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A COMPARATIVE STUDY ON THERMAL CONDUCTIVITY OF Al_2O_3/WATER, CuO/WATER AND Al_2O_3 – CuO/WATER NANOFLUIDS

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In this present study, the thermal conductivity of Al_2O_3/water, CuO/water and Al_2O_3 – CuO/water hybrid nanofluid were investigated experimentally. The two step method was adopted to prepare the hybrid nanofluid. Three different volume concentrations of nanofluids (0.05, 0.1 & 0.2%) were prepared by dispersing Al_2O_3 and CuO nanoparticles in water. The properties of single and hybrid nanofluids were measured by varying the temperature from 20^0C to 60^0C. The obtained results demonstrate that the thermal conductivity of nanofluids are the function of volume concentration and temperature. Also the experimental results showed that a maximum of 9.8 % enhancement of thermal conductivity was observed for 0.2% particle volume concentration. The experimental thermal conductivity values were compared with the theoretical thermal conductivity values.

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1. Introduction

Heat transfer through a fluid medium plays an important roles in all thermal management systems. The conventional heat transfer fluids such as water, Ethylene Glycol, propylene Glycol are used as a heat transfer fluids in all heat transfer applications. Due to poor heat transfer characteristics of conventional heat transfer fluids, numerous investigations have been carried out to by many researchers to investigate the thermal properties of micro sized particles dispersed fluids. Though the heat transfer characteristics of such fluids were increased, but the problems such as particle clogging in micro channel, quick sedimentation and erosion of tube materials were also increased. To overcome the above problems, a new kind of fluid was prepared by dispersing a metal or metal oxide particles with nanometer size (1-100nm) in conventional heat transfer fluids. In 1995, first nanoparticle dispersed fluid was prepared and coined as 'Nanofluid' by Choi [1]. During their research they observed that the thermal conductivity of nanofluids were increased about two times than the conventional heat transfer fluids. Nanofluids possess many advantages such as high dispersion stability, high surface to volume ratio and less particle clogging and so on compared to conventional heat transfer fluids with micron sized particles.

2. Literature review

In recent decades numerous experimental works have been conducted to investigate the thermal properties of different metal (Cu, Al, Ag, Au, Ni etc.) and metal oxides (CuO, Al_2O_3, TiO_2 etc.) nanofluids. Example for metal nanofluids and their thermal properties are given below. Eastman et al [2], Sahu et al [3], Haifeng et al [4], Taher et al [5], Shenoy et al [6] were studied the

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thermal properties of Cu nanoparticle dispersed fluids and observed that the enhancement of thermal conductivity is the function of % volume concentrations of nanoparticles in base fluids and the material of nanoparticles. Maddah et al [7] used silver and Al_2O_3 nanofluids, Zawrah et al [8], Chougule and Sahu [9], Zarkaria et al [10] also used Al_2O_3 nanoparticles and obtained better thermal property enhancements. Naik et al [11,12], Michel and Iniyan [13] were studied the thermal properties of CuO nanofluids and obtained better results. The literatures of CuO and Al_2O_3 nanofluids are summarized and listed in table 1.

From the literature reviews it was found that the researchers were focused their studied on single nanoparticles dispersed fluids. Very few researchers were studied the thermal properties of hybrid nanofluids. Hybrid nanofluids is a special kind of nanofluids in which two or more than two different types of nanoparticles dispersed in conventional heat transfer fluids. Botha et al [14] investigated the rheological, thermal and electrical properties of Silica/Silver hybrid nanoparticles dispersed transformer oil based nanofluids. They found that the thermal conductivity of hybrid nanofluids was increased with Silica concentration. The enhancement of thermal conductivity of Silver - MWCNT/water hybrid nanofluids was investigated by Munkhabayer [15]. They reported that the thermal conductivity of hybrid nanofluid increases with increasing the % volume concentration of nanoparticles in base fluids. Jana et al [16] presented the enhancement of thermal conductivity of nanofluids with single and hybrid nanoadditives. The experimental results showed that the thermal conductivity of nanofluids with copper nanoparticles was higher than the base fluids. But due to sedimentation and agglomeration of Cu-CNT nanoparticles in base fluids, the thermal conductivity was drastically decreased. Syam sundar et al [17, 18] reported the enhancement of heat transfer of CNT-Fe_3O_4 / water hybrid nanofluids under turbulent flow conditions and concluded that the thermal conductivity of hybrid nanofluids was enhanced by 29% with 0.3% volume concentrations at 60^0 C. Balla et al [19] carried out heat transfer experiments with CuO/Cu nanofluids in a pipe with constant flux to evaluate the effects of Reynolds number on convective heat transfer. It was observed from the experimental results that the heat transfer coefficient and pressure losses of nanofluids increases with increasing the volume fraction.

Nine et al [20] were synthesized and investigated the thermal characteristics of water based Al_2O_3 – MWCNT hybrid nanofluids with different weight concentrations. The experimental results showed that the thermal conductivity of hybrid nanofluids with spherical nanoparticles was slightly higher than that of nanofluids with single nanoparticles. Also they concluded that the thermal conductivity of hybrid nanofluids with spherical nanoparticles was higher than the cylindrical shaped nanoparticles. The literatures on hybrid nanofluids are summarized in Table.1

Table 1 Literatures of CuO, Al_2O_3 and Hybrid nanofluid.

Nanoparticle	Base fluid	Size (nm)	Enhancement of thermal property (%)	Preparation method	Ref.
CuO	DI water	20	12.4	Single step	21
	Water	31	5.5	Two step	22
	EG	31	9	Two step	22
	EG/water	27	15.6-24.5	Two step	23
	DI water	50	13-25	Two step	24
Al_2O_3	EG/water	36.5	9.8-17.8	Two step	23
	EG	13	12.82	Two step	25
	EG/water (20:80)	36	32.36	Two step	26
	EG/water (40:60)	36	30.51	Two step	26
Al_2O_3/Cu	Water	15	13.6	Single step	27,28,29
TiO_2/Cu	Water	55	68 (Heat transfer coefficient)	Single step	30
Nano Diamond/ Nickel	Water	30	21	Two step	31
Nano Diamond/ Nickel	EG	30	13	Two step	31
MWCNT/γ Alumina	Water		20.6	Two step	32
Ag/MWCNT/Graphene	DI water/EG		20	Single step	33
Ag/MWCNT/Graphene	DI water	<10nm	8	Single step	34

In this present work, the hybrid nanofluids with three different volume concentrations (0.05%, 0.1% and 0.2%) were prepared by dispersing Al_2O_3 and CuO nanoparticles in base fluids. Distilled water was used as a base fluid in this study. The main objective of this study is to investigate the thermal conductivity of the Al2O3 – CuO/water hybrid nanofluids for different temperatures and volume concentrations.

3. Preparation and characterization of hybrid nanofluid.

The hybrid nanofluids with different volume concentrations were prepared by dispersing Al_2O_3 and CuO nanoparticles into distilled water. In this present study two method was adopted to prepare the hybrid nanofluids. CuO and Al_2O_3 nanoparticles with an average diameter of 27nm and 50nm nm were used in this work. The thermo physical properties of Al_2O_3 and CuO nanoparticles are listed in Table.2

Table 2 Thermophysical properties of CuO and Al_2O_3 Nanoparticles

S.No	Nanoparticle /fluid	Mean Diameter (nm)	Specific surface (m^2/g)	Density (Kg/m^3)	Thermal conductivity (W/mK)
1	CuO	27	29	6310	32.9
2	Al_2O_3	50	15-20	3890	30

The X-Ray diffraction was used to determine the nanoparticles size. The XRD spectra a of Al2O3, CuO and Hybrid nanoparticles are shown in Fig.1 The average grain size of the hybrid nanoparticles was calculated using Scherrer formula.

$$\mathrm{D} = \left[\frac{K\lambda}{\beta\cos\theta}\right] \tag{1}$$

Where D is the average grain size of the nanoparticles, K is the shape factor, λ is the X-ray wave length, β is the line broadening at half the maximum intensity and θ is the Bragg angle. The amount of nanoparticles required to prepare the hybrid nanofluid with different volume concentrations can be calculated from equation (2). No surfactant was used in this work. To get uniform dispersion of hybrid nanoparticles in base fluid, the prepared nanofluids were sonicated for about 4 hrs. Then the nanofluids were stirred using magnetic stirrer for 1 hr. after preparing the hybrid nanofluids, sedimentation test was carried out. No sedimentation was observed for several hours.

$$\%\,\text{Volume Concentration}(\varphi) = \left[\frac{\dfrac{W_{nanopartile}}{\rho_{nanopartile}}}{\dfrac{W_{nanoaprtile}}{\rho_{nanopartile}} + \dfrac{W_{water}}{\rho_{water}}}\right] X100$$

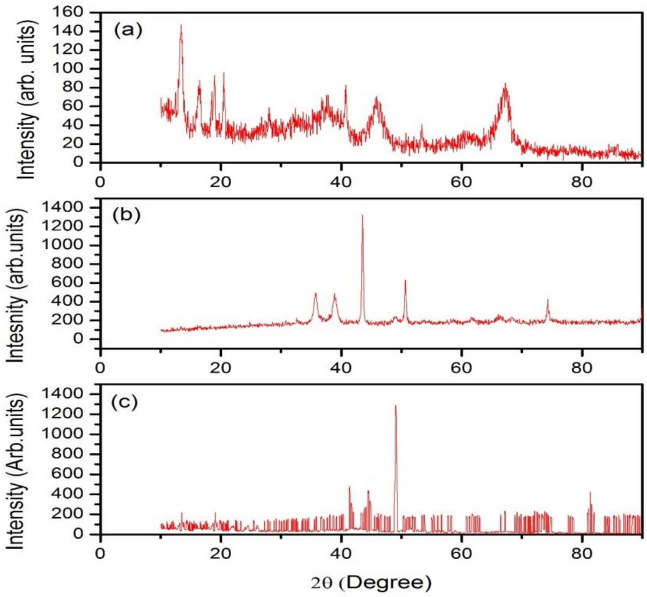

Fig.1 XRD patterns for (a) Alumina (b) CuO (c) Alumina –CuO (Hybrid) Nanoparticles

4. Experiments

4.1 Thermal conductivity measurements

Over the past few decades many researchers were used different techniques to measure the thermal conductivity of nanofluids. Due to the fast and simple construction compared to other techniques, the Transient Hot Wire (THW) method was used in this study [35]. The battery operated KD2 Pro thermal property analyzer (Decagan Devices Inc., USA) was used to measure the thermal conductivity of nanofluids. The transient hot wire technique was used in this instrument. The KS-1 sensor (60mm long and 1.3mm diameter) made of stainless steel was used in this study. The thermal property analyzer consists of a microcontroller (16 bit), Analog to Digital converter and Power control unit. The sensor was placed vertically into the nanofluids. The temperature changes in the nanofluids for every 5 sec. was measured by the sensor. The controller computes the thermal conductivity using the temperature Change - time data using the following equation and the real time datas were stored by the micro controller.

$$\mathrm{K} = \left[\frac{q}{4\pi(\Delta T_2 - \Delta T_1}\right] \times \ln\left(\frac{T_2}{T_1}\right) \tag{3}$$

The Schematic diagram of the experimental setup as shown in Fig.2 Before starting the experimental study, the accuracy of the sensor was calibrated by measuring the thermal conductivity of pure water. The comparison of experimental thermal conductivity values and the existing literature datas were shown in Fig.3. From the Fig.3 it was observed that the measured values were in agreement with the literature values with in ± 5% accuracy. The uncertainty of the measured values and the existing values were estimated as ± 5%.

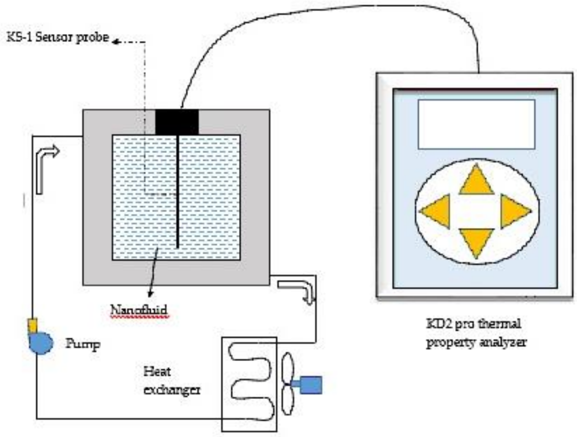

Fig.2 Schematic diagram of experimental setup used to measure the thermal conductivity of nanofluids.

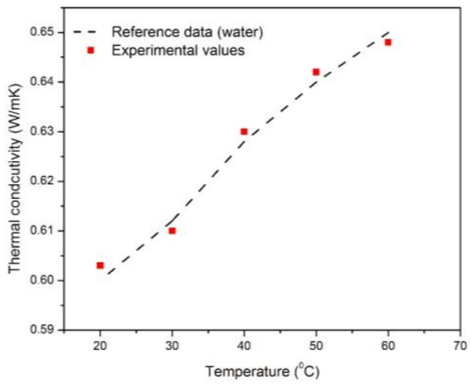

Fig.3 Thermal conductivity comparison with measure and reference data

5. Results and Discussions

The variations of thermal conductivity enhancements with time and temperatures were presented in detail. The experiments were carried out to measure the thermal conductivity enhancements of Al_2O_3/water, CuO/water and Al_2O_3- CuO/water naonfluids with different volume concentrations (0.05%, 0.1% and 0.2%). The Eq. (4) was used to calculate the thermal conductivity enhancements of nanofluids.

$$\%K_{enhancement} = \left[\frac{K_{nf} - K_{bf}}{K_{bf}}\right] \times 100 \tag{4}$$

Fig.4 shows the effects of volume concentrations of nanofluids on thermal conductivity enhancements. It can be understood that, the thermal conductivity of all nanofluids were increased with increase in volume concentrations of nanoparticles in base fluids. Similar cases were reported previously for different nanofluids [36-38]. It can be seen that the thermal conductivity of nanofluids are strongly depends on many factors such as volume concentrations of nanoparticles in base fluids, type and shape of nanoparticles, type of base fluids, temperature of base fluid, preparation methods and stability of particles [39,40]. It can be concluded that the Al_2O_3-CuO/water hybrid naonfluids have higher thermal conductivity enhancement than other nanofluids. The least thermal conductivity was observed in Al_2O_3/water naonfluids at 0.05 vol%. The experimental results also exhibits that, for all nanofluids thermal conductivity was enhanced linearly with all concentrations of nanofluids. The same results were obtained for Jiang et al [41] and Halefadl et al [42]. The thermal conductivity enhancements of Al_2O_3- CuO/water hybrid nanofluids are 2.7%, 6.7% and 9.8% for 0.05%, 0.1% and 0.2% respectively compared with water. The enhancement of thermal conductivity for Al_2O_3/water nanofluids are 1.5%, 2.2% and 6.1% and incase of CuO/water nanofluids are 2.4%, 4.8% and 8% respectively.

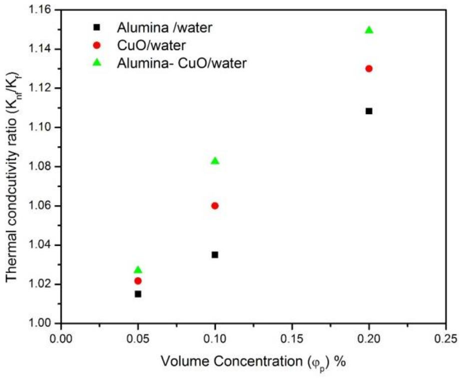

Fig.4 Thermal Conductivity ratio of different nanofluids as a function of % Volume concentrations

The effects of temperature on thermal conductivity enhancement of different nanofluids and the base fluids were measured within the range of 20^0C – 60^0C the variations of thermal conductivity enhancements of Al_2O_3/water, CuO/water and Al_2O_3- CuO/water naonfluids with different volume concentrations with respect to temperature are illustrated in Fig. 5-7. The experimental results clearly showed that the thermal conductivity enhancement was linearly increased with an increase in temperature. For all nanofluids, the maximum thermal conductivity enhancement was obtained for 0.2 vol% at 60^0C. The thermal conductivity was enhanced from 2.48% to 3.5%, 1.26% to 4.9%,1.81% to 5.52 for Al_2O_3/water, CuO/water and Al_2O_3- CuO/water naonfluids respectively at 0.2 Vol.% with every 10^0C. The thermal conductivity was enhanced due to the Brownian motion and collisions between nanoparticles in base fluids [43]. On the other hand at high vol% of hybrid nanofluids, the interactions of nanoparticles in base fluid were increased. Because of this interactions more numbers of nanoparticle chains were formed. This might be the reason to increase the thermal conductivity enhancement in hybrid nanofluid at high volume concentrations.

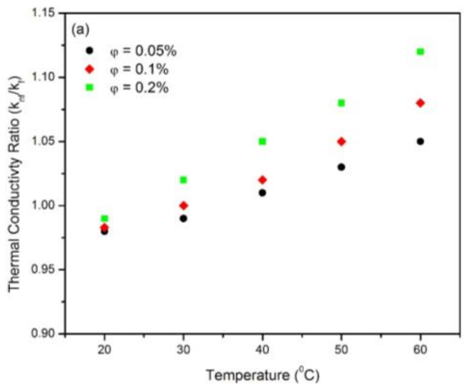

Fig.5 Thermal Conductivity of Alumina /water nanofluid as a function of temperature and nanoparticle volume concentration

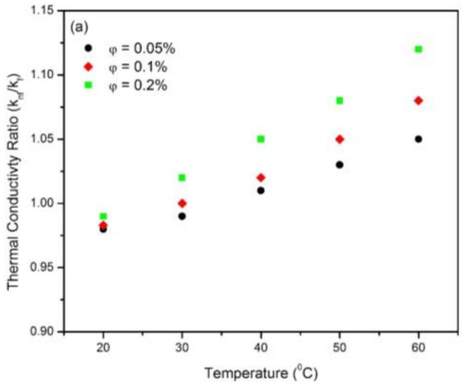

Fig.6 Thermal Conductivity of CuO /water nanofluid as a function of temperature and nanoparticle volume concentration

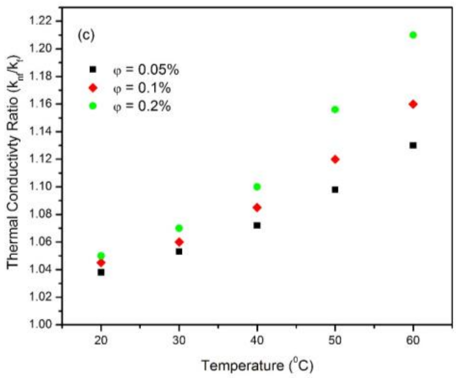

Fig.7 Thermal Conductivity of Alumina – CuO /water hybrid nanofluid as a function of temperature and nanoparticle volume concentration

The measured thermal conductivity values of Al_2O_3/water, CuO/water and Al_2O_3-CuO/water naonfluids were compared with the predicted values of existing models. The most common model used to determine the thermal conductivity of nanofluids was proposed by Hamilton – Crosser [44]. This model is expressed as follows

$$\mathrm{K_{nf}} = \left[\frac{K_p + (n-1)K_f + (n-1)\varphi(K_p - K_f)}{K_p + (n-1)K_f + \varphi(K_p - K_f)}\right] \times K_f \qquad (5)$$

Where 'n' is the shape factor, given as n= ($\frac{3}{\psi}$) (ψ is the sphericity of the particles).

The improved version of Hamilton – Crosser model was introduced by Wasp [45]. The Wasp model can be indicated as follows

$$\mathrm{K_{nf}} = \left[\frac{K_p + 2K_f + 2\varphi(K_f - K_p)}{K_p + 2K_f - \varphi(K_f - K_p)}\right] \times K_f \qquad (6)$$

Another prediction model was introduced to determine the thermal conductivity of nanofluids by Yu and Choi [46]. This model can be written as

$$\mathrm{K_{nf}} = \left[\frac{K_p + 2K_f + 2\varphi(K_p - K_f)(1+\beta)^3}{K_p + 2K_f - \varphi(K_p - K_f)(1+\beta)^3} \right] \times K_f \tag{7}$$

Where $\beta = \left[\frac{h}{r_p} \right]$, 'h' is the nanolayer thickness and 'r_p' is the radius of nanoparticles.

Fig 8 depicts the comparison of measured thermal conductivity values and the predicted values using different traditional models. It was observed from Fig.8 that the obtained experimental thermal conductivity values are higher than the predicted values. The predicted models were not considered the effects of particles size and the interfacial layer at the particle/liquid interface. This might be the reason to obtain the higher thermal conductivity in the experimental results.

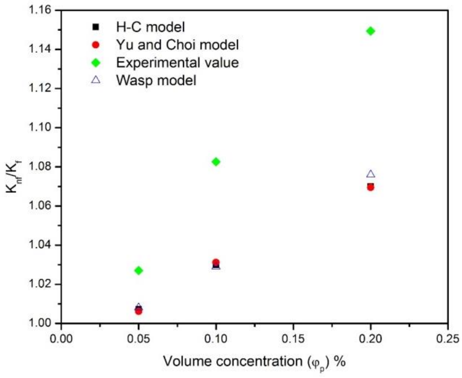

Fig.8 Comparison of measured thermal conductivity values and the theoretical predictions of the traditional models

6. Conclusions

In this work three types of nanofluids (Al_2O_3/water, CuO/water and Al_2O_3 - CuO/water) with three different concentrations (0.05%, 0.1% and 0.2%) were prepared by using two step preparation method. The effects of nanoparticle volume concentrations and Temperature on thermal conductivity enhancements were studied. The thermal conductivity of nanofluids were measured using a KD2 Pro thermal property analyzer.

The key findings of this experimental study were summarized as follows.

1. A significant thermal conductivity enhancements were observed in all types of nanofluids. This shows the nanofluids will be the promising next generation heat transfer fluids.
2. Thermal conductivity of all nanofluids were increased with the increase of particle volume concentrations in base fluids and temperature. In other words thermal conductivity of all nanofluids as a functions of particle volume concentrations and temperature.
3. The enhancement of thermal conductivity for Al_2O_3/water, CuO/water and Al_2O_3 - CuO/water were about 6.1%, 8% and 9.8% compared with base fluids respectively with 0.2 vol% at 60^0C.
4. Among all types of nanofluids Al_2O_3 - CuO/water hybrid nanofluids showed the higher thermal conductivity enhancement over the base fluids.
5. For all nanofluids thermal conductivity was increased linearly with increase of temperature.
6. The experimental thermal conductivity values were compared with the predicted model values and found that the experimental values were higher than the predicted values.

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