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Research on the preparation and properties of lauric acid/expanded perlite phase change materials

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ABSTRACT

In this study, a form-stable lauric acid/expanded perlite (LA/EP) composite was prepared by absorbing paraffin into porous networks of expanded perlite. The form-stable composite was characterized by using Differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FT-IR), Scanning electron microscope (SEM) techniques, durability and leakage test. Leakage test results showed that optimum and maximum mass fraction of LA contained in the composite without leakage is 70 wt.%. The FT-IR results revealed that there were physical interactions between the expanded perlite and the lauric acid. In addition, SEM images showed that LA can be quite evenly dispersed in the porous skeleton of EP. The melting temperature and latent heat of the form-stable EP/PA composite containing 70 wt.% lauric acid were determined as 43.2 °C and 105.58 J/g, presenting its suitable phase transition temperature, sufficient latent heat, good thermal stability for application as composite phase change materials (PCMs). The durability test showed that the leakage problems of PCMs composite can be greatly prevented because of the interaction between the expanded perlite and the LA. All the results suggested that the form-stable EP/PA composite has great potential in building applications for thermal energy storage.

1. Introduction

In recent years, with the rapid economic development, energy short age and environmental issues have become increasingly serious. Therefore, it is an important topic to improve energy utilization efficiency and protect environment [1]. Phase change materials (PCMs) are extensively employed as thermal energy storage media in many applications because of their capacity of storing and releasing a large amount of thermal energy during melting and solidifying at phase change temperature [2]. According to the phase change states, PCMs are often divided into three categories: solid–liquid PCMs, solid–solid PCMs and liquid–gas PCMs. Compared with other categories, solid–liquid PCMs possess the advantages of high latent heat density, lower cost as well as various choices, and have been utilized in various applications [3]. However, the leakage problem of liquid during the phase change process significantly has limited its application [4,5]. To overcome this problem, a new type of PCM composite is come into being, which is prepared by absorbing PCMs into polymers or porous materials, such as expanded perlite, gypsum and diatomite, to fabricate form-stable PCMs composite by direct incorporation method [6–9]. It is the simplest and cheapest method, especially for industrial production, in which liquid PCMs are directly added to porous materials [10]. Storing PCM in its small pores, the porous materials can not only improve the thermal conductivity of PCM, but also stabilize the shape of PCM in the phase change process [11,12].

The objective of this study was to assess the thermal performance, leakage, durability of solid–liquid PCMs. The microstructure and thermophysical properties of the LA/EP were characterized by scanning electron micro-scope (SEM), Fourier transformation infrared spectroscope (FT-IR), differential scanning calorimeter (DSC).

2. Materials and experimental

2.1. Materials

Lauric acid (LA), $C_{12}H_{24}O_2$, was purchased from Shanghai Better Chemical Co., Ltd., China. And it was directly used as received without further purification. Expanded perlite, (EP), used as the supporting material to prepare form-stable PCMs was purchased from Wuhan Perlite Factroy, China. The EP was sieved by 100–200 mesh sieve with the specific surface area of 1.312 m^2/g.

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Table 1
Criteria of leakage.

Leakage percent ($L\%$)	Phenomenon	Conclusion
$L\% \leq 10$	Trace amounts	Stable
$10 < L\% \leq 30$	A little bit leakage	basically remained stable
$30 < L\% \leq 50$	Moderate leakage	Unstable
$L\% > 50$	Severe leakage	Extremely unstable

2.2. Preparation

LA/EP composites were prepared by absorbing lauric acid into porous networks of expanded perlite. First, LA was melted at a temperature of 70 ± 5 °C for 2 h in an oven, and then immediately mixed with EP at ambient temperature and put back in the oven. The mixture was mixed in every hour until the LA was uniformly dispersed in the EP. Finally, the form-stable LA/EP composite was formed after cooling down at room temperature.

2.3. Characterization

2.3.1. Leakage test

In order to determine the maximum absorption ratio in which less PCMs leakage was observed, a series of PCM composites with different lauric acid mass fractions (30%, 50%, 70% and 90%, named as LA1–LA4) were prepared by absorbing lauric acid into porous networks of expanded perlite. After fabrication of PCMs, the leakage test was conducted to investigate the stability of the LA/EP composite. The sample was first put on the center of filter paper with the area of diameter 20 mm. Then, the composite was transferred in a 90 °C oven for 2 h, and then the LA trace on the filter paper was observed. Only the sample with the highest adsorption ratio, and less leakage happens when heated above the melting point of LA is recognized as stable PCM.

The leakage percent was determined using the equation as followed.

$$L\% = \frac{D_1 - D_0}{D_0} \times 100\%$$

where D_0 is the diameter of test area, 20 mm; D_1 is the diameter of seepage area after the leakage test. The criteria of leakage was shown in Table 1.

2.3.2. Absorptive capacity

Expanded perlite was immersed in lauric acid at 50 °C, 70 °C and 100 °C for 2 h to determine the absorptive capacity change. The absorptive capacity can be estimated by the following equations [13].

$$\varphi = \frac{m_2 - m_1}{m_1} \times \rho_{\text{sup porter}}$$

where φ is adsorptive capacity, g/cm^3, m_1 represents the weight of sample before the adsorption, and m_2 is the weight of sample of the studied sample after adsorption, g. $\rho_{\text{supporter}}$ is the density of expanded perlite, 2.3 g/cm^3.

2.3.3. Durability

The accelerated thermal cycling test was employed to investigate the durability of PCMs. The prepared PCM was heated at 50 °C for 1 min, and then cooled at 10 °C for 1 min. After several thermal cycles, respectively, the stability of PCM was determined using the following equation:

$$\Delta W(\%) = \left| \frac{W_1 - W_0}{W_0} \right| \times 100\% \quad (1)$$

Table 2
Result of the leakage test.

Samples	LA1	LA2	LA3	LA4
Test diameter (mm)	20	20	20	20
minimum diameter of leakage (mm)	20.1	20.2	20.3	22.8
maximal diameter of leakage (mm)	21.8	21.9	22.5	23.0
average diameter of leakage (mm)	20.95	21.05	21.4	22.90
Leakage percent ($L\%$)	4.75	5.25	7.0	14.5

where W_0 represents the weight of sample before thermal cycling test, and W_1 is the weight of sample of the studied sample after thermal cycling test.

2.3.4. FT-IR

FT-IR Spectra were recorded on an M-80 SPECORD (China) spectrophotometer using KBr tablets.

2.3.5. DSC

The phase change properties of composite were characterized using a differential scanning calorimeter (DSC) in the nitrogen atmosphere with a heating rate of 5 °C/min from 0 °C to 100 °C.

2.3.6. SEM

The samples were investigated via SEM conducted on an FEI Sirion 200 field-emission scanning microscope at an acceleration voltage of 25 kV.

3. Results and discussion

3.1. Leakage test

Table 2 shows the leakage result of the composites after leakage test. The experimental results show that there was no LA trace observed on the surface of the filter paper for the composite LA1, LA2 and LA3; however, very small amount of leakage was found within the circle area for composite LA4. It can be concluded that the optimum and maximum mass fraction of LA contained in the composite without leakage is 70 wt.%.

3.2. FT-IR

Chemical characterization of LA and the composite was carried out using FT-IR spectroscopy and the results are shown in Fig. 1.

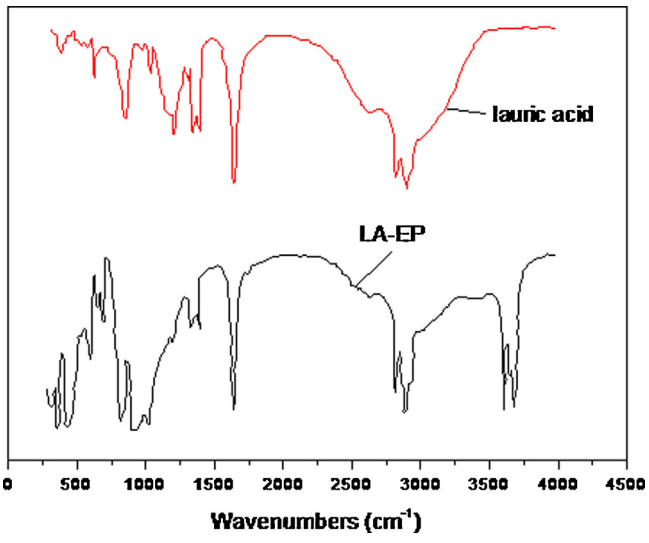

Fig. 1. FT-IR.