Applied Energy 182 (2016) 475–487

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Experiment study on the thermal properties of paraffin/kaolin thermal energy storage form-stable phase change materials

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HIGHLIGHTS

- Different particle sizes of kaolin were employed to load paraffin.
- The effects and reasons of particle size on thermal conductivity were studied.
- Thermal property and thermal stability of the composites were investigated.
- The leakage and thermal storage and release rate of the composites were studied.
- The effect of vacuum impregnation method on thermal conductivity was investigated.

ARTICLE INFO

Article history:
Received 16 June 2016
Received in revised form 21 August 2016
Accepted 25 August 2016
Available online 31 August 2016

Keywords:
Phase change materials
Clay mineral
Heat transfer
Thermal energy storage

ABSTRACT

In this paper, different particle sizes of kaolin were employed to incorporate paraffin via vacuum impregnation method. The paraffin/kaolin composites were characterized by Scanning Electron Microscope (SEM), X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimeter (DSC) and Thermogravimetry (TG). The results showed that the paraffin/kaolin composite with the largest particle size of kaolin (K4) has the highest thermal conductivity (0.413 W/(m K) at 20 °C) among the diverse composites. The latent heat capacity of paraffin/K4 is 119.49 J/g and the phase change temperature is 62.4 °C. In addition, the thermal properties and thermal conductivities of paraffin/K4 with different mass fraction of K4 (0–60%) were investigated. The thermal conductivities of the composites were explained in microcosmic field. The phonon mean free path determines the thermal conductivity, and it can be significantly affected by temperature and the contact surface area. The leaks, thermal storage and release properties of pure paraffin and paraffin/kaolin composites were investigated and the composites presented good thermal stabilities.

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1. Introduction

With the increasing consumption of fossil fuels, energy storage is becoming more and more important. Phase change materials (PCM) play a crucial role in thermal energy storage due to their high latent heat capacity [1]. PCM used in thermal energy storage include organic materials and inorganic materials. Organic materials are mainly paraffin wax [2,3], fatty acid [4], polymer [5], etc. Inorganic materials include hydrous salt [6,7], metal [8] and so on. Organic PCM have lots of advantages such as low price, chemical stability and non-toxic. Hence, organic materials are commonly used as PCM in thermal energy storage. Organic PCM can be classified into unitary, binary and ternary organic materials. Unitary organic PCM only contain one kind of PCM [9]. Binary organic PCM contain two kinds of organic PCM such as capric-palmitic eutectic mixture [10], stearic-capric eutectic mixture [11], and capric-lauric eutectic mixture [12]. Ternary organic PCM are ternary eutectic mixture such as lauric-palmitic-stearic eutectic mixture [13]. The leaks and flow of organic materials during the melting process are serious problems, which has a seriously impact on thermal energy storage. Additionally, the thermal conductivity of organic PCM is quite small. Thus, the thermal energy storage ability is badly limited. Hence, it is necessary to overcome such problems mentioned above [14].

In order to hold back the leakage of PCM, form-stable phase change materials (FSPCM) were researched in the past few years, thereinto, clay mineral-based FSPCM were widely researched [15]. On one hand, clay minerals have prominent pore structure and significant specific surface area. Hence, organic materials can be readily loaded into clay minerals. The PCM will be limited into the porosity and crystal structure of clay minerals, and the leakage

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http://dx.doi.org/10.1016/j.apenergy.2016.08.147
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and flow will be prevented significantly. On the other hand, the thermal conductivity of organic materials will be enhanced significantly after incorporating with clay minerals due to the high thermal conductivity of clay minerals [16]. Clay minerals used in FSPCM are commonly perlite [17], diatomite [18], attapulgite [10], vermiculite [19], kaolin [20], etc. Expanded perlite and vermiculite have significant pore structure [21]. The porosity of diatomite reaches up to 90% [22]. Attapulgite has remarkable specific surface area (300–600 m^2) [11]. Kaolin is employed to compound kaolin-based FSPCM due to the following advantages: nontoxic, low price, rich in reserves, etc. Otherwise, kaolin has stronger mechanical strength and higher thermal conductivity compared with other clay materials which have a pore structure. Therefore, kaolin-based FSPCM are commonly used for thermal energy storage in buildings and solar energy utilization [23,24]. Organic PCM commonly intercalate into the interlayer of the crystal structure or coat on the surface of kaolin [24]. There is no chemical reaction occurred during the preparation process. The main interactions between PCM and clay minerals are capillary force, surface tension, Van der Waal's force (VDW) and so on [25,26]. The thermal properties and thermophysical properties of the clay mineral-based FSPCM are well proved after being investigated.

The capric acid/kaolin, PEG600/kaolin, paraffin/kaolin, heptadecane/kaolin and capric-lauric acid/kaolin FSPCM were researched in the former studies, and the corresponding latent heat capacities were 27.23 J/g, 32.8 J/g, 94.8 J/g, 34.63 J/g and 42.36 J/g, respectively [27,28]. In addition, the thermal conductivities of capric acid/kaolin, PEG600/kaolin and heptadecane/kaolin were successfully enhanced by 5% expanded graphite. Specially, Li et al. [24] incorporated paraffin with three different kinds of kaolin (platelet kaolin, layered kaolin and rod kaolin). The result exhibited that the layered kaolin had relatively good thermal properties and thermal conductivity (0.78 W/(m K)). The clay mineral-based FSPCM are mainly utilized in building energy conservation [29], immersion suits and solar thermal energy storage [24,30]. The effect in such domain was well proved. The paraffin/kaolin FSPCM can be used for solar energy utilization and waste heat recovery. The applications of paraffin/kaolin composites in solar energy utilization mainly include solar domestic hot water system, solar water heating system and solar drying system [31–33]. Paraffin/kaolin FSPCM also can be used in waste heat transportation system (trans-heat system) [34]. Yet the effects of particle size, mass fraction and temperature on thermal conductivity of paraffin/kaolin composites have almost never been studied in the previous researches and the reasons have not been clearly analyzed in microcosmic field as well. The studies on the effects of particle size on thermal properties, thermal stability and thermal energy storage are still scarce.

In this paper, the influences of different particle sizes and mass fractions of kaolin within the paraffin/kaolin composites were researched. The effects of particle size, mass fraction and temperature on thermal conductivity were investigated. And the reason was explained in microcosmic field. The thermal conductivities, thermal properties and thermal stabilities of paraffin/kaolin with diverse particle sizes of kaolin were investigated. Meanwhile, the thermal conductivities, thermal properties and the leaks of paraffin/kaolin FSPCM with different mass fractions of kaolin were researched.

2. Experimental

2.1. Materials and characterization

The four kinds of kaolin with different particle sizes were obtained from the same place. K1, K2, K3 and K4 stand for the four

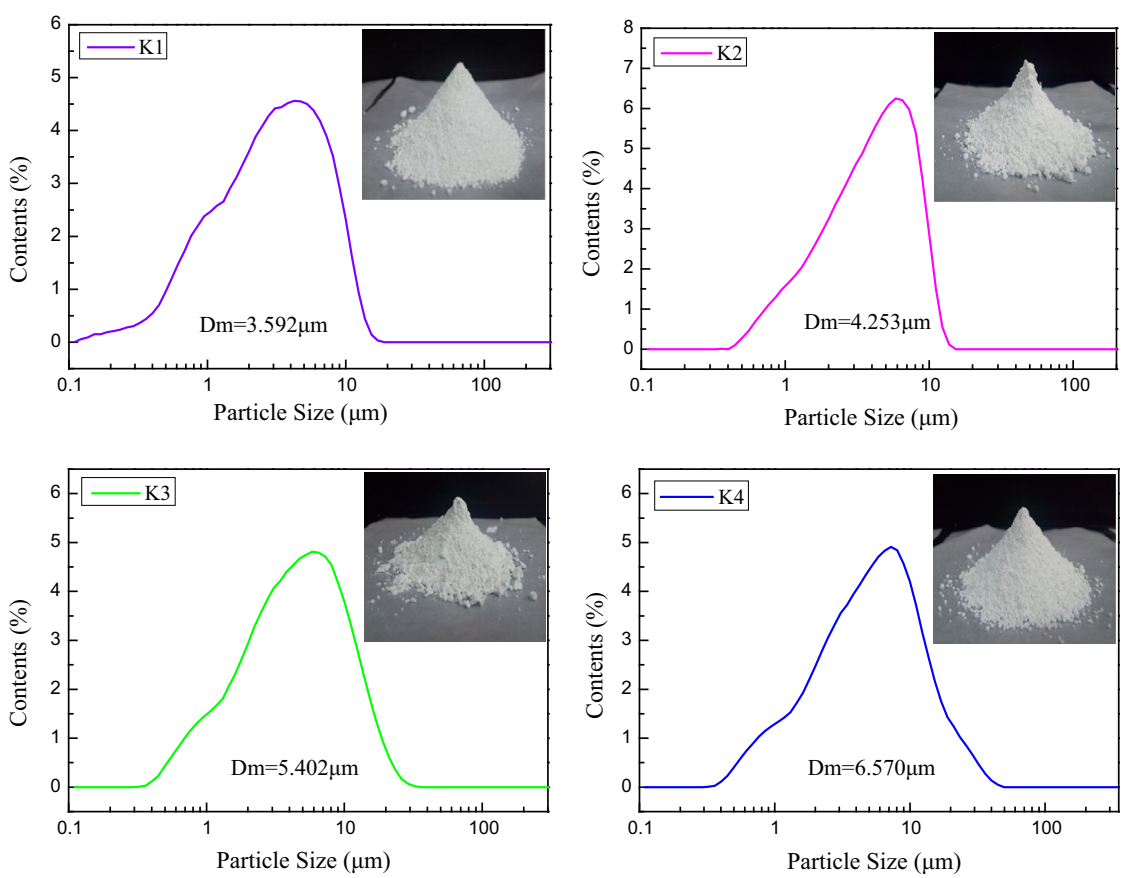

Fig. 1. The photographs of kaolin with different particle sizes.

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