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Heat transfer enhancement of phase change composite material: Copper foam/paraffin

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A R T I C L E I N F O

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A B S T R A C T

Phase change materials (PCM) can store heat during the phase change process. Because foam metal is light-weight, has a large specific surface area and conducts heat well, we chose it as a test material. The phase change material paraffin was embedded in copper foam metal to form composite phase change materials. We constructed a platform to test the thermophysical properties of pure paraffin and the composite materials, and the paraffin and composite phase change materials were processed using numerical simulations to analyze their phase change process. For these simulations, the Fluent software with Solidification/Melting and Porous Zone model was used. The results showed that copper foam can effectively improve the internal heat transfer uniformity of paraffin, reduce the heat storage time of paraffin wax by 40%, and improve the relationship between the total phase transition time and the heating boundary temperature in the copper/paraffin composite phase change materials.

1. Introduction

Phase change materials are widely used in electronic cooling to improve energy efficiency [1,2] and renewable energy storage [3,4]. These materials are chosen because of their ability to absorb and release large amounts of heat, keeping the temperature constant [5,6] during the phase change process. However, the lower thermal conductivity of the conventional phase change material decreases its energy storage efficiency and severely limits its applications in practical engineering. Currently, compounds of consisting of phase change materials and metals, ceramics or carbon nano-materials [7–9] are used to enhance the thermal conductivity of the materials.

Copper foam is a versatile material [10] that is light-weight, has a large surface area, good thermal conductivity, and small complex permittivity [11–14]. However, due to the randomness of the distribution of the pore structure of the metal foam itself, its heat transfer process must account for the thermal conductivity, convection and radiation of the pore structure [15]. To learn more about the metal foam heat transfer mechanism, scholars have conducted a great deal of research. Diani et al. [16] used X-rays to make transmission scanning images of metal foam and study the relationship between the drop in the air flow and the heat transfer coefficient of metal foam at different PPI. Sundarram et al. [17]. conducted a phase transition simulation of the melting and solidification of a single facing cubic metal foam structure; they used CFD software to research the influence of PPI and porosity on phase transformation. Lachheb et al. [18,19]. researched the heat storage and release process for phase change materials in filled and unfilled metal foam; they proved that padding the metal foam can increase the thermal conductivity and shorten the melting and solidification times of the phase change material. In this application, Qu et al. [20]. used metal foam composite phase change materials as the thermal management system of a lithium-ion battery; their results indicated that the composite material can effectively reduce the surface temperature of the lithium battery and improve battery safety. Baby et al. [21]. researched the heat transfer performance of filled and unfilled copper phase change material radiators; their results showed that copper-filled radiators can enhance the heat transfer performance. Nazari et al. [22]. studied the convective heat transfer problems of plate heat exchanger-filled metal foam in which the nanofluids came through; this study comprehensively evaluated the heat transfer effect of metal foam padding plate heat exchange at different flow rates.

This article studies the affects of temperature change on the thermal storage performance of the phase change material paraffin with and without copper foam as a filler material. It

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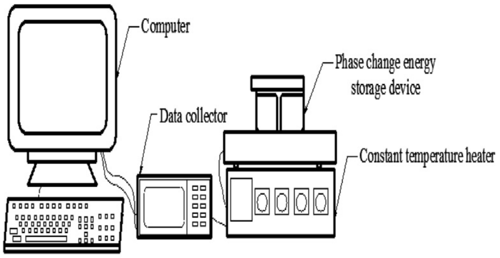
analyzes the relationship between the complete phase transition time and the heat source temperature of paraffin and of composite phase change materials. It simulates the phase change process of paraffin and composite phase change material using CFD software Fluent. Finally, this article analyzes the simulation results and discusses the impact of copper foam at different heat source temperatures on the heat storage performance of the phase change material.

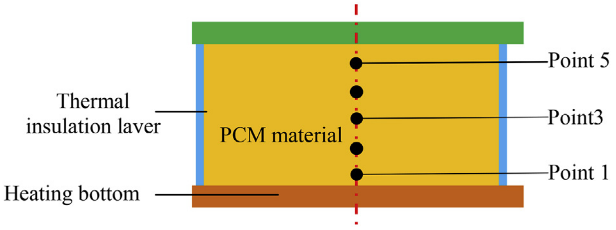
2. Experimental platforms to test material properties

The experimental test system is shown in Fig. 1a, b; it includes a phase change energy storage device, a temperature logger, and a constant temperature heating platform. The phase change energy storage device is shown in Fig. 1(b); it has a volume of 100 mm $-k\frac{\partial T}{\partial n}=q_0$ 90 mm $-k\frac{\partial T}{\partial n}=q_0$ 50 mm and is surrounded by 5 mm thick PVC insulation. The top and bottom are made of 8 mm thick aluminum and the sides and top are 10 mm of cotton insulation. During the test, six thermocouples were used, of which five (points 1–5) are distributed inside the storage material evenly spaced 10 mm apart; the sixth set of thermocouples was used to test the ambient temperature, as shown in Fig. 1.

In this experiment, the phase change material is 46 # industrial wax. The foam metal selected is bubble copper with a pore size of approximately 2–3 mm and porosity of approximately 97.3%. The paraffin wax heating into a liquid and foam copper was embedded into Liquid paraffin, the composite material of solidification is the composite phase change material that we want by a constant temperature heating way. The thermal analysis of the pure paraffin was made using DSC Q20 differential scanning calorimetry in a temperature range of 20–95 °C; the rate of the temperature increase was 1 °C/min, with nitrogen protection. The DSC test curve is shown in Fig. 2, which shows that the phase transition point temperature is 42.24 °C, and the latent heat is 170.4 J/g. Fig. 3 shows the temperature change curve of the solidification process of the paraffin measured by the experimental test system. A thermal diffusivity-NETZSCH LFA analysis of the pure paraffin and composite materials was made using the flash method thermal analyzer LFA 447. The thermal parameters are shown in Tables 1 and 2.



(a) Schematic diagram of structure



(b) Distribution of measuring points

Fig. 1. (a and b) Schematic diagram of experiment testing system.

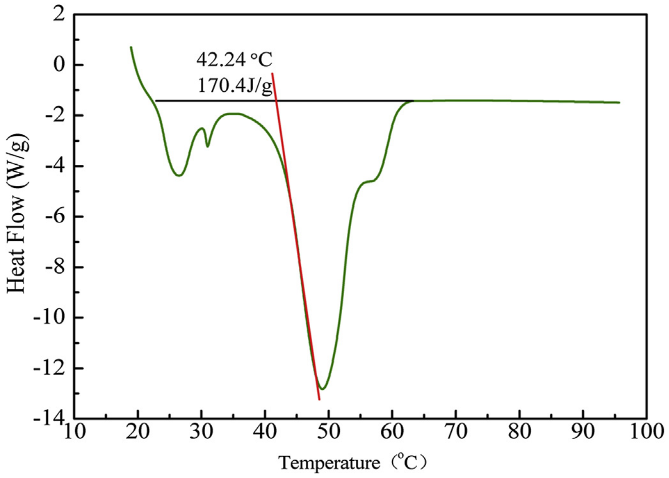


Fig. 2. The DSC curve of paraffin.

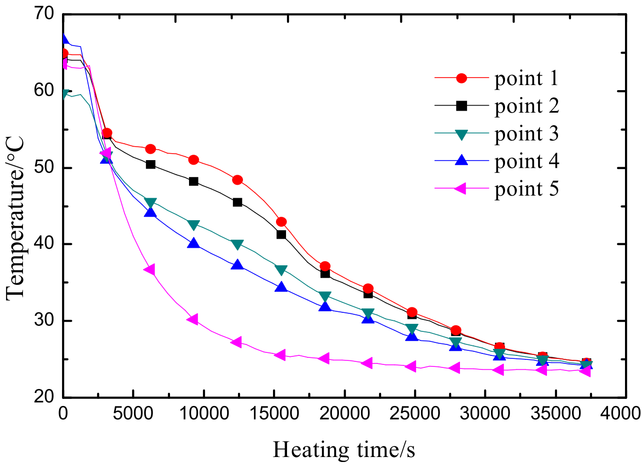


Fig. 3. The temperature curve of the pure paraffin during solidification.

Table 1
The thermal physical property parameter table of paraffin.

T/(°C)	A(m^2/s)	Λ(W·m^{-1}·K^{-1})	C_p (J·g^{-1}·K^{-1})
25 °C	0.097	0.487	5.012
38 °C	0.082	0.169	2.065
48 °C	0.042	0.065	1.548

Table 2
Thermophysical property parameters of the composite phase change material.

T/(°C)	a)m^2/s)	Λ(W·m^{-1}·K^{-1})	C_p (J·g^{-1}·K^{-1})
25 °C	0.856	2.879	3.351
38 °C	0.770	2.217	2.879
48 °C	0.249	3.112	10.547

In the tables, a is thermal diffusivity, λ is Coefficient of thermal conductivity C_p is Specific heat capacity.

3. Simulation

3.1. Geometric modeling of the boundary conditions

The numerical simulation model structure is shown in Fig. 1 (b). The boundary conditions of the sides and the top were set to