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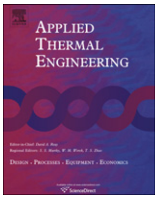

Performance assessment of heat storage by phase change materials containing MWCNTs and graphite

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HIGHLIGHTS

► We produce the MPCMs with MWCNTs and graphite by the direct-synthesis method.
► To assess the thermal resistance for MPCMs by the charging/discharging experiments.
► DSC experiments to assess the phase change properties of MPCM.
► The MWCNTs are better than graphite to modify the thermal performance of paraffin.
► The highest decreased phase change heat of MPCM with MWCNTs is 3.69%.

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ABSTRACT

This study reports the production of modified phase change materials (MPCMs) using the direct-synthesis method to mix paraffin with MWCNTs and graphite as the experimental sample. The MWCNTs and graphite were dispersed into three concentrations of 1.0, 2.0, and 3.0 wt.%. This study experimentally investigates the influences of the additive concentrations of the additives in the paraffin on their temperature and phase change heat variations by charging/discharging temperature difference and DSC experiments to evaluate the feasibility for thermal storage. Experimental results demonstrate that adding the MWCNTs was more effective than graphite in modifying the thermal storage performance of paraffin for most of the experimental parameters. Furthermore, adding MWCNTs reduced the melting onset temperature and increased the solidification onset temperature for paraffin. This makes the phase change heat applicable to a wider temperature range, and the highest decreased ratio of phase change heat was only 3.69%, compared with paraffin. This study demonstrates that for enhancing the thermal storage characteristic of PCMs by adding MWCNTs to paraffin to form MPCMs has great potential.

1. Introduction

The production of greenhouse gases in recent years has been restricted by the implementation of the Kyoto Protocol. The rate of increase in renewable or recovery energy is also a global trend. A survey of all the renewable energy sources reveals that solar energy has the most value in Taiwan, which lies in a subtropical area. However, the utilization of solar energy is restricted by the alternation of day and night and weather conditions. Thus, the development of highly efficient thermal storage materials and devices is a critical issue. Common thermal storage materials can be divided into two categories: single-phase materials and phase change materials (PCMs). PCMs have the advantage of high density of thermal storage, and can be grouped into three types based on phase change state: solid–solid PCMs, solid–liquid PCMs, and liquid–gas PCMs. Solid–liquid PCMs are best suited to thermal energy storage. Solid–liquid PCMs include organic PCMs, inorganic PCMs, and eutectics [1–4].

Most PCMs have the disadvantage of low thermal conductivity, making it difficult for them to overcome the problem of rapid load changes in the charging and discharging process [5]. Many studies have proposed various modified techniques to enhance the thermal conductivities of PCMs, such as inserting fins [6–8], adding metallic or nonmetallic particles with high thermal conductivity [9–11], incorporating porous matrix materials or expanded graphite [12–16], inserting fibrous materials [17–20], and incorporating macro, micro, and nano capsules [21–23].

The methods of enhancing the thermal conductivity of PCMs mentioned above are very helpful, and each has its own advantages.

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Nomenclature

ω	weight fraction, wt.%
C	controller
D	experimental data
F	flow meter
H	heat, kJ/kg
PW	paraffin
q	heat flow, W/g
R	ratio
T	temperature, °C
V	valve

Subscripts

a	additives
d	difference
H	heating
m	melting
mo	melting onset
mp	melting peak
o	onset
p	phase change peak
pw	paraffin
s	solidification
so	solidification onset
sp	solidification peak

Adding particles or fibers to PCMs is a convenient and cost-effective approach to enhance their thermal conductivity. However, these additives also create the problem of sedimentation because additives size, dispersion technique, and surface property of materials gradually result in lower thermal performance in the long-term. However, the viscosity of solid–liquid PCMs in the liquid state is much higher than water, so the additives with micron-scale may be stably suspended in the PCMs. The development of nanotechnology has led to nanoscale additives, which can more effectively solve the problems of sedimentation and increasing viscosity. Nano-additives have a high specific surface area (SSA) that can significantly enhance the heat transfer performance of PCMs.

Elgafy and Lafdi [24] added carbon nanofiber (CNF) to paraffin to enhance the thermal properties of PCMs. Adding CNFs at a concentration of 4 wt.% can increase the thermal conductivity from 0.24 to 0.33 W/m K. Zeng et al. [25] synthesized an organic phase change material (1-tetradecanol, TD)/Ag nanoparticles composite material. They also analyzed the effect of containing Ag nanoparticles on the thermal conductivity and phase change enthalpy of composite PCMs. The thermal conductivity of composite PCMs increases with the loading of Ag nanoparticles. The phase change enthalpy can be correlated linearly with the loading of TD, but the phase change temperature was slightly lower than that of pure TD. Shaikh et al. [26] indicated that paraffin with CNF and carbon nanotubes (CNTs) can enhance latent heat more than pure paraffin. Their study disagrees with the general concept that adding solid additives will reduce the latent heat of PCMs. Wang et al. [27] demonstrated that PCMs with multi-walled carbon nanotubes (MWCNTs) of 2.0 wt.% can increase the thermal conductivity by 35% compared to the original PCMs.

Ho and Gao [28] added alumina (Al_2O_3) nanoparticles to paraffin using an emulsion technique with a non-ionic surfactant as the experimental sample, and dispersed the nanoparticles into different concentrations (5 wt.% and 10 wt.%) to study their thermophysical properties. They reported that the dynamic viscosity and thermal conductivity of paraffin containing 5 wt.% and 10 wt.% of Al_2O_3 nanoparticles increased by approximately 20–28% and ten to four times compared with the original paraffin, respectively. Cui et al. [29] investigated the enhancement of thermal conductivity for soy wax and paraffin wax containing CNFs and CNTs with concentrations of 1, 2, 5, and 10 wt.%. Their experimental results show that the thermal conductivity of PCMs containing CNFs and CNTs increased more than the original PCMs. Adding the CNFs into PCMs more effectively increased the thermal conductivity than CNTs because the CNFs had better dispersion performance. Teng et al. [30] adopted a two-step method of adding MWCNTs and Al_2O_3 nanoparticles to paraffin, forming nanocomposite-enhanced phase change materials (NEPCMs). Their experimental results show that adding nano-materials to the paraffin slightly increased the phase change temperature and reduced the thermal resistance. Arasu and Mujumdar [31] investigated thermal storage by melting paraffin containing Al_2O_3 nanoparticles in a square enclosure followed by numerical investigation. The melting rate decreases with the increase in the volumetric composition of Al_2O_3 nanoparticles for both horizontal wall and vertical wall heating cases. This phenomenon is mainly the result of Al_2O_3 nanoparticles in the paraffin, which results in a relative increase of the dynamic viscosity compared to pure paraffin. The increased ratio of dynamic viscosity was higher than the effective thermal conductivity of paraffin with Al_2O_3 nanoparticles, thus significantly degrading its natural-convection heat transfer efficiency at the concentration of nanoparticles increased in the melted region.

The heated temperature of non-concentrating solar collector generally does not exceed 90 °C. Thus, paraffin was chosen as the PCM thermal storage material. The direct-synthesis method was employed to produce modified phase change materials (MPCMs) by adding the MWCNTs and graphite to paraffin. Charging/discharging temperature difference and differential scanning calorimeter (DSC) experiments were used to assess the charging/discharging temperature difference, onset temperature, peak temperature, and latent heat of melting/solidification for MPCMs and paraffin at the different temperatures, fixed heating and cooling rate to discuss the feasibility of MPCM in thermal storage system.

2. Experimental setup and procedure

2.1. Preparation of phase change materials

Fully refined paraffin (Choneye Pure Chemicals, Taiwan) served as the base materials in this study. The MWCNTs (20–30 nm, Cheap Tubes Inc) and graphite (3.2 um, HOMYTECH, Taiwan) are commercial materials used as additives to modify the paraffin. Fig. 1(a) and (b) shows field-emission scanning electron microscope (FE-SEM, LEO 1530, Zeiss, Germany) photographs of MWCNTs and graphite powder, respectively. The MWCNTs appear aggregated, and the outside diameter approximately met the specifications provided by the manufacturer. The graphite exhibited uneven particle size and aggregated phenomenon, but the overall particle size was generally lower than the manufacturer's specifications.

The MPCMs prepared by the direct-synthesis method were used to disperse the MWCNTs or graphite into three weight fractions (1.0, 2.0, 3.0 wt.%) in the paraffin, forming the experimental samples in this study. The main reason is to select the MWCNTs and graphite that are not easily oxidized and have excellent thermal conductivity. Paraffin was first melted to the liquid state by impermeable heating in water tank at 100 °C to successfully disperse the MWCNTs or graphite powder in the liquid paraffin. Then, the liquid paraffin was continuously stirred at 120 °C by an