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Thermophysical properties of TiO₂/CuO hybrid nanofluids for heat transfer applications

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ABSTRACT

Hybrid nanofluids are emerging as a new generation fluids because of their enhanced heat transport properties. In this work, thermal transport properties were investigated for TiO₂/CuO hybrid nanofluids. Morphological characteristics were studied using SEM (Scanning Electron Microscopy). Elemental composition and average crystallite size were determined using XRD (X-ray Diffraction) and EDX (Energy Dispersive Spectroscopy). Hybrid nanofluids were produced by suspending TiO₂/CuO nano powder of 1–50 nm into the water. Three different concentrations (0.01%, 0.03% and 0.05%) of the hybrid nanofluids were prepared. Thermal transport properties like density, viscosity, specific heat and thermal conductivity were assessed experimentally. The results depict that the thermal conductivity was enhanced by 65.8% in contrast to the base fluid at a volume concentration of 0.05%. Density, as well as dynamic viscosity, of TiO₂/CuO hybrid nanofluids at 0.05% concentration is increased and specific heat is decreased with the increase in volume concentration.

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KEYWORDS

Hybrid nanofluids; SEM; XRD; thermal conductivity; viscosity; density; specific heat

1. Introduction

Intensification of the transfer of heat has a remarkable role in the heat exchanging devices. Intensification of heat transfer means intensifying the heat transfer using basic principles of heat transfer. Methods of Intensification of heat transfer include active, passive and compound. Amongst all these methods, passive methods are more popular because of non requirement of external power and simplicity, while the active techniques use external power. A combination of two or more active or passive methods is involved in compound method. One of the methods of enhancement of transfer of heat in the base fluid is by suspending nanosized particles in the base fluids. Usage of mono nanofluids has gained popularity over the past few decades. However, with the advent of technology, the efficacy of mono nanofluids is decreasing. In this regard, researchers are trying to explore the usage of hybrid nanofluids for critical and specific applications. Nowadays, researchers are focusing on the analysis, stability, characterisation and preparation of hybrid nanofluids for heat transfer applications because of their low viscosity and high thermal properties. The most common problem in nanofluids is the stability of nanofluids. In order to attain stability of the nanofluids, various methods are being adopted. Few of them are altering the pH of the carrier fluid, using ultrasonication or magnetic stirring adding of surfactant. The preparation of nanofluids involved two strategies, namely, one as well as two step methods. In the two-step method, the nanoparticles are synthesised, and then nanofluids are prepared. The other method is one-step method, where the nano particles synthesis and dispersion are completely in one step, which is most suitable for metal having high thermal conductivity to avoid oxidation. The

main disadvantage of this method is to produce the nanoparticle large scale.

Various investigations on different types of nanofluids are carried out to analyse the characteristics, synthesis and preparation methods of nanofluids. Some of them are presented here. Suresh et al. [1] synthesised Al₂O₃-CuO/water hybrid nanofluid through thermal chemical method with different volume concentration while adopting two step method. They have reported that these hybrid nanofluids showed better thermo physical characteristics than the existing models. Sun et al. [2] reviewed the progress of hybrid nanofluids. His review comprised of stability, synthesis and characterisation of hybrid nanofluids in various fields. They concluded that less dynamic viscosity higher thermal conductivity of their performance of transfer with the their stability. Ravi Babu et al. [3]. explored the thermal conductivity in nanofluids made from Al₂O₃. They observed that the nanofluid's stability is an essential component to intensify the thermal conductivity of the nanofluids. Ghadimi et al. [4]. explored the addition of surfactant with ultrasonication in about 3 hrs can be stable nanofluid under any heat transfer application. Akbar et al. [5] observed that nanoparticles improved the stability and viscosity more than single fluids. Wei et al. [6]. observed the thermal conductivity rise with increases in temperature as well as volume fraction. Hybrid nanofluids (HNF's) showed superior conductivity than single SIC or TiO₂ nanofluids. Nabil et al. [7]. studied the thermo physical properties of TiO₂-SiO₂ HNF's by mixing water with ethylene glycol. They have reported on the increment in the thermal conductivity as well as heat transfer with the rise in the volume loading of the nanofluid. They have also noticed a better relative viscosity at the same condition. They have

proposed the regression equations which are valid across a temperature of 30°C to 70°C for 3.0% Concentration of the nanofluid. Sreenivasulu et.al [8]. analysed the rate of heat transfer as well as drop in pressure of water based nanofluid in a DPHE. They have noticed the transfer of heat augmentation with less friction penalty loss. Krishna varma et al. [9] reported on the augmentation in transfer of heat in a DPHE utilising ferric oxide nanofluids and varying cut twisted tapes. They reported that the ferric oxide nanofluids and varying cut twisted tapes combinedly are responsible for intensification of transfer of heat in DPHE. Aghayari et.al [10]. investigated the transfer of heat enhancement in DPHE with Al_2O_3 /water nanofluid. Augmentation is achieved with Al_2O_3 /water nanofluids. Sudarmadji et al. [11] conducted the experiments with hot Al_2O_3 /water nanofluid of distinct volume fractions, flowing inside the tube, whereas the cold water was passing through the annulus. They have observed that the Nusselt number increment in contrast to pure water under particular volume concentration. Duangthongsuk and Wongwises [12] reported on transfer of heat intensification using TiO_2 /water nanofluid flow in a DPHE in turbulent flow. Asirvatham et al. [13] examined the transfer of heat enhancement of Ag/water based nanofluid circulating in a DPHE at distinct volume concentrations. Sajadi et.al [14]. reported on the transfer of heat augmentation of TiO_2 /water based nanofluid through a DPHE at a Reynolds number of 5000. Aghayari et. al [15]. reported on transfer of heat intensification of Al_2O_3 nanofluid flow in a counter flow DPHE in turbulent conditions. Mohammed et al. [16] have carried out numerical studies on aluminium, copper, silicon and zinc oxide transfer of heat nanofluids in a DPHE by considering continuity, momentum and energy equations based on the finite volume method with louvred strip inserts. Shakiba and Vahed [17] used Fe_3O_4 /water nanofluids at a particular volume concentration in a DPHE. They used a model of single phase. They applied the technique of control volume. Bahiraei and Hangi [18] analysed the accomplishment of magnetic nanofluids of Mn-Zn/water in a DPHE in magnetic field comprising a quadrupole utilising the method of two-phase Euler-Lagrange. Huminic and Huminic [19] studied features of CuO and TiO_2 nanofluids in a DTHHE in laminar flow numerically. They have reported considerable intensification of transfer of heat with the rise in particle concentrations. Demir et al. [20] numerically studied the velocity as well as temperature of water-based TiO_2 , Al_2O_3 nanofluid flows in a DPHE and validated their data with the literature for TiO_2 nanofluid. They have also reported on the further possibility of heat transfer intensification in DPHE with return bend. Hong and Hrnjak [21] reported on the transfer of heat in pipes having return bend. They have shown that the intensification is because of the effect of fluid mixing, thermal and hydrodynamic development of secondary flow at the ultimate downstream in the U-bend. Clarke and Finn

[22–24] numerically explored the transfer of heat in refrigerant in an air chiller and in U-bends. They reported that the intensification in transfer of heat upto 20% with the return bend. Choi and Zhang [25] executed numerical studies in transfer of heat in Al_2O_3 /water nanofluid in a pipe fitted with the return bend. They concluded that the Nusselt number rises with the rise in Reynolds number. Prasad et al. [26] had analysed the transfer of heat and friction factor of Al_2O_3 /water nanofluid in a DPHE with return bend. They have noticed a heat transfer augmentation of 25% at 0.03% volume loading at a Reynolds number of 22,000. Krishna Varma et al. [27] conducted the experiment and reported that the maximum intensification in Nusselt number as well as friction factor with threaded rod inserts are 89.95%, 32.46% greater to the plain pipe. The ultimate thermal accomplishment was 1.75 with 0.05% nanofluid and inserts.

From the literature, it was found that a lot of work has been carried out on CuO and TiO_2 nanofluids individually. However, the combined effect of CuO/ TiO_2 (hybrid) nanofluids on the thermal behaviour has to be studied for certain critical applications like nuclear reactors. These data were rarely discussed in the literature. In this regard, the thermophysical properties of hybrid nanofluids are very important. Hence, in this work, it is aimed at the estimation of thermophysical properties of TiO_2 /CuO hybrid nanofluids.

2. Materials and methods

Nanoparticles of Titanium Oxide and Copper Oxide supplied by Sisco Research Laboratories Ltd. are immersed in water and hybrid nanofluids of TiO_2 /CuO are prepared. Thermophysical properties of the bulk particles are very important for heat transfer applications as the efficacy of the nanofluids depends on the thermophysical features of the bulk particles. Thermophysical features of TiO_2 and CuO nanoparticles are summarised in Table 1. Thermophysical features of TiO_2 and CuO nanofluids are depicted in Table 2. Table 3 summarises the quantity of powder required in grams for the preparation of 0.01%, 0.03% and 0.05% loading of the TiO_2 /CuO hybrid nanofluids for 500 ml of the water.

2.1. Physical characterisation

It is essential to know the morphological characteristics of the nanoparticles, because the surface properties like particle shape and size play a predominant role in the intensification of the transfer of heat. Scanning Electron Microscopy (SEM) and Xray Diffraction (XRD) are used to estimate the shape and size of the nanoparticles. SEM analysis was carried out on CuO and TiO_2 nanoparticles. The mean particle size was 50 nm. The shape of the CuO nanoparticles was found to be spherical. The spherical shape of the nanoparticles is good for better heat transport properties. It was noticed that the

Table 1. Thermophysical properties of TiO_2 and CuO.

Parameter	TiO_2	CuO
Molecular Weight	79.8658 gm/mol	79.55 gm/mol
Density	4.5 gm/cm ³	6.3–6.9 gm/cm ³
purity	99.5%	99.5%
Appearance	Powder(white crystal)	Black crystal power
Geometrical shape	Tetrahedral	Amphoteric
Melting point	1580°C	1026°C
Boiling point	2972°C	2000°C
Size of nano particle	<50 nm	<50 nm

Table 2. Thermophysical properties of base fluid (water), TiO₂ and CuO.

Parameter	Water	TiO ₂	CuO
Density(ρ) Kg/m ³	998	3900	6300
Specific heat, (C_p) J/kg C	4182	697	550.5
Thermal Conductivity, k (W/m C)	0.6024	11.8	37.0

Table 3. The quantity of TiO₂/CuO to synthesise the hybrid nanofluids at different volume proportions in a 500 ml of base fluid.

S. No	Volume Concentration, ϕ (%)	Weight of nano particles in Grams	
		CuO	TiO ₂
1	0.01%	0.315	0.225
2	0.03%	0.945	0.675
3	0.05%	1.575	1.125

particles were broadly spread and exhibited good homogeneity. The SEM images of TiO₂ and CuO are as shown in Figure 1(a-b). Particle sizes determined from the SEM as well as the XRD were in good agreement with each other. Energy Dispersive X-Ray Analysis (EDX) is an excellent technique which is utilised to find out the elemental composition in materials. It is a technique of chemical microanalysis. It is utilised in combination with scanning electron microscopy (SEM). EDS images of CuO and TiO₂ are depicted in Figure 2(a-b). The EDX analysis shows that the elemental composition of CuO comprises Cu 64.6%, O 21.7% and C 13.7%. Similarly, the elemental composition of the TiO₂ comprises Ti 63.9%, O 34.1% and C 2%. X-ray powder diffraction (XRD) is a unique method used for identification of crystalline materials. The examined material was excellently homogenised, grounded and average bulk composition was determined. The X-ray diffractometer is used to identify the Phase change composition. Figure 3(a) displays the XRD patterns of CuO within the Bragg's angle of 2θ between 20° and 100°. The XRD pattern depicts the good crystallinity of the CuO nanoparticles. All the diffraction peaks are similar to the peaks obtained with JCPDS card No 48-1548. Figure 3(b) depicts the XRD pattern of TiO₂ nanoparticles. The peaks are much similar to that in the JCPDS card No 21-1272. They represent the anatase phase.

3. Preparation of hybrid nanofluids

The conventional base fluids like water, engine oil, ethylene glycol and ethylene/water mixture are used commonly while preparing the hybrid nanofluids. TiO₂ and CuO nano powders were procured from the Sisco Research Laboratories Pvt. Ltd, Maharashtra, India. The size of the nanoparticles varied from 10 to 50 nm (as provided by manufacturer) with a 99.5% purity. The as procured nanoparticles were used in the preparation of the nanofluids without any further processing. A two-step method was used for the preparation of the hybrid nanofluids. Initially, 500 ml of distilled water was taken in a beaker, and surfactant (sodium dodecyl benzene sulphate) was added to the base fluid. Stirring is carried out for 30 min. Then, measured quantities of CuO and TiO₂ nanopowders were added to the solution. After the addition of the nanopowders, stirring is

executed using a magnetic stirrer for 60 min, accompanied by ultrasonication for 30 min. Magnetic stirring is done to remove the air bubbles formed during the blending of the nanoparticles in the carrier fluid. Ultrasonication is done to obtain dispersion stability in the nanofluid. Even if magnetic stirring is done, there is every possibility that the nanoparticles can get separated from the carrier fluid. To eliminate this issue, surfactant is added. Since the nanofluids exhibit better characteristics at low volume concentrations, the concentrations of the hybrid nanofluids considered were 0.01%, 0.03% and 0.05%. The weight of nanoparticles required for 0.01%, 0.03% and 0.05% concentration was estimated by using the Eq. (1). A modified form of Eq. (1) is shown as Eq. (2).

$$\frac{\phi_{pv}}{100} = \frac{\text{Volume of cerium oxide nanoparticles}}{\text{Volume of cerium oxide nanoparticles} + \text{Volume of water}} \quad (1)$$

$$\phi_{pv} = \frac{\frac{W_{\text{CeO}_2}}{\rho_{\text{CeO}_2}}}{\frac{W_{\text{CeO}_2}}{\rho_{\text{CeO}_2}} + \frac{W_{\text{water}}}{\rho_{\text{water}}}} \times 100 \quad (2)$$

Various concentrations (0.01%, 0.03% and 0.05%) of the nanofluids prepared using the magnetic stirrer and ultrasonic sonicator used were depicted in Figure 4(a-d). Prepared nanofluids after 1 day, after 60 days and the surfactant used for the mixing of the nanoparticles and the carrier fluid are as shown in Figure 5(a-c).

4. Assessing thermo-physical properties

Thermophysical properties are assessed to determine the performance parameters like heat transfer coefficient, thermal performance of the system and friction factor. Thermal conductivity is one of the crucial factors that enhance the thermal transport properties. By adding the hybrid nanoparticles to the carrier fluid, the thermal properties of the base fluid will enhance. This is because, the solids possess more thermal conductivity than liquids and addition of these solid particles to the liquid particles can enhance the thermal conductivity of the carrier fluid. Thermal conductivity of nanofluids can be determined theoretically using the Eq. (3). Viscosity, density and specific heat capacity can be determined using Eq. (4), Eq. (5) and Eq. (6). Thermo-physical features such as density, specific heat, viscosity and thermal conductivity of CuO/TiO₂ hybrid nanofluids for various concentrations (0.01% to 0.05%) and at various temperatures (20°C to 60°C) were experimentally determined and are pivoted in Table. 4

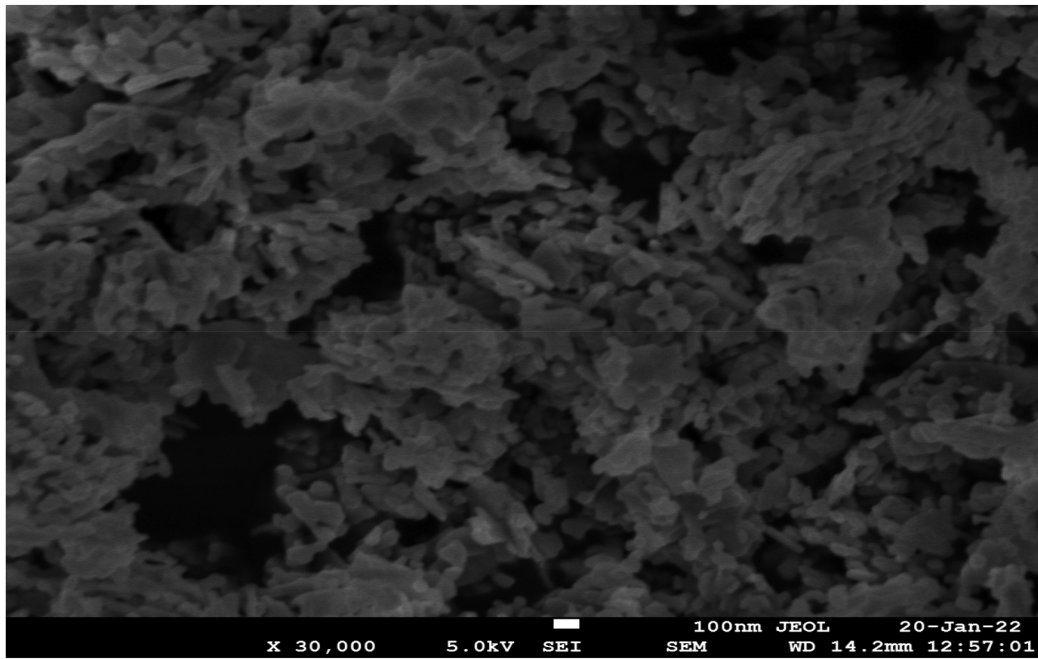
Thermal Conductivity (k_{hnf})

$$k_{\text{nf}} = k_{\text{bf}} \frac{k_{\text{np}} + 2k_{\text{bf}} + 2(k_{\text{np}} - k_{\text{bf}}) \phi}{k_{\text{np}} + 2k_{\text{bf}} - (k_{\text{np}} - k_{\text{bf}}) \phi} \quad (3)$$

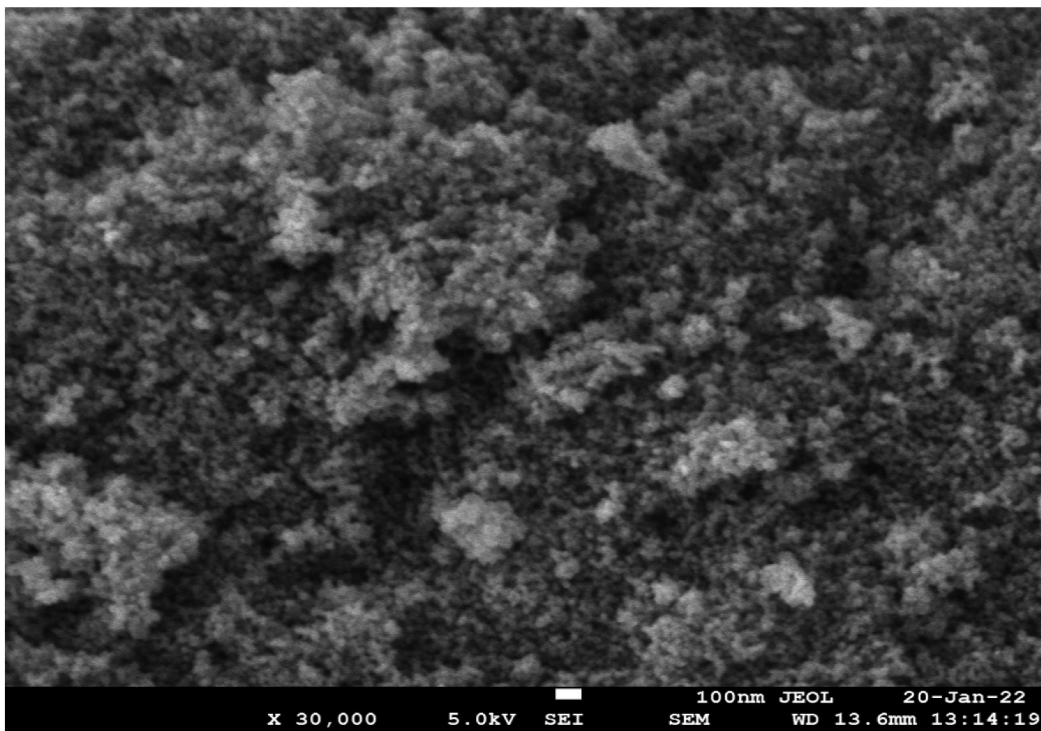
Viscosity of the nanofluid,

$$\mu_{\text{eff}} = \mu_f (1 + 2.5 \phi) \quad (4)$$

Density of hte nanofluid,



(a)



(b)

Figure 1. Sem images of (a) TiO_2 and (b) CuO .

$$\rho_{\text{nf}} = \varphi \rho_{\text{p}} + (1 - \varphi) \rho_{\text{f}}$$

Specific heat of the nanofluid,

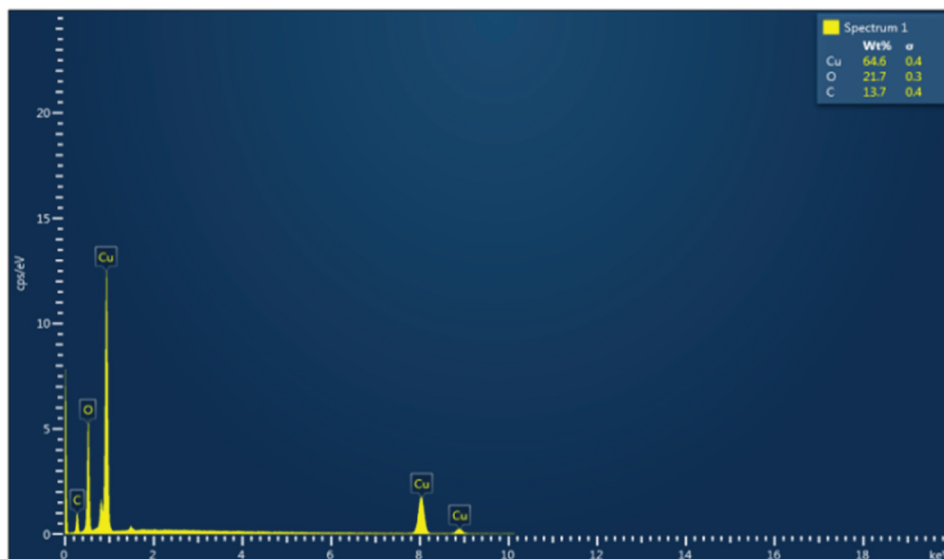
$$C_{\text{nf}} = (1 - \varphi) C_{\text{water}} + \varphi C_{\text{np}}$$

(5) 5. Results and discussions

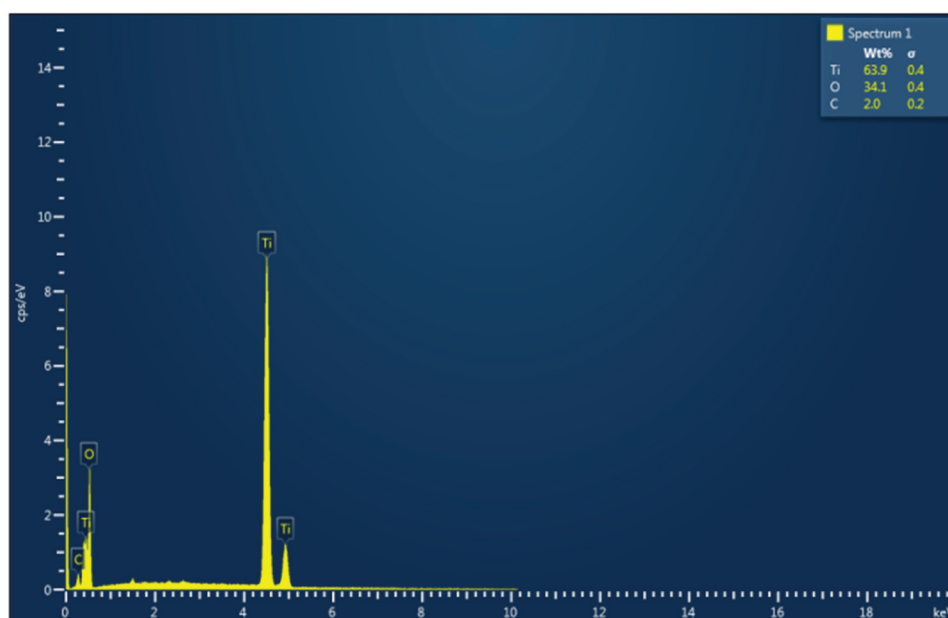
5.1. Thermal conductivity

The hybrid nanofluids exhibit good thermophysical properties and are significantly used to enhance the heat transfer behaviour [28–30]. Thermal conductivity

(6)



(a)



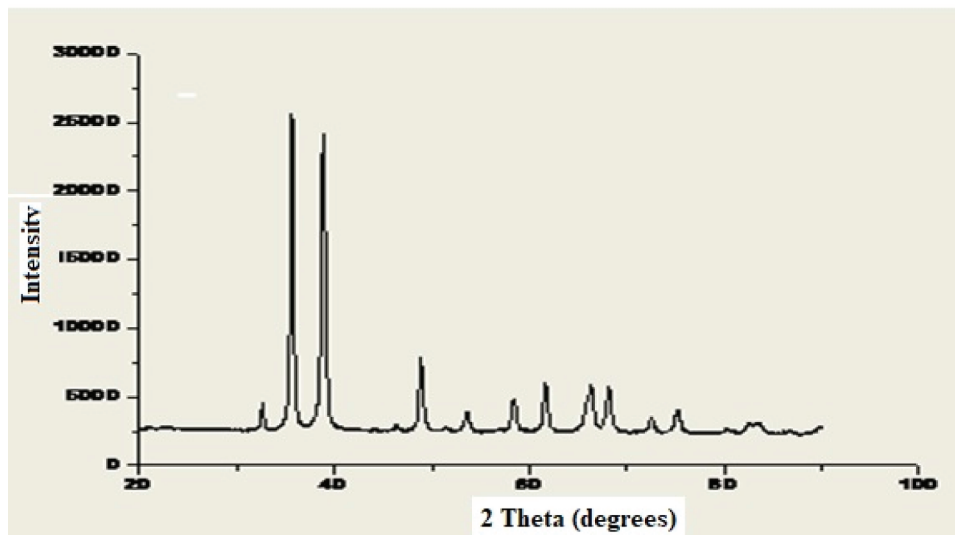
(b)

Figure 2. Images of EDS analysis of (a) CuO and (b) TiO₂.

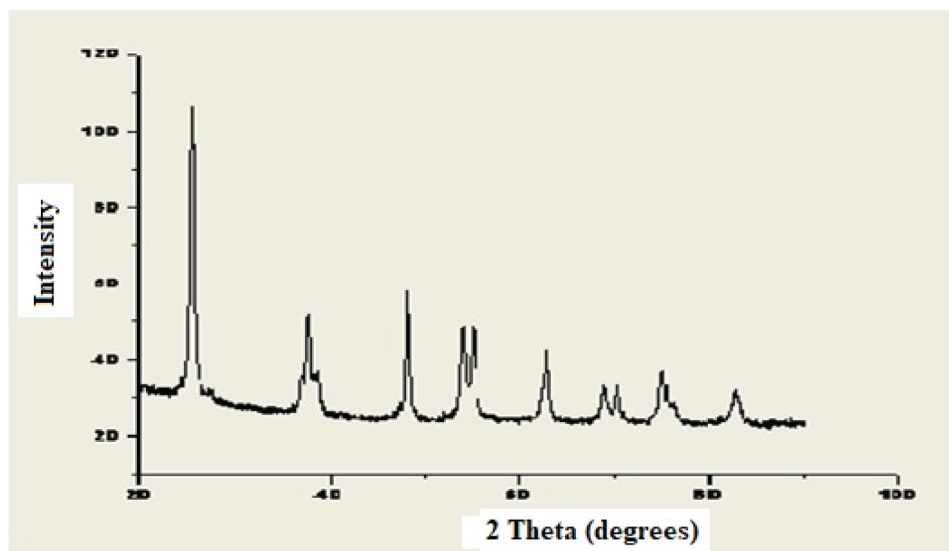
of the nano materials depends on the nanoparticle size, shape, material and dispersed conventional fluid corresponding to the temperature. Figure 6 depicts the variation of thermal conductivity of TiO₂/CuO hybrid nanofluids at various nanoparticle proportions of 0.01%, 0.03% and 0.05% and at various temperatures (20°C to 60°C). It displays that the thermal conductivity of TiO₂ /CuO nanofluids is augmented with increase in particle volume concentration. The thermal conductivity of TiO₂/CuO hybrid nanofluids at 0.05% concentration is 68.5% higher than that of the carrier fluid. This is due to the Brownian motion and mixing of nanoparticles inside the conventional fluid, which influence the thermal behaviour of hybrid nanofluids [31].

5.2. Viscosity of hybrid nanofluids

The pressure drop, as well as pumping power, depends upon the dynamic viscosity. Figure 7 depicts the variation of dynamic viscosity with distinct volume loadings of the TiO₂/CuO hybrid nanofluid and temperature. It is observed that the viscosity of TiO₂/CuO is inversely proportional to the temperature. It can be perceived that the dynamic viscosity of TiO₂/CuO with 0.05% volume concentration is more than that of 0.01% at a temperature of 50°C. Whereas it is decreased by 0.01% at a temperature of similar (0.01%) concentration. Hence, the viscosity of hybrid nanofluids primarily depends on the particle size, but has no marginal effect



(a)



(b)

Figure 3. XRD images of (a) CuO and (b) TiO₂ nanoparticles.

on the volume concentration and density of nano particles. The obtained results of thermal conductivity and viscosity of the hybrid nanofluids show similar results to that of Suleiman et al. [32,33]

5.3. Density of hybrid nanofluids

The density of hybrid nanofluids depends on friction factor, pressure drop, Reynolds number and Nusselt number. It has a considerable effect on the transfer of heat transfer accomplishment. Figure 8 depicts the variation of density of TiO₂/CuO hybrid nanofluids at various volume loadings and temperatures. It is observed from the plot that the density of hybrid nanofluids rises with the rise in volume concentrations, while it is reduced with the rise in temperature of TiO₂/CuO hybrid nanofluids. The density of TiO₂/CuO hybrid

fluids at 0.01% is lower than at 0.05%. It is also observed that at the higher volume proportion, the density of TiO₂/CuO hybrid nanofluids has increased [34].

5.4. Specific heat of hybrid nanofluids

Differential scanning calorimetry (DSC) is a device to estimate the specific heat capacity of the nanofluids. It is one of the most important thermal characteristics and a prominent factor in the heat transfer [35,36]. Figure 9 shows the relationship between the specific heat and temperature with various volume concentrations of TiO₂/CuO hybrid nanofluids. We know that the specific heat C_p of the hybrid nanofluid sample is represented by the area under the DSC curve, attained through basic equation. Eq. (7).

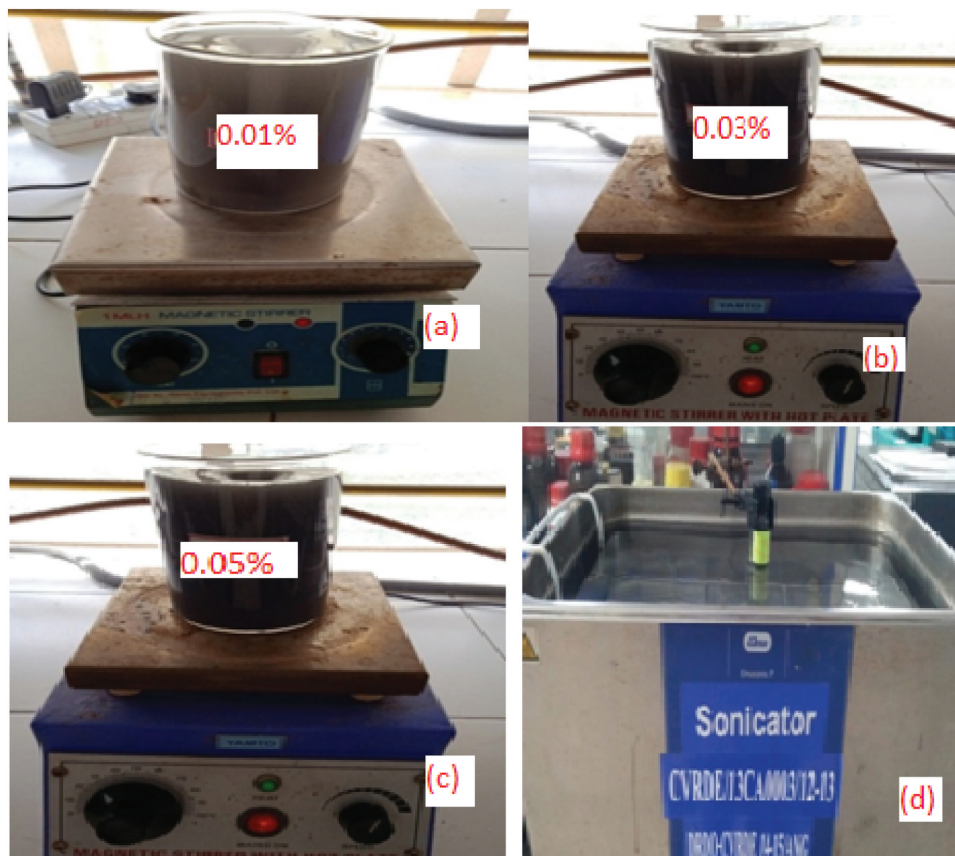


Figure 4. Various concentrations of the TiO_2 hybrid nanofluids a) 0.01% b) 0.03% c) 0.05% and d) ultrasonicator used.



Figure 5. Various concentrations of the nanofluids prepared (0.01%, 0.03% and 0.05%) a) after 1-day b). 0.01% ,0.03% and 0.05% (after 60 days) c) Surfactant (SDBS).

Table 4. Thermophysical properties of TiO_2/CuO hybrid nanofluids at various concentrations and temperatures.

Thermo physical properties values of TiO_2/CuO hybrid nanofluids (0.01%, 0.03% and 0.05%)					
S.NO	Vol Con. (%)	Density(ρ) (Kg/m ³)	Specific heat (C_p) (J/kg C)	Viscosity (μ) (N-s/m ²)	Thermal Conductivity (W/m C)
1	0.01%	1086.53	64.56	0.001034	0.6024
2	0.03%	1262.59	160.49	0.001083	0.6010
3	0.05%	1438.65	232.16	0.001143	0.999

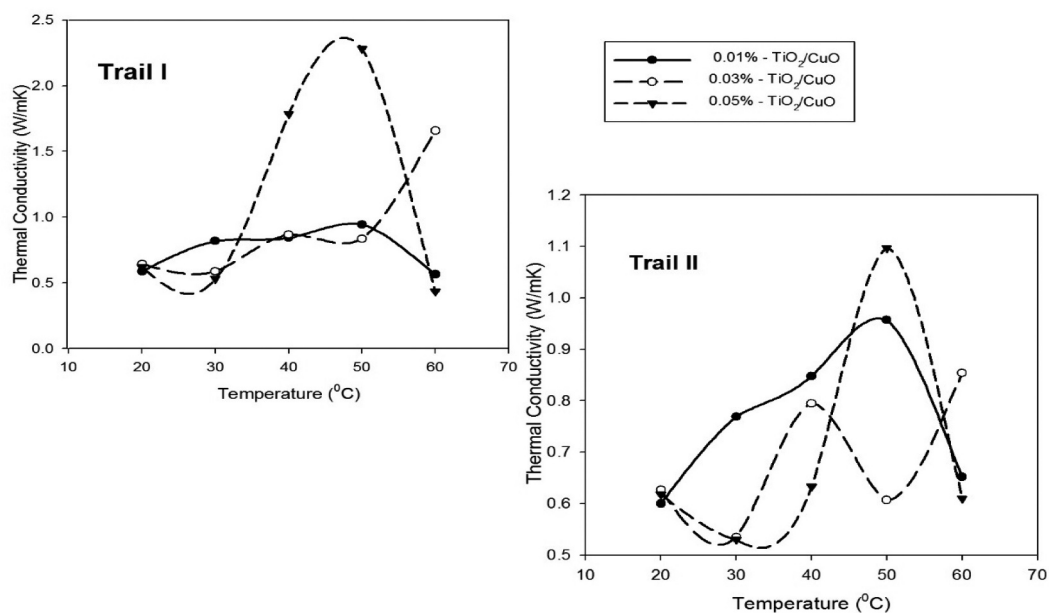


Figure 6. Variation of thermal conductivity with the increase in temperature °C.

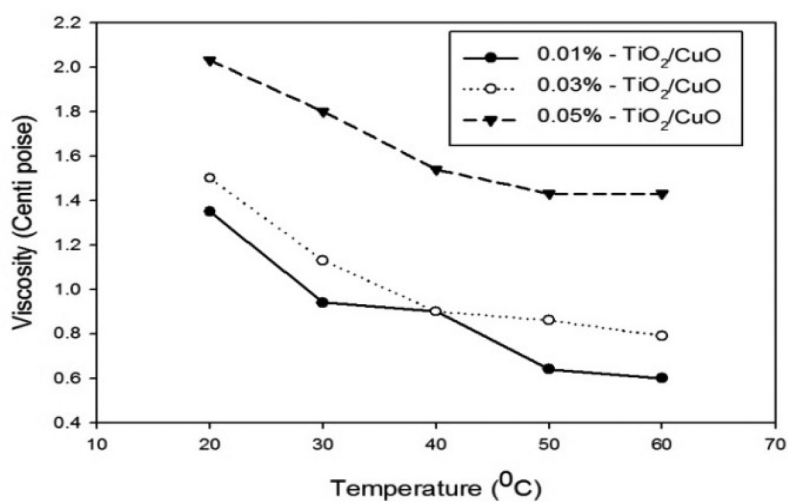


Figure 7. Variation of viscosity with the increase in temperature °C.

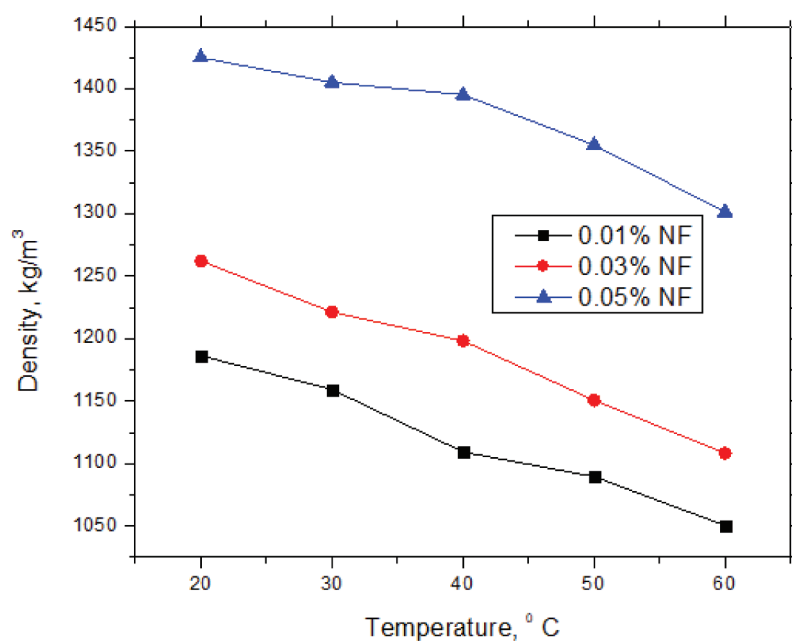


Figure 8. Density measurement at various concentrations and temperatures.

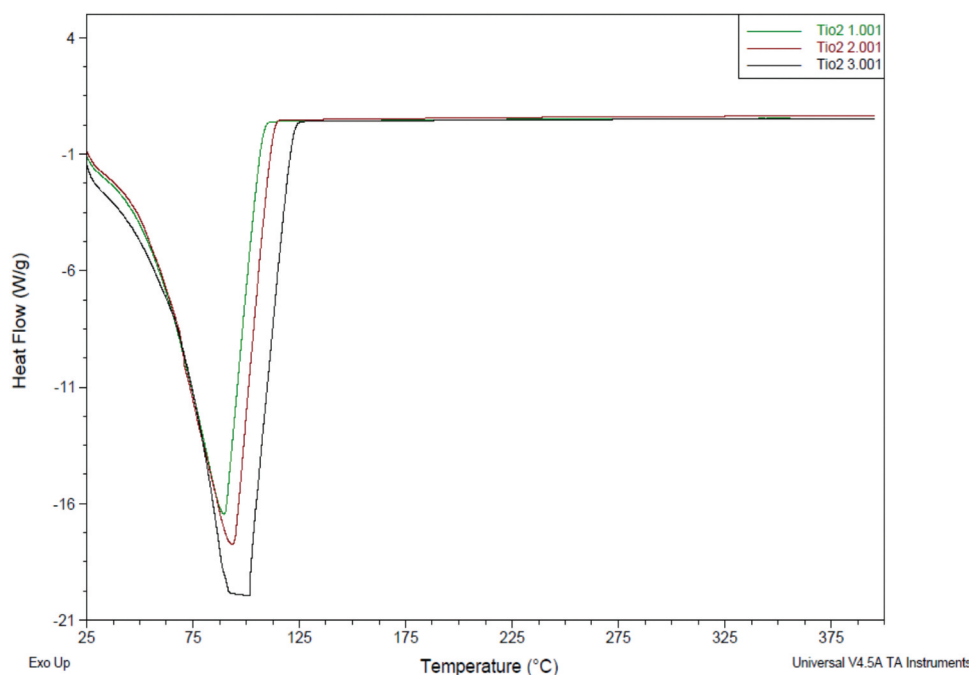


Figure 9. Variation of specific heat with increase in temperature °C.

$$C_p = Q/m\Delta T \quad (7)$$

Where Q is heat addition, m is the mass of the hybrid nanofluid and ΔT is deviation in the temperature range between 20°C and 70°C. Figure 9 shows that low specific heat $C_{p, hnf}$ can be attained in a hybrid nanofluid sample of large volume (ϕ). This is fact that the increase in the volume concentration resulting in the increase in density which transferred the energy to the molecules thereby reducing their specific heat [37–40].

The results revealed that the volume concentration of hybrid nanofluids has an inversely proportional to specific heat, an increase in temperature, and improved the specific heat of hybrid nanofluids by more than 60°C. Finally, the specific heat is also depends on the size of the nano particles and the mixture ratio.

6. Uncertainty analysis

Uncertainty analysis was carried out for various equipments and for various parameters following the procedure of [41]. It was found that the accuracy measurements were in the range of $\pm 2.2\%$, density measurements in the range of $\pm 1.5\%$, specific heat measurements were in the range of $\pm 1.2\%$ and that of the viscosity measurements were in the range of $\pm 2.1\%$ [42].

7. Conclusions

Experimental investigations were carried out to determine the thermal properties of TiO_2/CuO hybrid nanofluids. Specific heat, density, viscosity and thermal conductivity were determined for various concentrations and at various temperatures. The surface morphology, elemental composition and component identification of crystalline materials of the TiO_2/CuO nano particles were studied with the help of SEM, E-DAX and XRD pattern analysis. Based on the work carried out the following conclusions were drawn:

- The results confirm that the thermal conductivity is increased by 68.5% higher than that of the base fluid at a concentration of 0.05% of the hybrid nanofluids.
- The specific heat decreases in trend with nano particle proportion and temperature.
- It is observed that the thermal conductivity, density and dynamic viscosity of TiO_2/CuO hybrid nanofluids at 0.05% vol. have increased, when compared to the base fluid.
- It is also observed that the specific heat of TiO_2/CuO hybrid nanofluid at 0.05% concentration has decreased.
- It is concluded that the thermal properties are based on volume fraction, operating temperature and particle size of the hybrid nanofluids.
- The TiO_2/CuO hybrid nanofluids exhibited higher thermal conductivity than the base fluid. This shows the ability of these hybrid nanofluids to be used in heat transfer applications.
- This data is useful for researchers who want to carry out research in the area of heat transfer applications.

Nomenclature

C_p	Specific heat, J/kg K
d_i	Inner diameter of the tube, m
f	friction factor
k	Thermal conductivity, W/m K
Nu	Nusselt number
L_t	Length of the tube, m
Re	Reynolds number
Greek symbols	
ϕ	Particle volume concentration of the nanoparticles, %
ρ_{np}	Density of the nanoparticles, kg/m ³
ρ_w	Density of water, kg/m ³
μ	Viscosity, Pa-s

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