Preparation of CuO/Water Nanofluids Using Polyvinylpyrolidone and a Survey on Its Stability and Thermal Conductivity

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Abstract:
In this article CuO/water nanofluid was synthesized by using polyvinylpyrolidone (PVP) as the dispersant. Thenanofluid stability period and the heat transfer enhancement were determinedby measuring the thermal conductivities. To study the nano-fluid stability, zeta (ζ) potential, and absorbency were measured under different pH values and PVP surfactant concentrations; also thermal conductivity enhancement was measured based on different volume fraction of CuO nanoparticles and temperature. The results showed that the nano-fluid with PVP surfactant has a good stability of about a week in the optimum pH and PVP concentration which are 8 and 0.095,respectively. Furthermore, in the abovementioned concentration of pH and PVP, optimum CuO volume fraction of 6% was obtained, in which, the thermal conductivity enhancement is 17% at 25^{o}C. Finally, with changing temperature at optimum values (for PVP surfactant and CuO nanoparticles), 31% increase in thermal conductivity was obtained at 50^{o}C.
***Keywords:** Nano Fluid, Stability, Volume Fraction, Thermal Conductivity.*

1. INTRODUCTION

It has long been recognized that the suspensions of solid particles in liquids provide useful advantages in industrial fluid systems, including heat transfer fluid, magnetic fluid, and lubricant fluid [1–5]. Since the working fluids have the limitation of heat transfer performance, solid particles were dispersed in the working fluids to improve their thermal properties or heat transfer characteristics [2, 6–9]. Choi [10] coined the term "nanofluids" for the fluids with nanoparticles suspended in them.

Recent experiments on nanofluids have shown substantial increases in thermal conductivity and convective heat transfer coefficient with low particle volume concentrations compared with liquids without nanoparticles or with larger particles, and substantial increases in critical heat flux in boiling heat transfer [11–18]. Even though various methods have been developed to prepare nanofluids, those previous approaches still had instability problems caused by particle agglomeration in the base fluids. Preparation of stable nanofluids is the first step and key issue of nanofluid research and applications in order to prepare stable nanofluids, numerous investigations on colloidal dispersions have been conducted in view of particle motion analysis in various flow conditions and sedimentation characteristics studies on suspended nanoparticles in base fluids [19–21]. Efforts to synthesize nanofluids have often employed either a single-step method [22–26] or a two-step approach that first generates nanoparticles and subsequently disperses them into base fluids [11, 12, 15]. Among the various nanofluid preparation methods, the addition of surfactants was known to be effective to homogeneously disperse nanoparticles in the base fluids [27, 28]. The surfactants (e.g. Polyvinylpyrrolidone (PVP)) resulted in the electrostatic repulsion between surfactant-coated nanoparticles, which significantly reduces the particle agglomeration due to van der Waals forces of attraction [29].

In this research, the effects of nano-suspensions pH and surfactant (PVP) concentrations on the nano-suspension stability were investigated. In this regard, Zeta potential and absorbencywere measured to show the characteristic of the nano-suspensions system. Finally, the thermal conductivities of both of nanofluids were measured with transient hot wire (THW).

2. EXPERIMENTAL

2.1. Chemical

CuO nano powders with copper oxide content of >99.9% was used in the study, which was synthesized according to our previous article. The SEM, PSA, and XRD of CuO nano powdersare shown in Figure 1(a-c) which shows average diameter of 4 nm [30].

(a)

(b)

(c)

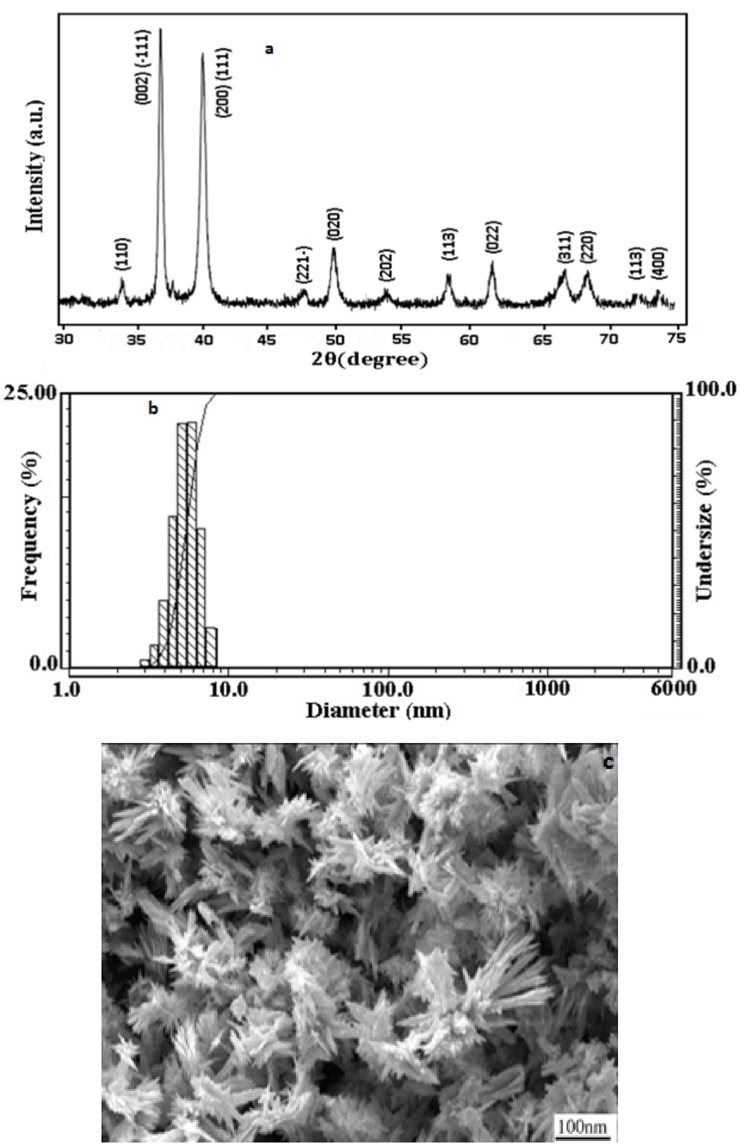

Figure 1: *(a) XRD pattern, (b) PSA pattern, and (c) SEM pattern of CuO nanoparticles.*

2.2. Evaluation of dispersion by using the UV–visible absorption spectrum

Evaluation of dispersion characteristics of the CuO nano-suspensions was accomplished using the UV–Visible absorption spectrum. The experiments were conducted using 100 ml of 0.01 M CuO nano-suspensions. Different concentrations of the surfactant (PVP) were added to the nano-suspensions, which were thoroughly stirred with magnetic stirrer for at least 1 h with 1100 rpm and sonicated with the ultrasonic disruptor for at least 9 h at 25°C. In addition, 15 ml of each nano-suspension was then poured into test tubes, and for a few days, the samples were allowed to sediment. The absorbency of the nano-suspensions was measured on a UV–Visible absorption spectrum after sedimentation. The pH value of the system was regulated with HCl and NaOH solution with accurate pH Meter.

2.3. Measurement of zeta potential and thermal conductivity

In examining the absorbency and sedimentation figures, 0.01 M CuO nano-suspensions were used. However, for measuring zeta potential, a higher amount of CuO nanoparticles was not appropriate. Instead, the dilute 0.005 M CuO nano-suspension was selected. A Malvern ZS Nano S analyzer measured the zeta potential. The measurement was run at V =10 V, T = 25^{o}C with switch time of t=20 s. The thermal conductivity of nanofluid was measured using the THW method applied in significant researches where the rises in the temperature of the hot wire are related to the thermal conductivity, k, of fluid [31].

3. RESULTS AND DISCUSSION

3.1. Preparation of nanofluid

To synthesize the nanofluids, the two-steps method was selected.In this study, CuO nanoparticles (0.01 M) solved in awater solution (100 ml) with PVP surfactant (0.003 M) were directly mixed in a 150-ml beaker. The nano-suspensions were thoroughly stirred with magnet, and then it was transferred into an ultrasonic disruptor and sonicated at 25^{o}C
Figure 2 illustrates the PSA of CuO–water nano-suspensions in the presence of PVP surfactant.
The average particle sizes obtained in the presence of PVP surfactant were about 63 nm. Therefore, the stabilization of CuO–water nano-suspensions with PVP surfactant is more suitable.

3.2. The influence of pH and PVP surfactant on the stability of CuO nano-suspensions

The stability of CuO nano-suspensions in aqueous solution is closely related to its electrokinetic properties. Well-dispersed nano-suspensions can be obtained with high surface charge density to produce strong repulsive forces. Then, the study of the electrophoretic behavior through measurement

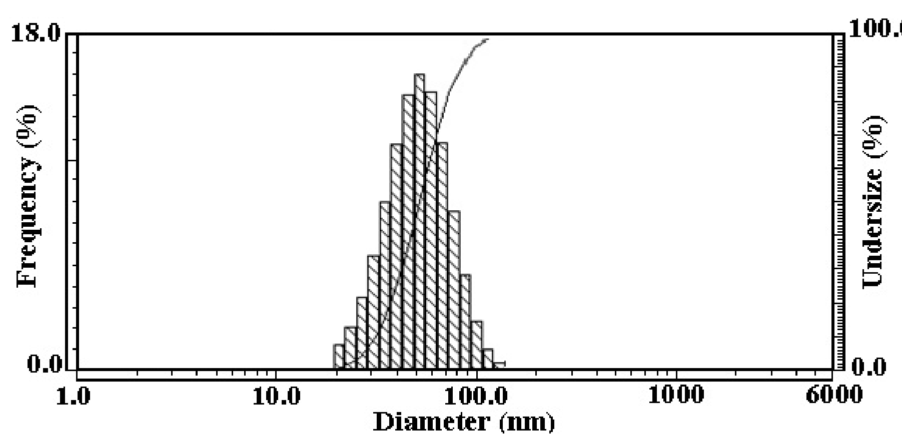

Figure 2: *PSA of CuO–water nano-suspensions PVP surfactant.*

of the zeta potential becomes important for understanding the dispersion behavior of CuO nanoparticles in a liquid medium [32–34].

The zeta potential values of CuO–water nano-suspensions with PVP surfactant at different pH values are presented in the Figure3 and Table 1.

According to the zeta potential values of CuO nano-powders, pH 8 can be selected as an operating pH for CuO-water with PVP surfactant. This is due to the higher absolute value of zeta potential in the aforementioned pH.

At pH less than 2, the zeta potential of the nanoparticles' surface (Figure 3) is at its lowest amount; therefore, the force of electrostatic repulsion between nanoparticles is not adequate to overcome the attraction force between nanoparticles. The absorbency (Figure 4 and Table 1) is smaller, and scattering stability is poor. As pH increases, the zeta potential of the nanoparticles' surface increases, so the electrostatic repulsion force

Table 1: *Effect of pH on the zeta potential and absorbency for water base-fluid with PVP surfactant.*

	Zeta Potential	Absorbency		Zeta Potential	Absorbency
pH	**water**	**water**	**pH**	**water**	**water**
2.0	2.10	0.03	**7.5**	16.9	0.75
2.5	3.50	0.09	**8.0**	18.4	0.80
3.0	4.10	0.16	**8.7**	17.5	0.77
3.5	5.30	0.20	**9.0**	16.0	0.73
4.0	6.70	0.27	**9.5**	15.3	0.69
4.5	7.80	0.33	**10.0**	13.9	0.62
5.0	8.10	0.37	**10.5**	12.1	0.61
5.5	9.80	0.41	**11.0**	10.2	0.55
6.0	10.3	0.48	**11.5**	9.90	0.52
6.5	12.0	0.53	**12.0**	8.10	0.49
7.0	13.4	0.67	---	---	---

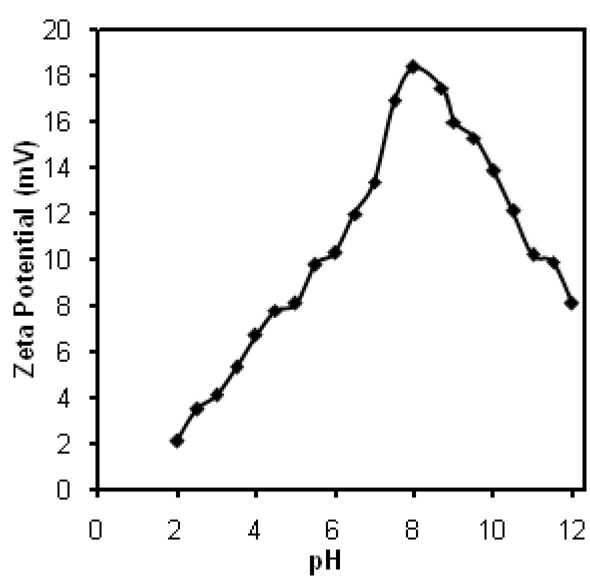

Figure 3: *Effect of pH on the zeta potential of CuO–water nano-suspensions with PVP surfactant.*

between nanoparticles becomes adequate to prevent attraction and collision between nanoparticles caused by Brownian motion.

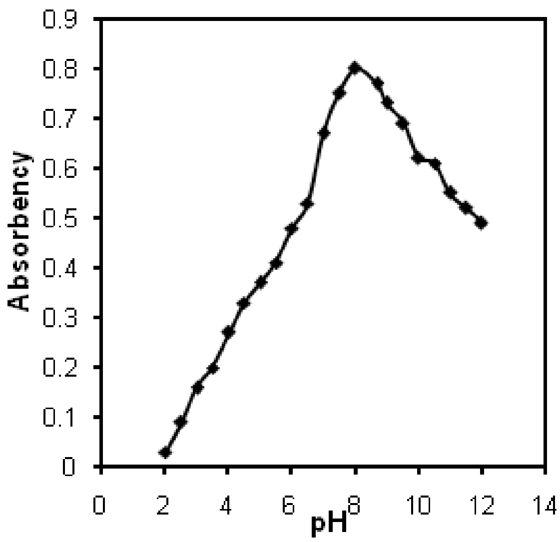

Figure 4: *Effect of pH on the absorbency of CuO–water nano-suspensions with PVP surfactant.*

The absorbency also becomes higher with rise in pH, leading to an improvement of the scattering stability of CuO nanoparticles. Having pH 8 for PVP surfactantthe zeta potential and the absorbency become even higher. The electrostatic repulsion force between particles is stronger, and the coagulated nanoparticles can be re-dispersed through mechanical force, so the scattering stability of CuO nanoparticles is at its best. As pH value continues to increase, the concentration of the pH regulation reagent (NaOH) in the system increases, which causes the compression of electrical double-layer, so lowering the zeta potential of the nanoparticles' surface and electrostatic repulsion force and the nano-suspensions illustrates a poorer scattering.

Figure 5 and Table 2 show the effect of PVP surfactant concentration on the stability of 0.01 M CuO nano-suspensions at pH 8.

Table 2: *Effect of PVP mass fraction on the zeta potential and absorbency for water base-fluid.*

	Zeta Potential	Absorbency
Mass Fraction	Water	Water
0.010	6.50	0.06
0.020	9.10	0.11
0.025	9.70	0.12
0.030	11.4	0.24
0.045	13.9	0.35
0.050	18.6	0.46
0.070	21.5	0.57
0.085	29.3	0.68
0.095	32.3	0.72
0.150	28.1	0.66
0.200	15.6	0.54
0.250	11.8	0.41

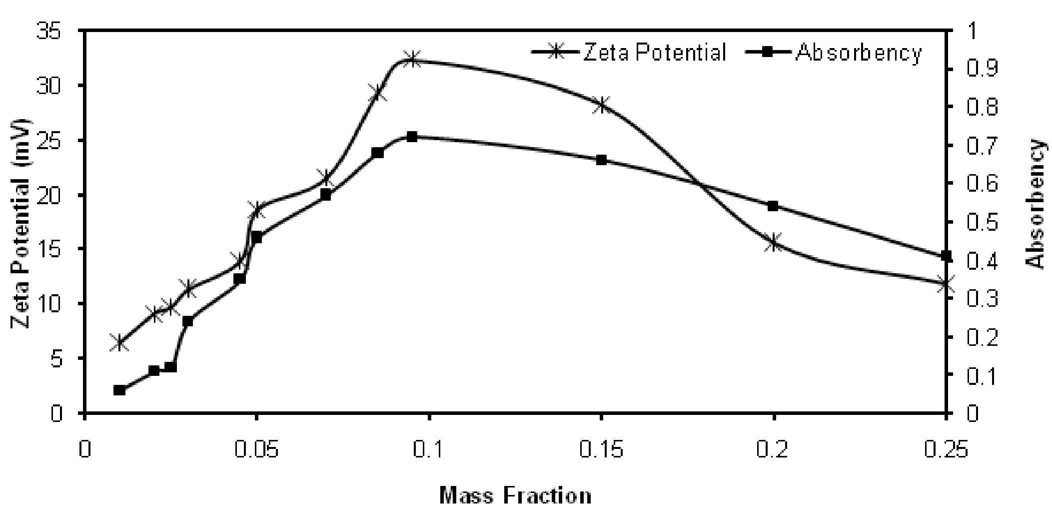

Figure 5: *Effect of PVP concentration on the zeta potential and absorbency of CuO-water.*

As the results show, with increasing PVP concentration, the surface charges on CuO nanoparticles remained positive, and the zeta potential along with the absorbency both firstly enhance and then reduce. In addition, the dispersion stability firstly increases and then decreases. The optimum concentration of the PVP was found to be 0.095 % wt. At this level of concentration, the zeta potential and the absorbency are maximal.

3.3. Measuring thermal conductivity of CuO-EG nanofluids

In this work, we investigated the change in the thermal conductivity of sample (CuO-water with PVP surfactant) with volume fraction and temperature. The thermal conductivity of nanofluids was measured by the THW method. To eliminate the efficacy of natural convection, data were collected only from 100-300 ms. As shown in Figure 6 and Table 3, the thermal conductivities of nanofluids improve as the concentration of particles increases (at 25°C). Notably, pH is 8 for CuO-water with PVP surfactant. In addition, weight percent of the surfactant is 0.05.

Even at a very low concentration of 1% (volume fraction), about 0.9 % increase is observed which is appropriate compared to the volume fraction of nanoparticles and also the maximum enhancement in thermal conductivity is 17% at 25°C.

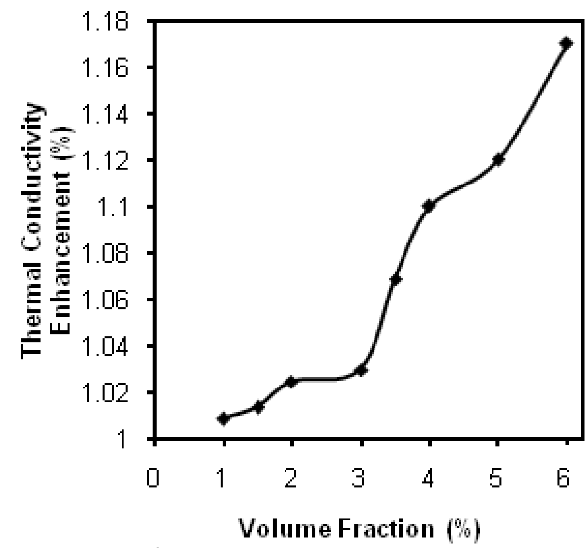

Figure 6: *Effect of volume fraction CuO nanoparticles on the thermal conductivity of nano-suspensions with PVP surfactant.*

Figure 7 and Table 3 represent the thermal conductivity enhancement ratios vs. temperature (°C) for CuO-water nanofluids with PVP surfactant. It is also worth noting that volume fraction of CuO nanoparticles is 6 (percentage).

Table 3: *Effect of volume fraction (%) and temperature on the thermal conductivity enhancement.*

Vol. Fra. (%)	Enh.Ther. Con. (%) Water	Temp. (°C)	Enh.Ther. Con. (%) Water
1.0	1.009	**10**	9.00
1.5	1.014	**15**	11.0
2.0	1.025	**20**	14.0
3.0	1.030	**25**	17.0
3.5	1.069	**30**	20.6
4.0	1.100	**35**	23.0
5.0	1.120	**40**	26.4
6.0	1.170	**45**	29.0
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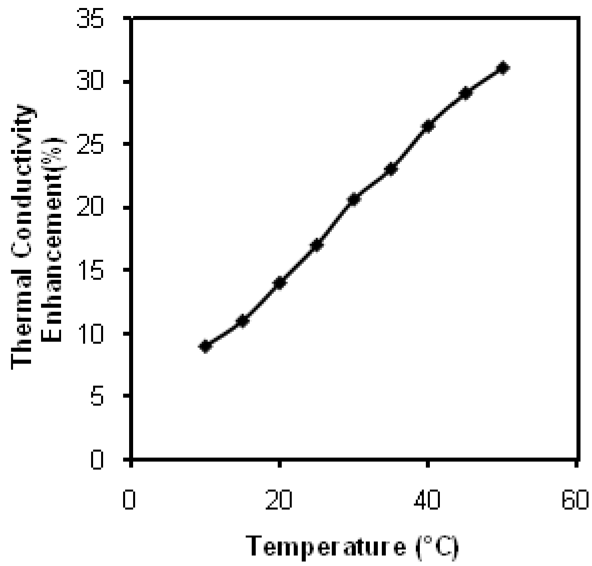

Figure 7: *Effect of temperature on the thermal conductivity CuO-water with PVP surfactant.*

Figure 7 indicates that the thermal conductivity increases with temperature rise and the maximum thermal conductivity is 31% at 50°C. In addition, in cases using PVP surfactant, thermal conductivity is much higher than the ones without PVP surfactant.

4. CONCLUSION

Based on the work performed in this paper, the following overall conclusions can be presented:

* When the CuO–water nano fluids were synthesized by two-steps method, the observed PSA showed better scattering.
* To select appropriate conditions for scattering nanoparticles, absorbency and zeta potential are essential basis. In addition, there is an excellent relationship between absorbency and zeta potential.
* The efficacy of pH on the stability of the CuO nano-suspension was investigated. At pH values of 8, an excellent dispersion of CuO nanoparticles was obtained.
* The stability comportment of the 0.01 M CuO nano-suspensions with PVP surfactant and concentration was investigated at pH 8by making use of zeta potential, absorbency techniques.
* The following were the optimized values: pH (8 with PVP surfactant and water base-fluid), surfactant concentration (0.095%wt), nanoparticles concentration for measuring thermal conductivity (6%), and temperature (50°C).

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