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Effects of Magnetic Fluid Concentration and Cell Size on Magneto-Optical Light Transmission

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Abstract – In this study, magnetic liquids were first synthesized using the "high temperature hydrolysis reaction" method, which is a novel method for synthesizing magnetic field sensitive colloidal nanoparticles. For magneto-optical characterization, the magnetic liquids were exposed to magnetic field (0-600 G) in DC regime. The effects of concentration, cell size and magnetic field strength on light transmittance were observed. The largest change in light transmission was 10.4% for the sample with a concentration of 74%, 8.4% for the sample with 71% and 7.4% for the liquid with 66%. As the concentration increased, the power change increased and it was found that light transmission was high at low concentrations. As the cell size increased, the power variation was found to increase accordingly. This was explained in terms of the number of particles per unit volume and early saturation. Magneto-optical characterization studies have shown that these liquids can be used in various devices such as gaussmeter design in the optical field. This study revealed that the behavior of magnetic liquids changes in the presence of a magnetic field and that this behavior is affected by various conditions. The results show that the effect of magnetic fields on magnetic liquids is affected by a wide range of parameters.

Keywords –Water-Soluble, High Temperature Hydrolysis; Ferrofluid, Magnetic Field, Magneto-Optical Transmission, Nanoparticle;

I. INTRODUCTION

Magnetic nanofluids (MNFs), also known as ferrofluids, are colloidal dispersions of magnetic nanoparticles (Fe_3O_4, γ-Fe_2O_3) and base liquids (hydrocarbons, water, etc.). They contain magnetism similar to other solid magnetic materials as well as fluidity similar to other liquids [1], [2]. The system of three basic components (core, coating and medium) that make up a magnetic fluid is known as the intersection of magnetism and optics [3] (see Figure 1). Suspensions are isotropic in the absence of a magnetic field. When an external field is applied, they exhibit anisotropic properties and magneto-optical phenomena such as birefringence, dichroism, magneto-optical transmission [4], [5], [6]. The magneto-optical properties of ferrofluids have attracted great interest in recent years due to their wide range of applications, such as tunable photonic devices, holographic optical tweezers, sensors and so on [7].

Nanoparticles in a magnetic fluid self-organize in the magnetic field by the balanced interaction of the repulsive and attractive forces of the medium.

Light transmission in suspensions of magnetic particles has been studied both theoretically and experimentally [8], [9], [10], [11], [12]. Due to the difficulties in the creation of monodisperse nanofluids with acceptable stability, early experiments were mostly focused on ferrofluids composed of micron-sized magnetic particles [13].

In 2008, Philip et al [14] first investigated magneto-optical effects in magnetic nanofluids. They found that in a critical magnetic field, where incident light is organized along the field orientation, the intensity of transmitted light in nanofluids drops significantly. The critical field intensity decreased with nanoparticle content according to a power law, and when the external field was removed, the transmitted light intensity returned to its initial value.

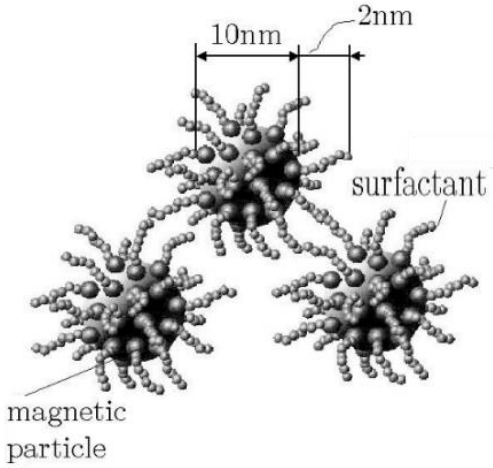


Fig.1 Diagram of magnetic liquid particles containing surfactant (particles and surfactant molecules are not shown to scale for clarity)

Rablau et al [15] studied the time evolution of magnetooptical transmission patterns in magnetic nanofluids. They found that the light intensity along the magnetic field direction decreases rapidly to zero and then gradually increases with time. They also found that the characteristic time 0 for the extinction of light varies almost inversely with the external field strength. Eloi et al [16] investigated the field dependence of light transmission in ferrofluids composed of nanosized particles. They proposed a new theory claiming that rotating particle aggregates should cause lower light transmission in the initial stage. They also determined that the formation of columnar aggregates is responsible for the minimum transmitted intensity.

In this study, magnetic liquid was produced using high temperature hydrolysis reaction, one of the ferrofluid synthesis methods. Light transmission experiments were carried out with the produced magnetic liquid under DC magnetic field for 6 different samples at different concentrations and different cuvette sizes. In the magneto-optical experimental setup, a magnetic field between 0-600 G was applied to the magnetic liquids.

II. MATERIALS AND METHOD

A. *Stages Of Magnetic Fluid Synthesis*

The flow chart for the high temperature hydrolysis method used for the synthesis is shown in Figure 2.

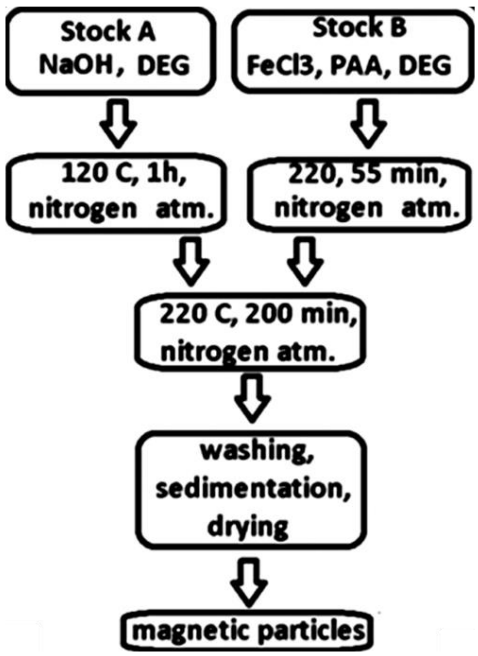


Fig. 2 Flow chart of the synthesis

DTA-TG (Differential thermal analysis - Thermogravimetric) analysis, FTIR (Fourier transform infrared spectroscopy) analysis, XRD (X-ray diffraction) analysis, VSM (Vibrating sample magnetometry) analysis, SEM (Scanning electron microscope) analysis, DLS (Dynamic light) Scattering analysis, TEM (transmission electron microscopy) analysis, as well as details of the chemicals used in the synthesis, high temperature hydrolysis reaction steps and magneto-optical experimental setup can be found in Küçükdermenci's thesis [18] and his studies [19], [20].

B. *System For Magneto-Optical Experiment Setup*

The main objective of the application is to study the variation of light transmission with the applied magnetic field during the transmission of a laser beam through a magnetic liquid. In the experiment, magnetic liquids with different concentrations and cuvettes with different light paths were used to observe the effect of these parameters on light transmission. In this experiment, the control of the devices and measurements were carried out under computer control thanks to the user interface.

The experimental setup is shown schematically in Figure 3. In the figure, box 1 represents the laser, boxes 2 and 3 represent the electromagnet and the magnetic liquid sample to be measured respectively, boxes 4 and 5 represent the gaussmeter and power meter respectively, and boxes 6 and 7 represent the power supply and the computer respectively. The power of the laser is read from the power meter detector at the output of the device and the device settings can be controlled via the computer. Thanks to the interface program written on the computer, the magnetic field, power and voltage values generated by the current supplied to the windings of the electromagnet can be obtained graphically and tabularly.

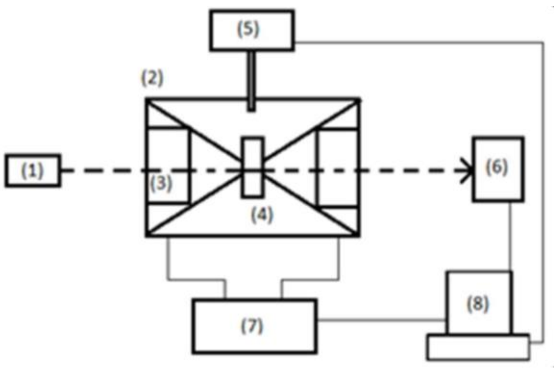


Fig. 3 General view of the magneto-optical setup

Laser: A He-Ne laser with a wavelength of 543 nm (green light) was used on the left side of the setup, in the hatched section shown in Figure 4. The maximum output power of the laser is 2.2 kW.

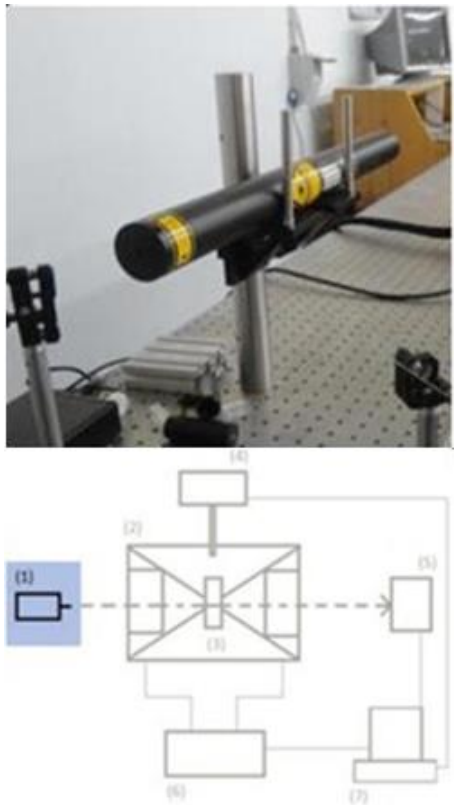


Fig. 4 Image of the light source laser and their location in the experimental setup

Electromagnet and Magnetic Liquid: Figure 5 shows an electromagnet generating a magnetic field in the medium. If voltage is applied to the windings of the electromagnet, a magnetic field is created in the perpendicular direction in response to the current in the windings.

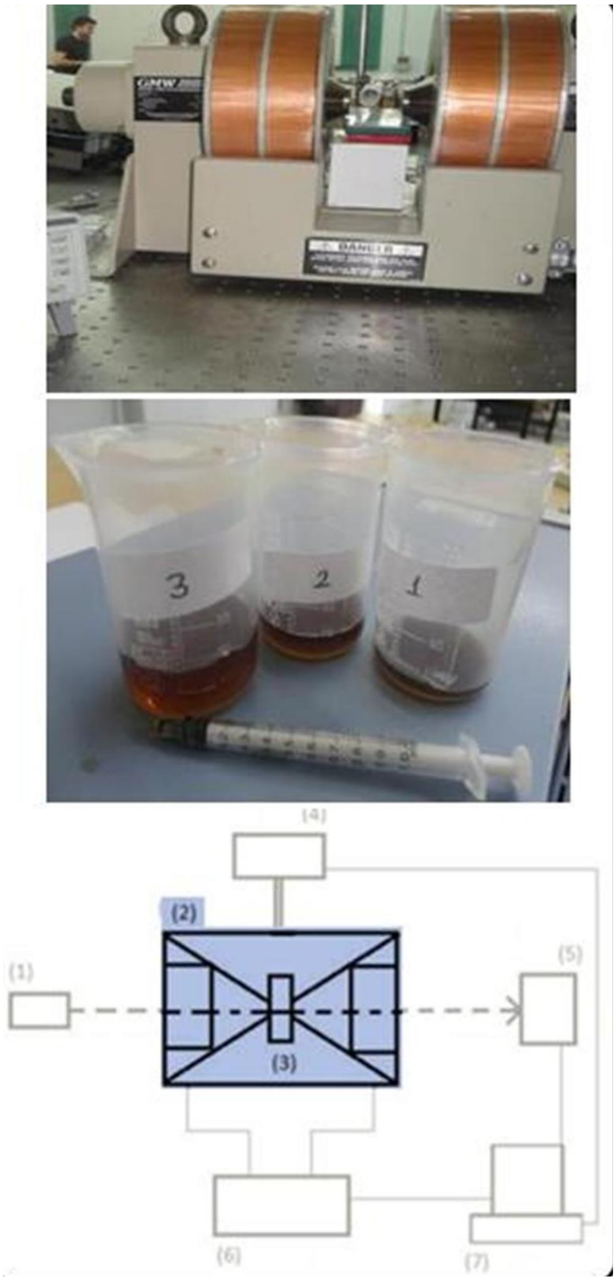
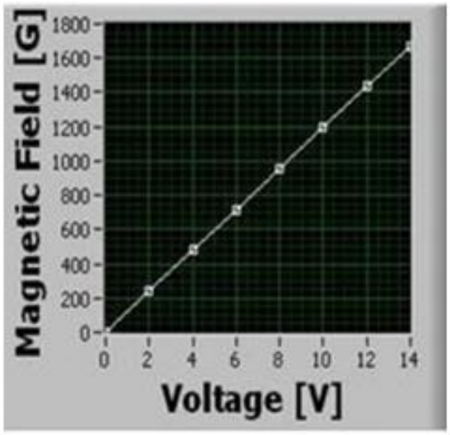


Fig. 5 View of the electromagnet (2) and magnetic fluid (3) and their location in the experimental setup

With the LabVIEW program, a magnetic field was obtained by applying a voltage between 0-14 Volts at 2 Volt intervals (see Figure 6). It is seen that the magnetic field obtained against the DC voltage applied to the windings by increasing 2 volts from 0 volts to 14 volts increases up to 1681 Gauss.



Voltage [V]	Magnetic Field [G]
0.000000E+0	2.853300E+0
2.000000E+0	2.415830E+2
4.000000E+0	4.844800E+2
6.000000E+0	7.121300E+2
8.000000E+0	9.571000E+2
1.000000E+1	1.200120E+3
1.200000E+1	1.441450E+3
1.400000E+1	1.681330E+3

Fig. 6 Voltage-magnetic field graph

III. Results

The aim of this study is to observe how the light transmittance of magnetic liquids varies with magnetic field as a function of concentration and cuvette width. Experiments were carried out with liquids with different properties, keeping all other variables constant and varying only one criterion (see Table 1).

Table 1. Properties of the 3 samples to be analysed according to concentration and cell size.

Criterion	Sample 1	Sample 2	Sample 3
Concen.	74% conc. 20mg/7mL	71% conc. 20mg/8mL	66% conc. 20mg/10mL
Cell size	2 mm	4 mm	10 mm

When analysing the concentration effect criterion, the particle size is 10 nm and the cell size is 10 mm. For the concentration effect, the three samples studied have concentration values of 74%, 71% and 66% respectively. When analysing the cell size effect criterion, the particle size is 10 nm and the concentration is 66%. For the cell size effect, the three samples studied have cell size values of 2mm, 4mm and 10mm respectively.

A. *The Effect Of Concentration On Light Transmission*

To examine the effect of concentration on light transmittance, separate magnetic field-power plots were generated for the three samples in LabVIEW (see Figure 7).

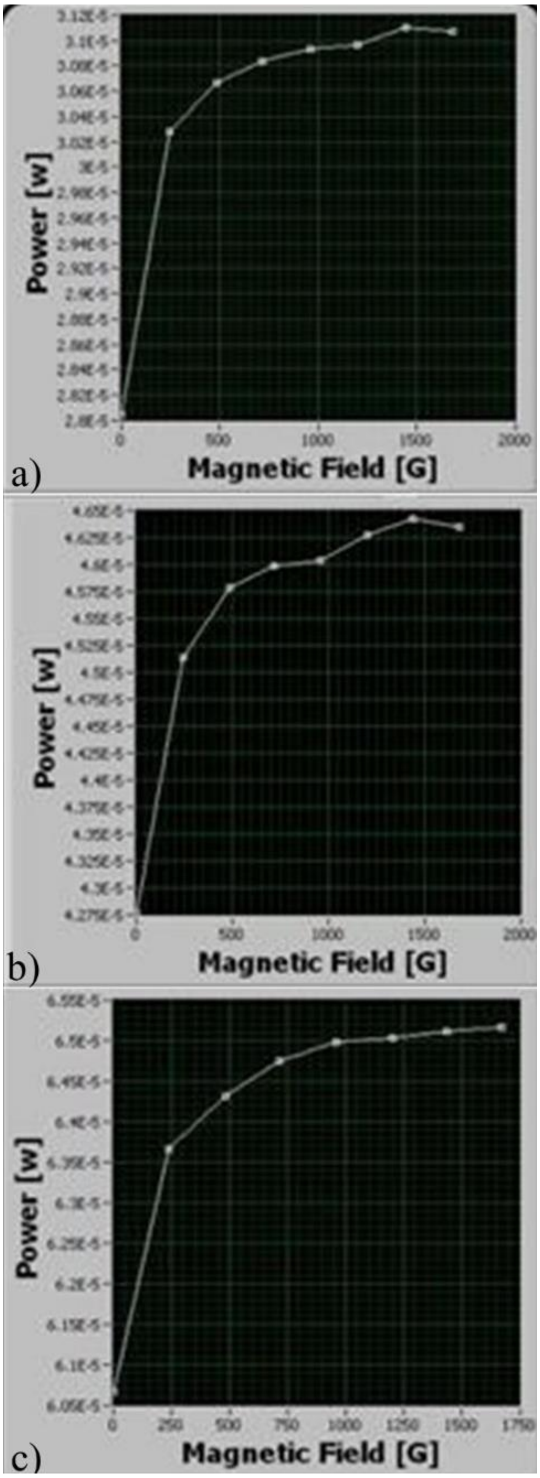


Fig. 7 Magnetic field-power plot obtained from magnetic liquids with different concentrations (a) 74 % (b) 71 % (c) 66 %

As seen in the graphs, the power of the laser passed through all three liquids increased with the magnetic field. However, this increases almost stabilized and saturated after a certain magnetic field value. This can be explained by the fact that the particles aligned with the magnetic field in the magnetic liquid and forming chain structures stabilize their alignment after a certain magnetic field value.

Equation (1) below was used to write the change in each liquid as a percentage:

$$\frac{I(G)-I(0)}{I(0)}=\frac{\Delta I}{I(0)}=\%change \qquad \text{Eq. (1)}$$

Although the magnetic field-power plots of the three liquids are similar in geometry, the calculated power variation values of each are different (see Figure 8). This confirms the conclusion that concentration is one of the factors that modify the light transmission under the influence of the magnetic field. As can be seen, the maximum change in the 74% liquid is 10.4%, the maximum change in the 71% liquid is 8.4% and the maximum change in the 66% liquid is 7.4%.

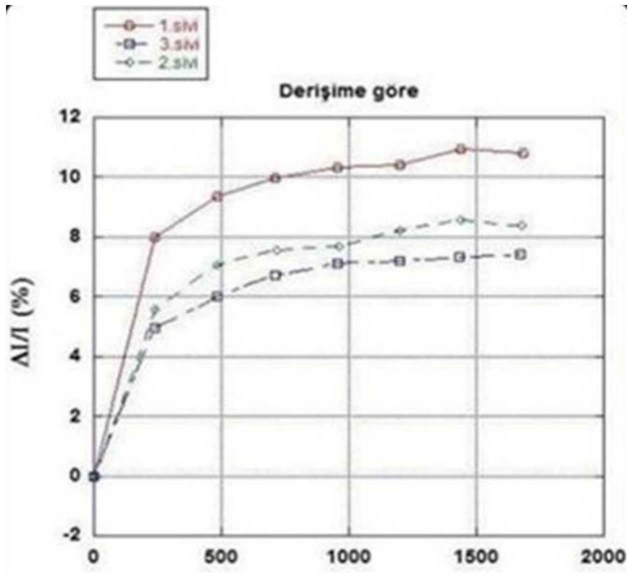


Fig. 8 Percent light transmittance comparison of concentration effect on 1st liquid 74%, 2nd liquid 71%, 3rd liquid 66%

B. *The effect of cell thickness on light transition*

Three different cuvettes of 2mm, 4mm and 10mm were used to observe the cell size effect. The experiments were performed by varying the cuvette widths and keeping the particle size constant at 10nm and the concentration constant at 66% and measurements were taken (see Figure 9).

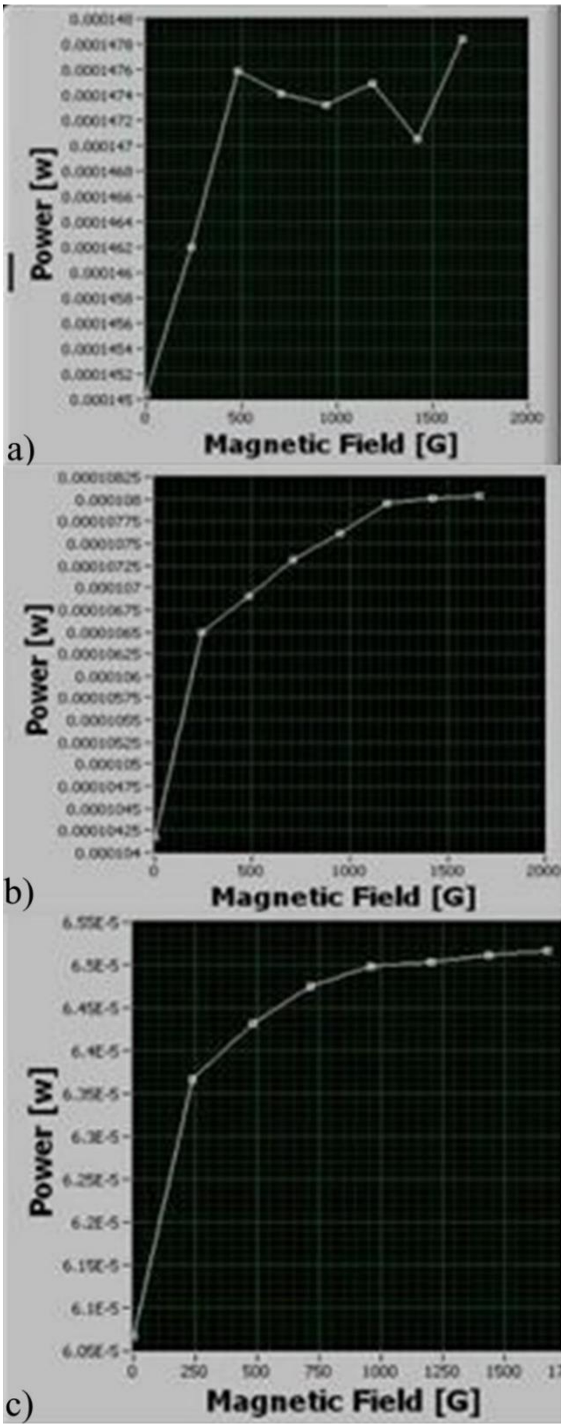


Fig. 9 Magnetic field-power plot of liquid in different cuvettes (a) 2 mm, (b) 4 mm, (c) 10 mm

For the 4 mm and 10 mm cuvettes the light transmittance increased as expected up to a certain magnetic field value, after which it saturated and the power stabilized. The 2 mm cuvette shows a similar pattern. However, the linearity is more distorted than the others, which can be explained by the "early saturation" of the liquid in the 2 mm cuvette.

For comparison, the percentage change in power for each liquid was calculated and plotted (see Figure 10). The maximum variation in power was 1.9% for the liquid in the 2 mm cuvette, 3.8% in the 4 mm cuvette and 7.4% in the 10 mm cuvette. The highest variation was observed in the largest cuvette.

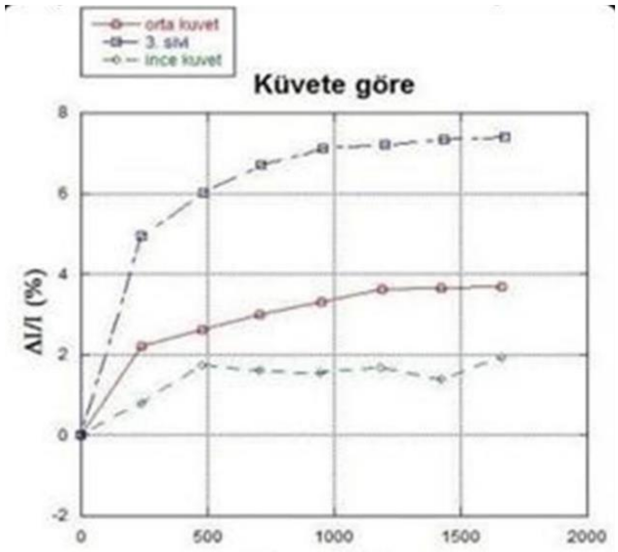


Fig. 10 Percentage comparison of the effect of cuvette width on light transmission. Thin cuvette light path is 2 mm, medium cuvette 4 mm, thick cuvette 10 mm

IV. DISCUSSION

The liquid with the highest concentration is the liquid with the highest strength change in light transmittance with a magnetic field. What distinguishes this liquid from the others is that it is denser, i.e., it contains more solids in the same amount of liquid. As the amount of matter increases, the number of particles affected by the magnetic field also increases, causing the change to be higher. In short, it can be said that as the concentration increases, the power change is higher for the same magnetic field change (see Figure 11).

According to the measurements, the liquid with the highest variation is the liquid with 74% concentration and 10 nm particle size in the 10 mm wide cuvette (see Figure 12). In this liquid, the sensitivity to the magnetic field is high when the change in strength is large over the same magnetic field range. The linear region of the response of this liquid to the magnetic field can be used to design a magneto-optical gaussmeter for low magnetic fields.

The results in this study show that the optical behaviour of magnetic liquids changes under magnetic field. The results are in agreement with the results of similar studies, which show that the change depends on various factors.

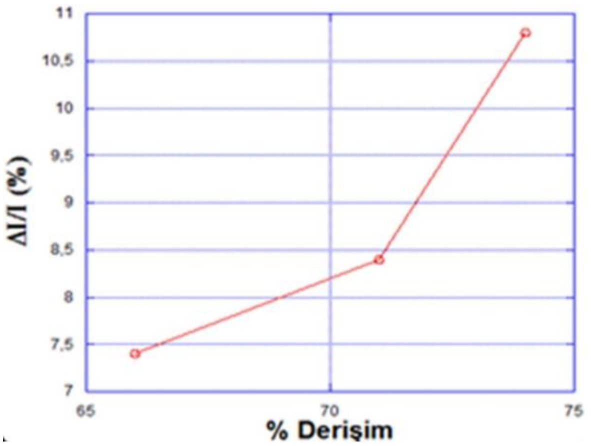


Fig. 11 Effect of change in concentration on percent power

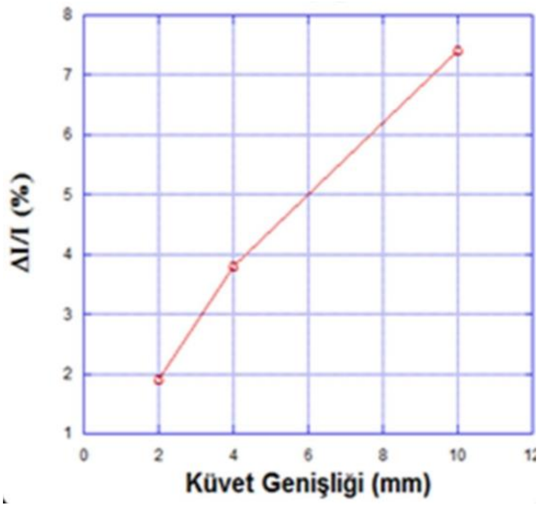


Fig. 12 Effect of cuvette width on power percentage

V. CONCLUSION

This study focuses on the factors affecting the behaviour of magnetic liquids under a magnetic field. The changes in concentration, cuvette width and light transmittance of magnetic liquids exposed to magnetic field are analysed and interpreted in percentage terms.

The LabVIEW interface programs created for the Gaussmeter, power meter and voltage source have been of great benefit in terms of speed, practicality and reliability. The same infrastructure will be used in all future studies with these devices. Magnetic field-power graphs revealed whether magnetic fluids are capable of sensing the magnetic field of the environment.

The maximum change in 74% liquid is 10.4%, in 71% liquid 8.4% and in 66% liquid 7.4%. The power change increased as the concentration increased and it was observed that the light transmittance was high at low concentration.

It is observed that the power variation increases when the cell size increases. This can be explained by the concepts of number of particles per unit volume and early saturation.

Studies on magnetic materials continue intensively and materials suitable for different applications are being developed. The results obtained in this study have added a new one to the researches and provided a new perspective. In future studies with magnetic liquids, these results can be taken into consideration and appropriate liquids and experimental conditions can be selected. In the future, more comprehensive results can be obtained for the reactions of magnetic liquids when exposed to magnetic fields by diversifying research on factors such as ambient temperature, humidity, wavelength.

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