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Characterization and thermal performance of nitrate mixture/SiC ceramic honeycomb composite phase change materials for thermal energy storage

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HIGHLIGHTS

- Nitrate mixture/SCH composite PCM was prepared by vacuum infiltration.
- PCM was embedded and dispersed in the porous structure of SiC wall.
- SCH induced slight shift of the melting and freezing temperature of PCM.
- The heat storage and release rates of PCM were improved by SCH.

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ABSTRACT

The composite phase change material (PCM) comprised of the nitrate mixture $KNO_3/NaNO_3$ (50:50 mol%) and SiC ceramic honeycomb (SCH) was prepared by vacuum infiltration. The SEM (scanning electron microscope) images indicated that the nitrate mixture was dispersed and embedded in the porous structures of the SiC wall. The DSC (differential scanning calorimeter) results showed that the melting and freezing temperatures of composite PCM shifted slightly compared with those of pure PCM, and the melting and freezing latent heats of composite PCM were 72.8 J/g and 70.3 J/g, respectively. The thermal performances of the pure PCM and the composite PCMs with different mass fractions of SCH were experimentally investigated. The results showed that the heat storage and release rates increased with the increase of the mass fraction of SCH in the composite PCM. In comparison with the pure PCM, the heat storage and release time of the composite PCM with 30 wt% SCH were reduced by 52.8% and 58.3%, respectively.

1. Introduction

In recent years, latent heat thermal energy storage (LHTES) using phase change material (PCM) has attracted great interests due to its large heat storage capacity during the phase change process. Among the different PCMs, the nitrate mixture $KNO_3/NaNO_3$ (50:50 mol%) has been successfully used in the high temperature LHTES, particularly in the solar thermal utilization systems [1,2]. The nitrate mixture has the advantages of large latent heat, proper melting temperature and good stability.

However, low heat conductivity hinders the utilization of many PCMs due to decreasing the heat storage and release rates, and different methods have been used to enhance the thermal conductivity of PCMs [3–6]. The use of porous materials, such as metal foam and honeycomb, have been investigated by many researchers because of their high thermal conductivity and large heat exchange area [7–9]. The thermal performance of PCMs has been improved efficiently by using the metal porous materials, however, metal materials cause the corrosion problem inside the nitrate salts at a high temperature [10,11]. SiC ceramic honeycomb (SCH) with open cell channels and high thermal conductive walls, has attracted considerable attentions. SCH with its high thermal conductivity has been successfully used as the collector of solar heat and the high temperature heat exchanger [12–14]. It has the advantages of low coefficient of thermal expansion, good thermal stability and a high

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service temperature [13,15]. Meanwhile, it is corrosion-resistant against the nitrate salts [16]. However, few papers reported the improvement of thermal performance of PCMs using SCH as the heat transfer promoter.

In this paper, a new composite PCM was prepared by vacuum infiltration. The nitrate mixture $KNO_3/NaNO_3$(50:50 mol%) was employed as PCM and SCH was used as the heat transfer promoter. The microstructure and thermal properties of composite PCM were characterized, and the thermal performances of the composite PCMs were investigated during the heat storage and release process.

2. Experimental

2.1. Samples preparation

A stainless steel cylinder vacuum container was designed to prepare the composite PCM. The cuboid SiC ceramic honeycomb (SCH) sample was from IBIDEN Co., Ltd. The thermal conductivity of SiC block is 27 W/m·K, and the density of SCH is 741 kg/m^3. The SCH sample and the solid nitrate mixture with the purity of 99% were placed in the container, which was heated from room temperature (about 25 °C) to 325 °C and the heating process lasted for 4 h to ensure that PCM was totally melted and infiltrated into the cells and pores of SCH. After that, it was cooled down until the PCM was solidified. The pressure in the container was kept below 20 Pa by pumping in the whole process.

2.2. Characterization

A scanning electron microscope (SEM, Hitachi-FE-SEM-S- 4800) was used to observe the microstructures of SCH and composite PCM. The thermal properties of pure PCM and composite PCM were investigated using a differential scanning calorimeter (DSC, METTLER TOLEDO-DSC-1) at 10 °C/min with nitrogen gas flow of 20 mL/min. The uncertainties of temperature and enthalpy measurement were within ±0.1 °C and ±1%, respectively. The thermal performances of the composite PCMs mixed with different mass fractions of SCH were investigated inside a cylindrical thermal energy storage unit (TESU) as shown in Fig. 1. One TESU was incorporated with SCH that was cut and arranged as to fit the size and form of the unit, and the other two were incorporated with SCH that was cut and arranged at random. The mass fractions of SCH in the TESUs were 30, 23 and 18% respectively. One K-type thermocouple was placed at the outermost position of the bottom in the TESU to measure the temperature evolutions of PCMs. The synthetic oil as heat source flowed down in the pipe located in the center of TESU. A flow meter was used to measure the flow rate of the circulated oil, and two K-

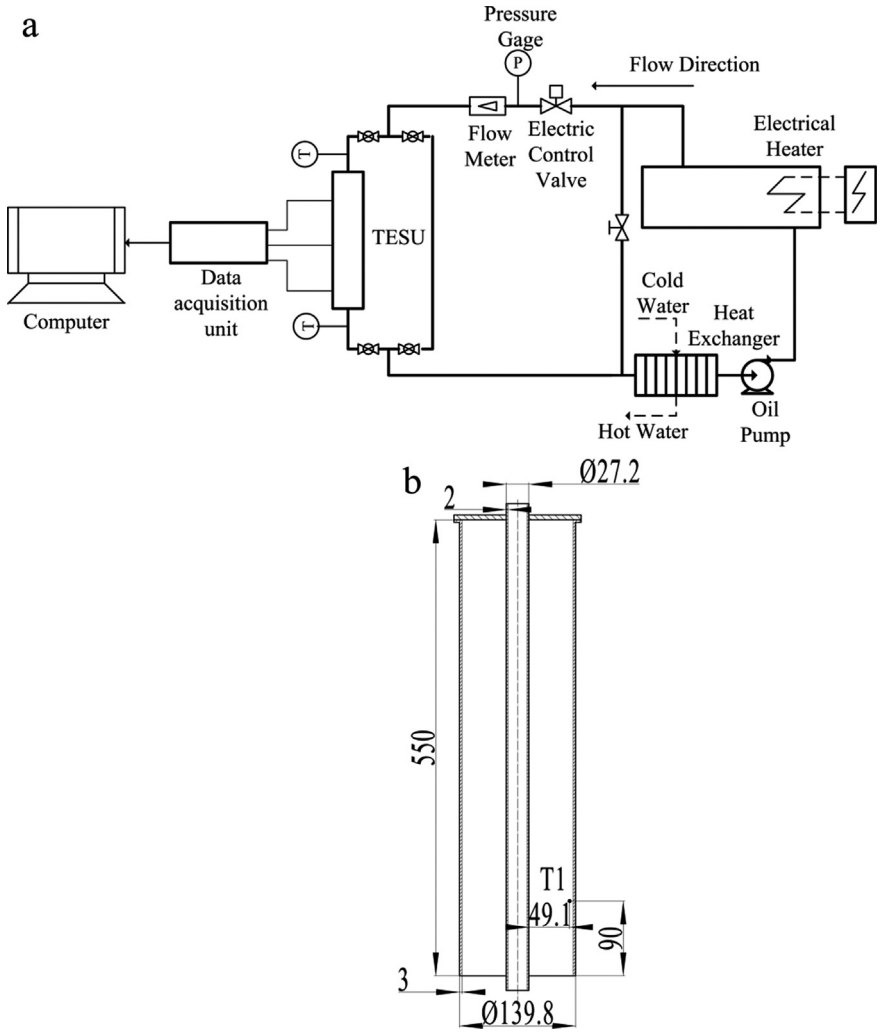

Fig. 1. Schematic of LHTES system (a) and thermal energy storage unit (unit:mm) (b).