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A Preliminary Study on the Thermo-optics Characteristics of Chromium Ferrite Ferrofluids

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Abstract. In this paper, we report the experimental observation of temperature influence on optical properties of ferrofluids comprising of chromium ferrite nanoparticles by a 1 mW He-Ne laser beam. An external thermal field was maintained perpendicular to the beam. In this research, the thermal response of chromium ferrite ferrofluids prepared by coprecipitation-sonochemical technique was studied. The preliminary investigation showed that the chromium ferrite ferrofluids have an excellent property as a candidate for a temperature sensor application showing a good response on the temperature treatment. Interestingly, we found a hysteresis phenomenon in one cycle in transmission light originating by varying temperature.

Keywords: Chromium ferrite, ferrofluids, sand, temperature sensor

1. Introduction

Ferrofluids are a stable colloidal suspension of ferromagnetic nanoparticles in certain liquid carriers composed of single-domain magnetic particles. The interaction of ferrofluids with the magnetic field is not only due to magnetic spin but also because of the flexibility of the fluid which facilitates particle orientation. Another exciting feature of ferrofluids is its sensitivity to physical field disturbances such as magnetic fields, electric fields, mechanical fields, and thermal fields.

The ferrofluids sensitivity has attracted many researchers' interest in developing ferrofluids based on optical sensors such as magneto-optics, electro-optics, elasto-optics, and thermos-optical sensors. The application of ferrofluids is widespread in various fields such as mechanical engineering, optical engineering, and biotechnology [1,2]. Therefore, studies on the magneto-optics properties of ferrofluids have been carried out by several researchers in order to develop optical-based magnetic field sensors. Konstantaki *et al.* showed the influence of ferrofluids as out-cladding overlayer of optical fibre long period grating on its spectral of under the static magnetic field [3]. In 2013, Pai and co-workers showed the phenomenon of the optical transient of ferrofluids [4].

In the previous years, several studies on the application of ferrofluids have been carried out in various fields, among others magneto-optical waveguide [5,6], magneto-optical wavelength filter [7], optical



switches [8,9], biosensors [10], hyperthermia treatment [11]. However, the physical parameter that needs to be considered in the application of ferrofluid in technology is the stability to temperature changes. In its application as an optical-based sensor, the changes in temperature will affect optical characteristics, such as changes in transmission intensity, optical wave polarization, and refractive index. Therefore, it is necessary to study the thermo-optical properties of ferrofluids. In this work, the ferrofluids were prepared by using chromium ferrite nanoparticles as magnetic particles obtained from natural sand.

2. Methods

Chromium ferrite ferrofluids were synthesized by the coprecipitation and sonochemical methods using natural sand as the main precursor. The detailed experimental set-up for preparing the sample and its structural characters were reported in our previous work [12]. In this work, the sample was placed in a glass box measuring with an area of $1.5 \text{ cm} \times 2 \text{ cm}$ and a thickness of 0.2 cm . Thermo-optical experiment was carried out by firing laser beams penetrating the glass box containing the ferrofluids sample. The intensity of the laser beam before and after penetrating the sample in the glass box was measured using a photodetector. The temperature on both sides of the glass beam is measured using a thermometer. The intensity recorded by the detector was maintained by varying temperature. The detailed of a set-up of a thermo-optical experiment is shown in Figure 1.

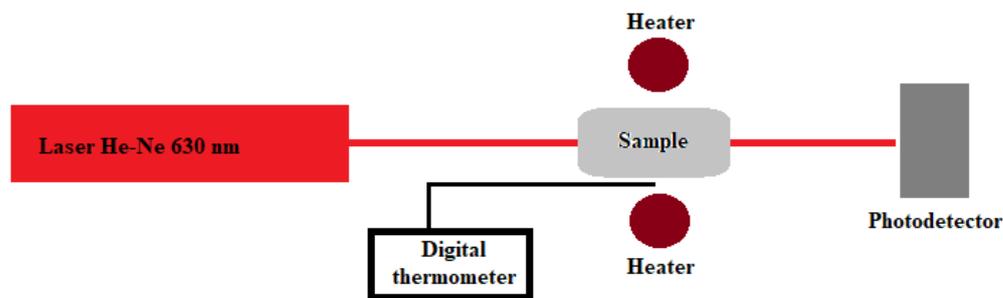


Figure 1. Set-up of the thermo-optics experiment.

3. Results and Discussion

The properties of the thermos-optics were examined by observing the changes in the intensity of the laser passed on the glass box containing chromium ferrite ferrofluid. Without the thermal field, ferrofluid was isotropic and showed little absorption so that the laser intensity was high. When the thermal field was applied, the shape of the ferrofluid magnetic chain absorbed more lasers so that the intensity of the laser beam decreased [13]. The greater the thermal or temperature field applied, the greater the ability of ferrofluid to absorb light. The results for optical transmission as the function of temperature for rising temperatures without being influenced by outside fields are shown in Figure 2.

Figure 2 shows a graph of the effect of temperature on the intensity of transmission. Figure 2 shows a graph of transmission intensity as a function of temperature for the state of chromium ferrite ferrofluids without a magnetic field. When the ferrofluid temperature was raised from room temperature to $81 \text{ }^{\circ}\text{C}$, the intensity of the transmission rises. When the temperature was lowered back to room temperature the transmission intensity drops but not through the same curve. In one cycle of temperature change from room temperature to $81 \text{ }^{\circ}\text{C}$ back to room temperature, the change in transmission intensity followed the curve with the hysteresis pattern.

Figure 3 shows a graph of transmission intensity as a function of temperature for the state of chromium ferrite ferrofluids under the influence of a magnetic field. The temperature rise of ferrofluid was recorded in one cycle from room temperature to $54 \text{ }^{\circ}\text{C}$ then lowered back to room temperature. In one cycle of changes at the temperatures starting at room temperature to $54 \text{ }^{\circ}\text{C}$ and then returned to room temperature, the changes in transmission intensity followed the curve with the hysteresis pattern as well. However, if we compare with Figure 2 for ferrofluid without the influence of the magnetic field, the presence of the external magnetic field imposed on ferrofluid influences the intensity of transmission,

i.e., the maximum intensity is lower than that without a magnetic field (Figure 2). From the two graphs in Figure 2, we can conclude that the effect of temperature on the intensity of the transmission is reversible.

The increase in laser light intensity after passing through the ferrofluid sample can be explained as follows. Chromium doping has an impact on enhancing the magnetic properties of magnetite which speeds up the process of agglomeration of ferrofluid due to thermal agitation. In the ferrofluid sample area subjected to laser light the absorption power decreases, so that the intensity of the laser transmission light increases as a function of temperature. The higher the temperature given, the higher the intensity value read at the photodetector. In addition, the chromium ferrite ferrofluid sensitivity was very high. Without the external field, ferrofluid was isotropic and showed little absorption so that the laser intensity was high. When the thermal field was applied, the shape of the ferrofluid magnetic chain absorbed more lasers so that the intensity of the laser beam decreased [14].

Puspitaningrum *et al.* have shown that magnetic fields affect optical transmission. This is due to agglomeration of magnetic particles which reduces the size of the particle in its liquid phase [14]. Since thermal agitation can suppress the ability of agglomeration [15], the intensity of optical transmission can be adjusted by changing the temperature of ferrofluid. Therefore, the greater the thermal field applied, the larger the intensity value because of the absorbance of ferrofluid decreases [16].

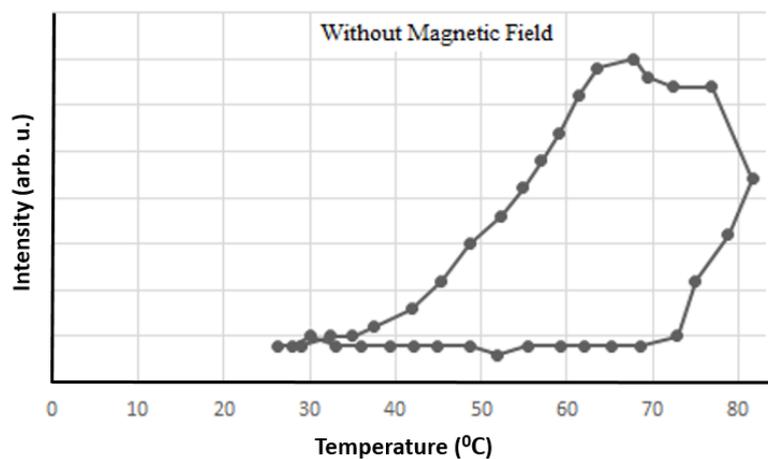


Figure 2. Graph of chromium ferrite ferrofluids response to temperature

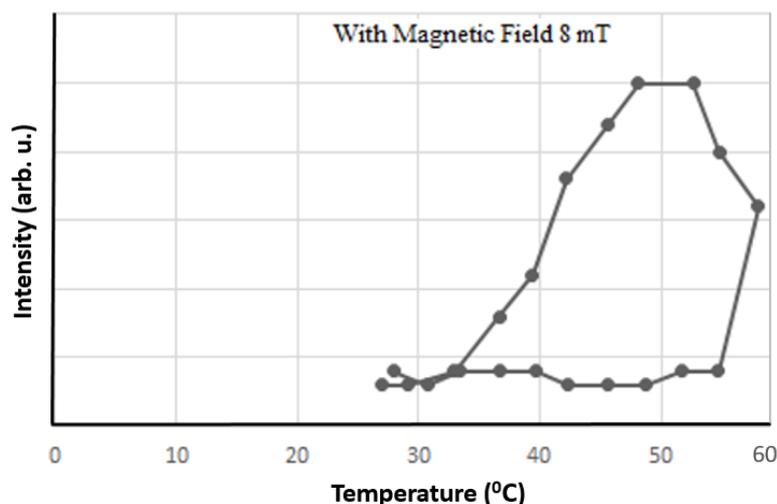


Figure 3. Graph of chromium ferrite ferrofluids response to temperature

The effect of ferrofluid temperature changes on transmission light intensity can be explained as follows. The disruption of the external thermal field caused by a heater near the ferrofluid sample will increase the temperature of the sample. This increase in temperature will trigger the thermo-optics effect which induces a thermal lens phenomenon due to changes in the refractive index of ferrofluid. The changes in the refractive index due to changes in temperature cause the self-defocusing or self-focusing nature of the lens to be changed by refractive index are positive or negative, so the intensity of the transmitted laser increases [4]. Thus, this study shows the potential of the synthesized chromium ferrite ferrofluids to be applied as a temperature sensor.

4. Conclusion

The thermo-optics effect has been shown in the chromium ferrite ferrofluids. The higher the temperature given, the higher the intensity value transmitted. The effect of temperature on the intensity of transmission was observed in one cycle that is starting at room temperature raised to a certain temperature and lowered back to room temperature. Therefore, this study opens a great opportunity in the application of chromium ferrite ferrofluid as a temperature sensor.

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Acknowledgments

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