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Experimental investigation toward obtaining the effect of interfacial solid-liquid interaction and basefluid type on the thermal conductivity of CuO-loaded nanofluids

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ABSTRACT

In this study the effect of temperatures, the CuO nanoparticles mass fraction, and basefluid of deionized water, ethanol and ethylene glycol were studied on thermal conductivity of nanofluid. CuO nanoparticles were dispersed in deionized water, ethanol and ethylene glycol separately by using ultrasonic waves. The stability of nanoparticles in basefluids was estimated by using DLS and Zeta Potential analysis. The results showed that with increase in the temperature and mass fraction of nanoparticles the relative thermal conductivity of nanofluid increases and for CuO/ethanol nanofluid the value of thermal conductivity is much higher than other nanofluids at higher temperatures and CuO nanoparticles mass fractions. In addition, the results showed that the interfacial interaction between basefluid molecules and nanoparticles' surface has major effect on nanofluid thermal conductivity; consequently, CuO/water nanofluid has higher interfacial interaction at various temperatures and nanoparticles mass fractions. Furthermore, the results showed that with the increase of nanofluid mass fraction up to 0.5 wt% insignificant change in relative thermal conductivity is resulted while for the values above 0.5 wt % the relative thermal conductivity of nanofluids enhance tangibly. Finally an empirical equation including temperature, nanoparticles mass fraction, and physical properties of nanoparticles and basefluid was obtained by using hybrid GMDH-type neural network to estimate relative thermal conductivity of nanofluid. The comparison between results of experimentation and proposed correlation showed that the deviation of calculated thermal conductivity from experimental values is majorly less than 10%.

1. Introduction

One of the crucial processes in petrochemical industries and consumer product is heat transfer and design of heat transfer equipment with the highest efficiency. For this purpose it is evident that many scientists and engineers focused on preparation of new method or material to increase the physical properties of conventional fluids [1, 2]. The application of new material for enhancing thermal properties of heat transfer fluids was began when Maxwell [3] proposed an idea of adding metallic particles to matrix material for increase of the electrical or thermal conductivity. Therefore, a new theory was proposed for estimation of effective conductivity of conventional fluid containing fine particles, (the slurries were prepared by adding particles with mean sizes between 0.1 and 100 μm [4]). Due to the agglomeration of these particles and, consequently, sedimentation, erosion, and high power needed for pumping the fluids, the application of these particles in fluids has been restricted to be used as heat transfer fluids. Due to the interesting properties nanofluids, (a dilute suspension of nanometer-size particles or fibers dispersed in conventional fluid such as water, engine oil, and ethylene glycol [5]), it is affordable to use them as a potential materials for preparation of heat transfer fluids [6–9].

Heat transfer surface and thermophysical properties of heat transfer fluid are the most important factors that have major impacts on heat transfer process [10]. The implementation of nanofluid, (with enhanced thermophysical properties), as a new generation of heat transfer fluids in cooling and heating process lead to decrease the size of heat transfer equipment [10 – 12]. Thus, it is needed to develop the experimentation and perform many researches on modification of nanofluid thermal conductivity and viscosity. Thermal conductivity of nanofluid depends on several parameters including nanoparticles size, temperature, nanoparticles mass fraction, and nanoparticles and basefluid types as well as the interaction between nanoparticles surface and basefluid molecules [1, 10–14].

It is mentioned in the literature that the interaction of nanoparticles

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Nomenclatures

T	Temperature (°C)
w	Nanoparticles mass fraction (wt%)
λ	Parameter depends of nanoparticles and basefluid properties
k_{nf}	Thermal conductivity of nanofluid (W/m.K)
k_{bf}	Thermal conductivity of basefluid (W/m.K)
k_p	Thermal conductivity of nanoparticles (W/m.K)
ρ_p	Density of nanoparticles (kg/m^3)
ρ_{bf}	Density of basefluid (kg/m^3)
R_k	Relative thermal conductivity of nanofluid
κ	Stephan Boltzmann constant, 5.670367×10^{-8} W/m^2·K^4
$C_{p,\ bf}$	Heat capacity of basefluid (j/kg.K)
β	Fraction of fluids that travel with nanoparticles
D	Mean diameter of nanoparticles (m)
φ	Volume fraction of nanoparticles in basefluid
$R_{k,\ Brownian}$	The relative thermal conductivity of nanofluid due to random motion of nanoparticles
$R_{k,\ Maxwell}$	The static relative thermal conductivity of nanofluid
f	Interaction parameter between nanoparticles' surface and basefluid molecules

surface and basefluids molecules has major impact on thermal properties of nanofluid due to the nanolayer which is formed around the particles surface that enhance the thermal conductivity of annofluid [5, 10, 11]. Therefore, in order to indicate the ability of nanofluid for heat transfer, the analysis of mentioned factor should to be taken into consideration within the related researches. Although there are many researches which have been carried out in regarding with the impacts of nanoparticles mass fraction, temperature, and nanoparticles size on thermal conductivity of nanofluid [15–20], there is not complete consistency about the results obtained by other researchers and it is needed to investigate the effect of basefluid types on thermal conductivity of nanofuid to explain the impact of the interaction between nanoparticles and basefluid on conduction heat transfer mechanism.

The effect of oxide nanoparticles on thermal conductivity of nanofluid has been reported by many researchers [10, 18–20]. It is reported in their study that with the increase of nanoparticles volume fraction the thermal conductivity of nanolfuid enhances up to 60% declaring intense effect of nanoparticles load on thermophysical properties of nanofluids [9, 10, 21].

Masuda et al. measured the thermal conductivity and viscosity of nanofluids containing Al_2O_3, SiO_2, and TiO_2 nanoparticles within the water as base fluid at different temperatures [22]. They reported that the relative thermal conductivity of nanofluid decreased with increasing temperature. Their results were different to many results presented by many other scholars.

Warrier et al. proposed a new correlation for the prediction of nanofluid thermal conductivity containing metallic nanoparticles. They measured the thermal conductivity Ag/water nanofluids at various nanoparticle diameters and volume fractions. They also exhibited that with declination in nanoparticles size of the thermal conductivity of nanofluid decreased. Their results were in agreement with their model predictions at various nanoparticles loads [23]. Beck et al. did a research for measuring the enhanced thermal conductivity of Al_2O_3/water and Al_2O_3/ethylene glycol nanofluids with different particle sizes. Their findings showed that the value of nanofluid thermal conductivity declines with the decrease in nanoparticles mean diameter below 50 nm [24]. Chen et al. [25] investigated the effect of nanoparticles size on thermal conductivity of SiO_2/water nanofluids. They concluded that with the increase in nanoparticles size the value of thermal conductivity ratio increases. They also showed that the interaction between nanoparticles surface and liquid molecules has major impact on thermal conductivity of nanofluid and with the increase of nanoparticles the interface thermal resistance declines for SiO_2/water nanofluid [26].

Chopkar et al. measured the thermal conductivity of water based nanofluids containing Al_2Cu and Ag_2Al nanoparticles. They studied the effect of nanoparticles volume fraction, size on the relative thermal conductivity of nanofluid. They exhibited that the relative thermal conductivity of nanofluid declines with nanoparticles diameter [1]. Munkhbayar et al. investigated effects of hybrid nanoparticles loads and temperature on thermal conductivity of water based nanofluid. Their results showed a significant enhancement on thermal conductivity of Ag–MWCNT/water hybrid nanofluid. Their results also declared that the maximum thermal conductivity of nanofluid, (at 40 °C), could be achieved at the condition where 0.05 wt% MWCNTs and 3 wt% Ag nanoparticles were used [27]. Xie et al. measured thermal conductivity of Al_2O_3/water and Al_2O_3/pump oil nanofluids [28]. They investigated the effect of nanoparticles mean diameter on thermal conductivity of nanofluids. They showed that with the increase of particle mean diameter the thermal conductivity of nanofluid declined.

The aim of this study is to investigate the effect of basefluid types on thermal conductivity of nanofluid containing CuO nanoparticles as well as find a comprehensive correlation for prediction of nanofluid thermal conductivity at various nanoparticles mass fraction and temperature. For this purpose, in this research the thermal conductivity of water, ethanol, and ethylene glycol based nanofluid containing CuO nanoparticles was measured at different mass fractions and various temperatures. Finally, a correlation including temperature, mass fraction, and nanoparticles and basefluids properties was proposed based on hybrid GMDH-type neural network method to predict thermal conductivity of nanofluid at various conditions.

2. Experiments

2.1. Materials

For preparation of CuO nanoparticles the precipitation method was implemented in which $Cu(NO_3)_2.3H_2O$ with 99.9% purity, (purchased from Merck Co. Germany), was dissolved in deionized water to prepare Cu^{2+} ions. Then, in order to precipitate $Cu2^+$ ions, sodium hydroxide, (NaOH with 99.99% purity, purchased from Merck Co. Germany), was also used during experimentation. Moreover, for preparation of nanofluid, deionized water, ethanol, and ethylene glycol with detailed physical properties presented in Tables 1, 2, and 3 respectively (purchased from Merck Co. Germany), were used as basefluids. In addition, deionized water was used for washing the laboratory dishes [29].

2.2. Instruments

In order to measure thermal conductivity of nanofluid a thermal properties analyzer, (KD2 Pro. Deacagon, USA) was used in this

Table 1
Physical properties of deionized water.

No	Properties	Value
1	Chemical formula	O-H-O
2	Molecular weight (g/mol)	18.06
3	Melting point (C°)	0.00
4	Boiling point (°C)	100.00
5	Maximum density @ 3.98 °C (g/cm^3)	1.000
6	Density @ 25 °C (g/cm^3)	0.997
7	Viscosity @ °C (cp)	0.890
8	Surface tension (dyn/cm)	71.97