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Thermal performance of co-electrospun fatty acid nanofiber composites in the presence of nanoparticles

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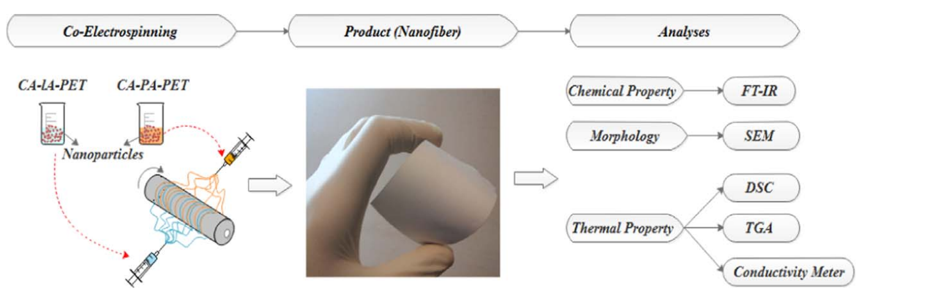
HIGHLIGHTS

- Nano fiber PCM composites are produced using co-electrospinning method.
- Fatty acid eutectics are used as the PCM and PET is used as the supporting matrix.
- Nanoparticles of Al_2O_3, Fe_2O_3, SiO_2 and ZnO are incorporated into the composite fibers.
- Nanoparticles promoted energy storage capacity and efficiency of the nano composites.

GRAPHICAL ABSTRACT



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ABSTRACT

Co-electrospinning of fatty acid eutectics in the presence of nanoparticles has been used to produce thermally conductive nanofiber composites with suitable phase-transition temperature range. Capric acid (CA), palmitic acid (PA) and lauric acid (LA) and their eutectics were used as the phase change materials (PCMs) and polyethylene terephthalate (PET) was used as the supporting matrix. Four different nanoparticles (Al_2O_3, Fe_2O_3, SiO_2 and ZnO) at different weight fractions were added to the fatty acid eutectic solutions which eventually appeared in the electrospun composites. The structure, morphology, thermal properties and energy storage capacity of the prepared nanocomposite-enhanced phase change materials (NEPCMs) were examined by Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and differential scanning calorimetry (DSC), respectively. The average diameter of nanocomposite fibers was found to be significantly smaller than that of pure composite fibers due to the increased conductivity in spin dope associated with the presence of nanoparticles. Also, the presence of nanoparticles has caused the phase transition temperature ranges (onset – offset) of the composite fibers to shift towards lower temperatures (e.g. lower melting point temperatures). The fabricated PCM composite have shown proper thermal conductivity, energy storage capacity and efficiency as well as phase transition temperature range all of which are necessary for low temperature energy storage/retrieval systems.

1. Introduction

There has been an increasing demand for efficient thermal energy storage/retrieval systems in recent years due to growing population and environmental concerns. Phase change materials (PCMs) are considered as one of the most promising environmentally-friendly systems for storing energy primarily due to their unique features such as high capacity for energy storage and small temperature change between

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Nomenclature

t	time (s)
T	temperature (°C)
T	transmittance
wt.	weight fraction

Abbreviations

CA	capric acid
C-L	capric-lauric
C-P	capric-palmitic
DMC	dichloromethane
DSC	differential scanning calorimetric
FTIR	fourier transform infrared spectroscopy
LA	lauric acid
NEPCMs	nanocomposite-enhanced phase change materials
PA	palmitic acid
PCM	phase change material
PEG	polyethylene glycol
PET	polyethylene terephthalate
PPV	polyphenylene vinylene
SEM	scanning electron microscopy
TFA	trifluoroacetic acid
TGA	thermogravimetric analysis

Subscripts

m	melting
w	weight
O	onset

storage and retrieval states. As a result, PCMs have found extensive applications in solar energy, near ambient heat transfer and energy conservation systems [1–5].

Among various PCMs, fatty acids hold most of thermo-physical properties needed for near ambient energy system applications including convenient range of melting temperature, non-toxicity and corrosiveness, appropriate chemical and thermal stability, high latent heat capacity and affordable price. Besides, individual fatty acids can be blended together to form eutectic mixtures with desired (lower) melting point temperatures [6–8]. However, most of phase change materials including fatty acids/eutectics suffer from low thermal conductivity coefficients that limit their capability for storing/retrieving energy at reasonable rates. To alleviate this shortcoming, nanoparticles such as Al_2O_3, and SiO_2 are normally incorporated into PCMs to promote heat transfer [9–13]. The other concern in using PCMs is that they are prone to leakage during frequent phase change process. Hence, PCMs should be held in predesigned containers/systems to prevent leakage during phase transition process. This is essential to reduce operational costs.

Composite fibers can be fabricated to hold PCM in place without significantly hindering heat transfer rates. In such composites, the PCM (e.g. fatty acids or eutectics) is supported by a polymeric matrix (e.g. polyethylene terephthalate or polymethyl methacrylate); such PCM composites are normally termed as "form-stable PCM composites" [14–30].

Over the past few years' various approaches have been developed to prepare form-stable fatty acid eutectic composites including self-polymerization, sol-gel, physical adsorption and electrospinning techniques [31–36] among which electrospinning is shown to be very simple and flexible for producing composite fibers with diameters ranging from micrometers to nanometers. Such electrospun composite fibers are highly porous with large specific surface area and mechanical strength, which are very important from practical point of view.

Co-electrospinning of different fatty acid eutectics has been used to fabricate PCM fibers with wide phase transition temperatures [21]. Also, single and double nozzle (coaxial) electrospinning have been employed to produce composite fibers of desired thermo-physical properties [13,20,21,37].

McCann et al. [37] have produced co-electrospun PCM composite fibers containing long-chain hydrocarbons by using coaxial electrospinning method. They used up to 45 wt% octadecan as PCM in the composites. The produced composite fibers are reported to be thermally stable with proper morphology structures in the core due to rapid hydrocarbon solidification. In a study by Chen et al. [38], polyethylene glycol (PEG) and cellulose acetate (CA) are used to fabricate PCM composite fibers in which PEG and CA acted as the PCM and supporting polymer, respectively. The composite was reported to have high thermal stability due to proper supporting features of the CA matrix.

Few researchers conducted electrospinning in the presence of nanoparticles to improve the thermal properties of nanofibers. In one study, Xie et al. [39] produced composite fibers with diameters ranging from 100 to 300 nm by electrospinning of polyphenylene vinylene (PPV) in the presence of TiO_2 nanoparticles. The effect of nanoparticles loading on the morphology of fibers has also been investigated. Their results have shown that smooth fiber surfaces are obtained for TiO_2 concentrations of up to 18 wt% and coarse surfaces are observed at larger TiO_2 concentrations. Fang et al. [31] used lauric acid and SiO_2 nanoparticles to produce nanocomposite fibers. Lauric acid was used as the PCM to absorb thermal energy and SiO_2 acted as the supporting material. Cai et al. [40] used ternary fatty acid eutectics of CA-LA-PA loaded with nanoparticles of SiO_2 to prepare PCM nanofibers. The fabricated composite was reported to be thermally stable with no considerable changes in the phase transition temperature range and enthalpy values observed after 50 cycles. In another study by Zong et al. [41], the electrospun composite of fatty acid eutectic mixture and SiO_2 nanoparticles were prepared for storage/retrieval energy applications. It was shown that the fatty acids and SiO_2 nanoparticles dispersed properly in the nanofibers network and suitable phase transition temperature and enthalpy values were obtained. Cai et al. [42] used polyethylene terephthalate and lauric acid and succeeded to produce electrospun PCM fibers loaded with SiO_2 nanoparticles by using a new technique of materials processing. They examined the effects of nanoparticles loading on thermal and structural properties of the produced nanofibers. It was reported that although addition of nanoparticles (SiO_2 in particular) affects the LA crystallization process and enthalpy values, the composite phase transition temperature range was remained almost unchanged.

Nonetheless, very few studies have been conducted on the co-electrospinning of fatty acid eutectics in the presence of nanoparticles. In fact, there are very limited pieces of information on the thermo-physical properties and structural characteristics of co-electrospun fatty acid eutectic nanocomposites containing different nanoparticles.

This study is performed to examine the effect of the presence of various nanoparticle on morphology and thermal performance (e.g. phase transition temperature range, energy storage capacity, heat transfer rate and thermal endurance) of the co-electrospun nanofibers of fatty acid eutectics and fill the knowledge gap currently existing in this area. To this end, fatty acid eutectics of capric-lauric (C-L) and capric-palmitic (C-P) are used as the PCM and PET as the supporting polymer. More specifically, the present innovative co-electrospinning method is used to combine thermal properties of C-L/PET and C-P/PET composite fibers in the presence of four different nanoparticles (Al_2O_3, Fe_2O_3, SiO_2 and ZnO) due to their availability and thermal properties. DSC, TGA, SEM and FTIR tests are conducted on the fabricated composite nanofibers to characterize the fibers. The electrospun form-stable