Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 132 (2016) 267–278

SOLAR ENERGY

www.elsevier.com/locate/solener

Evaluation of copper nanoparticles – Paraffin wax compositions for solar thermal energy storage

Saw C. Lin [a], Hussain H. Al-Kayiem [b,*]

[a] Department of Mechanical Engineering, Politeknik Ungku Omar, Jalan Raja Musa Mahadi, 31400 Ipoh, Perak, Malaysia
[b] Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak, Malaysia

Received 13 September 2015; received in revised form 30 December 2015; accepted 2 March 2016
Available online 24 March 2016

Communicated by: Associate Editor Luisa F. Cabeza

Abstract

Phase change materials have been used extensively as thermal energy storage mediums. The low thermal conductivity of the phase change materials remains a setback and reduces the performance of gaining and releasing of the thermal energy. In this study, 20 nm copper nanoparticles were dispersed into paraffin wax to synthesis Cu–PCM nanocomposites. Five samples have been prepared to investigate the thermal properties of the produced Cu–PCM nanocomposites (Copper–Paraffin wax nanocomposites). The results of the experimental characterization showed that the thermal conductivity of the Cu–PCM nanocomposites was increased by 14.0%, 23.9%, 42.5% and 46.3% when 0.5%, 1.0%, 1.5%, and 2.0% weight of nano Cu was dispersed in the PCM, respectively. The shift in the melting and solidification temperature showed that nano Cu has acted as nucleation agent to reduce the supercooling effect during the phase change process. On the analysis of the thermal degradation, nano Cu has improved the thermal stability of Cu–PCM nanocomposites without changes in chemical structure. The qualitative analysis showed that 20 nm nano Cu has hexagon shape with particles distribution size range from 15 nm to 125 nm. Site test, using integrated solar-TES system, showed efficiency enhancement by 1.7% when 1.0% nano Cu has been added to the paraffin wax. These encouraging results showed that nano Cu additive could be used to enhance the thermal properties of paraffin wax for solar thermal energy storage.

Keywords: Copper nano; Integrated solar collector; Nano additives; Nanocomposite; Solar thermal systems; TES

1. Introduction

The application of phase change materials (PCMs) in the thermal energy storage (TES) to utilize waste heat, space heating and cooling…etc. have been extensively increasing in recent years. Through experimental and numerical researches, Zalba et al. (2003), Sharma et al. (2009), and Al-Kayiem and Alhamdo (2012) have demonstrated the advantages of using PCMs as TES and its useful applications. However, PCM has the low thermal conductivity. Metal and non-metal nanoparticles were embedded into the PCM to improve the thermal properties of the mixture.

Han and Fina (2011) and Shi et al. (2013) have reported enhancement in the thermal properties mainly in the thermal conductivity of the mixtures when various nanofillers were mixed with PCM. Carbon nanotubes (CNT), as single wall carbon nanotubes (SWCNT), multiwalled carbon nanotubes (MWCNT), and graphite nanofibers (GNF)

* Corresponding author.
E-mail addresses: clsaw78@gmail.com (S.C. Lin), hussain_kayiem@petronas.com.my (H.H. Al-Kayiem).

http://dx.doi.org/10.1016/j.solener.2016.03.004
0038-092X/

are the most famous nanofillers used as additives to enhance the mixture thermal properties (Yu et al., 2008).

Paraffin wax (PW) and fatty acids have been used as thermal storage in solar heating and cooling applications but the major drawback is the low thermal conductivity. It leads to decreasing in heat storage during melting and heat retrieval during solidification due to super cooling (subcooling) effect occurs during melting and solidification processes. Organics and inorganics PCM have small super cooling effect as it is natural behaviour of the materials. Super cooling effect means that the PCM is not easily to melt during the melting process and requires higher heat absorption to change phase from solid to liquid. While, during the solidification processes, PCM starts to crystallize below its phase change temperature. This prevent the latent heat to be released at solidification temperature (Mehling and Cabeza, 2008 and Wu et al., 2009). Super cooling effect can be reduced by increasing the thermal conductivity of the PCM, hence improving heat diffusivity inside the material for better heat flow. One of the methods is to add nanoadditive that act as nucleation agent to decrease super cooling effect during solidification process and act as activation energy agent to overcome thermal resistance during melting process. Instead, Zhang et al. (2010) and Li et al. (2012) and reported the use of micro and macro encapsulation techniques to encapsulate the PCM. A novel microencapsulation technique introduced with a small average diameter of 0.5 μm PCM capsulation, while Castell et al. (2008) inserted metal matrix as fins into organics PCMs techniques. Researchers are likely to disperse nanofillers with high thermal conductivity such as GNF, CNT and metal nanoparticles into PCMs to enhance the thermal conductivity and heat transfer (Sari and Karaipekli, 2007; Kalaiselvam et al. 2012 and Lin and Al-Kayiem, 2012).

The thermal conductivity of the PW was enhanced by 35% and 40% when mixed with MWCNT by 1% and 2%, respectively (Wang et al., 2009). In another investigation, Wang et al. (2010a,b) have doped 1% of CNT into acid based PCM; the thermal conductivity was enhanced by 30%. The enhancement of 100% of thermal conductivity was observed when epoxy mixed with 1.5% CNT mass fraction (Song et al., 2005). A nonlinear behaviour of thermal conductivity with CNT loading in nanofluids was reported, but theoretically, showed a linear behaviour relationship (Biercuk et al., 2002; Xie et al., 2003). While, a study by Chopkar et al. (2006) proved that a strong nonlinear behaviour with about 200% thermal conductivity enhancement with less than 2% volume fraction of nanoparticles, which is probably due to stable suspension of Al_2Cu_3 particles mixture with 70:30 ratio percentage in ethylene glycol.

Recently, Verma and Tiwari (2015) published a review paper on the use of nano additives to enhance the solar collectors. The paper discusses and compares between the various experimental and numerical research works, reported so far, to enhance the thermal properties of the working fluids by nanoadditives. They concluded that there is a potential to enhance the solar PV and thermal systems by nano technologies. Among the 172 cited articles in the review paper; only two papers reported enhancement results on the PCM nanocomposite for solar TES. The first paper is published by Shin and Banerjee (2015). Eutectic of lithium carbonate and potassium carbonate (62:38 M ratio) was explored as a material for TES in concentrating solar power applications. A nanocomposite material was synthesized by mixing the eutectic with ~10–30 nm diameter spherical silica nano-particles at 1% concentration by weight. The study focused on enhancing the heat storage of high temperature inorganic (eutectic salt) solar thermal application. The laboratory testing conducted mainly on the specific heat, thermal conductivity, thermal diffusivity and morphology of the inorganic nanocomposite. The results showed that specific heat enhanced about 5–15%, thermal conductivity and thermal diffusivity improved by 35–45% and 25–28% respectively compared to undoped (pure) material. While, the second paper by Al-Kayiem and Lin (2014) presented investigation results from both; the laboratory testing on the thermophysical properties of Cu–PCM nanocomposites and real on site experimental measurement to test the actual performance of integrated solar water heater. They enhanced the paraffin wax properties by nanoadditives to synthesize nano-PCM composite for thermal energy storage. They dispersed 20 nm Copper nano particle and tested the enhanced performance of integrated solar water heater with TES.

However, this is representing evidence that the literature suffers a lack in the enhancement of paraffin wax by nanoadditives for TES applications. Also, it is an indication that there is a shortage on the actual performance testing of solar collector integrated with PCM nanocomposite.

This paper presents experimental results of thermophysical properties of PW when copper nanoparticles, later will be named as nano Cu, were added to produce Cu–PCM nanocomposite for TES in a solar collector. The nano Cu are chosen here as they are very small, and the small size metal additives are not widely investigated compared to CNT. In addition, it will not considerably increase the weight and volume of Cu–PCM nanocomposite. Four mixtures of Cu–PCM nanocomposites namely Nano Cu–PCM 1, Nano Cu–PCM 2, Nano Cu–PCM 3 and Nano Cu–PCM 4 are prepared and subjected to a series of experimental measurements to compare its physical properties with the pure PW. The studied properties are mainly the thermal conductivity, thermal properties, thermal degradation, chemical stability, shape and size of nanoparticles.

2. Experimental implementations

2.1. Materials

The 20 nm Cu powder nanoadditive used in the present investigation was procured from Dong Yang (HK) Int'l Group Limited. The base fluid used in this experiment is