an enhancement in thermal conductivity of SiO_2 /ethylene glycol of approximately 25% at a nanoparticles volume fraction of 5.0%, while for $\gamma\text{-Al}_2\text{O}_3$ /EG the increase in thermal conductivity was approximately of 28% at the same volume fraction.

The effects of temperature and volume fraction of nanoparticles on thermal conductivity of water and ethylene glycol based on SiO_2 nanoparticles were investigated by Zhu et al. [45]. They observed that, the increase both temperature and volume fraction leads to increasing thermal conductivity of studied nanofluids. Thus, the enhancement in thermal conductivity of SiO_2 /water and SiO_2 /ethylene glycol was 46.2% and 62.8% respectively, at a volume fraction

* Corresponding author.

E-mail address: aminea@tuiasi.ro (A.A. Minea).

Nomenclature

d	diameter, m
n	empirical shape factor
T	temperature, °C
R ²	accuracy of the fitted equations, –
u	estimated standard uncertainty, –
x	mass fraction, wt.%

Greek symbols

α	thermal diffusivity, m ² /s
β	thermal expansion coefficient, 1/T
γ	particle mass fraction, wt.%
ϕ	particle volume fraction, vol.%

Subscripts

f	base fluid
hnf	hybrid nanofluid
nf	nanofluid
p	particle
r	relative
tot	total
vol	refers to volume
wt	refers to weight

of 0.5% and temperature of 50 °C. The obtained results in this study are much higher than those reported in other studies [26,27].

In another study, Pang et al. [46] studied thermal conductivities of Al₂O₃/methanol and SiO₂/methanol at the temperature of 293.15 K using the transient hot-wire method. The results revealed that the thermal conductivity increase with increasing nanoparticles volume fraction. Thus, for a nanoparticles volume fraction of 0.5 vol.%, the increase in thermal conductivity was 10.74% and 14.29% compared to the base fluid for Al₂O₃ and SiO₂ nanofluids, respectively. This enhancement in thermal conductivity of nanofluids was attributed to formation of clusters in the fluid.

Akilu et al. [47] conducted experimental investigations to study thermal conductivity of SiO₂ nanoparticles in two base fluids (ethylene glycol and glycerol). Experiments were performed within the range of the temperature of 30 °C to 60 °C, for four volume fractions of nanoparticles (0.5%, 1.0%, 1.5% and 2.0%) and experimental data confirmed that, both studied nanofluids were obtained higher thermal conductivities than those of the base fluids and also that, the thermal conductivity increases with the increase of both volume fraction and temperature. The SiO₂/glycerol nanofluids showed higher enhancements in thermal conductivity with temperature and the volume fraction than SiO₂/ethylene glycol nanofluids compared to the base fluids, the enhancements being of 11.5% and 6.1% respectively, at a fraction of 2.0% and temperature of 60 °C. The enhancement in thermal conductivity of nanofluids was attributed of Brownian motion of nanoparticles. Based on experimental data, two regression models for the estimation of the thermal conductivity ratio for SiO₂/glycerol and SiO₂/ethylene glycol nanofluids were proposed. These correlations are valid for the nanoparticles with the size of 21 nm, the volume fractions of 0.5–4.0% and within the range of the temperature of 30–60 °C.

Zyla and Fal [1] carried out experiments on thermal conductivity of transparent SiO₂/ethylene glycol at a constant temperature of 298.15 K and they founded that, the thermal conductivity increase linearly with increasing volume fraction of nanoparticles.

The thermal conductivity of SiO₂/water nanofluid was investigated by Yan et al. [48]. The mass fractions of SiO₂ nanoparticles were 1.0%, 3.0% and 5.0% respectively, and the measurements were performed within the range of the temperature of 20 °C to 55 °C. The results showed, as in other studies similar, that the thermal conductivity increases with the increase both temperature and mass fraction, the main reason in the enhancement of thermal conductivity being the frequency of particles collision and energy transfer rate increase, which lead to the intensification of the movement intensity of nanoparticles.

Guo et al. [49] experimental investigated thermal conductivities both for SiO₂/water and SiO₂/ethylene glycol nanofluids with two nanoparticles volume fractions (0.5% and 1.0%), using an optimized transient hot wire method. They founded that, the thermal

conductivity of SiO₂/EG was higher than the thermal conductivity of SiO₂/water. Thus, the increase in thermal conductivity of SiO₂/EG was 3.2% and 9.6% respectively, while for SiO₂/water, the increase was 1.0% and 3.4% respectively for all studied fractions. The main reasons in the increase of thermal conductivity were attributed to the higher value of thermal conductivity due to Brownian motion and the difference in particle shape distribution. On the other hand, the results obtained by Guo et al. [49] are contradictory with the results report by Masuda [50]. In this study, thermal conductivity was measured for SiO₂/water and authors did not found an increase in the thermal conductivity ratio [50].

Experiments were conducted also by Guo et al. [51] to investigate the effect of temperature and content percentage of ethylene glycol on thermal conductivity of SiO₂ nanofluids. The base fluid was a mixture of water and ethylene glycol. Measurements were performed for content percentages of ethylene glycol from 0 to 100% and temperatures within 25–45 °C. Their results showed that, at a fixed temperature, the thermal conductivity decreases with the increase in ethylene glycol content percentage and also that, at a fixed ethylene glycol content percentage, the thermal conductivity increases with the increase in temperature. Finally, they concluded that, the ethylene glycol content percentage has a greater effect on thermal conductivity of SiO₂ nanofluids than the temperature.

Ferrouillat et al. [49] studied the thermal conductivities of SiO₂/water and ZnO/water nanofluids within the range of the temperature of 20–70 °C. Experiments were performed for two shapes of nanoparticles: spherical (sphere) and non-spherical (banana). In opposite with above presented results, the authors founded that the thermal conductivity of SiO₂/water nanofluids with spherical nanoparticles was less than that of base fluid and also that, the thermal conductivity of SiO₂/water nanofluid with non-spherical nanoparticles was slightly higher than that of spherical particles. The decrease in thermal conductivity of SiO₂/water with spherical particles can be caused by fact that the SiO₂ nanoparticles are manufactured of a porous material and the thermal conductivity was different by the thermal conductivity of pure silica.

The effects of temperature and volume fraction on thermal conductivity of SiO₂/polyalkylene glycol were experimental investigated by Sanukrishna et al. [50]. In their study, the measurements were carried out at volume fractions of nanoparticles and temperatures in the ranges 0.07–0.6 vol% and 20–90 °C respectively. The experimental data confirmed that, the thermal conductivity increases with increasing volume fraction of nanoparticles, and in contradictory cu other studies [45,47,48], the authors showed that, the thermal conductivity decreases with increasing temperature. The authors explain the decrease in thermal conductivity by the fact that, at higher temperatures, the molecules of liquid move away from each other, and therefore, the mean free path

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