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# Magnetic-field-tuned Insulator to Conductor Transition in Magnetorheological Suspension

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**Magnetorheological suspensions (MRSs) are smart materials that have the potential to revolutionize several industrial sectors because of their special rheological behaviors. In this paper, MRS, based on carbonyl iron (CI) microparticles that were dispersed in silicone oil with oleic acid, were prepared. We showed that the electroconductibility of MRS was significantly influenced by the intensity of the external magnetic field that was applied. The resistance value can vary from infinite to below 300 Ω after applying an external magnetic field. The results indicated that this MRS had the property of magnetic-field-tuned insulator to conductor transition. This system has potential applications in controllable MRS electrical devices.**

**Keywords :** electroconductibility, magnetorheological suspensions, magnetic materials, rheological properties, electrical properties

## 1. Introduction

Magnetorheological suspensions (MRSs), which can be transformed from the liquid state into the solid state by applying an external magnetic field, are intelligent fluids with the potential to revolutionize several industrial technologies. For their special rheological behaviors, MRSs have been applied to dampers, brakes, journal bearings, pneumatic artificial muscles, optics finishing, fluid clutches, and aerospace technologies [1-4]. Generally, MRSs are obtained from dispersing ferro- or ferromagnetic microparticles into a liquid phase matrix, which contains a carrier liquid and stabilizing additives or surfactants [5-8]. In an external magnetic field, the magnetic particles formed chains that orientated along the magnetic field line [9-12], which can revert to the initial phase when the magnetic field was annulled. The transformation degree depended on the intensity of the magnetic field applied.

The magnetic particles contacted each other in the chains under magnetic field. When the magnetic particles were conductive, these chains could be seen as conductive lines [13, 14]. The resistor of this type of MRS has infinite resistance in the absence of magnetic field, and the electroconductibility was significantly influenced by the intensity of the external magnetic field that was applied [15]. In a suitable magnetic field, the MRS system will transfer from an insulator to a conductor. In this paper, MRSs, based on carbonyl iron (CI) microparticles that were dispersed in silicone oil with oleic acid, were prepared. The electrical resistances R of MRSs that were dependent on the external magnetic field were discussed.


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## 2. Experiment

### 2.1. Sample preparation

The liquid matrix consisting of 47.5 g silicone oil and 2.5 g of oleic acid was introduced in a flask and was mixed at a frequency of about 100 rpm at 70°C. After thirty minutes, the oleic acid was entirely dissolved in the silicone oil. MRSs were formed by mixing the carbonyl iron (CI) microparticles (diameter of 2.5 μm) and three samples of the above liquid matrix. The CI massic percentages of MRSs were as follows: MRS1: 20%, MRS2: 40%, and MRS3: 60%, respectively.

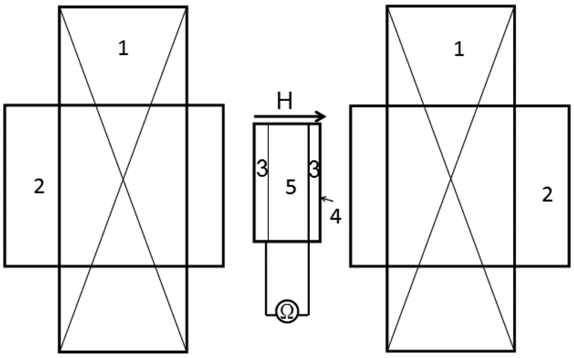


**Fig. 1.** Experimental assembly 1-magnetic coil; 2-magnetic core; 3-non-magnetic electrode; 4-glass container; 5-MRS; Ω-Keithley 2400 Source Meter; H-direction of the magnetic field intensity.

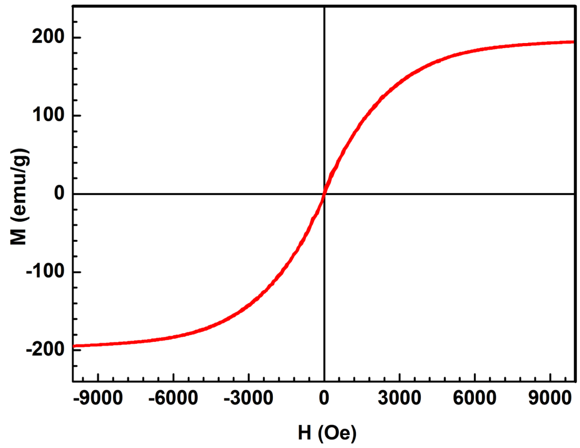


**Fig. 2.** (Color online) Magnetization curve for IC microparticles with the magnetic field H at room temperature.

### 2.2. Experimental Device

The magneto-resistor was a passive element of an electric circuit, with controllable resistance affected by the intensity of the external magnetic field. The MRS resistor consisted of a glass cube with MRS and two electrodes at two opposite sides. The experimental device used for the study of the electrical conductivity of MRSs in an external magnetic field is shown in Fig. 1. The magnetic properties of the magnetic particles were measured by vibrating sample magnetometer (VSM).

## 3. Results and Discussion

The carbonyl iron (CI) microparticles with the diameter of 2.5 μm were not washed before being used, and Fig. 2 depicts the magnetization curve for microparticles with the magnetic field H at room temperature. This curve showed that the particles can be magnetized under an external magnetic field, reaching a maximum moment (195 emu/g) when the magnetic field was about 6000 Oe.

The variation values of R under different magnetic field were recorded. The R-H curves for our samples are shown in Fig. 3. Similar trends were found in the three samples: MRS1, MRS2, and MRS3. Fig. 3a indicated that R decreased quickly during the initial increasing of the external magnetic field. In the absence of H, the resistor had a big resistance above of $10^{10}$ Ω. R decreased quickly when H increased to the changing H of 120 mT. Fig. 3b is the amplication of R in lower resistances. This figure indicated that R decreased slowly while H increased and reached a stable value of 300 Ω when H exceeded 800 mT.

In the absence of an applied field, MR fluids were reasonably well approximated as Newtonian liquids. The iron particles were randomly suspended in the carrier liquid. This system was an insulator with a huge resistance. In the presence of an applied magnetic field, the iron particles acquired a dipole moment aligned with the external field, causing particles to form linear chains aligned to the magnetic field line. The chains were electric leads because the iron was a good electric conductor, which led

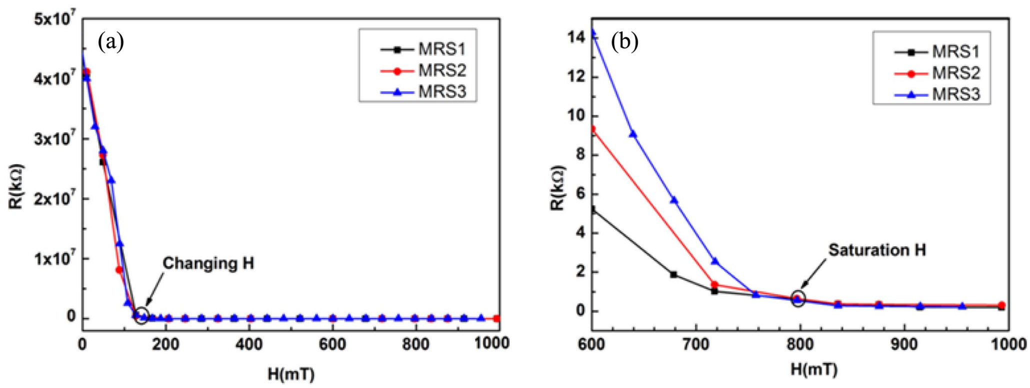


**Fig. 3.** (Color online) (a) Variation R by external magnetic field H. (b) Amplification in lower resistances.

**Table 1.** The parameters of R-H curves of samples.

| | MRS1 | MRS2 | MRS3 |
|---|---|---|---|
| Changing H | 127 mT | 127 mT | 125 mT |
| Saturation H | 875 mT | 875 mT | 875 mT |
| Saturation R | 220 Ω | 210 Ω | 250 Ω |

to the sharply decreasing of the MR resistance. The value of the resistance depended on the magnitude of the applied magnetic field. The resistance was the equivalent electrical resistance of contact between the magnetic dipoles lined up along the magnetic field lines. In the present of the magnetic field, the magnetic dipoles got close together, and the chain formed by the magnetic dipoles was thicker. These variations caused the decreasing of the resistance. R eventually reached a saturation point where increases of magnetic field did not decrease the resistance of the MRS for the stable chains. This phenomenon occurred around the saturation magnetic field of 800mT. The resistances were mostly stable when the magnetic field exceeded 800 mT.

The relative parameters are displayed in Table 1. The changing H, saturation H, and the saturation resistances were similar; this result indicated that the concentrations of CI did not really influence the conductive behaviors. The chains formed in H were effective when the chains contacted the two electrodes. With concentrations increased, the short chains increased, but they might not have formed the effective chains possibly due to the higher concentration of CI not reducing the saturation R.

The R variations with time for MRS2 under different magnetic intensity are shown in Fig. 4a. Time-varying resistance of MRS2 measurement was evaluated by varying the magnetic field intensity. A test should end with the acquisition of stable resistance and start a new test by only changing the magnetic intensity. The range of magnetic intensity was from zero to about 1000 mT, in which the resistance of MRS2 did not show any sensitiveness and was almost to the vanishing point during the around 120 second test. The R decreased quickly in the first twenty seconds under 403mT and, after that, the descent slowly changed. The variation rate under the higher H was smaller than that under lower H because the chains had been formed and the number of particles that were used to form a new effective chain decreased. Fig. 4b depicts the variation of R for MRS2 with the decreasing of H. The resistance maintained about 200 Ω from 800 mT and rocketed to $6.5 \times 10^4$ Ω under 0 mT. There were remanences of the particles from their micro-scale size. When the external magnetic field decreased, the particles could not go back to the states in Fig. 3a because of their remanence interactions.

## 4. Conclusion

In this work, MRSs, based on carbonyl iron (CI) microparticles dispersed in silicone oil with oleic acid as surfactant, were prepared. The particles could form conductive chains in external magnetic field. We analyzed the variation of electrical resistances (R) in alternative magnetic field (H) and found that the electroconductibility of MRS was significantly influenced by the intensity of the external magnetic field applied. The value of resistance could vary from infinite to below 300 Ω after applying an external magnetic field. These results indicated that this MRS had the property of magnetic-field-tuned insulator to conductor transition. This system has potential applications in controllable MRS electrical devices.

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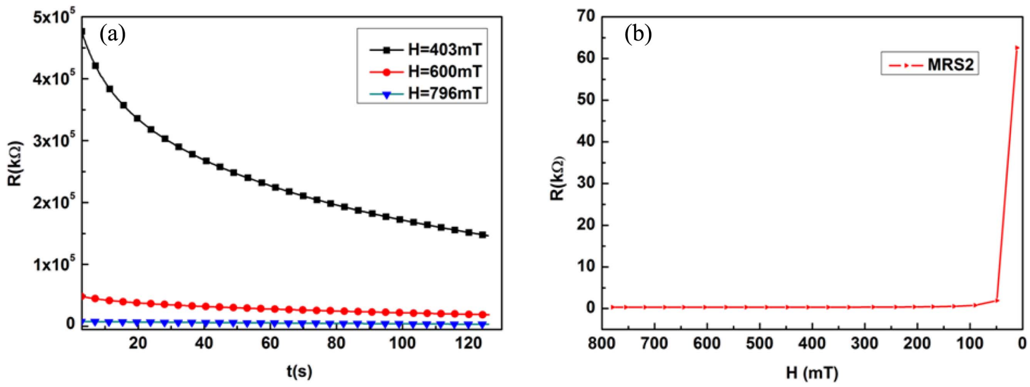


**Fig. 4.** (Color online) (a) Variation of R by time for MRS2 under different H. (b) Variation of R for MRS2 with the external magnetic field decreasing.

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