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Silica fume/capric acid-palmitic acid composite phase change material doped with CNTs for thermal energy storage

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ABSTRACT

Though very promising, fatty acids suffer from low thermal conductivity and leakage, which limits their heat storage applications. To overcome these problems, we used silica fume (SF) to house the fatty acid and prevent leaching during phase change and incorporated different amount (1.0, 3.0 and 5.0 wt%) of CNTs to improve the thermal conductivity to the desired level. For the experimental temperature range and better performance an eutectic mixture of capric acid(CA)-palmitic acid(PA) was prepared and investigated. The physicochemical and morphological characterizations of the fabricated shape stabilized-composite PCMs (SS-CPCMs) with/without CNTs were carried out using FTIR, XRD and SEM instruments. The DSC analysis results showed the SS-CPCMs had phase change temperatures of 19–26 °C and high latent heat capacity of 46–49 J/g, which are suitable for thermal energy storage (TES) in buildings. The SS-CPCMs showed good cycling TES reliability and chemical stability and also exhibited excellent thermal durability up to 140 °C. The CNTs doping process caused an appreciable increase in thermal conductivity and significantly reduced the charging and discharging times of the SS-CPCMs. Consequently, due to higher thermal conductivity, the SS-CPCM doped with 5.0 wt% CNTs can be considered as more promising composite for passive solar thermoregulation of building envelopes.

1. Introduction

Energy storage in a suitable form can increase the system efficiency by balancing the peak off-peak demand and can also facilitate incorporation of renewable energy into the energy infrastructure. Therefore, it can reduce the use of fossil fuel and CO_2 emission. There are several mature energy storage techniques available and commercialized; among them thermal energy storage (TES) has great potential in building technology. TES is already deployed in several fields from simple space cooling and heating to thermal management of electronic/electrical devices to large-scale electricity generation [1–4]. Nowadays, there is a growing emphasis on energy efficient smart building, which requires series of smart construction materials. For example, smart window, which is already in use, and can control the incoming light and heat. For the overall heat management of any smart building, an integrated TES and utilization system is required, along with the other technologies. Integration of a solar space heating and cooling system to a smart building can significantly reduce its consumption of traditional energy and can facilitate the incorporation of renewable energy resources [5]. However, this case requires suitable TES technique. One of the most suitable TES options is the latent heat storage using phase change materials (PCMs), which can store more energy in a smaller mass/volume compare to the sensible or other heat storage techniques. PCMs have greater flexibility, when incorporation in the building construction materials is considered. For example, PCMs can be integrated with gypsum wallboard, plaster, clay minerals, or within the concrete or any other suitable wall covering materials [6,7] to store thermal energy for smart buildings [8]. This kind of PCM incorporated building materials can provide 24 h heat management in the building and if required can be designed to absorb the waste heat as well.

PCMs are a large family with inorganic and organic materials, from simple salt hydrates, to paraffin waxes to non-paraffin organic compounds. These materials have long been investigated heavily for latent heat storage applications [9,10]. However, for advanced building materials, fatty acids (FAs), esters and alcohols are better fitted due to their characteristic properties and availability. FAs have high specific heat

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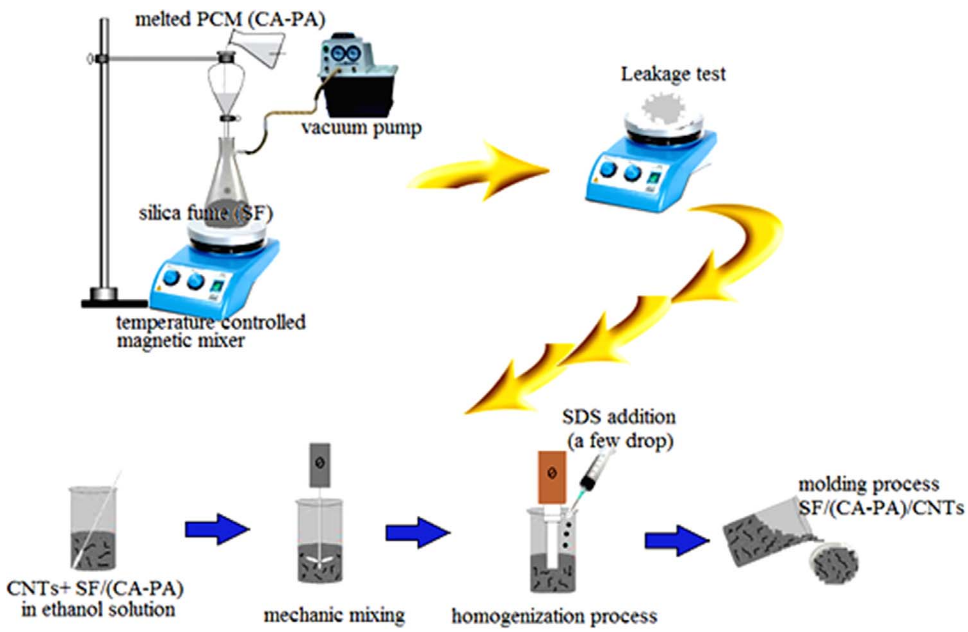

Fig. 1. The schema of the procedure used in the preparation of SS-CPCMs with/without CNTs.

capacity (1.9–2.1 J/g °C) compare to other organic PCMs, have better latent heat of transition as well as very small volume change, mostly no supercooling, non-toxic, producible from renewable resources [11–14]. Additionally, they have good surface tension (0.02–0.03 N/m) to retain within the host structures [15]. All these useful characteristic properties make them suitable PCMs for building technology. The leakage difficulty and low thermal conductivity of FAs are still major challenges that limit their utility prospective. To solve these problems they have been incorporated with suitable construction materials together with different thermal conductivity enhancers [16–19]. Silica fume (SF) or microsilica is cheap by-product of arc furnace and already in use as a mineral additive in cement industry. Use of SF basically gives better strength, durability and resistivity to the final structure [20,21]. Therefore, in recent years, it has been one of the most reasonable admixtures for the preparation of economic and lightweight energy efficient construction materials as component of smart green buildings. Wang [22] prepared a composite PCM by incorporating using stearic acid (SA) in to the SF. They observed that the maximum confinement percentage of SA within SF was 46 wt%, without any leaching during heating. They also reported that the formation of week hydrogen bonding between SF and SA could help to prevent the leaching. The prepared PCM also showed higher thermal conductivity and stability than that of the pure SA. Jeong et al. [23] fabricated composite PCMs using SF with hexadecane, octadecane and paraffin by vacuum impregnation method and all composites had higher latent heat storages capacity, better thermal stability. In another work, the thermal conductivity of capric acid (CA)/SF composite was improved significantly using exfoliated graphite nano platelets to achieve an energy saving concrete for building application [24].

Carbon nanotubes (CNTs) have long been used as the most efficient doping agents to increase the heat transfer properties within the pure PCMs or composite PCMs [25]. In this context, multi walled carbon nanotubes (marked as CNTs) have been mixed with paraffin in different concentration and enhanced thermal properties [26–29]. Li et al. [30] prepared SA/MWCNTs (5.0 wt%) composite and observed that the incorporation of CNTs enhanced the charging and discharging rates between 50% and 91%, respectively. Wang et al. [31] found that only 1.0 wt% of CNTs doping could improve the thermal conductivity of palmitic acid (PA) by about 30%. Tang et al. [32] also reported that the thermal conductivity of capric-myristic acid eutectic PCM could be increased from 0.173 W/m K (pure) to 0.213 W/m K (9 wt% CNTs), 0.258 W/m K (12 wt% CNTs) and 0.283 W/m K (15 wt% CNTs). Xu et al. [33] reported that only 0.26 wt% CNTs could get better charging and discharging rates of the paraffin/diatomite composite. Meng et al. [34] enhanced the thermal conductivities of eutectic mixtures of some FAs significantly with the addition of CNTs. However, FAs based composite PCMs and the enrichment of their thermal conductivities of building application is limited. Karaipekli et al. [35] added 1.0 wt% CNT into the expanded perlite/*n*-eicosane composite and observed significant enhancement of thermal properties of the composite.

Considering all these good properties of SF and FAs, in this work, CA was mixed with PA to achieve eutectic PCM with proper melting temperature for TES targets in building envelopes. The CA-PA eutectic PCM was vacuum impregnated in the SF and the TES properties of the produced SS-CPCMs were evaluated. Moreover, by taking into account of high thermal conductivity of CNTs, the prepared SF/(CA-PA) composite was doped with CNTs at three different weight ratios, 1.0%, 3.0% and 5.0%. Incorporation of CNTs improved the overall thermal properties of the prepared SS-CPCMs and allowed faster heat charging and discharging. The TES properties and thermal durability of the prepared SS-CPCMs with/without CNTs were studied using DSC and TGA techniques. Moreover, the chemical compatibility, morphology, cycling TES reliability and chemical reliability of the SS-CPCM showing best performance were also investigated by FTIR, XRD, SEM, DSC and TGA techniques.

2. Experimental

2.1. Materials

Capric acid (CA), palmitic acid (PA) and sodium dodecyl sulfate solution (SDS; 10% in H_2O) were supplied from Sigma-Aldrich. Silica fume (SF) used as lightweight concrete material was obtained from Dost Company (Istanbul/Turkey). The SF has SiO_2 content (> 99.8%), density of SiO_2 (2200 g/L), (1.46), silanol group density (SiOH/nm^2 :2.0), loss on ignition at 105 and 1000 °C/2 h (> 2.0 wt% and < 1.5 wt %, respectively). Its surface area was determined as 14.0743 m^2/g by using BET technique (Micromeritics Gemini VII 2390 V1.03). CNTs