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Abstract: Magnetorheological biosuspensions (MRSs) are prepared using honey (HB), turmeric powder (nT) and carbonyl iron (CI) microparticles at various concentrations. By impregnating a cotton fabric with MRSs and compressing the whole system between two copper plates, a magnetoresistor (MRs) is obtained. The resistance R and electrical conductivity σ of MRs are measured as a function of time for various values of magnetic field intensity. We show that σ increases with H and is sensibly influenced by the volume fraction Φ_{CI} of carbonyl iron. For fixed Φ_{CI} and H, we show that σ increases with concentration Φ_{nT} of turmeric.

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Cover Letter

Dear Editor,

Please find enclosed the manuscript “Magnetic field intensity effect on electrical conductivity of magnetorheological biosuspensions based on honey, turmeric and carbonyl iron” by Prof. Ioan Bica and Dr. Eugen Anitas, which I ask you to consider for publication in Journal of Industrial and Engineering Chemistry.

We present the fabrication of a new class of magnetorheological biosuspensions based on honey, turmeric powder and carbonyl iron particles at various volume concentrations. Using the obtained suspensions, a magnetoresistor has been fabricated. The resistance and electrical conductivity of the magnetoresistor are investigated in an external magnetic field. We report that these properties are sensibly influenced by the magnetic field intensity and by the quantity of chemical components. The observed effect can be used in various bio-medical and technical applications, such as in physiotherapy, adaptive tuned vibrations or seismic protection.

The paper starts with an introduction that presents a general background, explains the motivations for this work and the expertise on similar works. Then, we present the materials and methods used thorough this paper. A theoretical model which explains the physical mechanisms is developed.

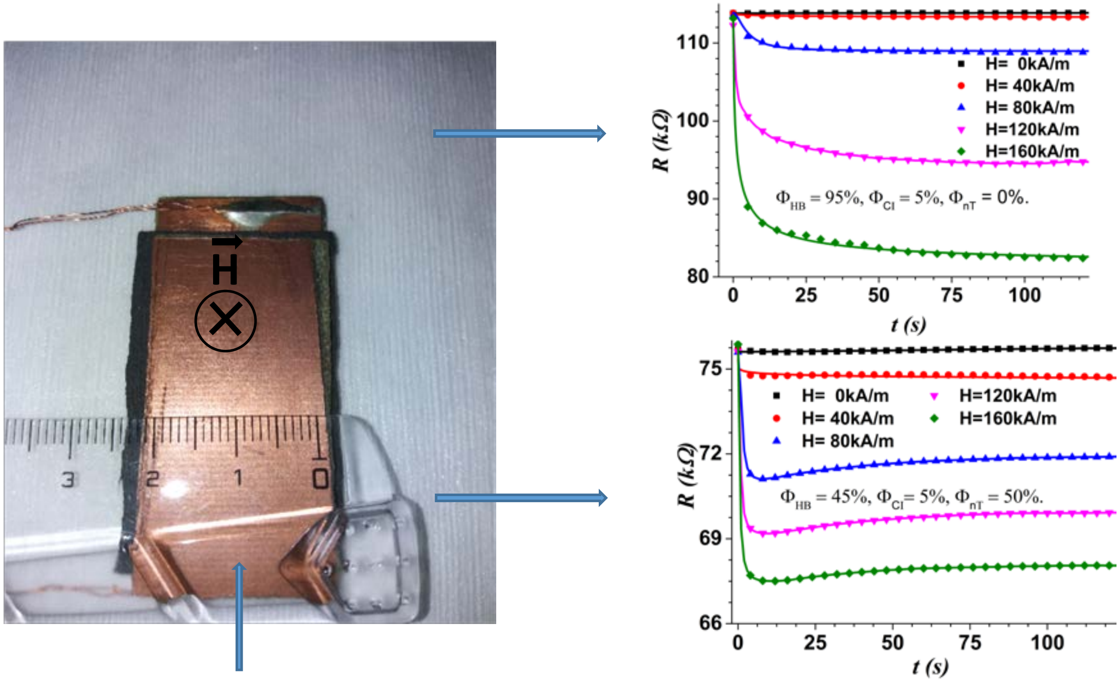
For its relevancy to medical and technical applications in which the obtained biosuspensions can be used and for its neat presentation, I hope that you will like the manuscript and find it suitable for publication in Journal of Industrial and Engineering Chemistry.

Sincerely,
Dr. Eugen Anitas

Highlights (for review)

- Magnetorheological suspensions based on honey, turmeric and carbonyl iron are fabricated.
- Magnetoresistors are manufactured based on the obtained magnetorheological suspensions.
- Electrical conductivity can be controlled by a magnetic field and concentrations of components.

***Graphical Abstract**



Magnetoresistor

$\Phi_{HB} - volume\ fraction\ of\ honey;$

$\Phi_{CI} - volume\ fraction\ of\ carbonyl\ iron;$

$\Phi_{nT} - volume\ fraction\ of\ turmeric.$

Magnetic field intensity effect on electrical conductivity of magnetorheological biosuspensions based on honey, turmeric and carbonyl iron

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(Dated: November 16, 2017)

Magnetorheological biosuspensions (MRSs) are prepared using honey (HB), turmeric powder (nT) and carbonyl iron (CI) microparticles at various concentrations. By impregnating a cotton fabric with MRSs and compressing the whole system between two copper plates, a magnetoresistor (MRs) is obtained. The resistance R and electrical conductivity σ of MRs are measured as a function of time t for various values of magnetic field intensity H. We show that σ increases with H and is sensibly influenced by the volume fraction Φ_{CI} of carbonyl iron. For fixed Φ_{CI} and H, we show that σ increases with concentration Φ_{nT} of turmeric powder.

Keywords: magnetorheological suspensions, honey, turmeric, carbonyl iron, electrical conductivity, magnetoresistor

I. INTRODUCTION

Magnetorheological suspensions (MRSs) belong to the class of smart materials, and generally consist from a liquid matrix such as mineral or silicone oil, in which magnetizable micrometer particles are dispersed. In an externally-applied magnetic field the particles are aligned along magnetic field lines forming aggregates. Their strength depends on the magnetic properties of the magnetizable phase and on the magnetic field intensity. Formation of aggregates in a magnetic field leads to modification of physical characteristics of MRSs and, in particular, of rheological ones [1–3]. This property of MRSs is used in fabrication of vibration absorbers and seismic protection [4], magnetically controlled clutches [5], passive electrical circuit components [6] etc.

The heavy mass of particles from the liquid matrix leads to sedimentation of the magnetizable phase which, in turn, induces a modification of the physical properties of MRSs with time. Avoiding this effect, totally or partially, is achieved by using additives [1–3]such as guar gum, magnetic nanoparticles of by fabrication of hybrid MRSs. In the latter case, the particles from the magnetizable phase are fixed in the pores of the absorbent sponge [7]. The metallic and magnetizable particles from the columns with magnetic dipoles in the liquid matrix, form a long chain of contact electrical resistances. When the columns of magnetic dipoles are in contact with two metallic electrodes, a magnetoresistor (MR) is formed [5, 6]. At a constant static magnetic field intensity the electrical resistance R of MR changes with time due to the viscosity of the elastic matrix. By fixing the magnetizable particles in a cotton fabric or in the pores of an absorbent sponge, the hydraulic resistance increases, and the motion of particles is restricted. Therefore, one obtains slow variations of the motion of magnetizable particles inside the matrix of MRS hybrid, as well as for the resistance R of MRs based on MRSs hybrid.

From another hand, MRSs based on liquids or semi-liquids produced by chemical synthesis are generally polluting and not suitable for use in medical applications. In order to avoid these issues, here we fabricate MRSs based on honey and turmeric. These substances have been used in folk medicine since ancient times, due to their many biological properties to possess, such as antitumor, antioxidant, antimicrobial, anti-inflammatory, and immunomodulatory effects, among others. Biological activities of honey [8, 9] and turmeric (Curcuma longa) [10] are mainly attributed to the phenolic compounds such as flavonoids. Flavonoids have been reported to exhibit a wide range of biological activities, including antibacterial, antiviral, antiinflammatory, antiallergic, and vasodilatory actions. In addition, flavonoids inhibit lipid peroxidation, platelet aggregation, capillary permeability and fragility, and the activity of enzyme systems including cyclo-oxygenase and lipoxygenase. Curcumin is known recently to have antioxidant, anti-inflammatory, anticancer effects and, thanks to these effects, to have an important role in prevention and treatment of various illnesses ranging notably from cancer to autoimmune, neurological, cardiovascular and diabetic diseases [10]. Furthermore, it is aimed to increase the biological activity and physiological effects of the curcumin on the body by synthesizing curcumin analogues.

Moreover, all living creatures perform their functions in a magnetic field of $25-26\ \mu T$ produced by the Earth. However, recent advances in technology exposes them to much bigger values of magnetic fields. As a result, many scientific studies are devoted to its effect on the health [11–15].

Preparation of materials and fabrication of devices which make use of the combined effects of honey, turmeric and a static magnetic field is still an open challenge. In

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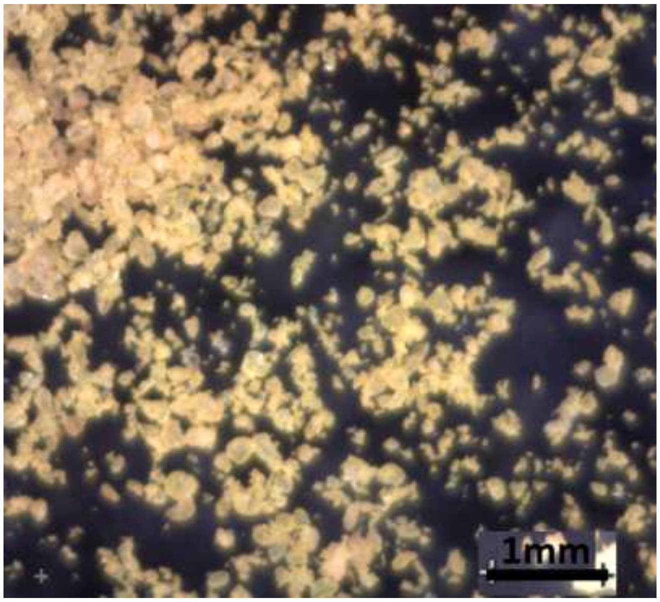

FIG. 1. Curcumin particles visualized with USB Microscop Digital, MV-900C, from Keyence [20].

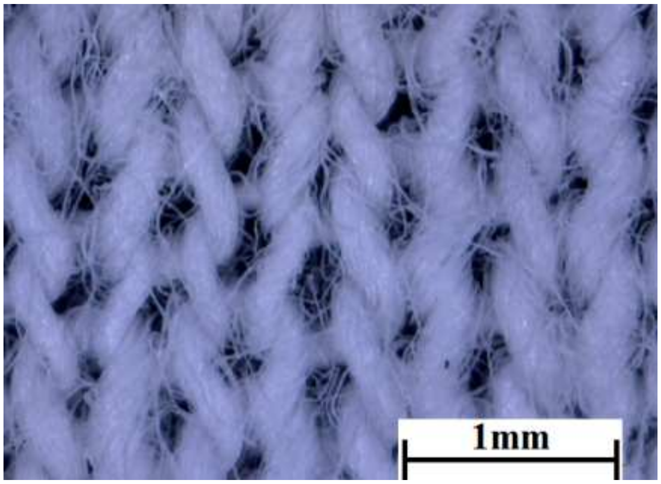

FIG. 2. Cotton fabric ([21]) visualized with USB Microscop Digital, MV-900C, from Keyence [20].

this work we address this issue and describe the fabrication process of a MRSs based on honey, turmeric and carbonyl iron at various concentrations. We show also that the electrical conductivity of MRSs can be sensibly modified in an externally-applied magnetic field.

II. EXPERIMENT

A. Production of magnetorheological suspensions

1. Materials and methods

Materials used for fabrication of MRSs are: carbonyl iron powder (CI; from Sigma-Aldrich) consisting of microparticles with diameters between 4.5 and 5.4 μm and Fe content of min. 97 % [16], polyfloral honey (HB; from Plantum) with a density of 1.42 g/cm^3 at 297 K [17], turmeric powder (curcumin; from Herbagetica) [18] with diameters between 12 and 320 μm, and cotton fabric [19]. The shape of curcumin particles is shown in Fig. 1 and the structure of cotton fabric is shown in Fig. 2.

Initially, we prepare samples S_i, $i = 1, \cdots, 5$ with the composition shown in Tab. I. After homogenization one obtains MRSs. In the second step, we cut five pieces of canvas cotton fabric with dimensions 4.5 cm × 2.5 cm. Finally, a volume of 0.4 cm^3 from each sample of MRS is used for soaking the canvas cotton fabric. Thus, one obtains hybrid MRSs, which we denote MRSi, $i = 1, \cdots, 5$.

TABLE I. Composition of MRSs samples. Here, $\Phi_{\rm CI}$, $\Phi_{\rm nT}$, $\Phi_{\rm HB}$ are the volume concentrations of carbonyl iron (CI), turmeric powder (nT), and respectively of honey (HB).

S_i	HB (cm^3)	CI (cm^3)	nT (cm^3)	$\Phi_{\rm CI}$ (%)	$\Phi_{\rm nT}$ (%)	$\Phi_{\rm HB}$ (%)
S_1	4.75	0.25	0.00	5	0	95
S_2	4.25	0.75	0.00	15	0	85
S_3	3.50	1.50	0.00	30	0	70
S_4	3.50	0.25	1.25	5	25	70
S_5	2.25	0.25	2.50	5	50	45

2. Production of magnetoresistors

Materials used for fabrication of MRs are MRSs from Tab. I together with textolite plates, from Sierra-Modellsport [22]. The plates are coated with Copper foils (TCu) on both sides. We cut ten pieces of TCu with dimensions 0.05 m × 0.02 m and to which we attach electrical conductors, as shown in Fig. 3. Between the Copper-coated sides of TCu we fix MRS and compress the whole system using a Wolfcraft press [23] up to 1.12 MN/m^2 for about 300 s. Fig. 4 left-part and right-part shows MRS without and respectively with addition of nT. Thus, one obtains MRS having a resistor body with dimensions 0.04 m × 0.020 m × 0.004 m, as shown in Fig. 5.

B. Experimental setup

The experimental setup used for investigating the properties of MRSs consists of an electromagnet A connected to a current source B, and which generates a static magnetic field whose intensity H can be continuously modified. The intensity H is recorded with the gauss-

FIG. 3. Textolite plate with Copper foils on both sides, and with an electrode wire attached at the top.

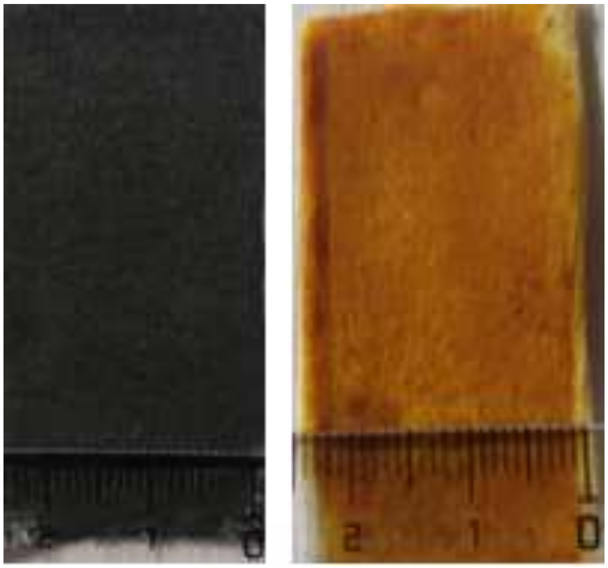

FIG. 4. Resistor body based on MRS. Left-part: HB with CI, or HB with CI and nT. Right-part: HB with nT.

meter C by using a Hall probe. The magnetoresistor a (Fig. 6) is placed half-way between the poles of the electromagnet. It is connected to the digital multimeter C, and the measured data are acquired by a recording board and collected by the computing unit D.

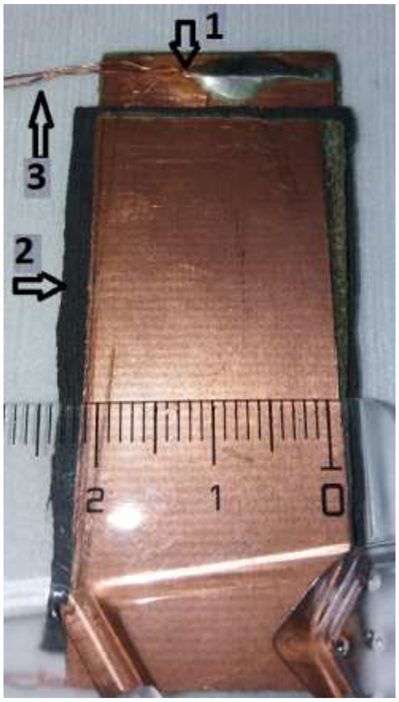

FIG. 5. Magnetoresistor: 1 - Copper electrode; 2 - resistor body; 3 - electrical conductor.

III. THEORETICAL MODEL

It is known that in the presence of a magnetic field, CI microparticles are aligned along the magnetic field lines (Fig. 7 Upper-part). An idealization of this situation is by considering that all CI particles are identical, microparticles chains are parallel and oriented along magnetic field lines, as shown in Fig. 7 Lower-part. According to this model, the magnetic dipoles are identical, the distances between particles are equal, the magnetic dipoles chains are equidistant and there is no interaction among them.

When a magnetic field of intensity $H = 0\ kA/m$ is applied, the distance between CI microparticles for MRSs without nT is [24]

$$X_0 = \begin{cases} d_m \dfrac{1}{\sqrt[3]{\Phi_{\rm CI}}}, & \Phi_{\rm nT} = 0, \\ d_m \dfrac{1}{\sqrt[3]{\Phi_{\rm CI}\left(1+\Phi_{\rm nT}\right)}}, & \Phi_{\rm nT} \neq 0. \end{cases} \tag{1}$$

The magnetic moment of CI microparticles can be calculated according to [26]

$$m = \frac{\pi}{6} d_m^3 \chi H, \tag{2}$$

where χ is the initial magnetic susceptibility, and is given by [25]

$$\chi = 3\frac{\mu_p - \mu_s}{\mu_p + \mu_s} \simeq 3, \quad for \quad \mu_p \gg \mu_s, \tag{3}$$

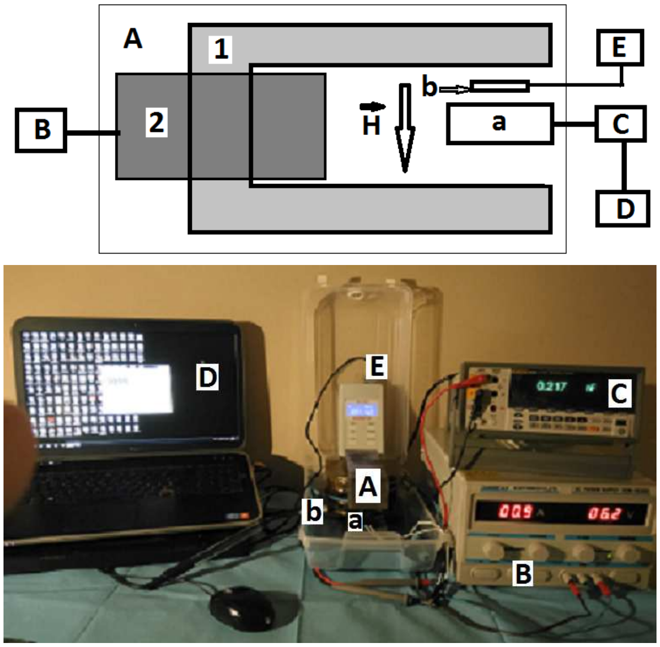

FIG. 6. Experimental setup. Upper-part: Ensemble configuration. Lower-part: Setup overview. A - electromagnet (1 - magnetic core, 2 - coil), B - source of continuous current, type RXN-3020D, C - digital precision multimeter, type 8846A, D - computing unit with software for data acquisition and processing, E - gaussmeter, type DX-102, $\vec{H}$ - magnetic field intensity vector, a - magnetoresistor, b - Hall probe connected to the gaussmeter DX-102.

where μ_p is the magnetic permeability of CI microparticles, and μ_s is the magnetic permeability of the viscous matrix.

In a magnetic field the dipoles are being attracted to each other, and their equation of motion, projected on ox-axis, is [24]

$$M\ddot{x} + 2\beta\dot{x} + \frac{3\mu_0}{\pi}\frac{\mu_s}{x^4}m^2 = 0, \tag{4}$$

where M is the mass of magnetic dipole, μ_0 is magnetic permeability of vacuum, x is the distance between magnetic dipoles at $t \neq 0$, and β is the particle friction coefficient. The later quantity can be calculated using [26]

$$\beta = \begin{cases} 1.5\pi\eta d_m, & \Phi_{\mathrm{nT}} = 0, \\ 1.5\pi\eta_{nT} d_m, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{5}$$

where η and η_{nT} are the viscosities of HB, and respectively of the mixture of HB and nT.

For the CI microparticles and viscous matrices used here [24] the first term in Eq. (4) can be neglected. Therefore, by using Eqs. (2) and (3) into Eq. (4), one obtains

$$2\beta\dot{x} + \frac{3\pi\mu_0}{4}\mu_s d_m^2 H^2 = 0. \tag{6}$$

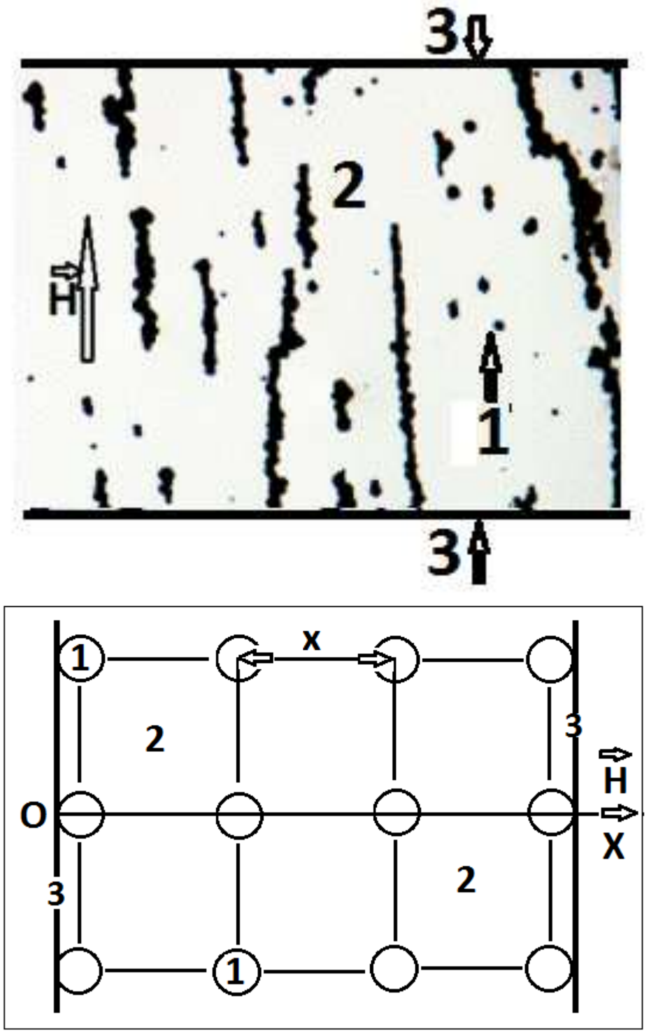

FIG. 7. Chains of CI microparticles aligned along magnetic field lines. Upper-part: Visualized at optical microscope. Lower-part: Theoretical model. 1 - magnetic dipole, 2 - viscous matrix, 3 - electrode, ox - coordinate axis, $\vec{H}$ - magnetic field intensity vector [24].

By imposing the conditions

$$x = \begin{cases} X_0, & t = 0, H \neq 0, \\ x, & t \neq 0, H \neq 0, \end{cases} \tag{7}$$

and integrating Eq. (6) one obtains the solution

$$x = \begin{cases} \dfrac{d_m\left(1 - P\sqrt[3]{\Phi_{\mathrm{CI}}}\right)}{\sqrt[3]{\Phi_{\mathrm{CI}}}}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{d_m\left(1 - P\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}\right)}{\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{8}$$

where $P = 3\pi\mu_0\mu_s d_m^2 H^2 t/(8\beta)$.

The dipole chains are formed in the empty spaces between the cotton fabric threads. The later one is found between two Copper electrodes connected to a digital multimeter. The resistance measured by the multimeter is an equivalent resistance R. It consists of the contact resistances in series R_j between magnetic dipoles. The chain of resistances R_j has its ends in contact with Copper electrodes. The number of magnetic dipoles can be approximated by

$$N_1 = \begin{cases} d_0/d_m, & \Phi_{\mathrm{nT}} = 0, \\ d_0/\left(d_m + d_{\mathrm{nT}}\right), & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{9}$$

where d_0 is the length of the dipole chains and it coincides with the thickness of MRs.

Thus, the resistance R_{1_j} of a single chain can be calculated from

$$R_{1_j} = \left(N_1 - 1\right) R_j \simeq N_1 R_j, \; for \; N_1 \gg 1. \tag{10}$$

The contact resistance between two neighboring dipoles can be approximated by

$$R_j = \frac{x}{\sigma_0 S_{\mathrm{C}}}, \tag{11}$$

where the distance x between neighboring dipoles is given by Eq. (8), $S_{\mathrm{C}} = 0.25\pi d_m^2$ is the contact surface area between metallic particles, and the electrical conductivity is defined as

$$\sigma_0 = \begin{cases} \sigma_0, & \Phi_{\mathrm{nT}} = 0, \\ \sigma_{0_{\mathrm{nT}}}, & \Phi_{\mathrm{nT}} \neq 0. \end{cases} \tag{12}$$

By using Eqs. (8) and (11) we obtain the resistance of dipoles chain as

$$R_d = \begin{cases} \dfrac{4}{\sigma_0 \pi d_m} \dfrac{1 - P\sqrt[3]{\Phi_{\mathrm{CI}}}}{\sqrt[3]{\Phi_{\mathrm{CI}}}}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{4}{\sigma_0 \pi d_m} \dfrac{1 - P\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}{\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}, & \Phi_{\mathrm{nT}} \neq 0. \end{cases} \tag{13}$$

In the volume of MRSs the number of dipoles can be approximated by

$$N = \begin{cases} \dfrac{\alpha V}{\Phi_{\mathrm{CI}} V_d}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{\alpha V}{\left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right) V_d}, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{14}$$

which can be rewritten as

$$N = \begin{cases} \dfrac{6\alpha L l d_0}{\pi \Phi_{\mathrm{CI}} d_m^3}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{6\alpha L l d_0}{\pi \left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right) d_m^3}, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{15}$$

where α is the absorption coefficient of MRSs, V is the volume of MRs, V_d is the volume of a single magnetic dipole, L is the length, and l is the width of MRS.

Then, by using Eqs. (9) and (15), one obtains the relation which gives the number of magnetic dipole chains

$$N_d = \begin{cases} \dfrac{6\alpha L l}{\pi \Phi_{\mathrm{CI}} d_m^2}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{6\alpha L l \left(d_m + d_{\mathrm{nT}}\right)}{\pi \left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right) d_m^2}, & \Phi_{\mathrm{nT}} \neq 0. \end{cases} \tag{16}$$

The resistance of MRs results from the parallel arrangement of resistance of magnetic dipole chains. Therefore, from Eqs (13) and (16) one obtains

$$R = \begin{cases} \dfrac{2d_m}{3\sigma_0 \alpha L l} \sqrt[3]{\Phi_{\mathrm{CI}}} \left(1 - P\sqrt[3]{\Phi_{\mathrm{CI}}}\right), & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{2d_m^2 \left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right)\left(1 - P\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}\right)}{3\sigma_{0\mathrm{nT}} \alpha l L d_0 \sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}, & \Phi_{\mathrm{nT}} \neq 0. \end{cases} \tag{17}$$

Then, by using Eq. (5) we rewrite (17) as

$$R = \begin{cases} R_0 \left(1 - \dfrac{\mu_0 \sqrt[3]{\Phi_{\mathrm{CI}}}}{4\eta} \mu_s d_m H^2 t\right), & \Phi_{\mathrm{nT}} = 0, \\ R_0 \left(1 - \dfrac{\mu_0 \sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}{4\eta} \mu_s d_m H^2 t\right), & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{18}$$

where the resistance R_0 of MRs at $H = 0$ is given by

$$R_0 = \begin{cases} \dfrac{2d_m}{3\sigma_0 \alpha L l} \sqrt[3]{\Phi_{\mathrm{CI}}^2}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{2d_m^2}{3\sigma_{0\mathrm{nT}} \alpha l L d_0} \dfrac{\left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right)}{\sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{19}$$

By considering that MRs are linear resistors, whose resistances are given by

$$R^* = \begin{cases} \dfrac{d_0}{\sigma L l}, & \Phi_{\mathrm{nT}} = 0, \\ \dfrac{d_0}{\sigma_{\mathrm{nT}} L l}, & \Phi_{\mathrm{nT}} \neq 0, \end{cases} \tag{20}$$

we obtain the electrical conductivities of MRs

$$\sigma = \frac{\sigma_{0m}}{1 - \frac{\mu_0 \sqrt[3]{\Phi_{\mathrm{CI}}}}{4\eta} \mu_s d_m H^2 t}, \quad for \quad \Phi_{\mathrm{nT}} = 0, \tag{21}$$

where

$$\sigma_{0m} = 3\alpha d_0 \sigma_0 / (2d_m \sqrt[3]{\Phi_{\mathrm{CI}}^2}), \tag{22}$$

and respectively

$$\sigma_{\mathrm{nT}} = \frac{\sigma_{0m\mathrm{nT}}}{1 - \frac{\mu_0 \sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}{4\eta_{\mathrm{nT}}} \mu_s d_m H^2 t}, \quad for \quad \Phi_{\mathrm{nT}} \neq 0, \tag{23}$$

where

$$\sigma_{0m\mathrm{nT}} = \frac{3\sigma_{0\mathrm{nT}} \alpha d_0^2 \sqrt[3]{\Phi_{\mathrm{CI}}\left(1 + \Phi_{\mathrm{nT}}\right)}}{2d_m^2 \left(\Phi_{\mathrm{CI}} + \Phi_{\mathrm{nT}}\right)}. \tag{24}$$

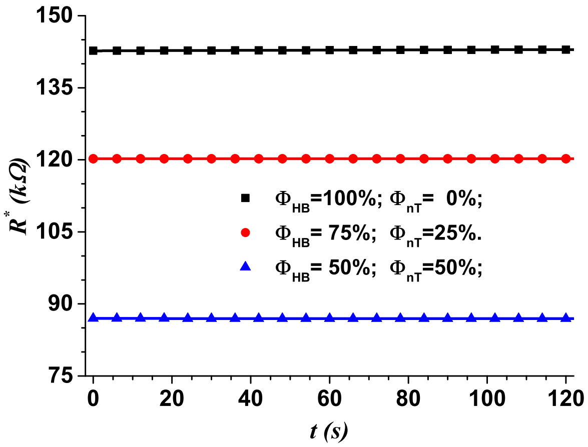

FIG. 8. The resistance R^* as a function of time t, measured at 24 h after manufacturing the resistors. Dots - experimental data; Continuous lines - polynomial fit.

IV. RESULTS AND DISCUSSIONS

The obtained resistors (see Fig. 4) containing only HB (i.e. without CI particles) at various concentrations with and without nT are introduced by turn between the poles of the electromagnet shown in Fig. 6. For fixed values of magnetic field intensity in the range $0 \div 160\ kA/m$, we measure the resistance R of the resistors, in steps of $40\ kA/m$ and with a time step of one second.

Fig. 8 shows the electrical resistance of resistors from Fig. 4 for various concentrations of HB and nT. We can observe that the resistance is cvasi-constant in time, it decreases with increasing the volume concentration of n. Moreover, since the resistors does not contain CI particles, their resistance is independent of magnetic field intensity H.

The electrical conductivity of the resistors is obtained by using the numerical values $d_0 = 0.40\,mm$, $L = 0.04\,m$, $l = 0.02\ m$ in Eq. (20). Thus, one obtains

$$\sigma^*\left(\Omega^{-1}m^{-1}\right) = \frac{0.0005}{R^*\,(k\Omega)}. \tag{25}$$

By using experimental data from Fig. 8 into Eq. (25) we obtain the dependencies $\sigma^* = \sigma^*(t)$ as shown in Fig. 9. The results show that by increasing the quantity of nT powder, the electrical conductivity of resistors increases.

By following a similar procedure for the magnetoresistors $MR_i, i = 1, \cdots, 5$ we obtain the variation of resistance with time, for fixed values of magnetic field intensity H, as shown in Fig. 10. The results show that the shape of the curves $R = R(t)$ for fixed values of H, are modified with increasing the volume fraction Φ_{CI}, in agreement with Eq. (18). From another hand, for fixed Φ_{CI} and for increasing values of Φ_{nT}, the values of resistances (Figs. 10d and e)) are smaller as compared with those measured for MR without nT powder, in agreement with Eqs. (18) and (19).

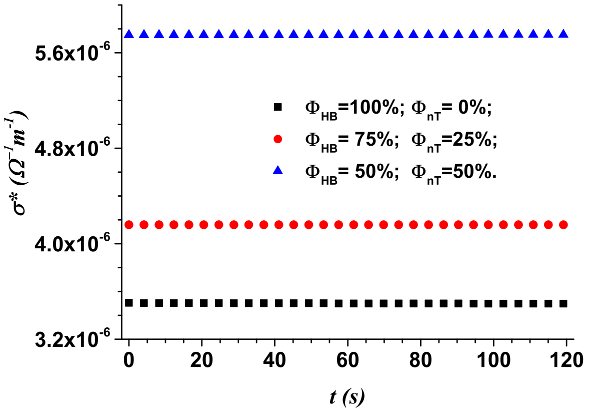

FIG. 9. The electrical conductivity σ^* as a function of time t, measured at 24 h after manufacturing the resistors. Dots - experimental data; Continuous lines - polynomial fit.

The dimensions of magnetoresistors coincide with those of the resistors. Thus, in order to obtain the conductivity of MRSs we use the data of $R(t)$ from Fig. 10 together with Eq. (25). The results are presented in Fig. 11(a), (b) and (c) and they clearly show that the electrical electrical conductivity increases with increasing the volume fraction of CI, and is sensibly influenced by the magnetic field intensity, in agreement with Eq. (21). Addition of nT powder leads to a further increase of the electrical conductivity, as seen in Fig. 11(d) and (e). Thus, the electrical conductivity of MRs can be controlled in a magnetic field by fixing the intensity H of the magnetic field, according to Eq. (23).

CONCLUSIONS

The materials produced from a mixture of honey, turmeric powder and carbonyl iron microparticles are magnetorheological suspensions at room temperature. Under the influence of a magnetic field or by changing the volume fractions of the components, the electrical conductivity of the obtained magnetorheological suspensions can be fixed and controlled in time. The magnetic field intensity is between 40 ÷ 160 kA/m and it can be obtained by using a neodymium magnet.

The possibility of changing the electrical conductivity of the biosuspensions can be useful in fabrication of devices in which the temperature can be fixed by the intensity of the electric current passing through the device. Heating the unhealthy areas, combined with the transport of bioactive substances from the honey or from the mixture of honey with turmeric, as well as with the effects of a static magnetic field, can be used as an effective medical treatment procedure. Moreover, magnetorheological suspensions obtained here are smart materials, environment-friendly, and can be used for various technical applications.

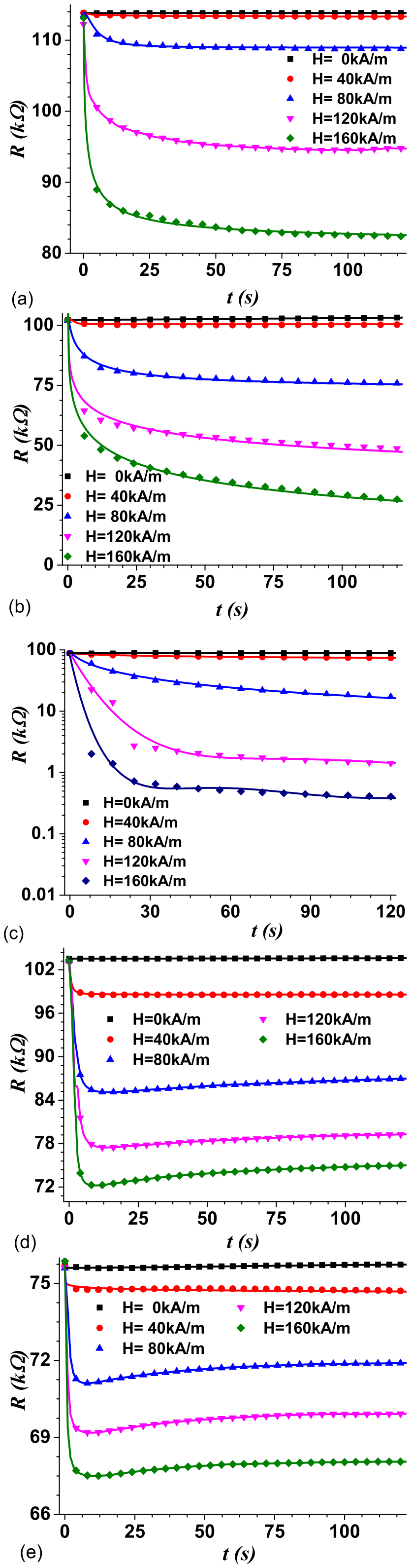

FIG. 10. Variation of resistance R (Eq. (18)) with time t for fixed values of magnetic field intensity H. a) MR_1. b) MR_2. c) MR_3. d) MR_4. e) MR_5.

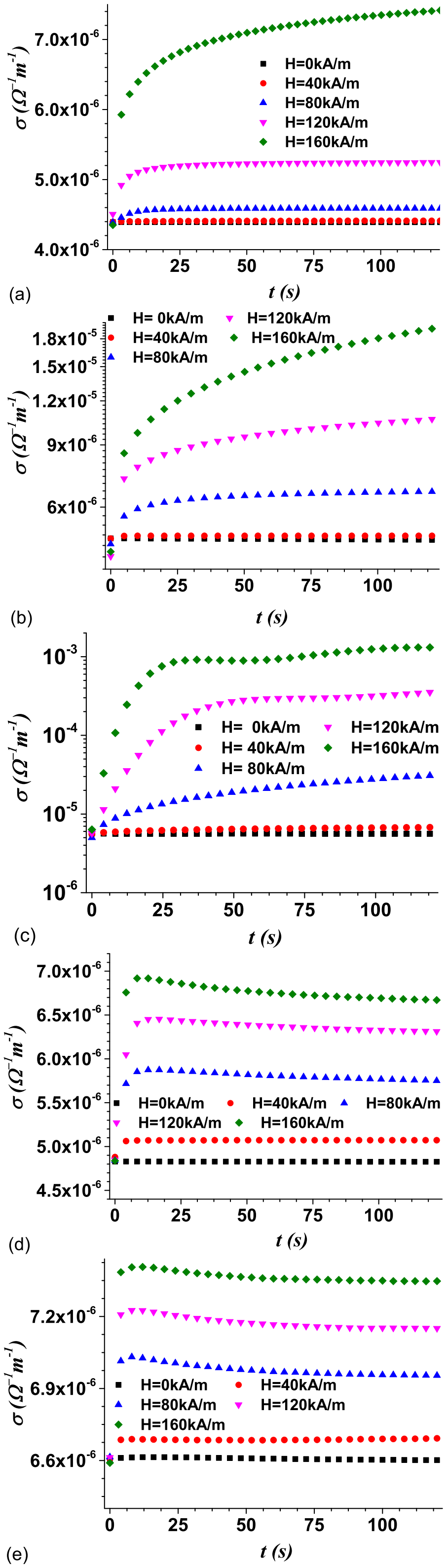

FIG. 11. Variation of electrical conductivity σ (Eqs. (21) and (23)) with time t for fixed values of magnetic field intensity H. a) MR_1. b) MR_2. c) MR_3. d) MR_4. e) MR_5.

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