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Effect of nanoparticle mixed ratio on stability and thermo-physical properties of CuO-ZnO/ water-based hybrid nanofluid

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The advanced hybrid nanofluids are the important outcome of the nanotechnology advancement where dissimilar nanosized particles were added together either using one step or two step method. CuO-ZnO hybrid nanoparticle/water based nanofluid of 0.01 vol% solid volume fraction at various mixed ratios was prepared using two step method. Ultra-sonication assured stability of nanofluid. Hybrid nanoparticles were characterized using FESEM-EDS, DLS and Zeta analysis for understating of morphology, shape and size of nanoparticle. Effect of pH and mixed ratio of nanoparticle on stability of hybrid nanofluid was analysed. With highest surface to volume ratio nanoparticles efficiently impacted on enhancement in thermal conductivity and density of base fluid by creating a nanolayer/film on the surface of nanoparticle. Based on the results empirical equation was generated and margin of deviation was measured for the validation.

Keywords: CuO-ZnO, hybrid nanofluid, solid volume fraction, MOD, ultra sonication, stability.

Introduction

Various studies proved that by nanofluids the thermophysical properties can be altered for the base fluid. Now researchers are improving the properties by adding hybrid nanocomposites in the base fluid and even in binary base fluid. Water is the basic heat transfer fluid used throughout the world and transportation in cold countries is the main issue. By adding agents like EG, propylene glycol, salts, and sugar we can lower the freezing point of water, but all the agents have their own limitations. Salts can corrode the metal pipes and researchers are explored water-EG at different volume fractions thermophysical properties at different working conditions[1]. The rate of heat transfer may vary with various parameters like, type of nanoparticle, size, shape, compatibility of hybrid nanoparticle, solid volume fraction and preparation methods. Nabil *et al.*[2] stated that various nanoparticles are used in the study like carbon nanotubes, metals (oxides, carbides, nitrides) and the effect on thermophysical properties like thermal conductivity, viscosity (Newtonian/non-Newtonian behaviour) was analysed.

Combination of dissimilar nanoparticles of distinct size, shape, thermophysical properties to be blended in base fluid to form hybrid nanofluid[3]. The essential properties could be tuned into the hybrid particle by adding at various concentrations of individual constituents. Which directly impact on the thermophysical properties like density, thermal conductivity, electrical conductivity and viscosity of the hybrid material[4]. These nanoparticles were added to a single/binary base fluid to form a nanofluid with better properties compared to base fluid like water, oil, ethylene glycol, propylene glycol etc.[5].

Wide range of applications were explored for ZnO and CuO nanoparticle based nanofluids. Which includes in hear exchangers[6,7] car radiator cooling system[8–10], antifreeze[11], microchannels[12], solar thermal energy[13], drilling fluids[14], nano refrigeration[15], CHF[16] and the study mainly concentrated on enhancing the rate of heat transfer and reducing the pumping power compared to base fluid.

Pattanayak *et al.*[17] studied the ZnO, CuO nanofluid mono/ hybrid performance in coolant for high heat flux application at 0.025–0.1 vol% solid volume fraction and studied its enhancement in density, viscosity, thermal conductivity and specific heat. Jeong *et al.*[18] studied effect of particle shape on performance of ZnO nanofluid. Results suggested that particles with rectangular shape had higher effect on viscosity and thermal conductivity of nanofluid compared to spherical shape particle.

Among other metal oxides ZnO and CuO nanoparticles could be prepared by simple precipitation method and applied in various applications of heat transfer. A very few studies were performed on heat transfer performance of ZnO/CuO based hybrid nanofluid at very low solid volume fraction. In the current paper ZnO and CuO nanoparticles were characterized by DLS and Zeta potential to understand the particle size and stability of the nanoparticle. CuO-ZnO hybrid nanofluid of 0.01 vol% solid concentration at 0:100, 10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20, 90:10 and 100:0 mixed ratios (MR) were prepared using two step method using distilled water as base fluid. The stability of the nanofluid was ensured by 8 min of ultrasonication without any surfactant. The thermo physical properties like thermal conductivity, density, were analysed at room temperature.

Nanofluid preparation:

The properties of ZnO and CuO are mentioned in Table 1. Nanofluid was magnetically stirred and ultrasonicated at different frequency from (0–100 kHz) for better stability which is referred as ultrasonic attenuation[19]. A ChromTech sonicator (Taiwan) was used for the dispersion of nanoparticles into the base fluid. After 15 min of sonication, nanofluids appeared completely homogeneous. No dispersant was added as it alters the effective thermal conductivity[20]. After the ultrasonication samples were kept aside for 5 min to minimize the sonication effect on the nanofluid and sedimentation test confirmed the stability of the nanofluid[21].

Table 1. Properties of nanoparticle

Properties	CuO	ZnO
Colour	Black	white
Purity (%)	98	99
Thermal conductivity ($Wm^{-1} k^{-1}$)	76	29
Density (g/cc)	6.3	5.6
Particle size (nm)	< ±30	< ±20
Particle shape	Spherical	Flaky

Fig. 1 demonstrates the preparation for hybrid nano fluid using by two-step method[1]. The nanoparticles were added to the base fluid based on the required mixed ratio, for 0.01 vol% solid volume fraction from eq. (1).

$$\varphi = \frac{\left(\frac{w}{\rho}\right)_{ZnO} + \left(\frac{w}{\rho}\right)_{CuO}}{\left(\frac{w}{\rho}\right)_{ZnO} + \left(\frac{w}{\rho}\right)_{CuO} + \left(\frac{w}{\rho}\right)_{water}} \tag{1}$$

Experimental

All the experiments were conducted at room tempera-

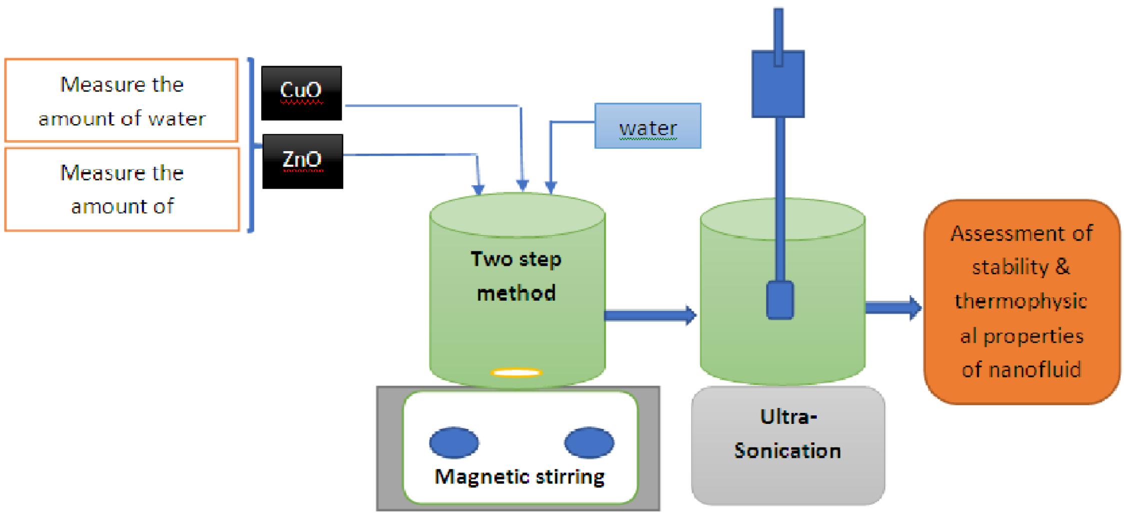

Fig. 1. The preparation of hybrid nanofluid.

ture (25°C) and atmospheric pressure conditions.

Methods of characterization:

The particle size, zeta potential and stability were analysed by Dynamic Light Scattering (DLS) technique at an angle of 173° using Zeta sizer nano series (ZEN3600-Malvern, UK). The morphology, shape and size of mono/hybrid nanoparticle was analysed using FESEM-EDS analyser. The nano particles were dispersed in distilled water using continuous low power ultrasonication (ChromTech ultra sonic processor) at 30 KHz and pH of the solution ranging from 2 to 12 was prepared by 0.1 *M* hydrochloric acid as acidic and 0.1 *M* sodium hydroxide solution as basic medium. After adjusting pH the nano fluid was magnetically stirred and ultrasonicated for better dispersion. The weight of the nano particle was weighed by digital weighing machine of 0.0001 accuracy. KD2 Pro (Decagon Devices, USA) instrument with transient hot wire method was used to measure thermal conductivity of nanoparticle and nanofluid.

Results and discussion

CuO-ZnO hybrid nanofluid of 0.01 vol% solid concentration at 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90, 0:100 mixed ratios (MR) and the pH of the base fluid was at 7.3.

FESEM-EDS analysis:

Fig. 2 confirms the CuO and ZnO nanoparticle size and shape. CuO nanoparticles were spherical in shape and ZnO nanoparticles were flaky in nature. CuO-ZnO hybrid nanoparticle represents uniform distribution of hybridised particles. The average particle size from FESEM results were about 25 nm which is in good agreement with DLS results from Table 2.

Effect of mixed ratio on pH and zeta potential:

Table 2 shows the addition of the nanoparticles varied the pH of the nanofluid which indirectly effected the zeta potential. The zeta potential of the hybrid nanofluid varied from absolute 2 mV to 40 mV which represented the stability of nanofluid. As Vandsburger[22] suggested more than ±30 mV represent stable nanofluid with good dispersion of nanoparticles. At MR 3, 5, 7, 8, 9, 10 and 11 showed > 30 mV of zeta potential (Fig. 4). The average hybrid nanoparticle size was about 25 nm (Fig. 3). The optimum mixed ratio was about 80:20 of CuO-ZnO.

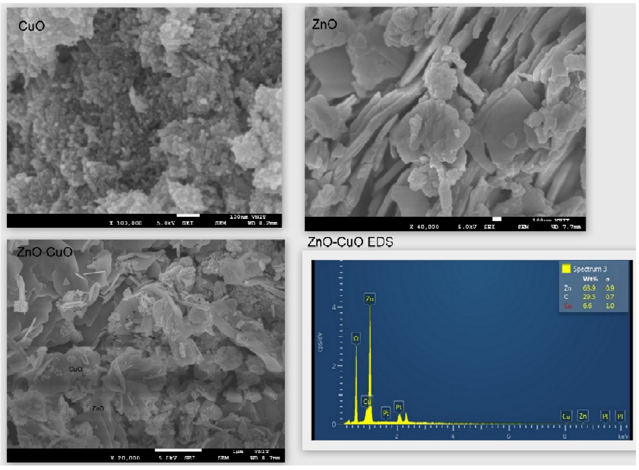

Fig. 2. FESEM-EDS image of CuO, ZnO, CuO-ZnO (10%:90% mixed ratio) hybrid nanoparticle.

Table 2. Effect of mixed ratio on pH, size and zeta potential of hybrid nanofluid

Base fluid	Mixed ratio (MR)			pH	Size	Zeta potential
	MR	CuO %	ZnO %		(nm)	(mV)
Distilled water	1	100	0	7.47	19.7	–16
	2	90	10	7.4	22.6	–2.14
	3	**80**	**20**	**7.26**	**22.7**	**–40.634**
	4	70	30	7.8	21.8	–24.1
	5	**60**	**40**	**7.3**	**25.4**	**–34.8**
	6	50	50	7.8	23.7	–4.8
	7	**40**	**60**	**7.55**	**28.2**	**–35.4**
	8	30	70	7.42	34.6	–31.4
	9	**20**	**80**	**7.55**	**21.3**	**–35.7**
	10	10	90	6.91	24.7	–33
	11	0	100	5.94	32.0	–32.1

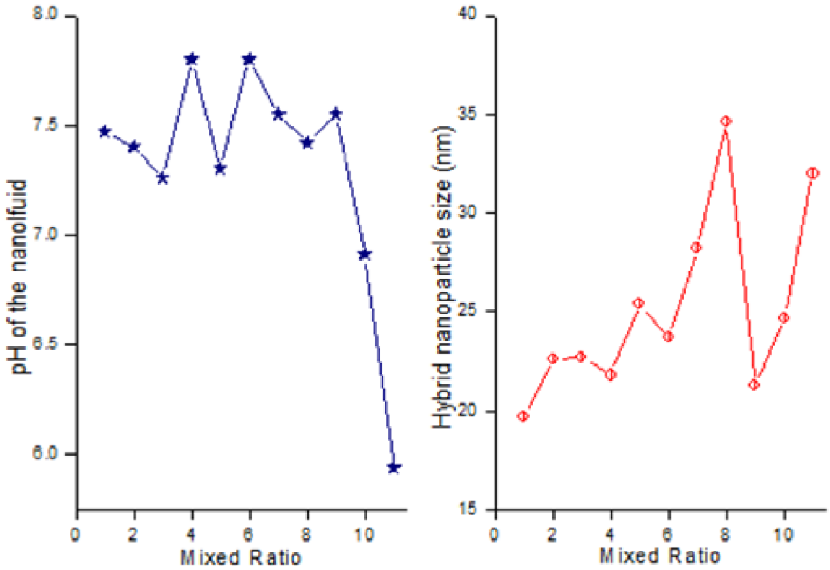

Fig. 3. Effect of mixed ratio on pH and particle size of hybrid nanofluid.

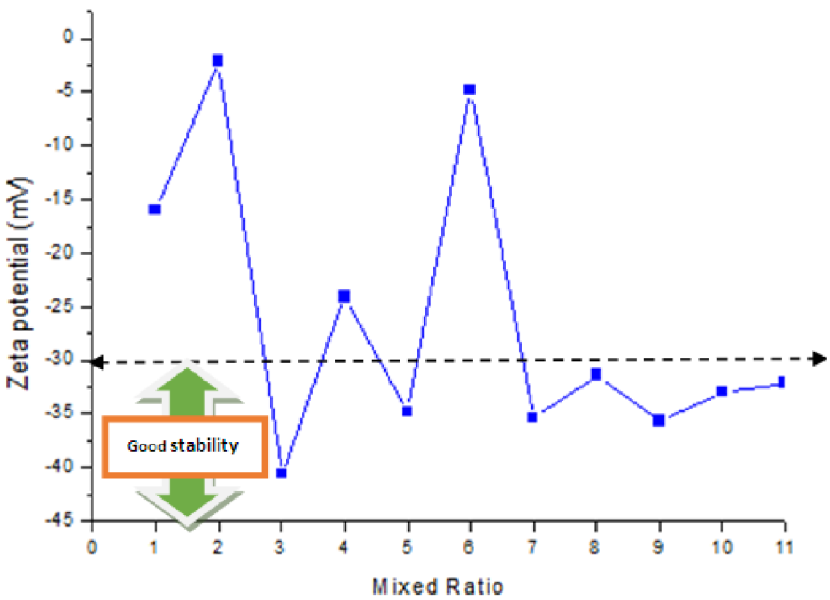

Fig. 4. Effect of mixed ratio on stability of hybrid nanofluid in terms of zeta potential.

Effect of mixed ratio on thermophysical properties of nanofluid:

Density:

Table 3 shows effect of mixed ratio on density of the nanofluid. As the nanoparticles are denser than base fluid (Table 1), the addition to base fluid definitely enhance the density of the base fluid[23] and also ultrasonication also enhanced the density of the nanofluid by decreasing the sedimentation rate[24]. The density increment was not higher than 2.5% of the base fluid at all the mixed ratios, represents the pumping power of hybrid nanofluid was same as base fluid.

Thermal conductivity:

Thermal conductivity of the hybrid nanoparticle and nanofluid was measured using KD2 Pro (Decagon Devices,

Table 3. Thermo physical properties of hybrid nanofluid at various mixed ratios

Base fluid	Mixed ratio (MR)			Thermal conductivity	Density
	MR	CuO %	ZnO %	($Wm^{-1} k^{-1}$)	(gm/cc)
Distilled water	1	100	0	0.62	1.001
	2	90	10	0.646	1.01
	3	**80**	**20**	**0.674**	1.012
	4	70	30	0.61	1.01
	5	60	40	0.530	1.007
	6	50	50	0.493	1.026
	7	40	60	0.49	1.012
	8	30	70	0.459	1.01
	9	20	80	0.41	1.007
	10	10	90	0.353	1.023
	11	0	100	0.392	1.01

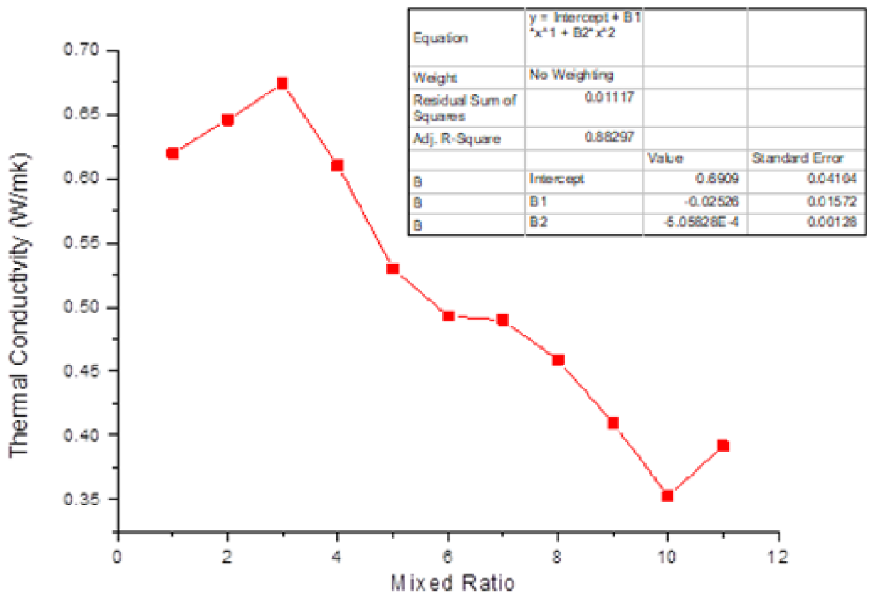

Fig. 5. **V**ariation of thermal conductivity at different mixed ratio and model predication.

USA) instrument with transient hot wire method. The thermal conductivity of base fluid was about 0.31 W/mk at 25°C. Thermal conductivity enhancement was measured by using eq. (2).

$$k_E = \frac{\boldsymbol{k}_{nf} - k_{bf}}{k_{bf}} \times 100 \qquad (2)$$

The maximum enhancement was 117% for only 0.01 vol% of hybrid nanofluid at 80:20 CuO-ZnO mixed ratio of nano particle without any addition of surfactant. The lowest enhancement was 14% at 10:90 CuO-ZnO mixed ratio. The optimum mixed ratio for better heat transfer fluid would be at 80:20 CuO-ZnO mixed ratio. Pattanayan *et al.*[17] studies showed thermal conductivity improvement about 0.82 W/mk at 0.1 vol% for CuO-ZnO hybrid nanofluid.

From the experimental results a new correlation was predicted (eq. (3)) considering hybrid mixed ratio (MR)[1] as variable at 0.01 vol% solid volume fraction (φ) and 25°C.

$$k_{nf} = 0.6909 - 0.02526\,(MR) - 5.05828 \times 10^{-4}\,(MR)^2 \quad (3)$$

The results from model equations were verified and margin of deviation (MOD %) was calculated from eq. (4)[25]. Most of the MOD predicted using polynomial second order equation was lesser than 5% which represent better validation.

$$MOD\% = \left| \frac{k_{Experimental} - k_{Predicted}}{k_{Experimental}} \right| \quad (4)$$

Conclusion

CuO-ZnO/water-based hybrid nanofluid of 0.01 vol% solid volume fraction at different mixed ratios was prepared using two step method.

FESEM-EDS, DLS confirms the size and shape of the hybrid nanoparticles to be well uniformed and lesser than 30 nm.

The morphology of both nanoparticles was mostly different which played major role in the thermal properties of nanofluid.

The optimum CuO-ZnO mixed ratio was at 80%:20% where thermal conductivity enhancement was about 117% compared to base fluid at 41 mV zeta potential.

Maximum enhancement in density was lesser than 2.5% at all mixed ratios.

Based on the experimental results a second order polynomial equation was proposed as modelling equation with MOD of < 5%.

Nomenclature:

Vol%: Volume percent, ϕ: Solid volume fraction, k: Thermal conductivity (W/mk), W: Weight (g), ρ: Density (g/cc), MOD: Margin of deviation, MR: Mixed ratio, T: Temperature (°C),

Subscript:

bf: Base fluid, np: Nano particle, E: Enhancement, nf: Nano fluid.

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