

PAPER • OPEN ACCESS

## Magnetorheological bio-suspensions membranes: Influence of magnetic flux density on the electrical conductivity and relative dielectric permittivity

To cite this article: I Bica 2018 *J. Phys.: Conf. Ser.* **1141** 012096

View the [article online](#) for updates and enhancements.

### You may also like

- [Review of graphene for the generation, manipulation, and detection of electromagnetic fields from microwave to terahertz](#)

David A Katzmarek, Aiswarya Pradeepkumar, Richard W Ziolkowski et al.

- [Flexible fiber-shaped energy storage devices: principles, progress, applications and challenges](#)

Jing Ren, Quanfu Xu and Yi-Gang Li

- [A quantum network stack and protocols for reliable entanglement-based networks](#)

A Pirker and W Dür



**ECS**  
The  
Electrochemical  
Society  
Advancing solid state &  
electrochemical science & technology

**DISCOVER**  
how sustainability  
intersects with  
electrochemistry & solid  
state science research

# Magnetorheological bio-suspensions membranes: Influence of magnetic flux density on the electrical conductivity and relative dielectric permittivity

I Bica<sup>1</sup>

<sup>1</sup>West University of Timisoara, Timisoara, Romania

E-mail: ioanbica50<at>gmail.com

**Abstract.** Magnetorheological bio-suspensions based membranes are fabricated using a microfiber cloth soaked with a mixture of honey, turmeric powder and carbonyl iron microparticles. Plane capacitors are manufactured by introducing the membranes between two parallel Copper plates. The electrical conductivity and the relative dielectric permittivity of the membranes are measured in a static magnetic field superimposed on an electric field with fixed frequency. The results show that the membranes can be used for fabrication of devices which require a controlled release of the bio-active components found in honey and TP, by fixing the value of magnetic field density.

## 1. Introduction

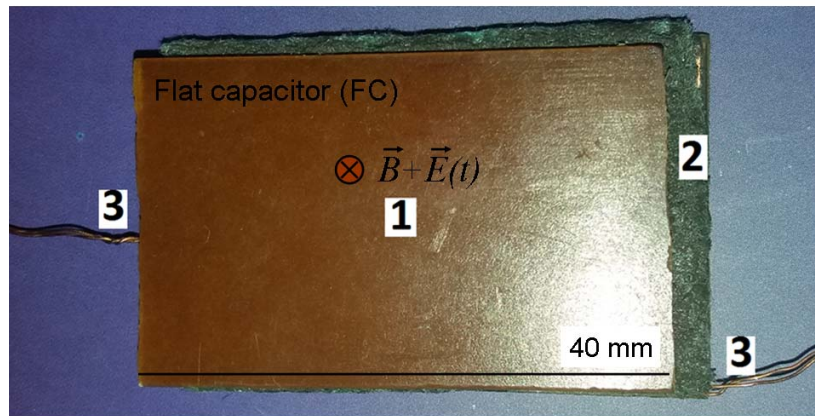
Homogeneous mixtures consisting from a liquid matrix, ferri/ferro-magnetic nano/micro-particles and additives are known as magnetorheological suspensions (MRS) [1–3]. Physical properties of MRS, and generally to any smart materials such as magnetorheological elastomers are significantly changed when they are subjected to a magnetic and/or electric field [4–8]. These effects arise usually as a result of various types of structures formed in the sample, such as from simple linear chains to complex fractal patterns [9]. Experimentally, their structure is most often determined by using the small-angle scattering technique [10], and the parameters are extracted in the framework of fractal theory [11, 12].

The liquid matrix used for fabrication of MRS is mainly mineral and synthetic oils, depending on the application. For stabilization of the magnetizable phase are used additives such as guar-gum, stearic acid etc. [13–16]. The magnetizable phase inside the MRS body consists from carbonyl iron microparticles [1–3, 13].

However, most of the liquid matrices and additives are environmentally pollutant and toxic for the human livings. Thus, their replacement with natural components for bio-medical applications is of high interest in recent years. To this aim, in Ref. [17] have been fabricated MRS membranes with honey as a liquid matrix and turmeric powder as additives. The mixture of honey and turmeric powder has been soaked into a cotton cloth, and thus a hybrid MRS has been obtained, where electrical properties are stable in the presence of an external magnetic field [17].

Here, we continue the investigations presented in Ref. [17] and significantly increase the volume concentrations of the bio-active components. The obtained bio-membrane is used as a dielectric material between the plates of a plane (flat) capacitor. The capacitance and resistance of the equivalent electrical scheme of the capacitor are measured in a static magnetic field superimposed on an alternating electric





**Figure 1.** The flat capacitor FC. 1 - textolite plate; 2 - bio-membranes based on MRS; 3 – electrical conductors. Both the magnetic and electric fields are perpendicular on the plates of FC.

field with fixed frequency. From the obtained experimental data we extract information concerning the variation of electrical conductivity and of relative dielectric permittivity with the magnetic flux density.

The obtained results can be used for fabrication of medical devices which require a controlled release of the bio-active components from the mixture of honey and turmeric powder.

## 2. Materials and Methods

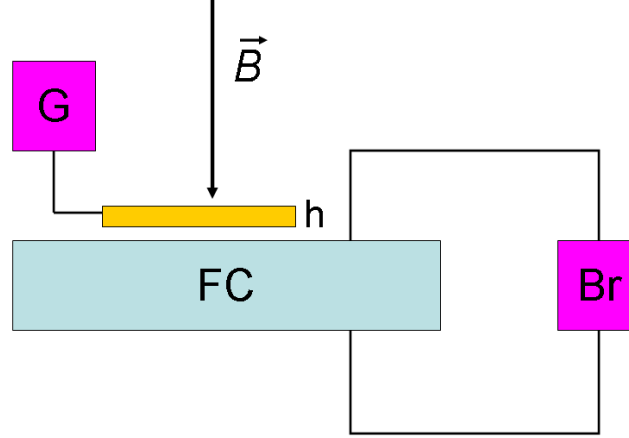
The materials used for fabrication of the bio-membranes based on MRS (bio-MRS) are: carbonyl iron (CI), which is a powder consisting of microparticles with diameters between 4.5 and 5.4  $\mu\text{m}$ , honey with a density of 1.375  $\text{g/cm}^3$  at 297 K, turmeric nano-powder with diameters between 12 and 20  $\mu\text{m}$  and a microfiber membrane. For fabrication of the flat capacitor (FC), two textolite plates covered with copper on one side (TCu) are used.

The main steps for manufacturing the bio-MRS and of the flat capacitor are the following: first, a volume of 1  $\text{cm}^3$  of honey is mixed with 0.6  $\text{cm}^3$  of carbonyl iron and with 0.4  $\text{cm}^3$  of turmeric powder until a homogeneous dark viscous liquid mixture is obtained. Then, the liquid mixture is deposited on the microfiber cloth, and the membrane based on bio-MRS is obtained. Finally, the membrane is deposited between the conducting sides of the two textolite plates and, after pressing, the plane capacitor with length  $L = 40$  mm, width  $l = 25$  mm and distance between plates  $d_0 = 1$  mm is obtained, as shown in Fig. 1.

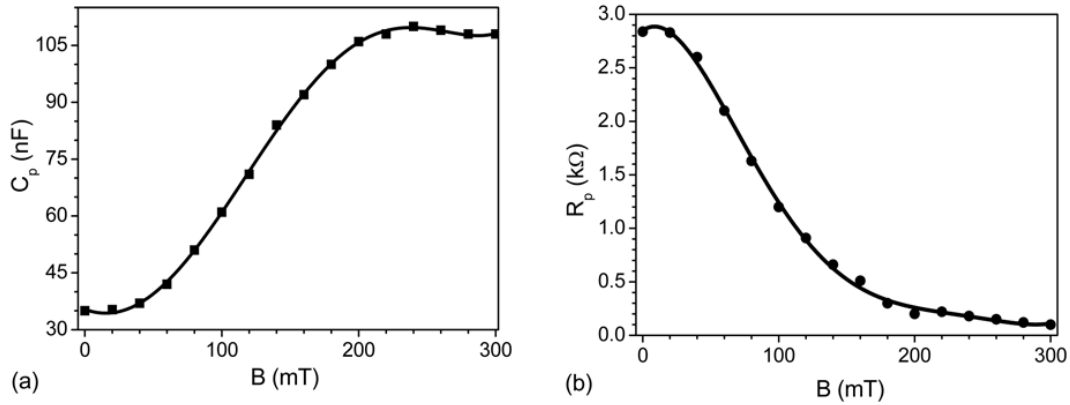
The experimental setup used for measuring the capacitance and resistance of the bio-MRS membrane is shown in Fig. 2. The setup consists of a continuous current electromagnet (not shown in Fig. 2) with the capacitor FC and a hall probe h (of the gaussmeter G) between its poles. The values of magnetic flux densities  $B$  are monitored with the help of the gaussmeter G. The bridge Br is electrically connected to the terminals of FC.

## 3. Results and discussions

The flat capacitor is fixed between the poles of the electromagnet and its terminals are connected to the RLC bridge Br fixed at frequency  $f = 1$  kHz. For values of magnetic flux density between 0 and 300 mT we measure the electrical capacitance and resistance of the equivalent circuit, in steps of 20 mT. During the experiment, the bridge Br shows that the equivalent electrical scheme of FC consists from an ideal capacitor connected in parallel with an ideal resistor. The corresponding capacitance  $C_p$  and resistance  $R_p$  are presented in Fig. 3a and 3b. The results show that the capacitance increase with magnetic flux density up to about 225 mT, and then it oscillates around a constant value at about 105 nF (Fig. 3a). The



**Figure 2.** Experimental setup (overall configuration): FC - flat capacitor, Br - RLC bridge, G - gaussmeter, h - hall probe,  $\vec{B}$  - magnetic flux density vector.



**Figure 3.** Variation with magnetic flux density  $B$  of the electrical capacitance  $C_p$  (a) and resistance  $R_p$  (b) of the bio-membranes.

resistance has a slight increase up to about 2.9 kΩ for flux densities of 20 mT, and then it decreases close to 0.1 kΩ at 300 mT (Fig. 3b).

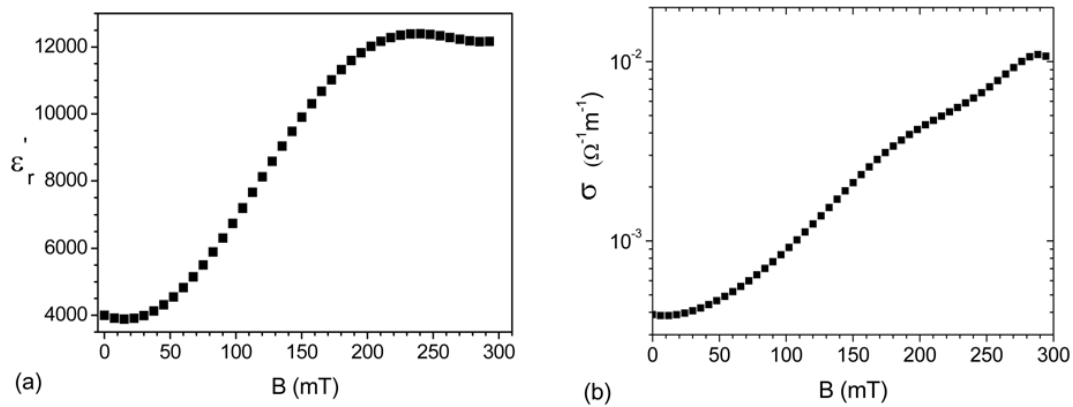
When an alternating electric field of intensity  $E = E_0 e^{-i\omega t}$  is applied, the membrane between the plates of the FC behaves as a dielectric, where the energy transported by the electric field is dispersed and absorbed. Here,  $E_0$  is the amplitude,  $\omega = 2\pi f$  is the pulsation, and  $i = \sqrt{-1}$ . These effects can be monitored by considering that the capacitance of FC is given by [18, 19]

$$C^* \equiv \epsilon_r^* \frac{S}{d_0} = C'(\omega) - iC''(\omega) = \frac{S}{d_0} \left( \epsilon_r'(\omega) - i\epsilon_r''(\omega) \right), \quad (1)$$

where  $C^*$  is the complex electrical capacitance,  $S$  is the common area between the plates,  $\epsilon_r^*$  is the complex relative dielectric permittivity,  $C'$  and  $C''$  are real and respectively, imaginary part of the complex capacitance,  $\epsilon_r'$  is the relative dielectric permittivity and  $\epsilon_r''$  is the dielectric loss factor.

In order to obtain  $\epsilon_r'$  and respectively  $\epsilon_r''$  we consider that the dipole admittance is given by [18]:

$$\frac{1}{Z_p} = \frac{1}{R_p} + \frac{1}{i\omega C_p} = \omega\epsilon_r''C_0 + i\omega\epsilon_r'C_0, \quad (2)$$



**Figure 4.** Variation with magnetic flux density  $B$  of the dielectric permittivity (a) and electrical conductivity (b) of the bio-membranes.

where  $Z_p$  is the impedance, and  $C_0$  is the electrical capacitance of FC without the bio-membrane. For numerical values of the vacuum dielectric constant  $\epsilon_0 = 8.85 \times 10^{-12}$  F/m and distance between plates of FC  $d_0 = 10^{-3}$  m, the capacitance of FC without the membrane becomes  $C_0 \equiv \epsilon_0 S/d_0 = 8.85$  pF.

By identifying the real and imaginary parts in Eq. 2, one obtains:  $\epsilon'_r = C_p/C_0$  and  $\epsilon''_r = 1/(\omega C_0 R_p)$ , and by using the dependence  $C_p = C_p(B)$  from Fig. 3a one finally obtains the variation of dielectric permittivity  $\epsilon'_r = \epsilon'_r(B)$  as shown in Fig. 4a.

The results show that the dielectric permittivity has a complex behavior with increasing  $B$ , and is characterized by the presence of a minima at 15.3 mT with  $\epsilon'_r = 3883$  followed by an almost linear increase in the range  $15.3 \div 239$  mT and a maxim at 239 mT with  $\epsilon'_r = 12536$ . By using the well known the relationship between electrical conductivity  $\sigma$  and the dielectric loss factor  $\epsilon''_r$  [18]  $\sigma = \omega \epsilon_0 \epsilon''_r$ , one can write that  $\sigma = \epsilon_0 / (C_0 R_p)$ . Thus, for numerical values  $\epsilon_0 = 8.85 \times 10^{-12}$  F/m,  $C_0 = 8.85 \times 10^{-3}$  nF and the dependence  $R_p = R_p(B)$  from Fig. 3b one obtains the variation  $\sigma = \sigma(B)$  as presented in Fig. 4b. The curve  $\sigma = \sigma(B)$  has a quasilinear dependence on  $B$ , up to about 288 mT, where it reaches a maximum at  $0.01067 \Omega^{-1}m^{-1}$ .

#### 4. Conclusion

We have prepared bio-active membranes based on honey, turmeric powder, carbonyl iron microparticles and a microfiber cloth. For honey volume fraction at 50 %, carbonyl iron microparticles at 30 % and turmeric powder at 20 % soaked into the microfiber cloth, one obtains a biodegradable hybrid MRS with a rich content of bio-active components. In a static magnetic field superimposed on an alternating electric field with constant frequency, the relative dielectric permittivity and electrical conductivity can be controlled by the applied magnetic field. This effect can be used in fabrication of medical devices which, for pre-established values of magnetic flux density and intensities of electric field, can perform a controlled release of the active components required for various medical treatments.

#### Acknowledgements

The paper is a result of the collaboration between JINR (Dubna, Russia) and the partner Universities/Institutes from Romania. Financial support from PN-III-P1-1.2-PCCDI-2017-0871 (CNCDI-UEFISCDI) project is acknowledged.

## References

- [1] H. A. Fonseca, E. Gonzales, J. Restrepo, C. A. Parra and C. Ortiz, Magnetic effect in viscosity of magnetorheological fluids, *J. Phys.: Conf. Ser.*, **637** 012102 (2016).
- [2] S. Sharma, Vibration Control in Quarter-Car Model with Magnetorheological (MR) Dampers Using Bingham Model, *J. Appl. Mech. Eng.*, **7** 1000299 (2018).
- [3] M. McKee and F. Gordaninejad and X. Wang, Effects of temperature on performance of compressible magnetorheological fluid suspension systems, *Journal of Intelligent Material Systems*, **29** 41 (2018).
- [4] W.-T. Chen, G.-B. Lin, S.-H. Lin, C.-H. Lu, C.-H. Hsieh, B.-L. Ma et al., Static magnetic field enhances the anticancer efficacy of capsaicin on HepG2 cells via capsaicin receptor TRPV1, *Plos ONE*, **133** (2018) e0191078.
- [5] J. Zhang, X. Meng, C. Ding, P. Shang, Effects of static magnetic fields on bone microstructure and mechanical properties in mice, *Electromagnetic Biology and Medicine*, In Press (2018) <https://doi.org/10.1080/15368378.2018.1458626>
- [6] K.-Q. Deng, P. Yun, T. Gong, Therapeutic Effects of Static Magnetic Field on Wound Healing in Diabetic Rats, *J. Diabetes Res.*, **2017** ID 6305370 (2017)
- [7] I. Bica and E. M. Anitas, Magnetic field intensity and graphene concentration effects on electrical and rheological properties of MREs-based membranes, *Smart Materials and Structures*, **26** 105038 (2017).
- [8] I. Bica and E. M. Anitas, Magnetodielectric effects in membranes based on magnetorheological bio-suspensions, *Materials and Design*, **155** 317 (2018).
- [9] J. L. Carillo, F. Donado and M. E. Mendoza, Fractal patterns, cluster dynamics, and elastic properties of magnetorheological suspensions, *Phys. Rev. E*, **68** 061509 (2003).
- [10] H. Brumberger, *Modern Aspects of Small-Angle Scattering*, Kluwer Academic Publishers, Dordrecht, 1995.
- [11] E. M. Anitas, Small-angle scattering from fat fractals, *The European Physical Journal B*, **87** 139 (2014).
- [12] E. M. Anitas, Microscale Fragmentation and Small-Angle Scattering from Mass Fractals, *Advances in Condensed Matter Physics*, **2015** Article ID 501281 (2015).
- [13] I. Bica, Y. D. Liu and H. J. Choi, Physical characteristics of magnetorheological suspensions and their applications, *J. Ind. Eng. Chem.*, **19** 394 (2013).
- [14] E. Esmailnezhad, H. J. Choi, M. Schaffie, M. Gholizadeh, M. Ranjbar, S. H. Kwon, Rheological analysis of magnetite added carbonyl iron based magnetorheological fluid, *J. Magn. Magn. Matter*, **444** 161 (2017).
- [15] N. Jahan, S. Pathak, K. Jain, R.P. Pant, Enhancement in viscoelastic properties of flake-shaped iron based magnetorheological fluid using ferrofluid, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **529** 88 (2017).
- [16] Y. Z. Dong, S.H. Piao, K. Zhang, H. J. Choi, Effect of  $CoFe_2O_4$  nanoparticles on a carbonyl iron based magnetorheological suspension, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **537** 102 (2018).
- [17] I. Bica and E. M. Anitas, Magnetic field intensity effect on electrical conductivity of magnetorheological biosuspensions based on honey, turmeric and carbonyl iron, *J. Ind. Eng. Chem.*, **64** 276 (2018).
- [18] A. Moliton, *Applied Electromagnetism and Materials*, Springer Science+Business Media, New York (2007).
- [19] J. Liu, Models of electromagnetic properties of composite media, PhD-Thesis, Iowa State University, Ames (2012). <https://lib.dr.iastate.edu/etd/12695/>