Synthesis and Charecterization of Copper oxide –Water Based Nanofluid For Heat Transfer Applications

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Abstract

The objective of the current research is to prepare copper oxide water based nanofluid for heat transfer application. The present work reports synthesis of nanocrystalline copper oxide using surfactant assisted wet chemical method. The average crystallite size of the copper oxide nanoparticles was calculated using XRD as 14 (±2) nm. The copper oxide-water based nanofluid was prepared using ultrasonic sonication method for potential use as a coolant for heat transfer applications. The heat transfer characteristics (thermal conductivity, specific heat and viscosity) of copper oxide nanofluid were determined using experimental set up as designed in the laboratory. The enhancement of thermal conductivity was observed as 20 % more compared to the earlier reported values for 0.1% volume concentration. This is an achievement of the present work.

1. Introduction

Water, engine oil, and ethylene glycol are the conventional fluids used for the heat transfer applications. Owing to their low heat transfer performance researcher has to think some alternative way to enhance thermal conductivity of nanofluids. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles (mm or micron sized), has been well-known for many years [1]. But due to increased pressure drop in the flow channel they were not accepted for practical applications. In present scenario suspending nano-sized (1 to 100 nm) particles in base fluids for enhancing thermal conductivity of base fluid is of great interest among the researches. Alumina (Al_2O_3) and copper oxide are the most common and inexpensive nanoparticles used by many researchers in their experimental investigations. [1]. Xuan and Li have reported the enhancement of 55% with 5% volume fraction in conductivity by using copper particle (> 100 nm) based nanofluids of transformer oil. The ANL group reported a 40% enhancement of conductivity with only 0.3% concentration of 10 nm-sized copper particles suspended in ethylene glycol [2]. In another study, Patel et al. [3] used transient hot wire method for measuring thermal conductivity. For the first time to prepare nanofluids gold and silver nanoparticles were used. It was reported that at room temperature, the conductivity of toluene-gold nanofluid was enhanced by 3–7% for a volume fraction of only 0.005–0.011% and it was attributed to the small size (~8–10 nm) of the particles. This literature survey shows that by using nanoparticles less than 10 nm enhances the thermal conductivity of water based nanofluid drastically. This can be achieved by using surfactant during synthesis to avoid the agglomeration of the nanoparticles [4].

2. Experimentation

Synthesis of copper oxide nanoparticles was carried out in the laboratory using surfactant assisted wet chemical method It is a two step process. In first step, copper sulphate ($CuSO_4$) is added with 0.1 M solution of NaOH. The surfactant sodium dodecyl sulphate is added drop-wise into aqueous solution of copper hydroxide. The solution was constantly stirred using magnetic stirrer at room temperature at 160 rpm. The pH of the solution was maintained as 9 by the addition of aqueous ammonia. The chemical reaction may occur as follows:

$$\mathbf{CuSO_4\ (aq.) + 2NaOH\ (0.1M) \longrightarrow Cu\ (OH)_2 + Na_2SO_4} \quad (1.1)$$

The prepared copper hydroxide gel was dried under IR lamp for 15 min. The dried powder was thermally heated in a muffle furnace at 500 ^{o}C for 3 hrs to get copper oxide.

$$\mathbf{Cu\ (OH)_2} \xrightarrow{500\ ^{o}C} \mathbf{CuO + H_2O \uparrow} \quad (1.2)$$

The phase of synthesized powder was confirmed by X-ray diffraction. Structural and optical characterization of synthesized copper oxide nanoparticles was done using X-ray diffraction and UV-visible spectroscopy.

Preparation of copper oxide water based nanofluid

The amount of copper oxide nanoparticles required for preparation of nanofluids is calculated using the law of mixture formula. A sensitive balance with a 0.001mg resolution is used to weigh copper oxide nanoparticles precisely. In the present work, water (70:30 by volume) was taken as the base fluid for preparation nanofluids. The weight of synthesized copper oxide required for preparation of 100 ml of water base nanofluid of a particular 0.1 % volume concentration is 0.608 gm. The prepared nanofluid sample was kept for observation and no particle settlement was observed at the bottom of the flask containing nanofluid even after five hours. The prepared nanofluid subsequently used for further experimentation was subjected to magnetic stirring process followed by ultrasonic vibration about 5 hours. The photographic view of CuO nanofluid magnetic stirring and sonication process using an ultrasonic cleaner is shown in the figure 1.1

Figure 1.1: (a-b): Magnetic stirring and sonification of nanofluid

Structural Characterization

X- Ray Diffraction

X- ray diffraction analysis (bulk) is carried out with Philips x - ray generator (Holland, PW- 1729) and Philips diffractometer PW 840. The X- ray generator has a target of copper (CuKα-1) with a wavelength of λ = 1.542 A. The calculated d values are compared with the standard values from the ASTM data file no. 05-661. The grain size measurement is carried out using Scherer formula

$$D = \frac{0.9\lambda}{\beta Cos\theta} \qquad (1.3)$$

Optical Characterization

UV Visible Spectroscopy

For UV-Visible absorption spectroscopy, Hitachi 330 double beam spectrophotometer was used. Thin film of synthesized nanocrystalline copper oxide was made in the laboratory and exposed to UV radiation (200-300 nm) and the absorption wavelength was determined from the intensity of the transmitted light.

Determination of properties of copper oxide – water based nanofluid

Density [5]

Using the density correlation equation for nanofluid as,

$$\rho_{nf} = \phi\,\rho_p + (1-\phi)\,\rho_{bf} \qquad (1.4)$$

Where; ρ_{nf} – Density of Nanofluid, $\Phi\rho_p$ –Concentration and Density of particle, ρ_{bf} –Density of Base fluid

Specific Heat [6]

For a given volume concentration of nanoparticles in the base liquid, the specific heat can be calculated using the mixture formula. This formula is valid for homogeneous mixtures and is given by the eq.5.

$$C_{p_{nf}} = \frac{(1-\phi)(\rho\, C_p)_{bf} + \phi\,(\rho C_p)_p}{(1-\phi)\rho_{bf} + \phi\rho_p} \qquad (1.5)$$

Where; C_{pnf}- Specific heat of nanofluid, Φ-concentration of nanofluid, $(\rho C_p)_{bf}$ -Density And Specific heat of base fluid, $(\rho C_p)_p$-Density and specific heat of particle.

Thermal conductivity [7]

The Maxwell developed a model to predict the effective thermal conductivity of solid-liquid suspension for low volume concentration of spherical microparticles suspensions.

$$k_{nf} = k_{bf}\{\frac{[(1+2\phi(1-(k_{bf}/k_{CuO}))/(2(k_{bf}/k_{CuO})+1)]}{[(1-\phi(1-(K_{bf}/k_{CuO}))/((K_{bf}/k_{CuO}+1)]} \qquad (1.6)$$

where, k_{nf}-thermal conductivity of nanofluid, kbf-thermal conductivity of base fluid (water) and k_{CuO}-thermal conductivity of copper oxide.

Viscosity [8]

The viscosity of nanofluids is calculated as follows

$$\mu_{nf} = \mu_{bf}\left(1 + 2.5\phi + 6.2\phi^2\right) \qquad (1.7)$$

μ_{nf} -viscosity of nanofiuid μ_{bf}-viscosity of base fiuid

Experimental Set up for heat exchange study of aluminium oxide nanofluid

The heat exchange characteristics of copper oxide nanofluid was determined using experimental set up designed in laboratory as shown in figure 2.1

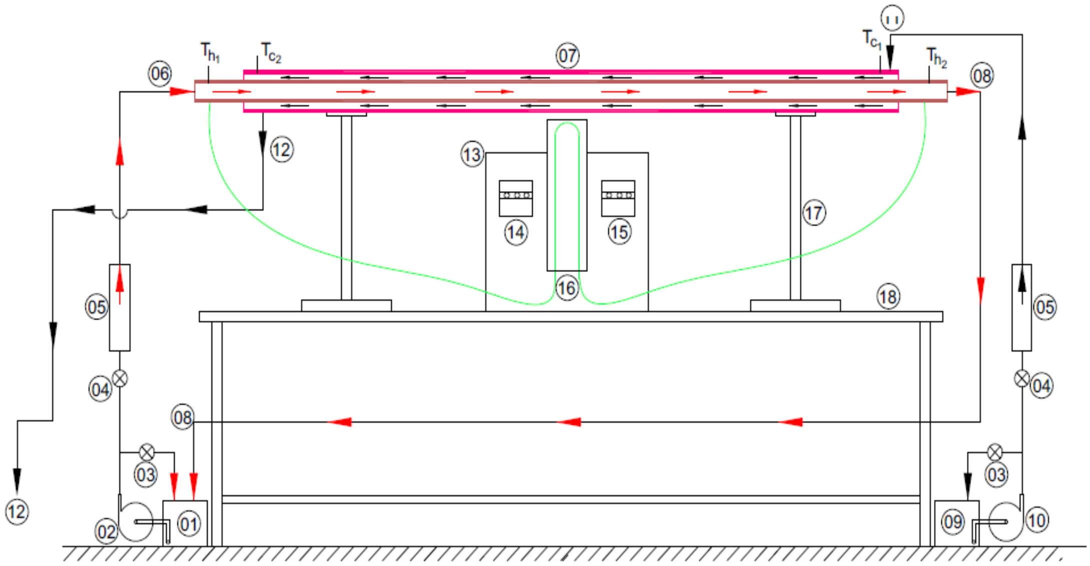

Fig 2.1: Schematic diagram of forced convection set up

01	Hot water tank	07	Test Section	13	Control pannel
02	Hot water pump	08	Hot water outlet	14	Temperature Indicator
03	By pass valve	09	Cold water tank	15	Temperature controller
04	Flow control valve	10	Cold water pump	16	Inverted U-tube manometer
05	Rotameter	11	Cold water inlet	17	Stand
06	Hot water inlet	12	Cold water outlet	18	Table

Experimental set up consists of test section having tube in tube heat exchanger. Inside tube is of copper and outside tube is of stainless Steel. Four thermocouples are connected to the test section, two at the inlet and two at the outlet of hot and cold water respectively. Two rotameters are connected at inlet of cold and hot water to measure the flow rates. Also control valves and bypass valves are provided at inlet of both the rotameters. Two centrifugal pumps are used to circulate the cold and hot water. Two tanks are used for storing the hot water and cold water. Electric heater is attached to the hot water tank having capacity of 1500watt. To measure the pressure difference between inlet and outlet of test section of hot fluid inverted U-tube manometer is used. Different twisted tape inserts are used. The current meter is used to measure the velocity of flow through inserted tube.

Nusselt number (**Nu**) [9]

It is the ratio of convective to conductive heat transfer across (normal to) the boundary.

$$\text{Nu} = \frac{hL}{k} \qquad (1.8)$$

where h is the convective heat transfer coefficient of the flow, L is the characteristic length, k is the thermal conductivity of the fluid. If its value closes to one, is characteristic of laminar flow. A larger Nusselt number corresponds to more active convection, with turbulent flow typically in the 100–1000 range.

Reynolds number [10]

Reynolds number is useful to represent whether the fluid flow is steady or turbulent

$$R = \frac{\rho VL}{\mu} \qquad (1.9)$$

Where, ρ = density of the fluid, V = velocity of the fluid, μ = viscosity of fluid, L = length or diameter of the fluid. If the number is < 2000, the flow is called Laminar and if > 4000, the flow is called turbulent.

3. Results and Discussion

X-ray Diffraction analysis:

Figure 3.1 represents XRD pattern of synthesized nanocrystalline copper oxide. It represents a single-phase of CuO with a monoclinic structure. The lattice parameters are a = 4.84 Å, b = 3.47 Å, c = 5.33 Å. The intensities and positions of peaks are in good agreement with the reported values (JCPDS file No. 05-661).Absence of any impurity peak indicates the purity of samples. The average crystallite size of CuO nanoparticles is found to be 14 (±2) nm using Scherrer formula.

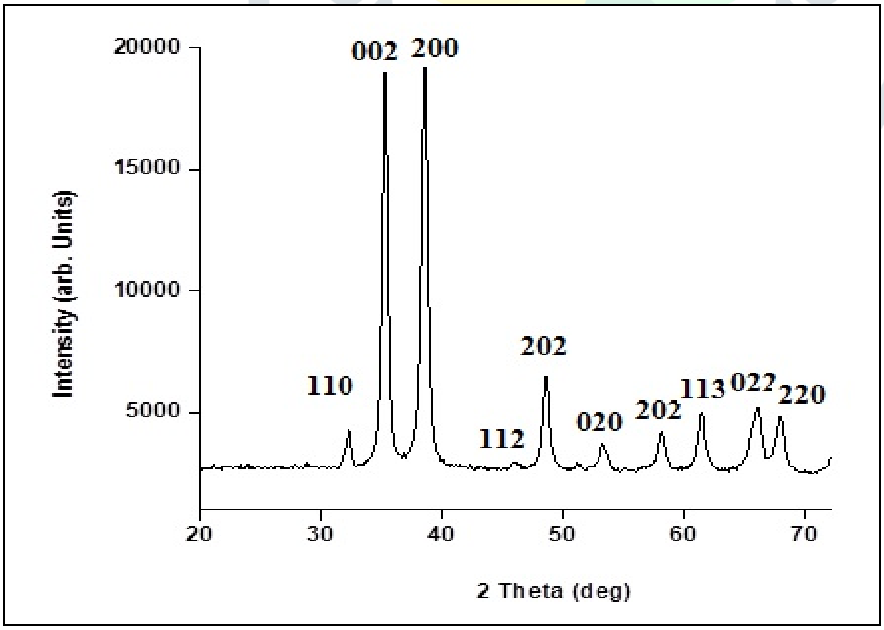

Fig .3.1: XRD of Copper oxide

Table 3.1: XRD analysis of nanocrystalline copper oxide

Peak no.	2Θ(deg.)	hkl	phase	d (A°) Cal.	d(A°) Std.	D(nm)
1	32.23	110	CuO	2.78	2.77	14
2	35.27	002	CuO	2.545	2.54	11
3	38.49	200	CuO	2.339	2.33	14
4	46.28	112	CuO	2.09	2.09	08
5	48.78	202	CuO	1.867	1.87	09
6	53.22	020	CuO	1.721	1.71	11
7	58.13	202	CuO	1.587	1.58	10
8	61.36	113	CuO	1.511	1.51	12
9	65.97	022	CuO	1.4163	1.41	07
10	67.96	220	CuO	1.379	1.38	16

The low particle size (D) is attributed to the addition of surfactant during synthesis. In the absence of the surfactant, the particles of 52 nm size were obtained. When the effective concentration of the SDS was added the particle size decreased from 52 nm to 14 nm .This decrease in size could be attributed to the capping effect of SDS, resulting in restriction on the growth of particles and controlling the size of copper oxide particles. With the increase in concentration of SDS, the capping action increases and hence the size of the particles decreases. The SDS not only had an effect on the size of particles, but also endowed the nanofluid with the required stability. In the absence of surfactant, the fluid was highly unstable and the particles started settling quickly. The surfactant modulates the available surface energy of the particles so that surface tension decreases and the Kelvin barrier moves allowing more particles to escape the aggregation process and generally lowering the mean particle size. [11]

Optical characterization

UV-visible spectroscopy

The UV- visible spectrograph for synthesized nanocrystalline copper oxide powder is depicted in figure 3.2.

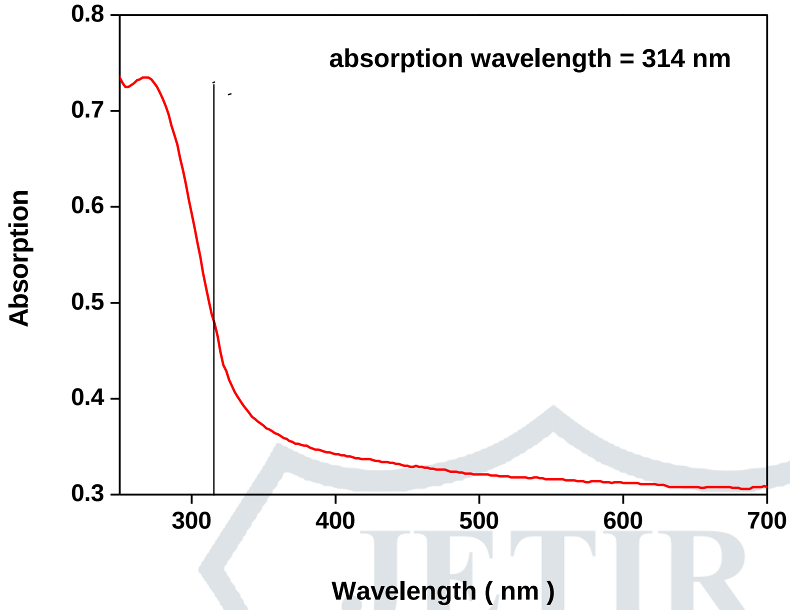

Figure 3.2: UV-visible spectrograph for copper oxide nanoparticles

The band gap for synthesized nanocrystalline CuO was observed as 3.9 eV. The indirect band gap of CuO nano particles (1.2eV) synthesized show similar values of already reported CuO nanoparticles (1.2eV) and the values are red shifted compared to bulk value (3.9 eV) due to the formation of surface defects [12]. The direct band gap (3.9 eV) is higher as compared to bulk values; this blue shift in the direct band gap is due to the quantum confinement effect. Optical absorption shows that the direct band gap verses indirect band gap permits the determination of the crystillinity of a material .If the direct band gap is higher as compared to indirect band gap the materials will be crystalline in nature.

3.3 Heat transfer properties of CuO nanofluid

The density, specific heat, thermal conductivity and viscosity of copper oxide nanofluid are calculated using equations 1.4-1.7 respectively. The results are presented in table no. 3.2.

Table 3.2: Comparative heat transfer properties of CuO nanofluid and water

Sr, No.	Nanoparticle/ Fluid	Avg.crystallite size (nm)	Density (Kg / m^3)	Thermal Conductivity (W /m K)	Specific Heat (J/kg/ K)	Viscosity (N-s/m^2)
1	CuO	14	1534.9	0.8015	6510	0.65
2	Water	-	997.5	0.628	4178	0.46

The higher valus of thermal conductivity of CuO nanofluid compared with water is attributed to the formation of suspended nanoparticles which increases the surface area and the heat capacity of the fluid. The suspended nanoparticles increase the effective (or apparent) thermal conductivity of the fluid. The interaction and collision among particles, fluid and the flow passage surface are intensified. Surface to volume ratio for nanoparticles is very high and this ratio increases with decrease in nanoparticle size.

Probably this could be one of the reasons for rise in the thermal conductivity of nanofluids. Figure 3.3 represents a graph of Nusselt umber verses Reynolds number for the prepared copper oxide water based nanofluid. As the Reynolds number increases then friction has to reduce.

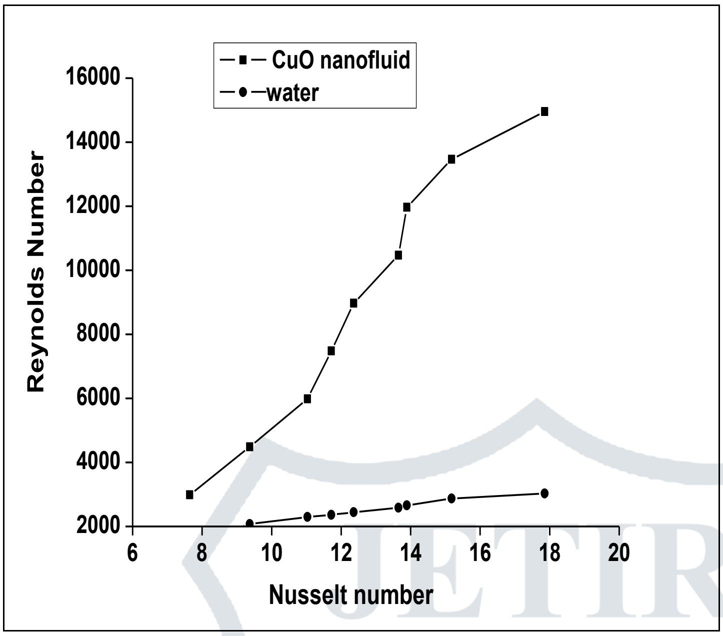

Figure: 3.3 Graph of Nusselt number vs. Reynolds number for water and nanofluid

At lower Reynolds number the friction factor is high however as the Reynolds number increases the friction factor drops .The Nusselt number increases with the increase in Reynolds number indicates that heat transfer enhancement takes place at higher Reynolds number. From graph it has been seen the comparison has lead to successful prediction that nanofluid has great heat transfer properties than that of the plain water Nusselt number is function of Reynolds number. Nusselt number increases with increase in Reynolds number. Hence, convective heat transfer rate is more with higher Reynolds number. The highest vale of Reynolds number in case of nanofluid is observes as 14925 while it was 3025 in case of plain water. This could be the reason for high heat transfer rate with copper oxide water based nanofluid as compared with plain water.

3.5 Conclusion:

Nanopowder of CuO of average crystallite size 14 nm was successfully synthesized by Surfactant Assisted Sol-gel method. Synthesized nanopowder is used for making nanofluid of Copper Oxide (CuO) by sonification method. Prepared nanofluid was used for study the heat transfer application of industry and day-to-day life. These results are compared with the results of these applications by using plain water. Copper oxide water based nanofluid exhibits better heat transfer rate compared with plain water. The synthesized nanofluid of CuO may used as a coolant in radiator of vehicles for better performance. It has demonstrated great potential applications in many fields such as microelectronics, transportation, heating, and cooling.

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