Solar Energy Materials & Solar Cells 143 (2015) 168–173

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

Thermal properties of shape-stabilized phase change materials using fatty acid ester and exfoliated graphite nanoplatelets for saving energy in buildings

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ARTICLE INFO

Article history:
Received 24 April 2015
Received in revised form
10 June 2015
Accepted 19 June 2015

Keywords:
Phase change material
Coconut oil
Palm oil
xGnP
Heat storage
Impregnation

ABSTRACT

This paper deals with the thermal performances of shape-stabilized phase change materials (SSPCMs) for energy saving in various fields. Two SSPCMs were prepared by impregnating coconut oil and palm oil, as phase change materials (PCMs), into exfoliated graphite nanoplatelets (xGnP), as a supporting material. Coconut oil and palm oil are types of organic fatty acid ester PCMs made from under-used and renewable feedstocks. However, they have a major drawback, namely their low thermal conductivity. To improve the thermal conductivity of organic fatty acid ester PCMs, xGnP can be effective. Therefore we prepared form-stable organic fatty acid ester PCMs with xGnP, using the vacuum impregnation method. In this study we used coconut oil and palm oil, which have latent heat capacities of 110.4 and 127.3 J/g and melting points of 26.78 and 17.26 °C, respectively. The organic fatty acid ester PCMs were incorporated into the porous structure of xGnP. The thermal conductivity of the produced SSPCMs were over 400% higher than pure fatty-acid ester PCM. Also, the latent heat were 82.34 and 77.18 J/g, respectively. The characteristics of the organic fatty acid ester PCMs were determined by using SEM, DSC, FT-IR, TGA and TCi.

1. Introduction

A significant portion of all the energy generated is consumed by the buildings in developed countries. For example, about 39% of the total US primary energy generated is consumed by buildings today [1,2]. High economic growth in Malaysia has led to a dramatic increase in its national energy consumption in recent years, particularly electrical energy used in commercial and residential buildings [3,4]. The development of different sources of renewable energy is the result of increasing fuel prices and a huge rise in greenhouse gas emissions. Nowadays, thermal energy storage (TES) systems can be used to reduce buildings' dependency on fossil fuels, to contribute to the more efficient use of energy, and to supply heat reliably. The main advantage of using thermal storage is that it can contribute to the matching of supply and demand at times when they do not coincide [5,6]. TES systems provide the potential to attain energy savings, which in turn reduce the environmental impact related to energy use; these systems actually provide a valuable solution for the correction of the mismatch that is often found between the supply and demand for energy [7–9]. Latent heat storage using phase change materials (PCMs) is one of the most efficient methods of storing thermal energy. PCMs have been applied to increase the TES capacity of different systems [10–12]. The use of PCMs provides a higher heat storage capacity and more isothermal behavior during charging and discharging, compared to sensible heat storage [6]. PCMs can provide a high-energy storage density when it changes phase from liquid to solid, and it can store energy at a constant temperature or within a limited range of temperature variation. So PCMs are widely used in building energy conservation [13–15]. PCMs are “latent” heat storage materials. Normally, the thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. Organic and inorganic materials are the two most common groups of PCMs [7,16]. Organic materials are further classified as paraffin and non-paraffin. Most organic PCMs are non-corrosive and chemically stable, performance little or no sub-cooling, are compatible with most building materials and have a high latent heat per unit weight and low vapor pressure. They have the disadvantages of low thermal conductivities, large changes in volume upon phase change, and flammability, though extensive investigations have been carried out to enhance their heat transfer rates [17–24]. Coconut oil and palm oil belong to the fatty acid organic PCM class, and are two of the most important oil crops in tropical regions. Therefore, an understanding of the thermal behavior of these edible oil products is

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http://dx.doi.org/10.1016/j.solmat.2015.06.040
0927-0248/

important for their many practical applications in the oils and fats industry [25]. Coconut oils in both virgin and RBD (refined, bleached, and deodorized) forms melt at 24 °C (76 °F) and palm oils melt at 18 °C (76 °F). Exfoliated graphite nanoplatelets (xGnP), which is a porous nano-sized carbon material, was used as a supporting structure, to improve the thermal conductivity and heat storage efficiency of the PCM incorporated into it on a microscopic scale [26]. This paper has used xGnP as a container of fatty acid organic PCMs. The application of fatty acid organic PCMs to various fields is difficult, due to their phase instability in the liquid state. Therefore, they need shape stabilization. To solve these problems, some investigators have studied the possibility of devising a container that can prevent the leaking of liquid PCMs, by using shape-stabilized PCM (SSPCM), microencapsulated PCM (MPCM), and incorporated PCM techniques [27–31]. In this study, we prepared thermal-enhanced fatty acid organic PCMs, using the vacuum impregnation process, with xGnP. The vacuum impregnation method guarantees the heat storage of a fatty acid organic PCM after the incorporation process. Therefore we studied thermal-enhanced fatty acid PCMs, to improve thermal conductivity and fire-retardant properties.

2. Experimental

2.1. Materials

This study used two liquid organic PCMs with different melting points: coconut oil and palm oil. Coconut oil and palm oil have economic feasibility and are eco-friendly. Coconut oil has a latent heat capacity of 110.4 J/g and a melting point of 26.78 °C. Palm oil has a latent heat capacity of 127.3 J/g and a melting point of 17.26 °C. These organic PCMs were obtained from Korea Similac Corporation in South Korea. The exfoliated graphite nanoplatelets (xGnP) were prepared from sulfuric acid-intercalated expandable graphite (3772), obtained from Asbury Graphite Mills, NJ, USA, by applying a cost and time effective exfoliation process initially proposed by Drzal's group [32]. Tables 1 and 2 show the physical properties of xGnP and the organic PCMs. Fig. 1 shows coconut oil and palm oil.

Table 1
Physical properties of xGnP.

Surface area (m^2/g)	20.41
Bulk density (g/m^3)	0.0053–0.010
Pore volume (cm^3/g)	0.081
Thermal conductivity (W/mK)	2–300
Specific heat capacity (J/KgK)	710

Table 2
Physical properties of fatty-acid based organic PCMs.

	Coconut oil	Palm oil
Melting point (°C)	26.78	17.26
Latent heat (J/g)	110.4	127.3
Thermal conductivity (W/m K)	0.3210	0.2891

2.2. Preparation

The coconut oil/xGnP and palm oil/xGnP SSPCMs were prepared using the vacuum impregnation method as follows. A diagram of the vacuum impregnation system is shown in Fig. 2. The xGnP was dried in a vacuum oven before the impregnation process. It was put inside a filtering flask, which was connected to a water tromp apparatus, to evacuate air from the porous structure of the xGnP. Then, a valve between the flask and a container with 200 g of liquid PCM was opened, to allow the PCM to flow into the flask and cover the nanoparticles of xGnP. The vacuum process was continued for 90 min, and then air was allowed to enter the flask again, to force the liquid organic PCM to penetrate the porous structure of the xGnP. After the penetration process, excess PCM remained in the flask, and was removed through a filtering process. The coconut oil/xGnP and palm oil/xGnP SSPCMs in a colloidal state were filtered through 1 µm filter paper until a granular sample appeared, which was dried in a vacuum drier at 80 °C for 48 h. Fig. 3 is a picture of the appearance of the SSPCMs, taken at 20.0 °C in the laboratory. As shown, xGnP is a type of black powder, and the prepared coconut oil/xGnP and palm oil/xGnP SSPCMs are both types of black granule.

2.3. Characterization techniques

The morphology and microstructure of the SSPCMs were observed by means of scanning electron microscopy (SEM) at room temperature. An SEM with an accelerating voltage of 12 kV and working distance of 12 mm was used to collect the SEM images. The samples were given a gold coating a few nanometers in thickness [32]. Fourier transform infrared spectroscopy (FTIR: 300E Jasco) was also utilized to monitor the change of chemical groups upon curing. Clear potassium bromide (KBr) disks were molded from powder and used as backgrounds. The samples were analyzed over the range of 525–4000 cm^{-1}, with a spectrum resolution of 4 cm^{-1}. All spectra were averaged over 32 scans. This analysis of the composites was

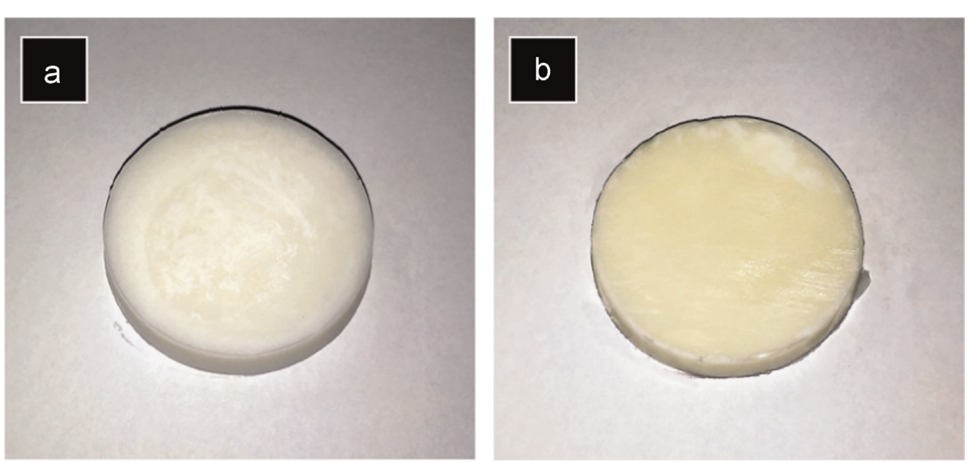

Fig. 1. Morphology of (a) coconut oil and (b) plam oil.