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A novel composite Phase change material of Stearic Acid/Carbonized sunflower straw for thermal energy storage

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ABSTRACT

In this research, a novel form-stable composite Phase change material (PCM) of Stearic Acid (SA)/Carbonized sunflower straw (CSS) was prepared by vacuum impregnation method. Fourier Transform Infrared Spectroscopy (FT-IR) was used to measure the chemical compatibility of SA/CSS. The thermal properties and thermal stability were investigated by differential scanning calorimetry (DSC) and thermogravimetry analysis (TGA) techniques. The results show that the SA/CSS melted at 66.4 °C with the latent heat of 186.1 J/g and freezed at 65.9 °C with the latent heat of 186.7 J/g and the composite PCM have a good thermal reliability above its working temperature. Moreover, the thermal conductivity of SA/CSS was 0.33 W/m/K which was 106.3% higher than that of SA. All results indicated that SA/CSS have suitable thermal properties used as thermal energy storage applications such as solar heat energy storage system and energy conservation buildings.

1. Introduction

In recent years, thermal energy storage (TES) system have become the important technology to increase the solar energy utilization efficiency due to the gradually shortage of fossil energy and the increase emission of greenhouse gas. Phase change material (PCM) can storage and release thermal energy during the phase change process which has been widely studied and applied in TES system. Up to now, many PCMs have been researched such as paraffin [1], polyhydric alcohols [2] fatty acids [3,4] and so on.

Among the PCMs, stearic acid acted as a promising organic PCM has been extensively used because of the high energy density, proper phase change temperature, non-supercoiling and non-corrosion [5], etc. However, two disadvantages of the leakage problem during the solid-liquid process and low thermal conductivity limit its application. In order to solve these problems, a new type of composite PCM composed by supporting material and phase change material has been developed [6,7]. The composite PCM (CPCM) can maintain the solid shape even when the phase change component melted. Therefore, it is necessary to devote to the development of supporting materials with high thermal conductivity and adsorption capacity. The previous study shows that the plant straw such as crop straw and rice straw can be used as supporting materials for PCM [8,9]. However, the sunflower straw (SS) which has the nature porous structure and with the advantages of low-cost and good chemical compatibility with PCM has not been studied as the matrix of phase change material.

In this study, we intend to use the sunflower straw as the supporting material to provide a new kind of composite PCM. Firstly, the SS was carbonized to obtain the carbonized sunflower straw (CSS) with high thermal conductivity which was acted as the supporting material. Then the composite phase change material of SA/CSS was prepared by vacuum impregnation method. The chemical compatibility was characterized by FT-IR. And the thermal properties were characterized by DSC and TGA. Moreover, the thermal conductivity of the CPCM of SA/CSS was also investigated.

2. Experimental

2.1. Materials

The stearic acid (SA, 97.5% pure) was purchased from Tianjin Guangfu Fine Chemical Research Institute. The sunflower straw (SS) was obtained from the countryside in Shanxi province of China.

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2.2. Preparation of form-stable CPCM

Fig. 1 schematically illustrates the procedure for the composite PCM. The sunflower straw (SS) was carbonized in the furnace at 400 °C for 2 h using the carbon sintering method. The resultant samples were washed with distilled water and dried in the oven to obtain the carbonized sunflower straw (CSS). Then the mixture of SA and CSS (mass ratio: 9:1) were firstly added in a beaker and vacuumed to 0.1 MPa for 10 min in a vacuum drying oven. Then the oven temperature was set to 80 °C to make the SA melted and impregnated into the porous of CSS. The next step is switch off the vacuum pump to allow the air to enter the oven and force the SA penetrate into CSS. After cooling, the samples were put onto the filter paper at 80 °C for 1 h to remove the SA absorbed in the surface of CSS and the prepared CPCM was named SA/CSS.

2.3. Characterization of form-stable CPCM

The chemical compatibility of the CPCM was characterized by Fourier Transform Infrared Spectroscopy (FT-IR, Spectrum 100, Perkine-Elmer, spectra from 400 cm^{-1} to 4000 cm^{-1} with a resolution of 2 cm^{-1} using KBr pellets). The differential scanning calorimetry (DSC, DSC 2014 polyma, NETZSCH) was used to measure the thermal properties of CPCM with the heating and freezing rate of 10°/min under nitrogen atmosphere. The thermal stability of the CPCM was investigated by thermogravimetry analysis (TGA, STA 8000, Perkine-Elmer) from room temperature to 600 °C with the heating rate of 10°/min under a constant stream of nitrogen. The thermal conductivity was measured by laser thermal conductivity method.

3. Results and discussion

3.1. Chemical properties of form-stable CPCM

Fig. 2 shows the FT-IR spectra of the SA and SA/CSS. From the spectrum of SA, the peak at 1698.73 cm^{-1} was caused by the functional group of carbonyl group (C=O). The peaks at 2915.30 cm^{-1} and 2848.24 cm^{-1} represent the stretching vibration of the C–H bond in $-CH_2$ and $-CH_3$ groups of SA. Absorption bands at 1472.50 cm^{-1} and 1297.43 cm^{-1} are due to the deformation vibration of C–H bond in $-CH_2$ group of SA. Absorption bands at 721.40 cm^{-1} belongs to the rocking vibration of C–H bond in-CH_2 group. The bonds at 941.32 cm^{-1} is attributed to out of plane bending of hydroxyl (–OH) group of water molecules. In the spectrum of SA/CSS, the intensity and position of the peak is completely similar with SA which prove that the CSS have a good compatibility with SA that make SA/CSS more suitable for thermal energy storage.

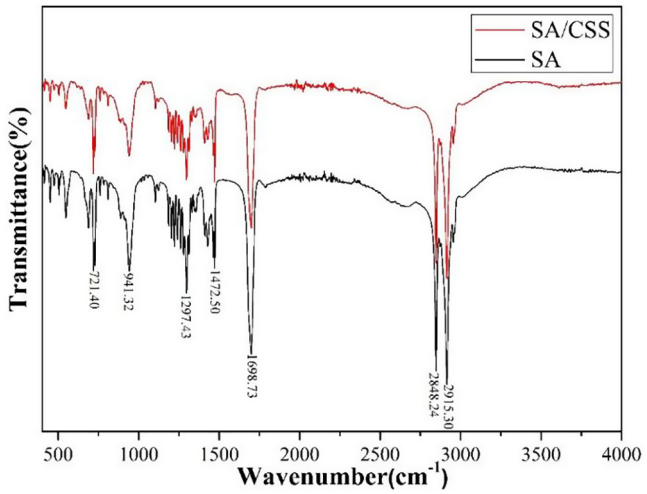

Fig. 2. FT-IR spectra of SA and SA/CSS.

3.2. Thermal properties of form-stable CPCM

Fig. 3 shows the DSC curves of SA and SA/CSS. It can be seen that the SA and SA/CSS melted at 68.1 °C and 66.4 °C and freezed at 66.3 °C and 65.9 °C, respectively. Compared with SA, the melting and freezing temperature of SA/CSS changed in a reasonable range which was caused by the physical interaction between SA and CSS, this results was also in agree with Sarı's [10] report.

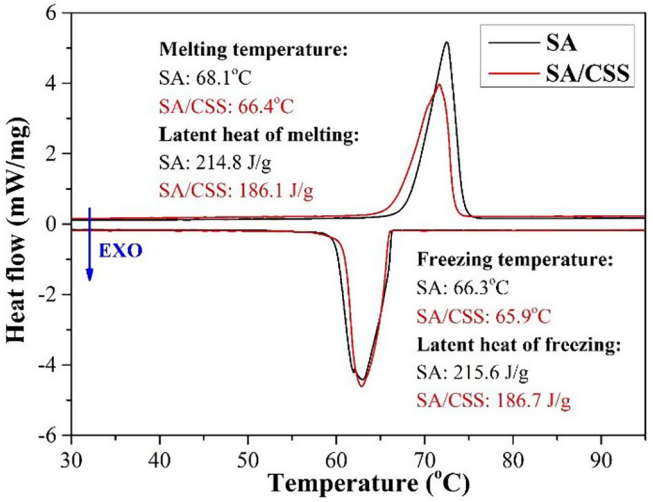

Fig. 3. DSC curves of SA and SA/CSS composite PCM.

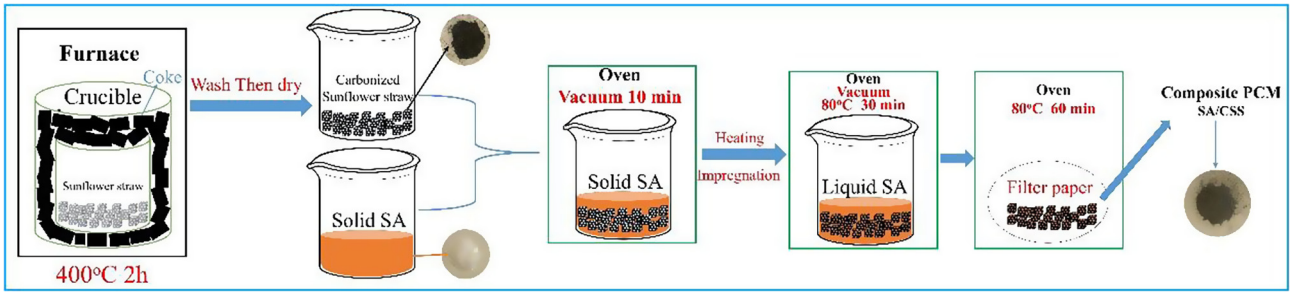

Fig. 1. The experimental process for preparation of composite PCM of SA/CSS.