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Thermal properties of sodium nitrate-expanded vermiculite form-stable composite phase change materials

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ABSTRACT

This paper focused on the preparation and characterization of a novel thermal storage material applied in thermal storage. Sodium nitrate-Expanded vermiculite (EV) composite phase change materials were prepared by direct impregnation method. The chemical composition is investigated by X-ray diffraction (XRD). Scanning electron microscope (SEM) revealed that EV is porous structures, and sodium nitrate was stably adsorbed in the pores of EV. Further, the adsorptive capacity of EV to sodium nitrate is 734.6%. Meanwhile the thermal conductivity of composites is higher than single component, and the silicon carbide can improve the thermal conductivity of composites obvious. After 200 h heat treatment, differential scanning calorimeter (DSC) result indicated that the melting temperature changes are <3.9 °C and thermal enthalpy changes are <5.0%. All the results indicated that the composite materials can be as a good candidate to be applied in thermal energy storage fields.

1. Introduction

Thermal energy storage is a key process that it has been widely applied in various energy transportation and utilization system. Three major technologies currently being considered for heat storage include: sensible heat, latent heat, and reversible chemical reaction heat storage. Among the three technologies, latent heat thermal energy storage is the most promising for heat storage due to the consistent temperature and relatively high latent heat [1–3]. Phase change materials (PCMs) are latent heat energy storage materials which possess the advantages of high storage density in small temperature interval [4–8].

Recently, in the middle-high temperature thermal storage fields, molten nitrates salts have many advantages to be researched in thermal storage. Xiao [9] researched sodium nitrate, potassium nitrate and their mixture were used as the base materials, and expanded graphite with high thermal conductivity and thermo-chemical compatibility was used as an additive to enhance the thermal conductivity. Olivares [10] also studied the thermal compatibility of molten nitrite/nitrates salt for solar thermal energy storage in different atmospheres. Among the molten nitrates salts, sodium nitrate seems to be a good material for thermal storage. Its latent heat is relatively high. Moreover it is a single component with a high commercial availability and is easier to manufacture than eutectic salt. However, the molten sodium nitrate belongs to the solid-liquid PCM, and special encapsulation is required to prevent the leakage during solid-liquid phase transition process. Therefore, it is necessary to study the heat transfer, packing enhancement and long-term stability in thermal storage. The form-stable composite PCMs contain solid-liquid PCM and supporting material can fix this problem [11, 12]. At present, expanded graphite [13–15], diatomite [16,17], carbon nanotubes [18] are being used to prepare form-stable composite PCMs. However, there are several troubles for the composites such as high cost, low heat storage density et al.

Expanded vermiculite (EV) has a series of features, such as very low density, low thermal conductivity, high fire resistance and strong sound absorption, what makes it attractive for use as lightweight construction aggregate, thermal insulation filler and soil modifier. Moreover, it also has good chemical compatibility and adsorption ability with PCMs. Therefore, EV can be as a good candidate to prepare form-stable composite PCMs. However, low thermal conductivity (0.065 W/(m · K)) limits its utility in latent heat storage system [19–22]. High thermal conductivity material is introduced into composites can solve this problem.

In this paper, the sodium nitrate-EV composites were prepared as a novel form-stable PCM by direct impregnation method. The method is simple and feasible. The properties of composite PCMs were characterized by SEM, FT-IR, DSC et al. analysis techniques. All the results

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Table 1
Chemical constituents of the EV (wt%).

Constituent	SiO_2	Al_2O_3	MgO	CaO	K_2O	Fe_2O_3	Other
Ratio	48.3	19.6	13.8	1.2	8.6	7.3	1.2

indicated that EV can be utilized as a good adsorption material in thermal energy storage fields.

2. Experiment

2.1. Materials

Sodium nitrate with purity ≥99.0% is supplied by Beijing Chemical Reagent Company (Beijing, China), and used without further purification. Expanded vermiculite (EV) is furnished by Lingshou Yixin Minerals Co., LTD (Hebei, China) with average particle size is ranging from 0 mm to 4 mm, bulk density of 180 g/L, and pH of 7–8. It can be seen from Table 1 that the EV is mainly composed of SiO_2, Al_2O_3, and MgO. Fig. 1 showed the images of EV, it can be seen that much layer structure in vermiculite. Prior to the experiment, the samples are previously dried at 105 °C for 24 h. Silicon carbide is obtained from Wuhan (Hubei, China) with the average particle size is 200 mesh.

2.2. Methodology

In this study, the composites are prepared by direct impregnation method. Sodium nitrate is employed as a thermal storage medium, and EV as the adsorption material. A schematic of the impregnation system is showed in Fig. 2. The EV is dried at 105 °C for 24 h. Later the EV is put into the metal net. The adsorption setup is placed in the centre of muffle furnace and it is filled with fluid sodium nitrate at 350 °C. Later the EV is surrounded by metal net which fastened by a supporting stick. This adsorption process is sustained for 120 min. After the adsorption process, sodium nitrate-EV composites are taken out and cooled to room temperature.

The adsorption theory can be illustrated as follow: In the surface hydroxyl groups, the silicon atoms at the surface tend to maintain their tetrahedral coordination with oxygen. They complete their coordination by attachment to monovalent hydroxyl groups, forming silanol groups. The different types of silanol groups and alumina's hydrous oxide surface groups in EV are showed in Fig. 2. These groups give the adsorption property to EV.

The adsorptive capacity can be estimated by the followed equation. Where ε(wt%) is adsorptive capacity, *wt%*, m_1 represents the initial mass of sample, and m_2 is the mass of sample after adsorption:

$$\varepsilon(\mathrm{wt\%}) = \frac{m_2 - m^1}{m_1} \times 100\% \qquad (1)$$

According to Eq. (1), the adsorptive capacity of EV to sodium nitrate is 734.6 wt%.

Thermal conductivity (λ) of composite PCMs is determined by thermal conductivity meter, and mass ratios are given in Table 2. 50 g sample is mixed and grinded into 80 mesh, further 1 ml binder (Aluminum dihydrogen phosphate) is added to the samples and shaped round pie of Φ50 mm under 20 MPa for 1 min.

Thermal stability of composite samples is investigated by DSC. The samples are prepared by direct impregnation method, and the mass ratios are showed in Table 3. EV is added in the melting sodium nitrate at 350 °C in the muffle furnace. The thermo physical properties of composites are investigated by DSC.

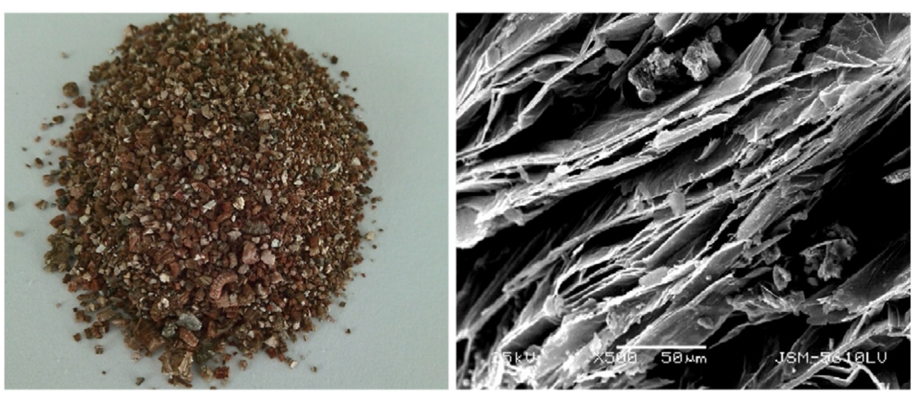

Fig. 1. Expanded vermiculite images.

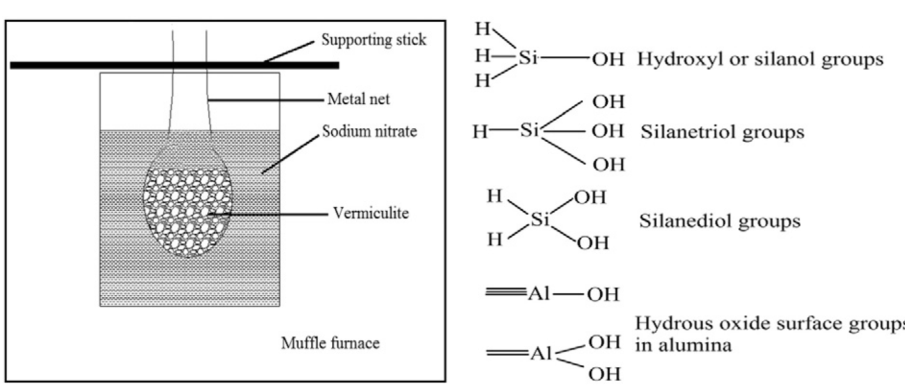

Fig. 2. Preparation diagram of form-stable composite PCMs.