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MICROWAVE LOSS POWER IN COMPOSITE MAGNETIC FLUIDS

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Abstract. Frequency (*f*) and biasing field (*H*) dependence of the complex magnetic permeability $\mu(f, H) = \mu'(f, H) - i\,\mu''(f, H)$, and of the complex permittivity $\varepsilon(f, H) = \varepsilon'(f, H) - i\,\varepsilon''(f, H)$, of three kerosene based magnetic fluid samples, over the range *200 MHz* to *3 GHz* and *0* to *35 kA/m*, respectively, were analyzed. Sample MF1 contained $Ni_{0.4}Zn_{0.6}Fe_2O_4$ particles, sample MF2 contained $Mn_{0.6}Fe_{0.4}Fe_2O_4$ particles and sample MF3 was obtained by mixing MF1 and MF2 in a 1:1 proportion. Based on the complex magnetic permeability and complex dielectric permittivity measurements of each sample for different field values, the total specific loss power (due to magnetic and dielectric losses) was computed. Theoretical specific loss power of the composite sample MF3 was also computed. The computation was based on the superposition principle in the approximation of no inter-particle interactions. The experimental values of the specific loss power were compared to the theoretical ones.
In zero biasing field, the measured specific loss power was found to be in good agreement with the theoretical values. With the increase of the biasing field, deviations of the experimental values from the theoretical results were observed. These differences are due to the biasing field induced particle agglomerations.
The paper proves the potential usefulness of the mixing technique in the design of microwave electromagnetic absorbers.

1. Introduction

Magnetic fluids are stable colloidal suspensions consisting of ferro-ferrimagnetic nanoparticles dispersed in a carrier liquid and coated with a surfactant, in order to prevent particle agglomeration [1]. Their properties can be extended to some nanostructured materials, such as special paints with electromagnetic absorbent properties.

The specific electric power dissipation, p_e, in a dielectric medium, due to dielectric relaxation processes, depends on the frequency of the electromagnetic field, f (Hz), and on the imaginary part of the complex dielectric permittivity, ε'' ,of the medium and it is given by [2]:

$$\frac{P_e}{V} = p_e = \pi\varepsilon_0\varepsilon'' f E_0^2 \tag{1}$$

where P_e is the electric power dissipation, V is the volume of the sample, E_0 represents the amplitude of the electric component of the electromagnetic field and ε_0 is the free space permittivity.

The specific magnetic power dissipation, p_m, in a magnetic medium, due to magnetic relaxation and ferromagnetic resonance processes, is given by [2]:

$$\frac{P_m}{V} = p_m = \pi\mu_0\mu'' f H_0^2 \tag{2}$$

where P_m is the magnetic power dissipation, H_0 represents the amplitude of the magnetic component of the electromagnetic field, μ_0 is the free space permeability and μ'' is the imaginary part of the complex magnetic permeability of the medium.

The total specific power dissipation, in a material having both dielectric and magnetic properties, and subjected to an electromagnetic field, is given by the sum:

$$p = p_e + p_m \tag{3}$$

The aim of the paper is to analyse the total power dissipation in a composite magnetic fluid and to correlate the mixture composition with its absorbent properties. This result would be of interest in the design of electromagnetic nanostructured absorbers.

2. Samples

Three commercial kerosene based magnetic fluid samples were considered for investigation:

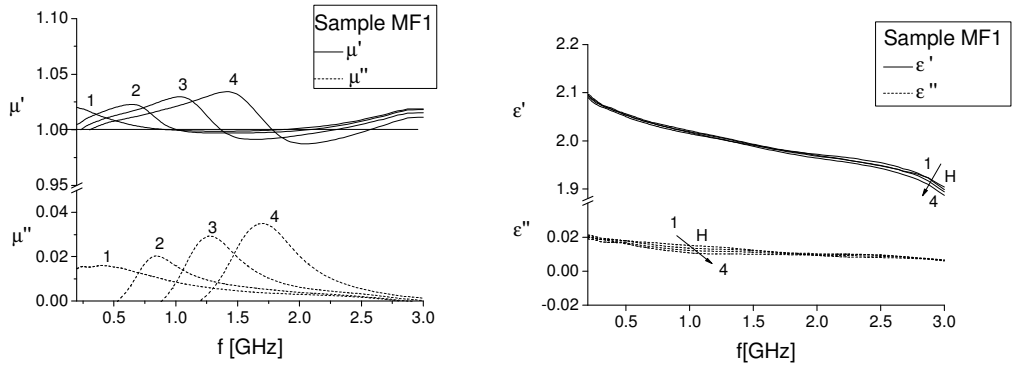
- sample denoted by MF1 with $Ni_{0.4}Zn_{0.6}Fe_2O_4$ particles;
- sample denoted by MF2 with $Mn_{0.6}Fe_{0.4}Fe_2O_4$ particles;
- sample denoted by MF3 was obtained by mixing MF1 and MF2 in a 1:1 proportion.

3. Experimental setup

The measurements of the complex magnetic permeability and of the complex dielectric permittivity were made by means of the short-circuited coaxial transmission line technique, over the frequency range 200 MHz to 3 GHz. The coaxial cell containing the sample was subjected to a perpendicular biasing field, *H,* having values between *0* and *35 kA/m.* Details of the method are given in Ref. [3].

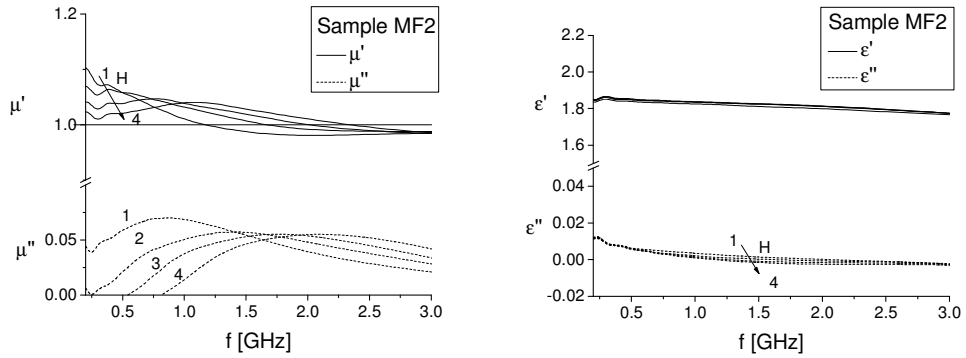
4. Experimental results and discussions

The frequency and biasing field dependences of the complex magnetic permeability and of the complex dielectric permittivity of all three samples are presented in figures 1 – 3.



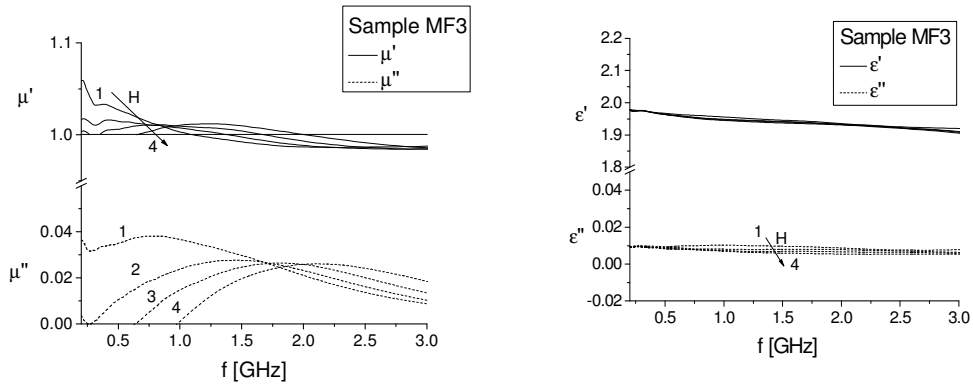
a) b)

Figure 1. Frequency and field dependence of the complex magnetic permeability (a) and of the complex dielectric permittivity (b) for sample MF1, for *H=0 kA/m* (1); *H=15.23 kA/m* (2) ; *H=24.46 kA/m* (3); *H=35.28 kA/m* (4)



a) b)

Figure 2. Frequency and field dependence of the complex magnetic permeability (a) and of the complex dielectric permittivity (b) for sample MF2 for *H=0 kA/m* (1); *H=15.235 kA/m* (2); *H=24.649 kA/m* (3); *H=35.286 kA/m* (4).



a) b)

Figure 3. Frequency and field dependence of the complex magnetic permeability (a) and of the complex dielectric permittivity (b) for sample MF3 for *H=0 kA/m* (1); *H=15.235 kA/m* (2) ; *H=24.649 kA/m* (3); *H=35.286 kA/m* (4).

Based on the complex magnetic permeability and complex dielectric permittivity measurements of each sample for different field values, the total specific loss power (due to magnetic and dielectric losses) was computed. The results are presented in figure 4.

Theoretical specific loss power of a composite sample can be computed, based on the superposition principle in the approximation of no inter-particle interactions using the equation

$$p_{composite} = \sum_{i=1}^{n} \varphi_i p_i \tag{4}$$

where n is the total number of constituents, φ_i is the volume fraction and p_i is the total specific loss power of the ith constituent. In case of sample MF3 the number of constituents is $n=2$ and the volume fraction of each constituent is 0.5. Using equation (4) we computed the theoretical specific loss power for sample MF3. The results are presented in figure 4.

From figure 4 it can be seen that the theoretical results are in good agreement with the experimental ones in zero biasing field (figure 4 a)). By increasing the biasing field the difference between the experimental specific loss power and the theoretical predictions increases. This may be explained in terms of particle agglomerations which are induced by the biasing field.

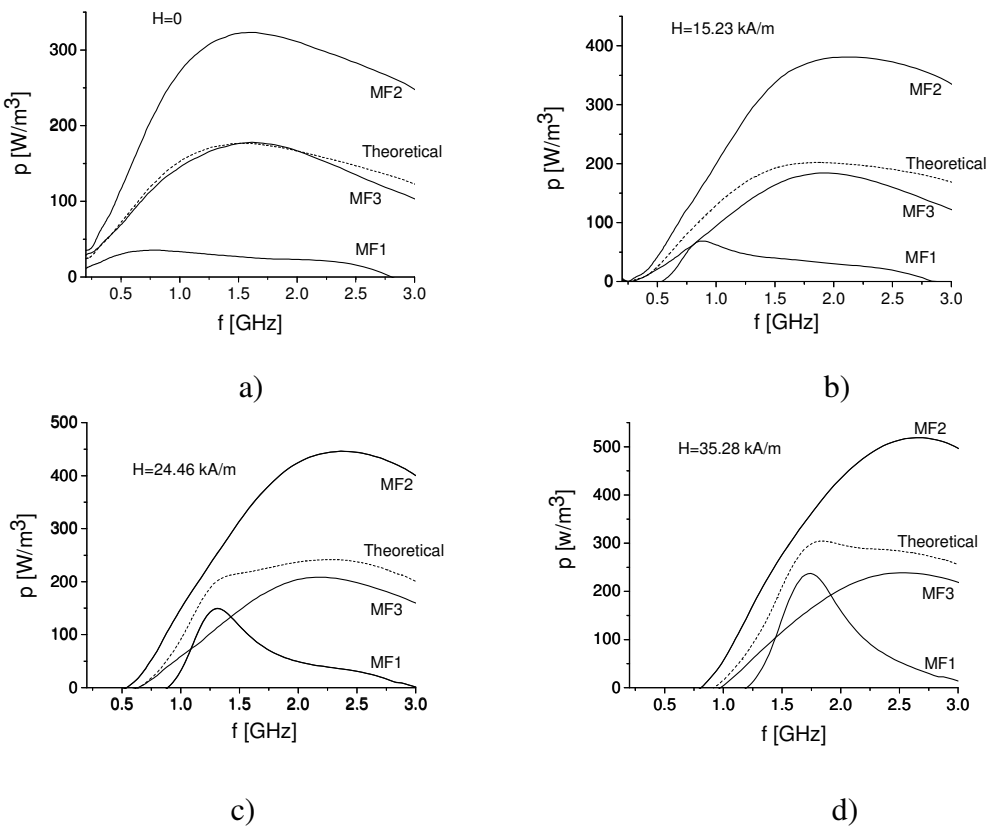


Figure 4. Total specific loss power of the investigated samples

4. Conclusions

In order to test the superposition principle on a composite magnetic fluid sample, measurements of frequency and biasing field dependences of the magnetic permeability and dielectric permittivity of two magnetic fluid samples and their mixture were performed.

Based on these measurements the total specific loss power was experimental determined, for each sample. Theoretical specific loss power of the composite sample was also computed, based on the superposition principle in the approximation of no inter-particle interactions. A good agreement between the experimental and theoretical results was found in zero biasing field, while with the increase of the biasing field, some deviations were observed. These deviations may be assigned to the biasing field induced particle agglomerations.

The results obtained for zero biasing field are of potential interest in the design of microwave electromagnetic absorbers.

Acknowledgments

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