

Synthesis and Heat Transfer Characterization of Copper Oxide Nanofluids with Two Different Base fluids

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Abstract

Copper oxide (CuO) nanoparticles with average crystallite size 35 nm, were synthesized using citric acid assisted sol-gel auto combustion method with a view to use them in heat transfer application. The prepared copper oxide nanoparticles were subjected to annealing in a muffle furnace maintained at temperature 550°C for 6 h. Structural and phase parameter were evaluated with the help of X-ray diffraction technique (XRD). Single phase monoclinic structure of CuO was verified through X-ray diffraction analysis. Thermal characterization using TGA-DTA were studied. Scanning electron micrograph suggest branched structure formation with some agglomeration. The prepared CuO nanoparticles were dispersed uniformly in two different base fluids firstly in deionized water and then in mixture of deionized water and ethylene glycol (E.G. + D.I. water) in equal proportions to prepare nanofluid. Thermal conductivity and zeta potential measurement of nanofluids were carried out for different volume fractions. The thermal conductivity increases with increase in volume fraction for the prepared nanofluids. The stability decreases with increase in volume fraction for both nanofluids. A comparative study had made for both nanofluids to use them for heat transfer application.

Keywords: *CuO Nanoparticles, XRD, Sol-gel auto-combustion, Base fluid, Thermal conductivity, Nanofluid*

1. Introduction

Nanofluid plays an important role in heat transfer application in industry as well as different electronic, electrical as well as power generation systems. [1,2] nanofluid is new kind of fluid developed by Choi [3]. It is made by dispersing small amounts of nanoparticles of metals or metal oxides (having size between 1 to 100 nm) in a base-fluids such as water, glycols, oils or mixtures of such base fluids. The addition of such nanoparticles to the conventional base fluid increases the heat transfer performance of conventional fluids by significant amount. Because of nanosized and having large surface to volume ratio of nanoparticles has emerging

properties such as homogeneity, more stability, high thermal conductivity, higher viscosity etc. Many researchers reported that thermal conductivity of conventional base fluid increases effectively on adding nanoparticles to the conventional base fluids [4]. The metal oxides nanoparticles such as CuO, Al₂O₃, ZnO, TiO₂, SnO₂, CeO₂ etc. are having higher thermal conductivity, better stability, good electrical insulation, and cost-effective material therefore these are widely used for nanofluid preparation [5]. Metal oxide nanoparticles exhibit smaller particle size of the order of few nanometer dimensions, large surface to volume ratio, superior properties, highly chemically stable, easy to prepare, more reactive etc. characteristics

feature which are altogether different than that of the bulk material [6]. In the literature, copper oxide has been investigated for various properties by many researchers [7].

It has been reported that, nanoparticles when dispersed in base fluid like water to form a nanofluid show enhanced conductivity as compared to base fluid [8]. Nanofluids are prepared by two different methods i.e., i) One Step method ii) two step methods. In one step method nanoparticles are synthesized and directly dispersed in a base fluid for preparation of nanofluid. In two step method nanoparticles are prepared with suitable method and then obtained nanoparticles are mixed with base fluid to form nanofluid for different applications [9].

CuO nanoparticles has multifunctional properties with variety of applications in the areas of coolants, catalyst, batteries, magnetic storage, solar energy, superconductors etc. These nanoparticles have great advantages over conventional materials because of their large surface to volume ratio. Different methods have been available to prepare copper oxide nanoparticles [10]. Preparation of stable nanofluids is very important to avail all advantages of it hence preparation of stable nanofluid is of challenging task in the research area [11].

As discussed in above literature study that many researchers had worked on oxide nanofluids prepared either by single step or two step method and using either D.I. water or glycols such as ethylene glycol, propylene glycols or oils as base fluids but in this research work an attempt had made to compare the thermophysical properties of copper oxide nanofluid with different base fluids such as D.I water and hybrid base fluid (D.I. + ethylene glycol)

The method used and the sample prepared by using A. R. grade chemicals to prepare copper oxide nanofluid are as discussed below in detail

2. Material and Methods

2.1. Material

All chemicals used to prepare copper oxide nanofluid are of analytical grade. The chemicals used for synthesis are of copper oxide nanofluid are Copper nitrate ($\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$), citric acid ($\text{C}_6\text{H}_8\text{O}_7$), ammonia (NH_3), deionized water and ethylene glycol, acetone ($\text{CH}_3)_2\text{CO}$. polyvinyl alcohol.

2.2. Synthesis methods of copper oxide nanoparticles

Stable copper oxide nanofluid is made by using two step method. In first step CuO nanoparticles are prepared by using solgel auto combustion method. Under constant magnetic stirring of copper nitrates and citric acid which were dissolved separately in distilled water (100 ml each) in the stoichiometric ratio. Well dissolved copper nitrates and citric acid are then mixed and magnetic stirred to get a homogenous mixture. The pH of so formed solution was neutralized by adding ammonia drop by drop. This solution then subjected to constant magnetic stirring with hot plate at temperature 80°C till the solutions transforms into gel. As gel formation took place then obtained gel further heated at 110°C till auto combustion. After combustion obtained black ash like product allowed to cool to room temperature. Then final product after combustion fine grinded to have a fine black powder which was nothing but CuO nanoparticles. The prepared nanoparticles were sintered at temperature of 550°C for 6 hours.

2.3. Characterization of CuO nanoparticles

The structural characterizations were made using X-ray diffraction technique (XRD). X'PERT PRO PAN analytical X-ray diffractometer was employed to record the X-ray diffraction pattern with Cu- $K\alpha$ radiations at room temperature and in the 2θ range of 20° - 80° . The thermal characterizations were carried out using

TGA-DTA studies with help of DTA 60 thermal analyzer in a nitrogen atmosphere. The temperature varies from room temperature to 1200°C. The surface morphology was tested through scanning electron microscope (JSM, IT200, JEOL Japan) at an accelerating voltage 5.43 kV and at working distance 3.1 mm. The dispersion stability of prepared CuO nanofluids was characterized by measuring zeta potential using zeta sizer nano series (ZEN3600- Malvern, UK), Thermal conductivity of prepared nanofluids for different volume fractions of nanoparticles was measured using KD2 Pro thermal property analyzer, Decagon devices Inc.

2.4. Preparation of copper oxide nanofluids with two different base fluids

The stable nanofluids preparation is an important aspect to use them as heat transfer application. The nanofluids are generally prepared by two methods i.e. single step method or two step method. In this work CuO nanofluid prepared by two step method.

The above prepared CuO nanoparticles with volume fraction 0.05, 0.10, 0.15, 0.20, 0.25 firstly added to D.I. water as base fluid then secondly added another base fluid which is mixture of deionized water and ethylene glycol in the ratio 50:50, using the law of mixtures.

To obtain stable colloidal suspension without any type sedimentation, the Probe ultrasonication for 1h applied to nanofluids. Polyvinyl alcohol in 1:10 ratio is used as surfactant or capping agent to coat nanoparticles to increase stability of nanofluid for heat transfer application.

3. Results and Discussion

3.1. X-ray diffraction (XRD) analysis

The X-ray diffraction pattern for CuO Nanoparticles using PAN analytical, X-ray powder diffractometer with Cu-K α radiation of wavelength 1.54Å as shown in **Fig.1**.

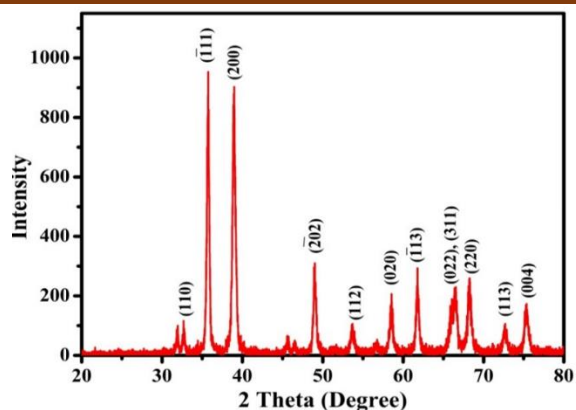


Fig. 1: X-ray diffraction pattern of copper oxide nanoparticles

The peaks appeared in the XRD pattern shows the crystalline nature of synthesized CuO nanoparticles. No characteristics peaks of any other phase of CuO were observed. Obtained diffraction pattern of CuO nanoparticles is in close agreement with the JCPDS card (card no: 01-080-1916). Thus, the XRD pattern confirms the synthesis of copper oxide having single phase monoclinic structure and nanocrystalline form without any kind of impurity phases. The average crystalline size of CuO nanoparticle was 35 nm, calculated from Debye-Scherrer formula [12, 13].

$$D = \frac{k\lambda}{\beta \cos\theta}$$

3.2. Scanning Electron Microscopy (SEM) of CuO Nanoparticles.

The surface morphology plays important role to study the surface structure of the sample. The surface morphology of the prepared CuO nanoparticles were studied through Scanning electron microscopy technique (SEM). **Fig. 2** depicts the SEM image of copper oxide nanoparticles.

It is evident from the following **Fig. 2** that there is uniform growth of particles with branched structure with some agglomeration of nanoparticles. The grain size calculated using linear intercept method.

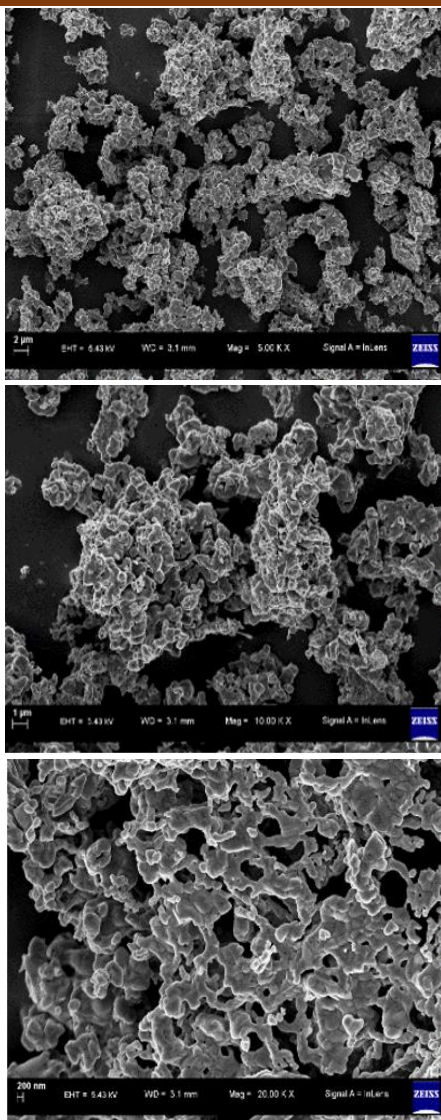


Fig 2: Scanning Electron images of CuO nanoparticles

3.3. Thermal (TG/DTA) study of CuO Nanoparticles

The T-hGA study was carried out to find out thermal stability of the nanoparticles. **Fig. 3** shows TG/DTA graph of CuO nanoparticles. The sample was tested up to temperature of 1200°C. Nearly 12% weight loss occurs in the sample above 926°C. The DTA curve of copper oxide we have seen that two endothermic curve at 100°C and 950°C this shows that vaporization of water and physical change due to reduction.

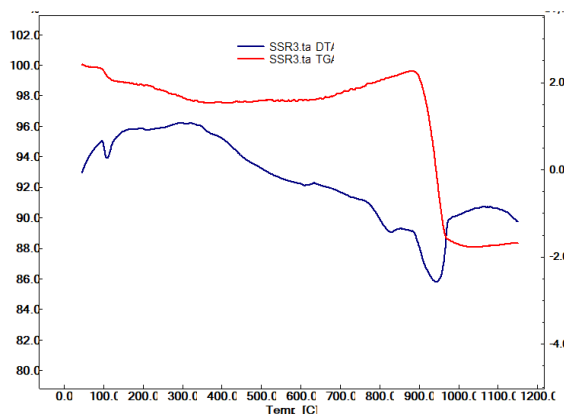


Fig 3: TG/DTA graph of CuO nanoparticles

3.4. Thermal conductivity of CuO Nanofluids

Transient hot wire technique is widely used for measurement of thermal conductivity of nanofluid. The thermal conductivity of the copper oxide nanofluids was measured using KD₂ pro thermal analyzer. It consists of handheld microcontroller and sensor needle which contains a heating element and thermistor. The calibration of sensor needle was done by measuring thermal conductivity of D.I. water, the measured value of thermal conductivity of D.I. water was in closely matched with reported value. Thermal conductivity measurement for 0.05, 0.10, 0.15, 0.20 and 0.25 volume % for both CuO nanofluids were carried out using this KD₂ Pro thermal property analyzer and the values of effective thermal conductivities are listed in **table 1**.

Table 1: Effective Thermal conductivity of CuO nanofluids

Sr. No.	Volume Fraction	Effective Thermal Conductivity	
		D. I. Water	D.I. water + E.G.
1	0.05	1.115	1.112
2	0.10	1.159	1.165
3	0.15	1.247	1.272
4	0.20	1.339	1.379
5	0.25	1.462	1.495

The observed ratio of thermal conductivity of nanofluid to base fluid increases with volume fraction for both the nanofluids (D.I. water and mixture (50:50) of D.I. water and ethylene glycol). The obtained thermal conductivity ratios are in good agreement with Maxwell model for effective thermal conductivity of solid- liquid mixture **Fig. 4**. The Maxwell model for effective thermal conductivity is given by the following relation,

$$K_{eff} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\phi}{k_p + 2k_{bf} - (k_p - k_{bf})\phi} k_{bf}$$

Where, K_p = particle thermal conductivity,

K_{bf} = Thermal conductivity of base fluid,

Φ = Nanoparticle volume fractions.

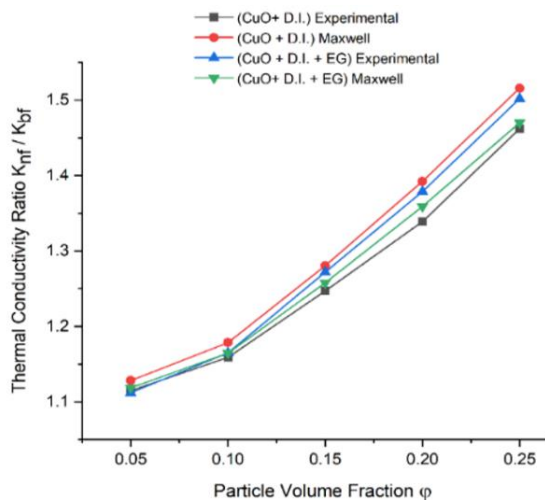


Fig 4: Effective Thermal conductivity ratio of nano fluids with nanoparticle volume fraction.

The above **Fig. 4**, shows the relation between effective thermal conductivity ratio of nano fluids with nanoparticle volume fraction. It was found to that the effective thermal conductivity enhancement is greater in CuO nanofluid with base fluid E.G. + D.I. water as compared to the D.I. water. The freezing point of base fluid E.G.+ D.I. water (50:50) is nearly -37°C and its boiling point is 107°C therefore it is widely used in heat transfer applications.

3.5. Zeta potential of CuO Nanofluids

Zeta potential measurement is an indication of dispersion stability of the nanofluid. Particles with more positive than +30mV or more negative than -30mV are considered as stable. The dispersion stability of prepared CuO nanofluids was characterized by measuring zeta potential using zeta sizer nano series (ZEN3600- Malvern, UK) The zeta potential measurement of prepared copper oxide nanofluid shows good stability for both nanofluids. For 0.05, 0.10, 0.15 vol% of (particle volume fraction) nanofluid has good stability as compared to 0.20 and 0.25 vol%. As nanoparticle volume fraction increases magnitude zeta potential decreases as shown in the following **Table 2** and shown in the **Fig. 5**.

Table 2: Zeta potential measurement of CuO Nanofluid

Sr. No.	Volume Fraction	Zeta Potential in mV	
		D. I. Water	D.I. water + E.G.
1	0.05	-30.08	-34.10
2	0.10	-28.62	-32.24
3	0.15	-27.52	-31.62
4	0.20	-24.94	-27.13
5	0.25	-22.41	-25.48

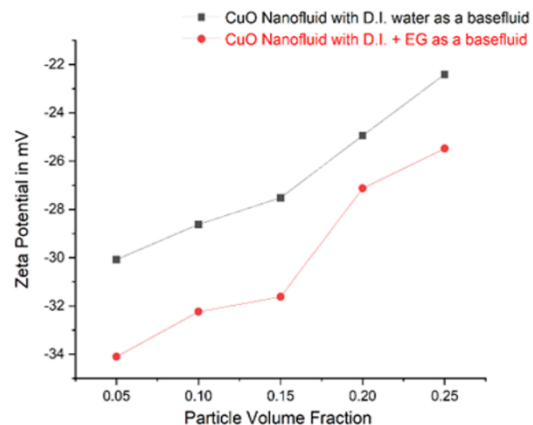


Fig 5. Particle volume fraction Vs Zeta potential of Nanoparticles

4. Conclusion

Copper oxide nanofluids for two different base fluid prepared successfully using two step method. In first step synthesis Copper oxide (CuO) nanoparticles using solgel auto combustion method.

The obtained XRD confirms the single-phase monoclinic structure of CuO nanoparticles having size 35 nm. The Scanning electron micrographs confirmed the branched structure with some agglomeration. The TG/DTA study of CuO shows nearly 12% weight loss in sample at temperature above 926°C. In second step synthesized CuO nanofluids for nanoparticle volume fraction 0.05, 0.10, 0.15, 0.20 and 0.25 vol % for both base fluids i.e., i) deionized water and ii) mixture of deionized water and ethylene glycol (50:50) characterized for heat transfer applications. Thermal conductivity measurement study for both nanofluids shows that effective thermal conductivity increases with volume fraction of nanoparticles. The zeta potential measurement of both nanofluids resulted that stability of nanofluid decreases with increasing volume fraction of nanoparticles. The both nanofluid shows good stability for volume fraction 0.05% and 0.10%. The second base fluid E.G. + D.I. water has more effective thermal conductivity and stability than D.I. water also the base fluid E.G. + D.I. water has the freezing point -37°C and high boiling point 107°C than D.I. water, therefore it has been widely used in heat transfer applications.

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