Effect of Magnetic Field on Thermal Conductivity of the Cobalt Ferrite Magnetic Nanofluids

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Abstract. Stable magnetic nanofluids of cobalt ferrite nanoparticles were synthesized by chemical co-precipitation method. The structural, morphological and magnetic properties were characterized by the X-ray diffraction (XRD), Transmission Electron Microscopy (TEM), and Vibrating Sample Magnetometer (VSM) respectively. The XRD study revealed the spinel structure of the prepared cobalt ferrite nanoparticles with \( Fd-3m \) space group. Prepared nanoparticles were found to be spherical in nature with average particles size of 10 nm. The prepared cobalt ferrite nanoparticles were exhibit near superparamagnetic behavior. These superparamagnetic cobalt ferrite nanoparticles used for the preparation of the magnetic nanofluids in ethylene glycol with various volume fraction concentrations viz. 0.2%, 0.4%, 0.6%, 0.8%, and 1%. The thermal conductivity of the ethylene glycol was significantly enhanced by dispersing the cobalt ferrite nanoparticles. The thermal conductivity of the prepared cobalt ferrite / ethylene glycol (COEG) magnetic nanofluid were also responded to the magnetic field intensity and shows increasing trend with increasing magnetic field intensity.

1. Introduction
Nanofluids are the colloidal dispersion of the nanosized particles of various materials in the host liquid [1]. The area of research is more attracted to the researchers from last few decades due to their promising properties in heat transfer systems [2]. Magnetic nanofluids (Ferrofluids) are the important class of the nanofluids and the magnetic materials. The ferrofluids are the suspension of the magnetic nanoparticles which exhibits properties of the fluids as well as the magnetic [3]. A wide range of carrier fluids are used and some magnetic nanofluids are commercially available to satisfy different applications. However, the choice of a carrier fluid for magnetic nanofluids suitable for heat transfer applications needs some additional requirements such as high conductivity, high heat capacity, high thermal expansion coefficient, etc [4]. Conventional heat transfer fluid (such as water, oils, ethylene glycol, etc.) could be a superior option for advanced applications [5-7].
Magnetic nanoparticles used in magnetic nanofluids are usually prepared in different sizes and morphologies from metal materials (ferromagnetic materials) such as iron, cobalt, nickel as well as their oxides (ferrimagnetic materials) such as magnetite (Fe$_3$O$_4$), spinel-type ferrites (MFe$_2$O$_4$, M is the metal divalent ion), etc. Among the spinel ferrites, Cobalt ferrite (CoFe$_2$O$_4$) is of great interest as promising materials for many applications [8-10]. For these reasons, engineers and scientists are keenly interested in determining their characterization. On the other hand, in the conventional heat transfer fluid, Ethylene glycol is an organic complex that is commonly used in numerous engineering applications, such as for antifreeze and other industrial products [11]. The use of ethylene glycol as a working fluid for convective heat transfer in automobiles, heat exchangers, liquid-cooled computers, fuel cells, heat pipes, heat pumps, etc [11-17].

Hence, in way of this, in the present investigation, we have employed a chemical co-precipitation method to synthesize CoFe$_2$O$_4$ nanoparticles. The cobalt ferrite nanoparticles were characterized further for their structural, morphological, magnetic properties and dispersion stability in order to explore various properties. The paper is intended to a relationship between thermo-magnetic properties and concentration of CoFe$_2$O$_4$ in nanofluids, which would be of great importance to the nanofluids.

2. Experimental

2.1. Synthesis of cobalt ferrite nanoparticles and preparation of nanofluids.

Primary chemicals were purchased from Merck Millipore of AR (analytical grade) grade. The chemical coprecipitation technique was used for the synthesis of CoFe$_2$O$_4$ nanoparticles [10]. To obtain the precursors the cobalt nitrate and ferric nitrate are separately dissolved in the stoichiometric ratio 1:2. To get the uniform assortment both the solutions are assorted together and stirred for the 1 h. The pH value of the assortment was checked and found to be 4. Further, the 2M solution of NaOH was added in the assortment to increase the value of pH up to 9. The assortment heated at boiling temperature for 2 h up to the black precipitation was obtained. After cool down the assortment, the obtained black precipitation was washed several times by water. Moreover, the 2M solution of HNO$_3$ was added to remove impurities present in prepared precipitation and stirred for the 1 h. Further, the supernatant solution is removed and the residue is cleaned by water and acetone by three times. The obtained nanoparticles were dried overnight at the 60°C in a microwave furnace. These cobalt ferrite nanoparticles were used to the preparation of the ferrofluid in the concentration of (0.2%, 0.4%, 0.6%, 0.8%, and 1% by volume) by dispersing them into ethylene glycol. To achieve uniform dispersion the prepared nanofluids were employed in ultrasonication for 3 hours, hence CoFe$_2$O$_4$ – ethylene glycol nanofluids were obtained.

2.2. Characterizations

The structural, morphological, elemental and magnetic analysis of prepared cobalt ferrite magnetic nanoparticles was studied using X-ray diffractometer (XRD), Transmission Electron Microscope (TEM), and Vibrating Sample Magnetometer (VSM). The magnetic properties saturation magnetization ($M_S$), remanence magnetization ($M_R$), and coercivity ($H_C$) of the CoFe$_2$O$_4$ nanoparticles were analyzed from M-H plot obtained from VSM. The transient hotwire technique is employed to measure the thermal conductivity of ferrofluids using the KD2 pro (Decagon Devices Inc.). An electromagnet is used to generate the uniform magnetic field. The electromagnet is connected to a DC power supply to provide desired magnetic field intensity. The intensity of the magnetic field is measured using a gauss meter. All the measurements are carried out twice and average values are used in the present study.

3. Results and Discussions

3.1. Structural, Morphological and Magnetic Analysis
FIGURE 1. (a) X-ray diffraction, (b) TEM micrograph and (c) M-H plot of the cobalt ferrite nanoparticles

The observed XRD pattern of prepared spinel CoFe$_2$O$_4$ nanoparticles is shown in Fig. 1 (a). From the figure, it can be revealed that the prepared nanoparticles have a well-crystalline phase. The crystal planes of (220), (311), (222), (400), (422), (333), (440), (531), (620), (553), and (444) were observed in XRD, it was also compared with the Joint Committee on Powder Diffraction Standards (JCPDS) (card number-96-591-0064). The XRD data reveals that the sample was crystallized in a single phase spinel structure corresponding to the $Fd-3m$ space group [18]. The calculated structural parameters are listed in table 1.

Table 1. Molecular weight (Mw), Lattice constant (a), crystallite size (D), particle size (D'), X-ray density ($\rho_{\text{XRD}}$), Bulk density ($\rho_{\text{BULK}}$), Porosity (P %), lattice microstrain ($\varepsilon$), dislocation density ($\delta$) and specific surface area (S) of cobalt ferrite nanoparticles

| Sample   | M$_W$ (g/mol) | a (Å)  | D (nm) | D' (nm) | $\rho_{\text{XRD}}$ (g/cm$^3$) | $\rho_{\text{BULK}}$ (g/cm$^3$) | P (%) |
|----------|---------------|--------|--------|---------|-------------------------------|-------------------------------|-------|
| CoFe$_2$O$_4$ | 234.62        | 8.374  | 10.40  | 9±2     | 5.424                         | 3.759                         | 32.02 |

Table 2. Saturation magnetization ($M_S$), Remanence magnetization ($M_R$), Coercivity ($H_C$), effective anisotropy constant ($K_{\text{eff}}$), surface anisotropy ($K_S$), magnetic moment per formula unit ($\eta_H$), maximum magnetic diameter ($D_m$) of cobalt ferrite nanoparticles

| Sample   | $M_S$ (emu/g) | $M_R$ (emu) | $H_C$ (Oe) | $K_{\text{eff}}$ ($10^5$ erg/cm$^3$) | $K_S$ ($10^2$ erg/cm$^2$) | $\eta_H$ ($\mu_B$) | $D_m$ (nm) |
|----------|---------------|-------------|------------|-------------------------------------|--------------------------|--------------------|------------|
| CoFe$_2$O$_4$ | 70.30         | 25.74       | 149.85     | 1.14                                | 0.78                     | 3.21               | 8.63       |

3.2. Effect of Magnetic Field on Thermal Conductivity

The thermal conductivity of the CoFe$_2$O$_4$/ethylene glycol nanofluids is shown in Fig. 2 (a-b). The observations are noted for the 0.2 % to 1.0 % volume fraction. In Fig. 2 (a-b) CoFe$_2$O$_4$/ethylene glycol nanofluid in the presence of a magnetic field is shown. For instance, at 0.2% vol. the thermal conductivity of the nanofluids increasing with increasing volume fraction at 0G to 50G and at 150G were increasing from 0.269 W/mK, 0.278 W/mK, and 0.280 W/mK respectively and same behavior observed for 0.4%, 0.6%, 0.8%, and 1% Vol. also, and a similar trend are shown for the al the
magnetic field strength. As the expected concentration of nanoparticles is a very important parameter in the thermal conductivity of nano-fluid CoFe$_2$O$_4$. With increasing Volume concentration of CoFe$_2$O$_4$, more chains in a magnetic field are created. So the thermal conductivity increases with the growth of the length of the chain [19]. When the magnetic field is applied to the nanofluid, the magnetic chains expand under the influence of an external field and hence thermal conductivity changed with increasing magnetic field strength (0G-150G).

![FIGURE 2](image-url). (a-b) Effect of magnetic field on thermal conductivity of the CoFe$_2$O$_4$/Ethylene glycol nanofluids.

The nanoparticles chains are created in a shorter time and hence thermal conductivity increases faster for the lower magnetic fields strength. Such an interpretation is entirely agreement with our results [20].

4. Conclusions

The cobalt ferrite (CoFe$_2$O$_4$) nanoparticles synthesized by the Chemical co-precipitation method. The cobalt ferrite nanoparticles and the prepared nanofluids were characterized further for their structural, morphological, elemental, magnetic properties and dispersion stability in order to explore various properties. It shows the prepared CoFe$_2$O$_4$ nanoparticles of spinel structured and 10 nm superparamagnetic, spherical in nature. The prepared nanoparticles were used to prepare stable CoFe$_2$O$_4$/ethylene glycol nanofluids were prepared using a two-step method. Cobalt ferrite nanofluids of various concentrations (0.2%, 0.4%, 0.6%, 0.8%, and 1% by volume) are prepared by dispersing appropriate amount of nanoparticles in water. Further, we attempt to study the thermal conductivity of the CoFe$_2$O$_4$/ethylene glycol nanofluids under the influence of the magnetic fields ranging from 0G to 150G at the 300K. The thermal conductivity of the nanofluid was found to be increasing with increasing volume fraction and magnetic field strength. The nanofluids at smaller magnetic field strength show faster growth in the thermal conductivity. This behavior of the magnetic nanofluids could open various applications of magnetic nanofluid such as heat transfer in automobiles, magnetic sealing, heat exchangers, liquid-cooled computers, fuel cells, heat pipes, heat pumps, etc.

5. References

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