Electro-optics Behaviors of Fe₃O₄ Ferrofluids: A Preliminary Study

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Abstract. In this paper, we report the experimental observation of electro-optics effect in the ferrofluids comprising of Fe₃O₄ nanoparticles by a 1 mW He-Ne laser beam. An external electric field was applied perpendicular to the beam. Ferrite ferrofluid was prepared by using a coprecipitation-sonochemical technique. The effect of the electric field on the optical properties of ferrofluid was still too weak as we had expected. One possibility that can be suspected as the cause is that the electric field applied to ferrofluid is still too weak.

Keywords: Ferrofluids, electro-optics, nanoparticles, Fe₃O₄, optical properties

1. Introduction
Ferrofluids are stable colloidal suspensions of sub-domain sized ferrite particles dispersed in a liquid medium by a suitable surfactant agent. A great diversity of applications has been proposed, including micromechanical sensor [1], nondestructive defect sensors [2], tunable optical filters [3,4], optical fiber modulator [5], cell toxicity study [6], quantification of biomolecule agglutination [7], and so forth.

So far, research on the response of ferrofluids to the influence of magnetic fields has been carried out [8]. Research on the influence of the electric field on ferrofluids has also attracted the attention of many researchers, especially regarding the structure of ferrofluids, manipulation of particles and cells in microfluidic devices through negative magnetophoretic [9]. Rajnak et al. investigated the formation and aggregation patterns of ferrofluids particles under the influence of the electric field [10]. Hardon et al. showed the effect of electric fields on changes in the electric dipole moment of ferrofluids particles [11]. However, the study of the influence of the electric field on the optical properties of ferrofluids has not been widely carried out. Therefore, research on the effect of electro-optics in ferrofluids needs to be examined in depth to explore its potential in the field of ferrofluids-based electric field sensors.

2. Methods
In this work, the ferrofluids were obtained from the synthesized-sample prepared by Puspitaningrum et al. [12]. Excitingly, the natural sand was employed as a central precursor in arranging ferrofluids. The structural properties were also reported in previous work. Here, we focused on the electro-optical properties of the ferrofluids. The experimental set-up of electro-optics used in this work is presented in Figure 1. The sample that was induced by an electric field was transmitted by a laser light (1 mW He-
Ne laser beam). The laser light, after transmitting the sample, was captured by the detector and the data were then recorded by the data reader as intensity data. In this experiment, the electric field varied from 1 to 140 volts.

![Diagram](image)

**Figure 1.** Set of electro-optics experiment

3. Results and Discussion

The effect of electro-optics was examined by examining the effect of the electric field on the intensity of laser light transmission that penetrates ferrofluid samples placed in the electric field space. Figure 1 shows a set of electro-optical experiments. The effect of the electric field on the optical properties of ferrofluid is presented in Figure 2. In general, the intensity of the transmission light increased when the potential difference in the sample ends was increased from 0 to 20 volts. When the voltage was continuously increased to 100 volts, the optical properties remained stable. In this case, the electric field could change the optical properties of material.

![Graph](image)

**Figure 2.** The graph of the effect of the electric field on the optical properties of ferrofluids

Under the influence of the electric field, there was a force that disturbed the position, orientation, and shapes of molecules of ferrofluids. In another word, the application of a direct current electric field induced the change in refractive index. In the case of anisotropic material, the electric field applied affects the polarization of transmission light [13]. In this study, the effect of the electric field on the optical properties of ferrofluids was still too weak as we had expected. One possibility that can be suspected as the cause is that the electric field applied to the ferrofluids was still too weak. By enhancing the electric field of higher than such electric field range, it is predicted that the significant change in the optical properties of the ferrofluids will be found. Therefore, it cannot produce electro-optical effects that can change the optical properties of the ferrofluids.
4. Conclusion
The electro-optical effect has been investigated in the ferrofluids subject to an electric field in the range of 0 to 140 volts. However, by increasing the electric field of higher than 140 volts, it is predicted that the significant change in the optical properties of the ferrofluids will appear. Therefore, further research is needed with a higher level of the electric field.

References
[1] Saga N and Nakamura T 2002 Elucidation of propulsive force of microrobot using magnetic fluid Journal of Applied Physics 91 7003
[2] Goubault C, Jop P, Fermigier M, Baudry J, Bertrand E and Bibette J 2003 Flexible Magnetic Filaments as Micromechanical Sensors Physical Review Letters 91
[3] Philip J, Rao C., Jayakumar T and Raj B 2000 A new optical technique for detection of defects in ferromagnetic materials and components NDT & E International 33 289–95
[4] Mahendran V and Philip J 2012 Nanofluid based optical sensor for rapid visual inspection of defects in ferromagnetic materials Applied Physics Letters 100 073104
[5] Nair S S, Thomas J, Suchand Sandeep C S, Anantharaman M R and Philip R 2008 An optical limiter based on ferrofluids Applied Physics Letters 92 171908
[6] Huang Y, Kim J-H, Park S-I, Shao H and Kim C-O 2003 Preparation of nanometric Cu0.4Fe1−xOFe2O3 for treatment of tumor Journal of Applied Physics 93 8444–6
[7] Mathieu J-B and Martel S 2009 Aggregation of magnetic microparticles in the context of targeted therapies actuated by a magnetic resonance imaging system Journal of Applied Physics 106 044904
[8] Philip J and Laskar J M 2012 Optical Properties and Applications of Ferrofluids—A Review Journal of Nanofluids 1 3–20
[9] Thanjavur Kumar D, Zhou Y, Brown V, Lu X, Kale A, Yu L and Xuan X 2015 Electric field-induced instabilities in ferrofluid microflows Microfluidics and Nanofluidics 19 43–52
[10] Rajnak M, Petrenko V I, Avdeev M V, Ivankov O I, Feoktystov A, Dolnik B, Kurimsky J, Kopcansky P and Timko M 2015 Direct observation of electric field induced pattern formation and particle aggregation in ferrofluids Applied Physics Letters 107 073108
[11] Hardoň Š, Kúdelčík J, Bury P and Gutten M 2018 Influence of Electric and Magnetic Fields on Dielectric Response of Oil-Based Ferrofluid Acta Physica Polonica A 133 477–9
[12] Puspitaningrum A, Taufiq A, Hidayat A, Sunaryono, Hidayat N and Samian 2017 Optical Properties of Fe3O4 Magnetic Fluid from Iron Sand IOP Conference Series: Materials Science and Engineering 202 012054
[13] Saleh B E, Teich M C and Saleh B E 1991 Fundamentals of photonics vol 22 (Wiley New York)

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