Synthesis and Optimization of Metallic Nanofluids using Electrical Explosion of Wires in Liquids

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ABSTRACT

Nanofluids, dispersed nano-sized particles in liquds have been drawing the attention for the research and industrial field. This study has been focusing on controlling the size, oxidation, and agglomeration of the nanoparticle by adjusting the plasma of EEWL and the base fluid, including water and ethanole and other common liquids. To identify the effect of the key parameters in EEWL, such as the applied electrical voltage, the capacitance, the type of metal wire and the solvent volume, the sensitivity analysis has been performed in terms of the size of nanoparticles. Based on this analysis, the optimization of the EEWL process for producing the metallic nanofluids has been carried out. In addition, the morphology of these metallic nanofluids was observed using high-resolution transmission electron microscopy.

Keywords: Metallic nanofluid, Electrical explosion of wire(EEL), Synthesis, Optimization

1 INTRODUCTION

Avanced cooling technology is one of the most vital needs in many industrial applications, such as heat transfer, automotive, electronics, biomedical device, manufacturing and others. However, there is the limitation of the conventional coolants. Nowadays, nanofluids, dispersed nano-sized particles in base fluids, have drawn tremendous interest from scientific and industrial communities because of their unique properties. In particular, nanofluids have gained interest as heat transfer fluids. Due to the high thermal conductivity of nanoscale metal particles, metal-nanofluids may significantly enhance thermal transport capabilities[1-5].

There are two kinds of preparation methods: an one-step method and a two-step method[6-8]. The two-step method forms nanoparticles using physical or chemical synthesis techniques and disperses them in basic fluids. The one-step method forms nanoparticles directly in basic fluids. A promising one-step method, physical synthesis technique, is the electrical explosion of wires in liquids (EEWL)[9]. Through the electrical explosion of wires, metallic nanoparticles are produced and directly dispersed into basic liquids. The EEWL has advantages, such as high-purity nanoparticle production without surfactant (non-toxic) unlike chemical technique, oxidation prevention using dense media and spherical nanoparticle production[10, 11].

In this study, three different metallic nanofluids were fabricated using EEWL. The effects of the energy deposited in the exploding wire was analyzed in terms of the size and shape of the metallic nanoparticles. The morphology was observed by FE-SEM and high-resolution transmission electron microscopy (HR-TEM). The size of nanoparticles was measured using a sub-micron size.

2 EXPERMENTAL SETUP

The metallic wire around 100 μm in diameter was installed in the cylinder filled with the liquids. The capacitor was charged to around 3kV and 5kV, and the current flowed through the metallic wire when the spark-gap switch was closed. High-temperature plasma was generated by the electrical energy deposited in the wire and was condensed by the basic fluids. A self-integrated Rogowsky coil and a high-voltage probe were used to measure the current and voltage waveforms, respectively.

There are many parameters can influence the metallic nanoparticles produced by EEWL. In this study, we examined the effects of capacitance, the solvent volume, and the metallic wire type. The experimental setup cosists of the high voltage power generator module, the switching part, and the solution chamber, as shown in Figure 1.

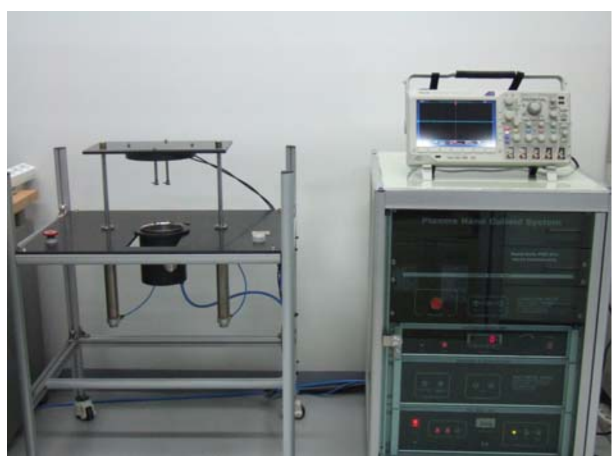

Figure 1: Illustration of the experimental setup

2.1 Synthesis of the metallic nanofluids

Three different metallic nanofluids including Ag, Cu and Al nanoparticles were produced in three kinds of fluids: Water, Ethanol, and Ethylene glycol by the EEWL method. Their fabrication condtions of the metallic nanofluids are summerized in Table 1.

Wire Materials	Cu, Ag, Al
Voltage(kV)	3,5
Capacitor(μF)	7.5, 30
Solvent	Water, Ethanol, Ethylene glycol
Volume of solvent(ml)	500,1000
Concentration(vol%)	0.001

Table 1: Summary of the fabrication conditions of the metallic nanofluids

Figure 2 shows the photographs of Ag nanofluids by the EEWl method. The color of the Ag nanofluid was changed corresponding to the fabrication conditions and concentrations.

Figure 2: The manufactured metallic nanofluids according to the sovlent voulme

Calculations of the deposited energy in the metallic wires on the basis of the measured current and voltage were carried out to identify the effect of the solvent type of the EEWL process.

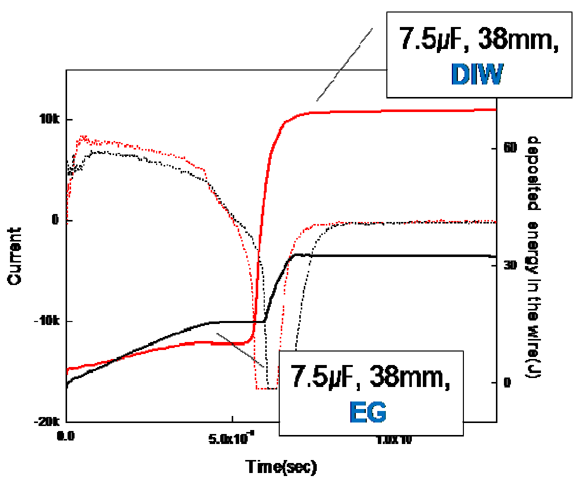

Figure 3: Effect of the liquid type on current and deposited energy for Cu nanofluids

Figure 3 shows the effect of the basic liquid type on the current and the deposited energy in the metallic wires. In case of Cu nanofluids, the percentage of the deposited energy in the wire to the input energy is 70.22% for Water and 50.96% for Ethylene glycol. As the deposited energy increases, the size of the Cu nanoparticles decreases.

In the EEWL process, the current drop is attributed to increase the resistivity of the metallic wire due to the vaporization of the wires in the basic liquids. It was also observed that the low capacitance let to the faster electrical explosion of the metallic wires and the shorter time of the plasma formation. In addtion, experimental results show that the larger capacitor produced the smaller metallic nanoparticles.

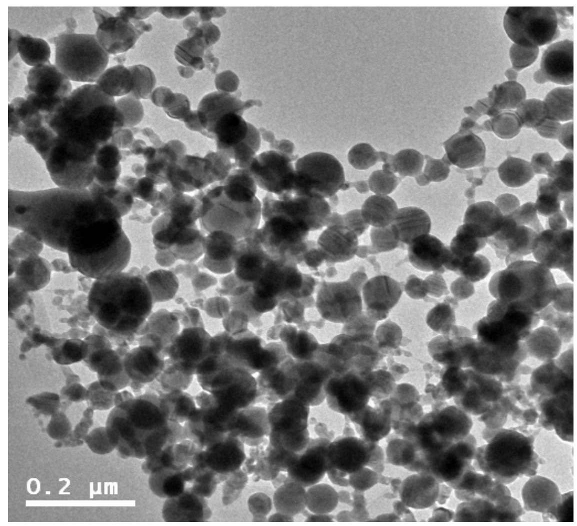

Figure 4: TEM image of Ag nanofluids produced by EEWL

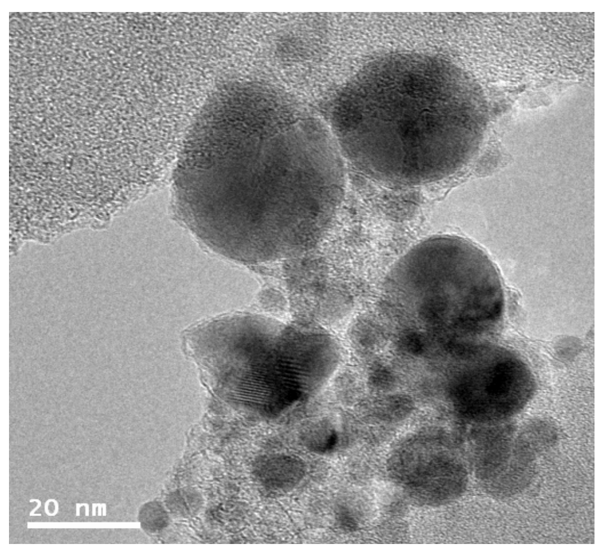

Figure 5: TEM image of Cu nanofluids produced by EEWL

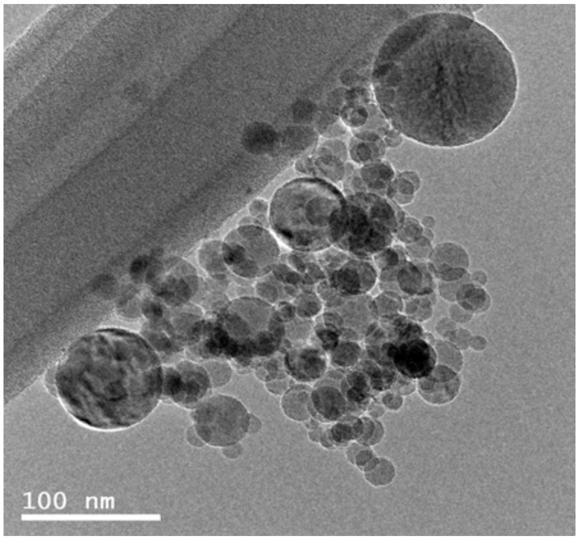

Figure 6: TEM image of Al nanofluids produced by EEWL

The morphology and size of the metallic nanoparticles were analyzed. Figure 4, Figure 5 and Figure 6 show the typical TEM micrographs of the Ag, Cu, Al nanofluids. The coagulation of the metallic nanoparticles may result from the drying process of the TEM and SEM sample preparation, as shown in Figure 7. It was observed that the metallic nanoparticles produced by the EEWL process have the spherical shape. Their surface is smooth.

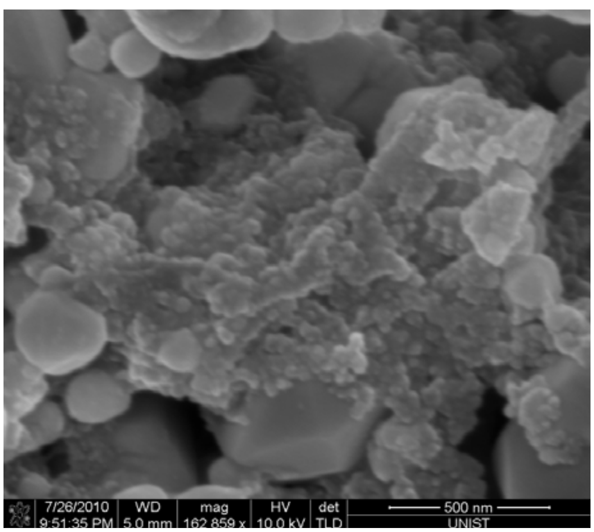

Figure 7: SEM image of Ag nanofluids produced by EEWL under 5kV

Figure 7 and Figure 8 show the typical SEM and TEM micrographs of the Ag nanofluids produced by EEWL under 5kV. It is observed that the higher voltage led to the smaller size of the the metallic nanoparticles. However, the difference of the zeta potential is relatively small according to the change of the input voltage

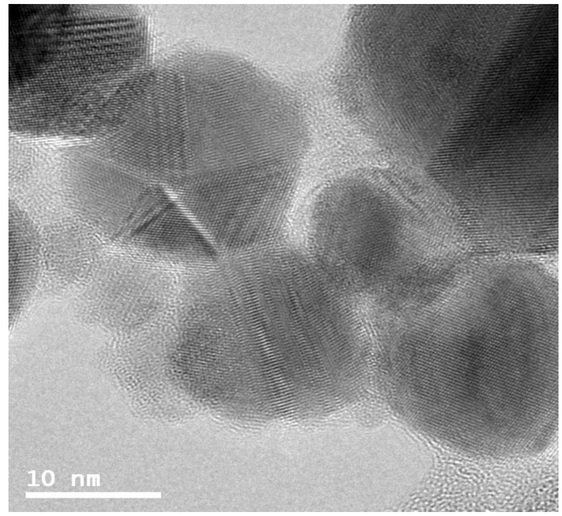

Figure 8: TEM image of Ag nanofluids produced by EEWL under 5kV

Figure 9 and Figure 10 show the histogram of size-distribution of Ag nanoparticles produced by the EEWL method under 5kV and 3kV The average size of the Ag nanoparticles is 66.8nm for 5kV and 115.8nm for 3kV. In case of 5kV input voltage, the size of the Ag nanoparticle was decreased. However, there are three separate distribution peaks of the histogram which may come from nonequilibrium conditions of the EEWL process or aggregation of the some metallic nanoparticles.

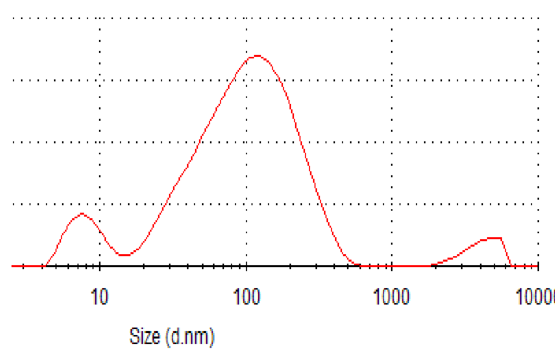

Figure 9: Size distribution for Ag nanoparticles in water prepared by EEWL under 5kV

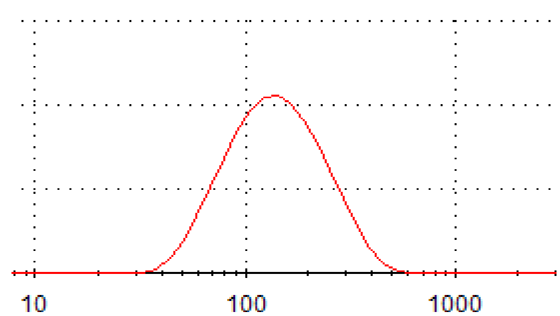

Figure 10: Size distribution for Ag nanoparticles in water prepared by EEWL under 3kV

3 CONCLSUION

In this study, three different metallic nanofluids were produced by the EEWL method. The effects of the deposited energy in the exploding metallic wire were analyzed in terms of the size and shape of the metallic nanoparticles. The higher deposited energy led to the decrease of the metallic nanoparticles. There is the change of the deposited energy in the metallic wire accroding to the type of basic fluids. The morphology of Cu, Ag, and Al nanofluids was also observed by FE-SEM and high-resolution transmission electron microscopy (HR-TEM). Although the higher voltage produced the smaller metallic nanopartics, the size distribution becomes broader due to non-equilibrium conditions of the EEWL process

REFERENCES

[1] P. Cheng, S. Choi, Y. Jaluria, D. Li, P. Norris, R.D.Y. Tzou, Journal of Heat Transfer, 131, 030301, 2009.

[2] O.P. Siwach, P. Sen, Materials Science and Engineering: B, 149, 99-104, 2008.

[3] Y. Xuan, Q. Li, Journal of Heat Transfer, 125, 151-155, 2003.

[4] H.E. Patel, S.K. Das, T. Sundararajan, A.S. Nair, B. George, T. Pradeep, Applied Physics Letters, 83, 2931-2933, 2003.

[5] K.V. Wong, O. De Leon, Advances in Mechanical Engineering, 2010, 1-12, 2010.

[6] D.W. Zhou, International Journal of Heat and Mass Transfer, 47, 3109-3117, 2004.

[7] A.K. Santra, S. Sen, N. Chakraborty, International Journal of Thermal Sciences, 47, 1113-1122, 2008.

[8] J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, Applied Physics Letters, 78, 718-720, 2001.

[9] C.H. Cho, S.H. Park, Y.W. Choi, B.G. Kim, Surface and Coatings Technology, 201, 4847-4849, 2007.

[10] E.J. Park, S.W. Lee, I.C. Bang, H.W. Park, Nanoscale research letters, 6, 1-10, 2011.

[11] E.J. Park, L.H. Bac, J.S. Kim, Y.S. Kwon, J.C. Kim, H.S. Choi, Y.H. Chung, Journal of Korean Powder Metallurgy Institute, 16, 217-222, 2009.