Energy Conversion and Management 80 (2014) 103–109

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Thermal energy storage performance of paraffin-based composite phase change materials filled with hexagonal boron nitride nanosheets

Xin Fang [a,b], Li-Wu Fan [a,b,*], Qing Ding [a], Xiao-Li Yao [a], Yu-Yue Wu [a], Jian-Feng Hou [a], Xiao Wang [a], Zi-Tao Yu [a], Guan-Hua Cheng [c], Ya-Cai Hu [a]

[a] Department of Energy Engineering, Institute of Thermal Science and Power Systems, Zhejiang University, Hangzhou 310027, People's Republic of China
[b] Key Laboratory of Efficient Utilization of Low and Medium Grade Energy (Tianjin University), Ministry of Education of China, Tianjin 300072, People's Republic of China
[c] Zhejiang Provincial Key Laboratory of Solar Energy Utilization and Energy Conservation Technologies, Zhejiang Energy and Radiation Institute, Hangzhou 310012, People's Republic of China

ARTICLE INFO

Article history:
Received 2 December 2013
Accepted 10 January 2014
Available online 7 February 2014

Keywords:
Thermal energy storage
Phase change materials
Composites
Hexagonal boron nitride
Thermal conductivity enhancement

ABSTRACT

An experimental assessment was performed on the thermal energy storage performance of a novel family of paraffin-based composite phase change materials (PCMs) filled with hexagonal boron nitride (h-BN) nanosheets. A series of composite PCM samples were prepared at different loadings (0, 1, 2, 5, and 10 wt.%) of h-BN nanosheets in the absence of any surfactants. The composite PCMs were subjected to a variety of characterization techniques. It was shown that the thermal conductivity of the composite PCMs, in both solid and liquid phases, increases by a factor up to 60% with raising the loading of h-BN nanosheets. The melting/solidification points of the composite PCMs were found to be nearly unvaried upon adding h-BN nanosheets, whereas their latent heat of fusion slightly decreases with the loading. In addition, acceleration of both melting and solidification heat transfer rates, afforded by the increased thermal conductivity of the composite PCMs, was clearly exhibited. The observations suggested that h-BN nanosheets may serve as promising fillers for preparing custom high-conductivity composite PCMs toward thermal energy storage applications.

1. Introduction

The growing economics and population create an imperious need of exploiting and utilizing renewable energy sources toward a sustainable energy future [1]. Because of the intermittent and variable nature of most available renewable energy sources, solar, tide, and wind for example, reliable and efficient energy storage units are required to be integrated into the energy conversion systems, in an effort to reduce the mismatch between energy supply and demand.

Latent heat thermal energy storage by the means of solid–liquid phase change materials (PCMs) has been studied and practiced in the past several decades [2]. Organic PCMs, paraffins for example, have proved to be good candidates for low-to-medium temperature thermal energy storage. In light of the relatively low thermal conductivity (~0.2 W/mK) of organic PCMs, however, great efforts have been dedicated to increasing their effective thermal conductivity through addition of inserts or extended surfaces made of highly conductive materials [3]. Recently, inspired by the extension of functionality of nanofluids [4], composite PCMs filled with highly conductive nanoparticles, carbon nanomaterials for example, have received increased attention. In the literature, this novel family of composite PCMs with enhanced thermal conductivity is often coined as NePCMs [5].

Two-dimensional (2D) planar carbon nanomaterials, from single-layer graphene to multi-layer graphite nanosheets/nanoplatelets, have been identified to have better performance in enhancing the effective thermal conductivity of composite PCMs, as compared to their wire- or tube-shaped counterparts [6,7]. Such outperformance of 2D carbon nanomaterials has been understood in relation to their geometry-induced low thermal interface resistance against the matrix PCMs [8]. Consequently, other 2D ordered nanocrystals of elements other than carbon are of great interest, such as boron nitride (BN) [9]. The hexagonal BN (h-BN) has a crystal structure similar to graphene and the intrinsic thermal conductivity of h-BN nanosheets has shown to be of a high value [10]. The effective thermal conductivity of a h-BN-filled epoxy, serving as a thermally conductive underfill material in electronic packaging, was found to be as high as 3.35 W/mK at a loading of 80 wt.%

* Corresponding author at: Department of Energy Engineering, Institute of Thermal Science and Power Systems, Zhejiang University, Hangzhou 310027, People's Republic of China. Tel./fax: +86 571 87952378.
E-mail address: liwufan@zju.edu.cn (L.-W. Fan).

http://dx.doi.org/10.1016/j.enconman.2014.01.016
0196-8904/

Nomenclature

k	thermal conductivity, W/mK
K	relative thermal conductivity enhancement, defined in Eq. (1)
Greek symbols	
ΔH	latent heat of fusion, kJ/kg
ϕ	loading
λ	wavelength, nm
θ	diffraction angle, deg
Subscripts	
eff	effective
m	matrix
wt	weight (mass)

[11]. In the available literature, h-BN has widely been used in preparing thermosetting polymeric composites, such as polysioxane [12], epoxy resins [13–15], polybenzoxazine [16], and polyvinyl alcohol [17]. The high performance and relatively low cost of h-BN nanosheets, comparing to the prohibitively expensive graphene, shed light on their great potential in serving as fillers for preparing high-conductivity composites. There is, however, so far a lack of attempt to use h-BN nanosheets to prepare composite PCMs for the purpose of thermal energy storage.

In this paper, a novel family of paraffin-based composite PCMs filled with h-BN nanosheets will be prepared. Thermal energy storage performance of the h-BN-filled paraffin-based composite PCMs will be tested, including both characterization of their thermal properties and evaluation of their melting/solidification rates.

2. Experimental section

2.1. Materials and sample preparation

The matrix PCM in this work, a paraffin wax with a nominal melting point of 58 °C, was supplied by Sinopharm Chemical Reagent Co., Ltd., China, while the nanofillers, h-BN nanosheets (purity >99.5 wt.%), were supplied by Nanjing XF NANO Materials Tech Co., Ltd., China. Prior to use, the paraffin was subjected to premelting and degassing in a vacuum oven (maintained at 105 °C) for 12 h, while the h-BN nanosheets were predried under the same condition. In the absence of any surfactants, composite PCM samples were prepared following a *two-step* protocol. The predried h-BN nanosheets, at various given loadings, were first added into melted paraffin to form mixtures that were rigorously stirred on a magnetic stirrer kept at 80 °C for 30 min, followed by intensive probe ultrasonication for another 30 min. In this work, the loading of h-BN nanosheets was ranged from 1 to 10 wt.%, along with a reference sample (0 wt.%) of pure paraffin.

2.2. Structural and microscopic characterizations

A series of characterizations were performed on the raw materials and paraffin/h-BN composites in order to examine their structural and microscopic features. The crystalline structures of the paraffin, h-BN nanosheets, and composite PCMs were examined using an X-ray diffractometer (XRD, X'Pert PRO) with Cu Kα X-ray radiation (λ = 0.154 nm). The actual shape, size, and thickness of the h-BN nanosheets as-received were inspected visually using both scanning electron microscope (SEM) and transmission electron microscope (TEM). TEM imaging was also performed on sliced composite PCM samples (in the solid phase at room temperature) in an effort to visualize the dispersion of h-BN nanosheets in the composites.

2.3. Thermal property measurements

The measured thermal properties of the composite PCMs included thermal conductivity, latent heat of fusion, and melting/solidification points. The characterization methodology adopted in this work was similar to that outlined in our previous work [8]. A Hot Disk Thermal Constants Analyzer (TPS 2500S, Hot Disk AB, Sweden) was employed to measure the thermal conductivity. This instrument is based on the principle of transient plane source (TPS) technique. As illustrated in Fig. 1, a specially designed aluminum holder, with the aid of a constant-temperature water bath with a stability of 0.01 °C, was fabricated in an effort to provide precise temperature control during thermal conductivity measurements. In this study, the measurements were performed on composite PCM samples in both solid and liquid phases over a temperature range of 10–80 °C, which encompasses the nominal melting point of the paraffin wax under examination. Special attention was paid to suppress the natural convection effect during measurements of liquid samples by adopting a short heating time (3 s), a low heating power (200 mW), and a small sample volume (6 mL). Details of the design of the sample holder and measurement procedure have been presented in Ref. [8].

The latent heat of fusion and melting/solidification points of the composite PCMs were determined experimentally using a differential scanning calorimeter (DSC). DSC tests were also carried out from 10 to 80 °C at a constant ramping rate of 5 °C/min. Both the TPS and DSC instruments were calibrated with standard samples of known thermal properties prior to use. In order to ensure the data accuracy and reproducibility, multiple specimens, prepared from at least 3 different batches, were tested for each composite PCM sample for both thermal conductivity and energy storage property measurements.

2.4. Phase change heat transfer tests

In addition to determination of the above-mentioned thermal properties, the actual thermal energy storage performance of the novel composite PCMs was evaluated through phase change heat transfer tests. The test rig featuring a simple design, as illustrated in Fig. 1, mainly consisted of a water-jacketed aluminum holder.

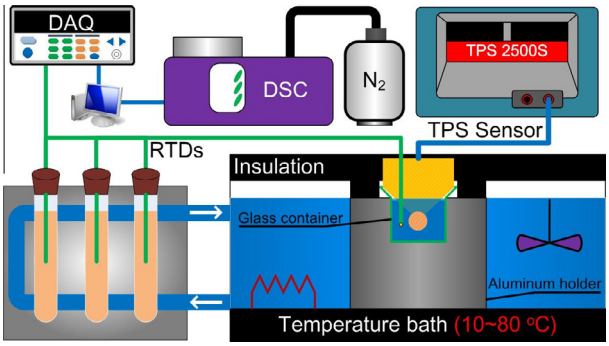

Fig. 1. Schematic diagram of the experimental setup for thermal property measurements and phase change heat transfer tests.