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Effect of characteristics of media on cobalt and iron nanoparticles prepared by arc discharge method

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ABSTRACT

Above a critical size, cobalt (Co) and iron (Fe) nanoparticles (NPs) aggregate due to magnetic dipole–dipole interaction into chains. In this paper, the effect of liquid environment on nucleation, growth and aggregation of Fe and Co nanoparticles is reported. The iron NPs were prepared by novel arc discharge method in ethylene glycol and 1-propanol and the cobalt NPs were prepared by that method in five liquid environments: ethylene glycol, 1-propanol, ethanol, methanol, and deionized water. SEM and FE-SEM observations were employed for morphology of the NPs. Meanwhile, in this case, the effect of media was discussed by considering the characteristics of the solution such as size, shape and dipole moment of its molecules. Preparation of Fe results shows that compared to 1-propanol a denser agglomeration can be seen among the NPs dispersed in ethylene glycol and the NPs possess a broader size distribution. Preparation of Co NPs in five solvent results if a solvent has large molecules with small dipole moment then the NPs will be larger in size. When three different amounts of surfactant PVP is added to prepared Fe nanofluid, it can be concluded that a low PVP content leads to more uniform NPs with rather clear boundaries.

1. Introduction

In recent years, nanoparticle (NP) materials have attracted more attentions because of the different physical properties from those of the corresponding bulk material [1]. Magnetic nanoparticles have attracted special attention, because of their potential for using in various fields such catalysis, ferro fluids, magnetic refrigeration, motors, and electrical power transformation and Magnetorheological (MR) fluids [2–6]. The properties of magnetic NPs and their potential applications strongly depend on composition, size; shape, crystallinity and structure of metal NPs and various approaches have been developed to control them. Therefore, control of size and shape is very important for tuning its properties over a wide range.

A large number of reports are available on the synthesis of metal NPs in solution by different methods such as photochemical [7–9], electrochemical [10,11], chemical reduction [12–18], microwave-assisted processing [19], ultrasound processing [20], gamma irradiation [21–25], ion irradiation [26] and plasma processing [27]. Synthesis of metal NPs using chemical methods usually involve toxic chemicals which can be dangerous to our environment. Additionally, these methods are usually expensive. Among these the electrical arc discharge in liquids is very interesting due to simplicity of the apparatus building and cost-effective procedure to generate a high yield of NPs and of course in one step. On the other hand, in this method, changing the main parameters such as in arc current, voltage and liquid environment can result in nanostructures with diverse specifications.

Recently, some attempts have been made toward fabrication of NPs by arc discharge in liquids [28–31]. Further to our more recent studies on preparation of magnetic NPs, our research group has recently focused on preparation of pure iron (Fe) and cobalt (Co) NPs and investigating the effect of electric current on size and morphology of NPs by arc discharge method [32,33], investigating some size-dependent characteristics of Fe–Co NPs using a co-precipitation route [34], Spin-dependent transport properties [35] and a theoretical investigation on capacitive properties of Fe/MgO/Fe trilayers [36].

Here, we have synthesized Co and Fe NPs using arc discharge method and investigated the effect of synthesis media on the properties of synthesized NPs. For this purpose, Co NPs have been synthesized in five different media, ethanol, methanol, deionized water, ethylene glycol and 1-propanol and their properties have been compared and Fe NPs have been synthesized in two different media, ethylene glycol and 1-propanol, and their properties have been compared.

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We aimed to prepare a magnetic fluid using arc discharge method in liquid medium. Our investigation have shown that the arc discharge method is a good alternative, a relatively cheap process, and also environmentally friendly. To the best of our knowledge, this method of preparing the Co and Fe NPs by arc-discharge is not reported to date.

2. Experimental procedure

A schematic diagram of the arc discharge method in liquids is shown in Fig. 1. The preparation system is composed of two main parts: a high current DC power supply and a reactor including an anode, a cathode, and a micrometer. A DC Miller machine was used as the power supply. In our experiments, the cathode was held fixed within the arc chamber and the micrometer brought the anode close to the cathode. Two pure (99.960%) Co rods each of diameter 6 mm and two pure (99.990%) Fe rods each of diameter 5 mm were respectively used as the electrodes in each experiment and a 62 V DC voltage and 30 A current are applied between the electrodes. In these experiments only the anode is consumed during the arc discharge process, hence its diameter is especially important. The electrodes were submerged into EG and were vertically placed along the same axis about 1 mm apart. 200 ml of EG was used and prior to the reaction it was degassed for 90 min.

Initially, we brought the two electrodes into contact leading to a high current density. Then, the arc discharge slowly detached the moveable anode from the cathode. During the experiment, the arc gap was maintained at a preset value of about 1 mm to ensure a continuous arc discharge. During the arc discharge process, Co is ablated continuously from the anode and condensed into the liquid. During the process, a soot-like deposit was observed to be formed in the solution. In order to extract the dispersed particles, the solution was centrifuged for 10 min at 9000 rpm.

The produced precipitate was washed for five times with acetone and the samples were dried in Ar. To make the samples ready for view, a sputter coater (BAL-TEC Model SCDOOS) was applied to coat the samples with a thin layer of gold. Then, the field emission scanning electron microscopy (FE-SEM) analysis was taken by a FE-SEM instrument (Hitachi model S-4160) at room temperature and then, the scanning electron microscopy (SEM) analysis was taken by a SEM instrument (Phillips model XL-30) at room temperature.

3. Results and discussion

The liquid used in an arc discharge provides an environment in which the electric discharge gets carried out and all the physical and chemical interactions during the nanoparticle fabrication occur. Thus, characteristics of the solution such as size, shape and dipole moment of its molecules would have significant effect on the NP formation. Furthermore, stability of the NPs in the solution depends on nature of the interactions between the NPs and molecules of the solution. In the first part of this work, we will report fabrication process of the Fe NPs in ethylene glycol and 1-propanol and also investigate effects of the liquid environment on their size and stability. These two solutions were chosen because of the difference in their symmetry and carbon chain lengths. A scanning electron microscopy (SEM) image of the iron NPs is provided in Fig. 2. It can be seen that the NPs are generally spherical in shape and the average size of the NPs even though due to their agglomeration size estimation from these images would not be very accurate. However, average size of the NPs (Fig. 3) prepared in ethylene glycol were measured to be about 35–90 nm and the NPs prepared in 1-propanol were about 35–75 nm. Compared to 1-propanol, a denser agglomeration can be seen among the NPs dispersed in ethylene glycol and the NPs possess a broader size distribution. Fig. 2 reveals that the NPs dispersed in ethylene glycol agglomerate into clumps and these clumps also, as is obvious from Fig. 2(a), stick together to form some highly porous clusters while in Fig. 2(b) an almost uniform distribution with clear boundaries can be seen. In order to investigate the phase purity and crystal structure of nanoparticles we examined the NPs prepared in ethylene glycol by the XRD. Fig. 4 presents the XRD pattern of Fe nanoparticles. A main peak observed at about $2\mu = 44.53$ is assigned to the diffraction from the (1 1 0) plane of body center cubic (BCC) α-Fe. Another peak observed at $2\mu = 63.45$ which corresponds to the (2 0 0) plane. The peaks are in agreement with the JCPDS 06-0696 standard card. The particle size estimated using Scherrer's formula was about 14.56 nm.

Chemists vastly use polymers to control the growth process and crystal arrangement of minerals. Polymers interact differently with different faces of the crystals and can selectively hinder or boost growth of a special face. Moreover, poly (N-vinyl-2-pyrrollidone) (PVP) has been widely used as a stabilizer to work with EG for the synthesis of divers kinds of NPs. Molecular configuration of the vinylpyrrolidone (PVP) polymer has two resonances. In a polar environment such as water the amino acid band tends to transform into a hydrophilic –N+=C–O-band. Presence of the C–C bonds along with the C–O– bond causes the PVP molecule to be realized as a suitable surfactant. Fig. 5 shows morphology of the iron NPs in ethylene glycol with three different amounts 0.1, 0.5 and 4.5 ml of 0.003 molar PVP solutions in EG added to sample. It is observed from the figure that morphology of the iron NPs depends on the PVP concentration [see panels (a), (b) and (c)]. So it can be concluded that a low PVP content leads to more uniform NPs with rather clear boundaries. We can see that in Fig. 5(a) the NPs are

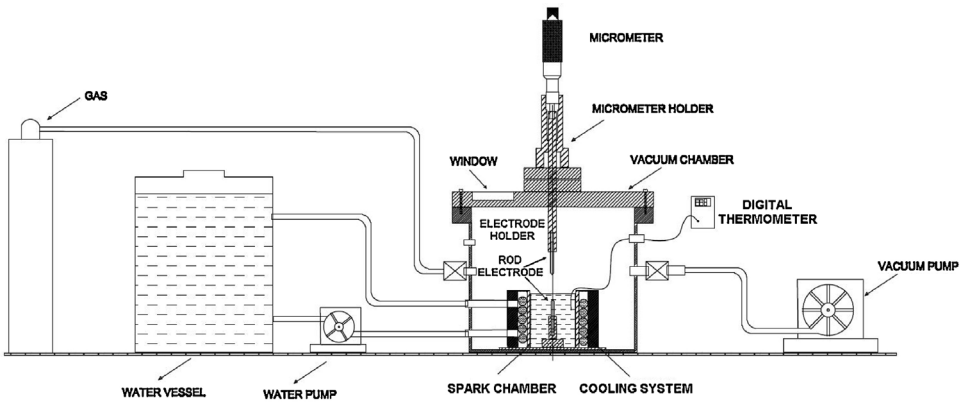

Fig. 1. Schematics of the nanoparticle fabrication system.