Rekayasa Respons Termomagnetik pada Komposit PCM Berbasis Asam Laurat untuk Aplikasi Penyimpan Energi Termal

PPMI FMIPA ITB 2026, Skema Penelitian Kompetitif

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Abstract

This study investigated the thermomagnetic response of lauric acid (LA) composites incorporating different magnetic nanoparticles, Fe_3O_4 and $NiFe_2O_4$ (mass fraction = 2 wt%), with particular emphasis on the role of nanoparticle magnetic characteristics in heat transfer and melting dynamics under a non-uniform magnetic field. The results showed that in the absence of a magnetic field, the incorporation of nanoparticles enhances heat transfer and accelerates the melting process, reducing the melting time of LA/Fe_3O_4 and LA/$NiFe_2O_4$ composites by approximately 9% and 3%, respectively, compared with pure LA. By contrast, applying a magnetic field inhibited melting and qualitatively increased the mushy zone thickness. As a result, the melting time increased by 40% for the LA/Fe_3O_4 composite and by 12.5% for the LA/$NiFe_2O_4$ composite compared with the corresponding samples without an applied magnetic field. The observed differences are discussed in terms of the combined effects of the distinct physical characteristics, thermophysical properties, and magnetic properties of the respective nanoparticles, and the associated heat-transfer processes. In particular, the change in conductive and convective heat transfer is measured by thermal conductivity and apparent viscosity. It may affect the internal flow field, nanoparticle migration, and convection intensity under the influence of buoyancy and Kelvin body forces. These findings provide valuable insights into the potential applications of nanoparticles and magnetic fields in phase-change materials to alter heat transfer through magnetic-field-induced fluid motion driven by the temperature-dependent magnetic properties of the material.

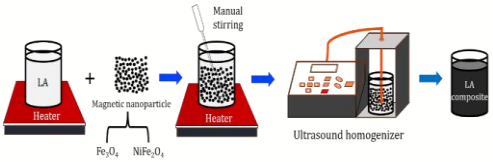
Keyword: Magnetic-composite lauric acid; Heat transfer; Melting dynamics; Kelvin force; Thermomagnetic convection.

Introduction

- Latent thermal energy storage (LTES) is a highly efficient method for storing thermal energy, utilizing phase change materials (PCMs).
- Efficient heat transfer in PCMs is essential for optimizing the absorption and the release of thermal energy, particularly during the phase transition process, where conduction and convection are the dominant modes of heat transfer.
- Thermomagnetic convection is a convective heat transfer driven by the interaction between temperature-dependent magnetization and a non-uniform magnetic field. In this case, it is caused by the Kelvin force that arises in a magnetically susceptible magnetic composite PCM. This phenomenon represents the fundamental mechanism of thermomagnetic devices.
- The present study investigates the melting dynamics of lauric acid composite by comparing the effects of two superparamagnetic nanoparticles, namely Fe_3O_4 and $NiFe_2O_4$, under the influence of a non-uniform magnetic field.

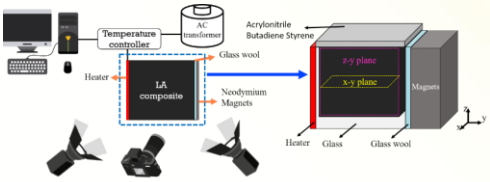
Research Method

Preparation of LA composite

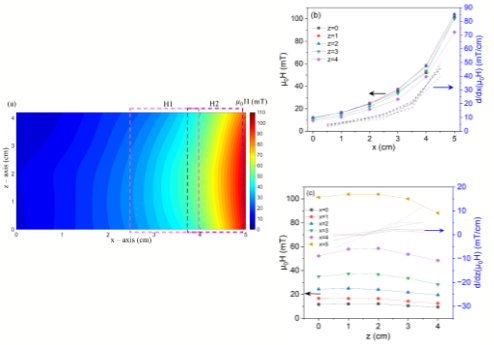


Picture 1. Preparation process of LA composite.

Asymmetrical melting experiment

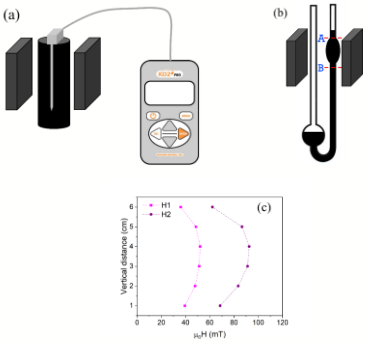


Picture 2. The experimental setup for the melting experiment.



Picture 3. (a) Magnetic field distribution in the x–z plane; magnetic field gradients along the (b) x- and (c) z-directions

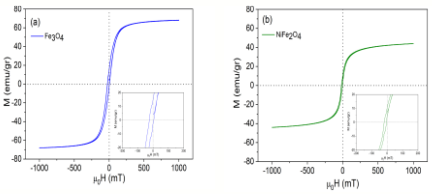
Thermal conductivity and viscosity measurements



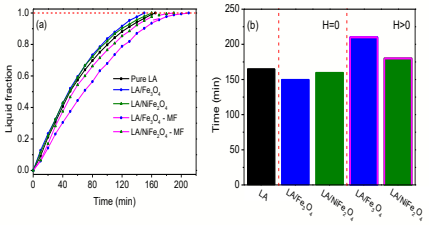
Picture 4. Schematics of the experimental setups used for measuring (a) liquid thermal conductivity and (b) viscosity under an applied magnetic field; (c) vertical magnetic field distribution for configurations H1 and H2

Discussion & Result

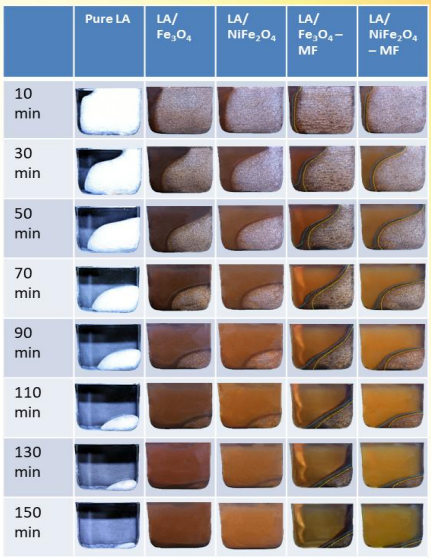
magnetization results for Fe_3O_4 and $NiFe_2O_4$ nanoparticles, measured at room temperature (25 °C)



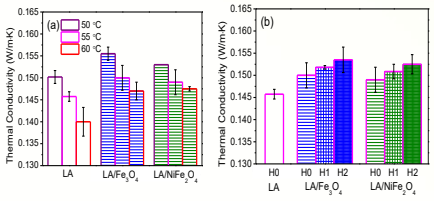
Picture 5. Magnetisation curves of (a) Fe_3O_4 and (b) $NiFe_2O_4$ nanoparticles. Insets show magnified views of the low-field regions



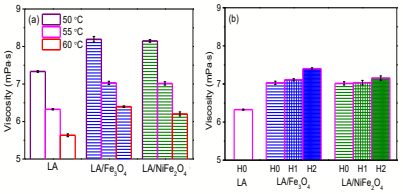
Picture 6. (a) Liquid fraction vs composites; (b) Total melting time of pure LA and LA composites.



Picture 7. Evolution of the melting process under different conditions



Picture 8. Liquid thermal conductivity (a) temperature dependence and (b) magnetic-field effect.



Picture 9. Viscosity (a) temperature dependence and (b) magnetic-field effect.

Conclusion

- In the zero magnetic field of LA composite, the melting process is primarily driven by the thermophoresis effect that aligns with the heat flux.
- The addition of nanoparticles accelerates the melting process by approximately 9% for the LA/Fe_3O_4 composite and 3% for the LA/$NiFe_2O_4$ composite compared to pure LA. The mushy zone in the LA composites is more distinctly defined than in pure LA, with the widths of the mushy zones in both composites being nearly identical.
- Under the influence of a non-uniform magnetic field, the Kelvin force arises in the same direction as the heat flux, driving thermomagnetic convection. This phenomenon suppresses natural convection and subsequently decelerates the melting process by 28.6% and 15.8% for the LA/Fe_3O_4 and LA/$NiFe_2O_4$ composites, respectively, compared to the case zero magnetic field.
- The higher magnetic susceptibility of Fe_3O_4 relative to $NiFe_2O_4$ contributes to the Kelvin force having a higher effect in the LA/Fe_3O_4 composite, leading to a lower melting rate compared to the LA/$NiFe_2O_4$ composite.