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FORMATION OF DIFFERENT Cu NANOPOWDERS AND STABILITY OF Cu FLUIDS PRODUCED BY ELECTRICAL EXPLOSION OF WIRE IN LIQUID

In this study, copper nanoparticles and nanofluids were synthesized by electrical explosion of wire (EEW) in liquid media such as water, ethanol, and acetone. The effect of the different conditions on the properties of the as-synthesized Cu powders and nanofluids were investigated. X-ray diffraction (XRD) analysis was employed to measure the phase of the as-synthesized powder. Only pure Cu phase appeared in case of acetone condition, but CuO and CuO_2 phases could be observed in the others. The EEWed particle size was broadened from under 50 to 100 nm. The results showed that acetone was the best condition for achieving smaller particles, preventing the oxidation of the Cu particles and good stability of the nanofluids.

Keywords: Cu nanopowder, Cu nanofluids, electrical explosion of wire, stability of nanofluids

1. Introduction

Copper nanoparticles and nanofluids have received a lot of attention and investigated extensively thanks to their remarkable properties such as electrical conductivity, catalytic and low cost in comparison with gold and silver. The copper nanoparticle was applied in various fields including lubricants, catalysts, conductive films, sensor, magnetic recording media and biomedical devices. [1,2]. Copper nanofluids are also shown very promising candidates for heat transfer application [3]. Nano-sized copper particles and Cu nanofluids were prepared through the various kind of physical and chemical methods such as thermal decomposition, radiation methods, physical vapor deposition and wet chemical methods, etc. [4-6]. Among these methods, the electrical explosion of wire (EEW) is an attractive method of fabrication the nanosized powders and nanofluids due to the simple and promising methods for low-cost production. Because of that EEW has been employed in many studies to synthesise copper nanoparticle and its nanofluids. However, most of the research only focused on using EEW to prepare an initial material for the next steps of processing with the support of others auxiliary methods like heat treatment [7-9] or only conducted in individual condition ambient. There are few studies given out the effect of EEW working conditions on the properties of the prepared Cu particles and the stability of Cu nanofluids. In this work, the electrical explosion of wire in liquids was used to explode Cu wire in acetone, ethanol, and DI water, respectively. The effects of ambient condition on properties of Cu nanoparticles and the stability of Cu nanofluids were investigated with the aim of enriching the knowledge in this field and give out a comparison for helping the selection suitable conditions in specific applications.

2. Experimental

The Electrical explosion of wire in the liquid process was used to prepare copper nanofluids and nanoparticles. The experimental procedure of the EEW process was described previously [10]. In this research, the typical experimental conditions are presented in Table 1. The copper wire (0.2 mm in diameter and 27 mm in length; Nilaco) was used to prepare the copper suspensions by exploding it in 0.5 liters of acetone, ethanol, and DI water, respectively. The number of explosions was calculated about 100 times for each process. After the explosion, the prepared suspension was sonicated for 5 minutes before analysis. The stability of the obtained Cu dispersions was evaluated by using Turbiscan Lab (Formulaction Co., France) and zeta potential analyses. In addition, to determine the phase and the morphology of the nanopowder, a small amount of powder was taken out from the fluid by centrifuging and dried under vacuum condition and then collected for the X-ray diffraction (XRD) and field emission scanning electron microscopy (FE-SEM) analyses. The shape and size of the nanoparticles were carried out by TEM. Finally, depending on the analysis results the effect of condition factors on the properties of as-produced nanopowders and the stability of the obtained fluids was estimated.

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TABLE1

Conditions of the EEW process

Capacitance	30 μF
Charging voltage	3 kV
Cu wire diameter	0.2 mm
Wire length	27 mm
Ambient liquid	Acetone, Ethanol, DI water

3. Results and discussion

The XRD diffraction patterns of the as-synthesized powders are shown in Fig. 1. For all samples, the XRD patterns show the major diffraction peaks at 43.29; 50.43 and 74.13° corresponding to (111), (200) and (220) planes of the fcc structure of pure Cu (JCPD no. 71-4610). However, only the sample prepared in acetone shows the peaks of pure Cu, meanwhile there is the presence of a small peak at 36.41° corresponding to the CuO_2 phase for sample exploded in ethanol and the diffraction peaks of overlapping phases CuO and Cu_2O for the sample produced in DI water. This result indicates that when acetone was used as a liquid condition in EEW, the oxidation of Cu particles during the explosion time was prevented. The oxidation of Cu particles increased in case of ethanol and DI water was used in EEW

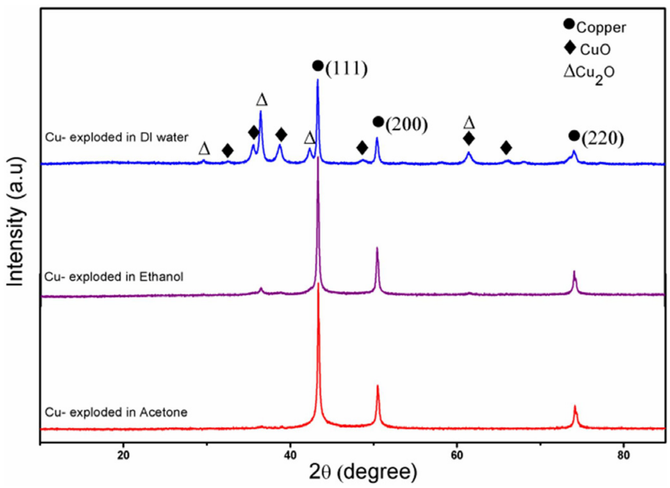

Fig. 1. XRD pattern of Cu nanopowder prepared by EEW in acetone, ethanol and DI water

process. The appearance of CuO and Cu_2O phase is attributed to the interaction of Cu with oxygen diluting in the liquid when the Cu vapor condensed. Furthermore, the formation of copper nanoparticles and copper oxide can be presented by the following steps. Firstly, due to the resistance of the solid wire being much smaller than that of the liquid condition, the electric energy is only deposited on the wire. The rate of the energy injecting to the wire becomes higher and higher. When the energy density exceeds the binding energy, the Cu wire was boiled up in a burst, a plasma formation and a shockwave scatter into the ambient medium leading to the formation of explosion zone. And then, the superheated vapor and boiling droplets of the exploding Cu wire are rapidly cooled down by collision with the liquid molecule and finally, the nanopowders are formed. Besides the formation of nanoparticles, in some ways, the explosion affected to the molecule of the liquid leading to the emission of the free oxygen. These new-created nanoparticles in the explosion zone are very active, therefore, it could react with oxygen diluting in the liquid easily and immediately, resulting in the formation of copper oxides. The oxidation of copper could be expressed by the two following equations [11].

$$Cu + O_2 + H_2O \rightarrow Cu_2O \tag{1}$$

$$Cu_2O + O_2 \rightarrow CuO \tag{2}$$

According to these equations, and apply to the acetone, ethanol and DI water condition, it could be predicted that the formation of oxygen and H_2O could not occur in the acetone, therefore only pure Cu phase was formed in the explosion zone. For ethanol, it has potential to create a suitable environment for the formation of Cu_2O, but it is not enough for continuing the formation of CuO. In case of DI water condition, due to the existence of H_2O and diluted oxygen the oxidation of Cu nanoparticles found on the core-shell diffusion controlled mechanism [10,11]. Thus, the oxidation took place initially on the surface of the particles and formed a Cu_2O shell (Eq. (1)). Then oxygen infiltrated the oxide shell and the reaction was continued following by Eq. (2). Because of that, the phases of Cu_2O and CuO were created.

Fig. 2. shows the FE-SEM photograph of the as-synthesized powder. It could be seen that the powders were nearly spherical in shape when it was exploded in acetone and ethanol. However,

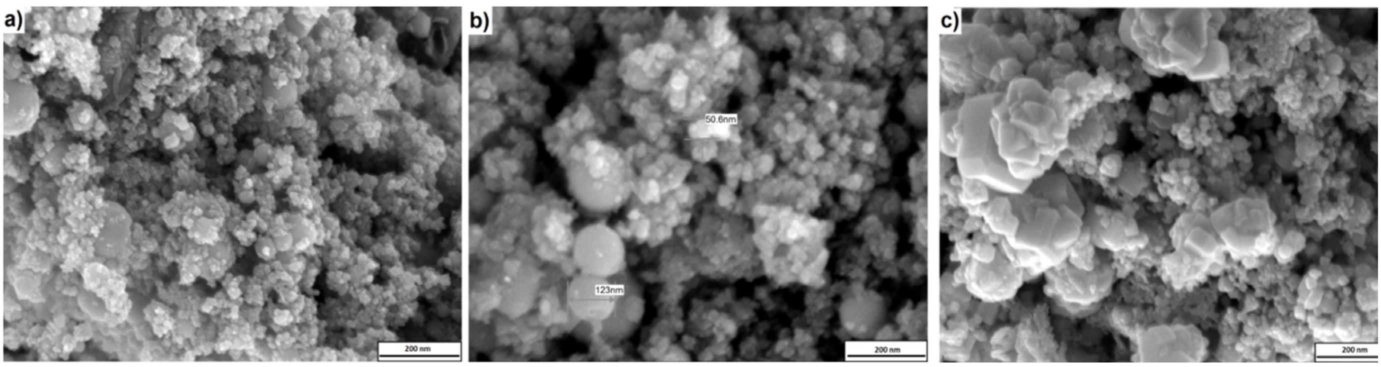

Fig. 2. FE-SEM images of the Cu particles exploded in a) acetone, b) ethanol and c) DI water condition

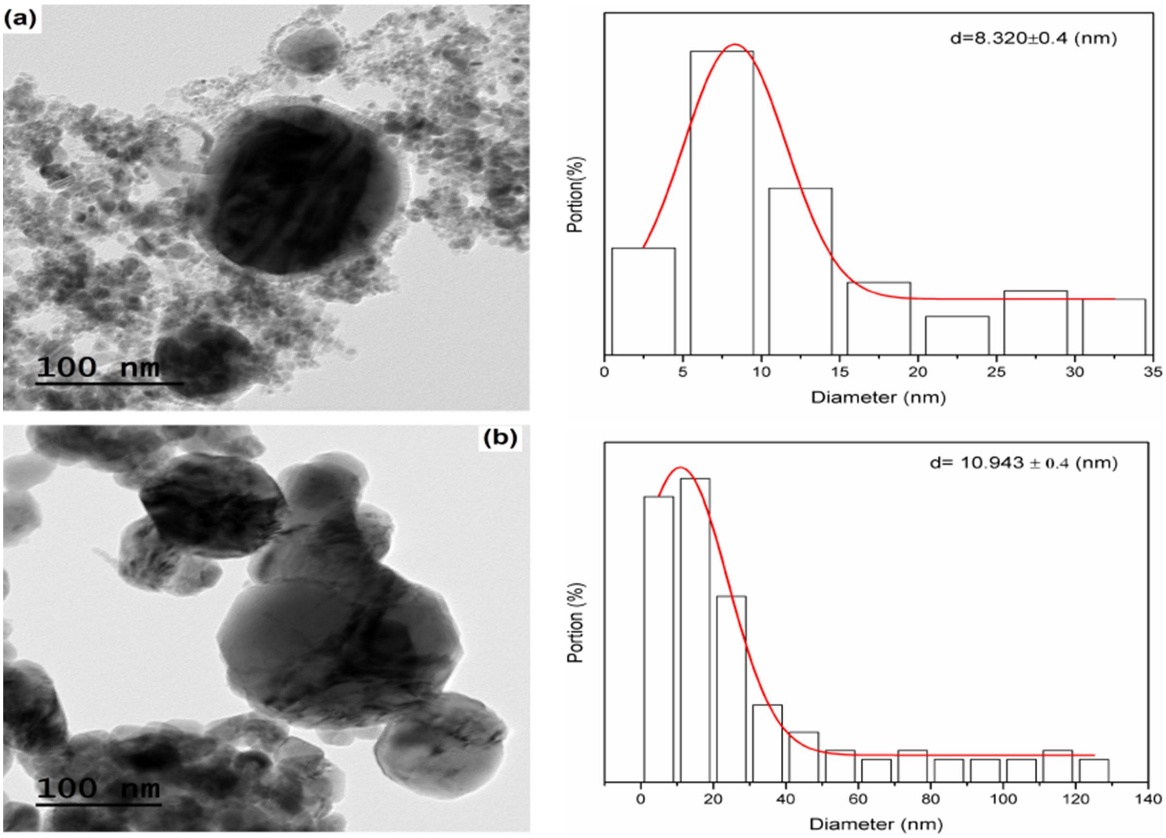

Fig. 3. TEM photograph of the nanopowders produced by the explosion of wire in: a) acetone and b) DI water

when DI water was used, besides the majority of the spherical shape, a small amount of the irregular shape was observed. From the TEM results Fig. 3, the particle sizes and particle distribution of the prepared powders were observed and classified into two groups: the first one with a diameter under 50 nm and the second one with a diameter in arrange of than 50-100 nm and the first group is dominant.

While investigating the particle shape with the phases of as-synthesized Cu nanopowders in different conditions, it could be revealed that only the CuO phase and irregular shape exist in the sample prepared in DI water. It predicts that the formation of the irregular shape could be a consequence of the presence of CuO phase. In fact, this supposition has been mentioned in some previous studies [12-14] and the formation mechanism of the irregular shape could be explained by a mechanism following. Fist, after the explosion, nucleation in the supersaturated vapor produces Cu nanoclusters, these Cu nanoclusters are then rapidly oxidized and turn into CuO nanoparticles. Then, these CuO nanoparticles tend to directionally self-organize and aggregate through a possible oriented attachment mechanism [15]. Because of that point, the anisotropic growth process starts and resulting in the creation of the irregular structure of the as-synthesized powder synthesized in DI water condition (Fig. 3b).

The stability of Cu nanofluids in this work was examined by using a multiple light scattering method. The delta (ΔT) backscattering and transmission profiles and the comparison about the stability of them are shown in the Fig. 4 and Fig. 5. It can be seen that, for Cu-acetone colloid (Fig. 4a), the ΔT transmission profile does not show any change because there is no transmission light went through due to the homogenous and concentration high enough of the opaque colloid. The variation of backscattering fell slightly versus time. The total decrease of backscattering level was about 1.2% after 3 days. However, after 1.5 months the sedimentation of this nanofluid cannot be recognized the change by naked eyes (Fig. 5). In case of DI water condition (Fig. 4b), there was aggregation at the beginning of the experiment, leading to the increase in backscattering for whole sample height. Due to the sedimentation occurred strongly, therefore the backscattering decrease at the top and decrease at the bottom. Furthermore, the big peak of transmission illustrates the clarification in the sample. With the Cu colloid prepared in ethanol (Fig. 4c), both transmission and backscattering signals increased over the time. On the first day, a variation of transmission signal gradually rose to the top of the bottle. After one day, almost particles sediment on the bottom, the transmission signal became flatter or the variation was constant due to the pure ethanol. This behavior revealed that the Cu nanofluids prepared by EEW in ethanol are unstable. The mean value of delta transmission, ΔT calculated between 5 mm and 45 mm of the sample tube of the nanofluids in different liquids for the time is presented in the Fig. 5. The Cu nanofluids in ethanol sample exposed the highest mean value of ΔT among samples, and the ΔT value dramatically increased up to about 60% within 1 day and reached 65% three days after the dispersion, illustrating the worst dispersion stability. The mean value of ΔT for the Cu nanofluids in DI water considerably increased with time and reached 28% three days after disper-

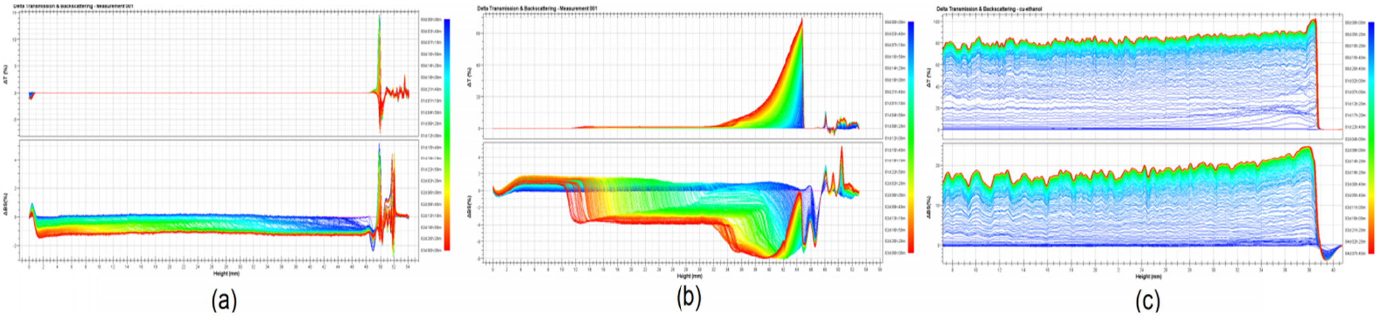

Fig. 4. Transmission and backscattering profiles of Cu nanofluids prepared by EEW in (a) acetone, (b) DI water and (c) ethanol in 3 days

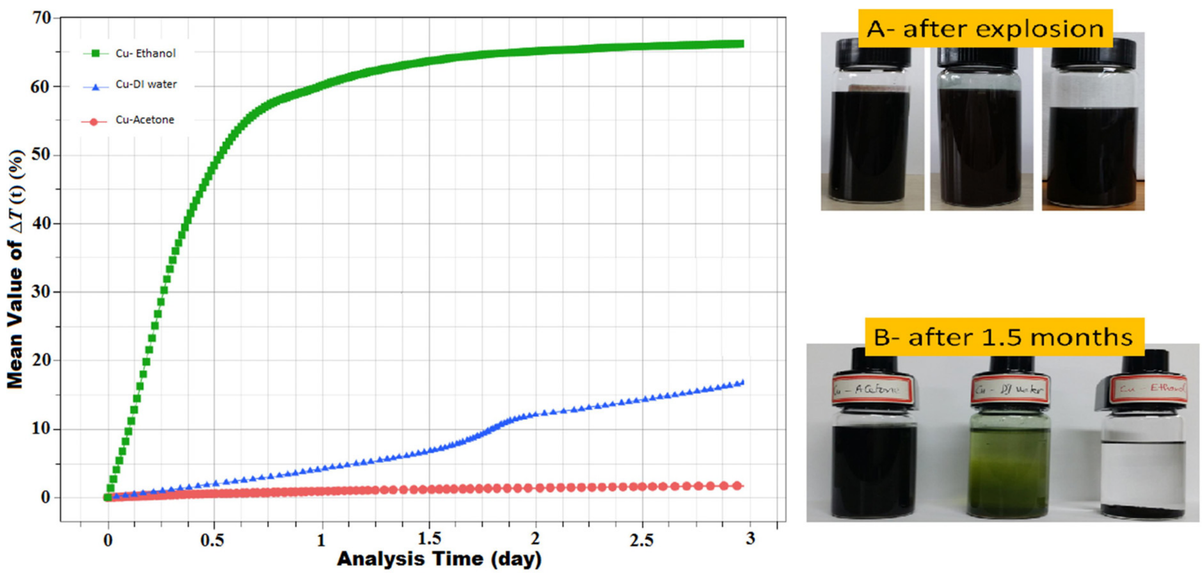

Fig. 5. Turbican stability index

sion. Contrastingly, the initial value of ΔT for Cu nanofluids in acetone was very low and remained constant thereafter. This value was only 2% three days after dispersion. Therefore, it is suggested that the acetone is highly effective in improving the long-term stability of Cu nanofluids. In addition, it is noted that the most important property of nanofluids is the tendency of the particles to aggregate. The aggregation of nanoparticles dispersed in fluid media occurs frequently and the stability of the dispersion is determined by the interaction between the nanoparticles. Many previous studies have reported that the stability of the dispersion in a liquid are highly related to its electrokinetic properties [16]. The suspension can be more stable with high surface charge value due to strong repulsive forces between two similar charged particles. Therefore, in this study, the zeta potential analysis was used for determining the surface charge of Cu nanoparticles in colloids [17,18]. This is a well known and widely accepted technique for understanding the state of the nanoparticle surface and valuation the stability of the nanofluids. Thus, in this work, zeta potential values of Cu colloids were investigated. The results showed that the zeta potential value of Cu nanofluids in ethanol, DI water were 0.59 mV, 8.03 mV, respectively. This confirmed the instability of Cu nanofluids in DI water and ethanol because a low zeta-potential value means Cu nanoparticles surface change was small, therefore, it could not prevent the agglomeration due to weak electrostatic forces. In contrast to that, the zeta potential of Cu particles in acetone was 31.93 mV which is high enough to keep the nanofluids stable because the threshold of stability of a colloidal system in terms of the zeta potential is about ±30 mV [19].

4. Conclusions

The properties of Cu nanoparticles and the stability of Cu nanofluids prepared by EEW in different liquid conditions were investigated. The particle morphology, phases of the prepared powders and the stability of the nanofluids are affected by the liquid condition. Generally, the as-synthesized Cu particle has a spherical shape, but the irregular shape was created in case of the DI water condition. Meanwhile, only pure Cu phases were observed when acetone was used, CuO phase occurred in ethanol condition and the overlapping of CuO and Cu_2O phases existed in DI water.This indicates that acetone is a good preventing oxidation condition for synthesis pure Cu nanoparticles in EEW process. The stability of Cu nanofluids that prepared in acetone condition after nearly 2 months predicts a potential for applying as a heat transfer liquid, surfactant condition, or in coating and electromagnetic interference shielding applications.

Acknowledgments

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