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Thermal conductivity and heat transfer performance enhancement of phase change materials (PCM) containing carbon additives for heat storage application

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ABSTRACT

In thermal storage system, a high thermal conductivity of Phase Change Materials (PCM) is required to complement the crystallization phenomenon of the PCM during the discharging process. In this study, PCM with carbon additives, Multi-walled Carbon nanotube, Graphite and Graphene, are manufactured and the thermal conductivity of the PCM is measured by the transient hot-wire method for thermal storage application. The thermal conductivity of the PCM is enhanced by adding the carbon additives, and the effect of Poly Vinyl Pyrrolidone (PVP) as a dispersion stabilizer on the thermal conductivity is evaluated. It is found that the heat transfer rate enhances up to 3.35 times in the case of Graphite at 5.0 vol%. It is finally concluded that Graphite is the most promising candidate for heat transfer enhancement of stearic acid among three carbon additives even though Graphene gives the highest thermal conductivity enhancement.

Amélioration de la conductivité thermique et de la performance de transfert de chaleur de matériaux à changement de phase (PCM) contenant des additifs de carbone pour une application d'accumulation thermique

Mots clés : Nanotube carbone ; Graphite ; Taux de transfert de chaleur ; Conductivité thermique ; Accumulation thermique

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Nomenclature

k_{pure}	thermal conductivity of the pure stearic acid, $Wm^{-1}K^{-1}$
k	thermal conductivity of the nano PCMs, $Wm^{-1}K^{-1}$
n	sample count
$\dot{Q}$	heat transfer rate (W)
R_1	fixed resistance, Ω
R_2	fixed resistance, Ω
R_v	variable resistance, Ω
R_w	resistance of hot-wire, Ω
u	uncertainty
x	sample mean
X	sample measurement error of thermal conductivity

1. Introduction

Thermal storage system has been paid attention from the view points of the efficient storage and utilization of thermal energy. The purpose of thermal storage system is to collect the excess heat source, to secure the heat source stably, and to supply it for resolving the time discordance of energy supply and demand by thermal storage. This system is applied in a variety of ways in the related fields (Zalba et al., 2003; Shin et al., 1987; Jesumathy et al., 2012; Chang et al., 1999; Meng et al., 2011; Padhmanabhan et al., 2011; Fumoto et al., 2013). Zalba et al. (2003) reviewed the thermal energy storage with phase change on materials, heat transfer and applications including 150 materials and 45 commercially available phase change materials (PCM). Recently, Osterman et al. (2012) reviewed the PCMs based cooling technologies for free cooling applications, encapsulated PCM, air-conditioning and sorption cooling systems.

During the heat exchange in thermal storage system using the PCM, the latent heat is released from the PCM to the low-temperature tube (discharging process). However, during the discharging process, the crystallization of the PCM starts on the outer wall of the low-temperature tube. Due to the crystallization of the PCM, the heat transfer performance is reduced between the PCM and the tube. The reduction of thermal storage/release rate is just the reflection of the heat transfer performance degradation caused by the low thermal conductivity of the PCM.

The addition of nano particle into the base fluid has been studied and developed to improve the low thermal conductivity of the base fluid (Maxwell, 1873, Choi, 1995). According to the reports, the addition of the nanoparticles with a high thermal conductivity can recover the low thermal conductivity of the PCM. Especially some studies reported about the improvement of the thermal conductivity by adding Multi-walled Carbon nanotube (MWCNT) or Graphite on the PCM. The thermal conductivity of the Paraffin wax including MWCNT composites increased with the mass ratio of MWCNTs (Jifen et al., 2009) and the thermal conductivity of Paraffin wax was increased by impregnating porous graphite matrices. (Andrew et al., 2006) Also, the thermal conductivity of SA increased with increasing mass fraction of expanded graphite and carbon fiber (Ali et al., 2007).

In this study, Stearic Acid (SA) is chosen as the PCM for the thermal storage system application at the working temperature of 71 °C, MWCNT, Graphite and Graphene are used as the additives, and Poly Vinyl Pyrrolidone (PVP) is used as a dispersion stabilizer of carbon additives (Lee et al., 2008a,b). It

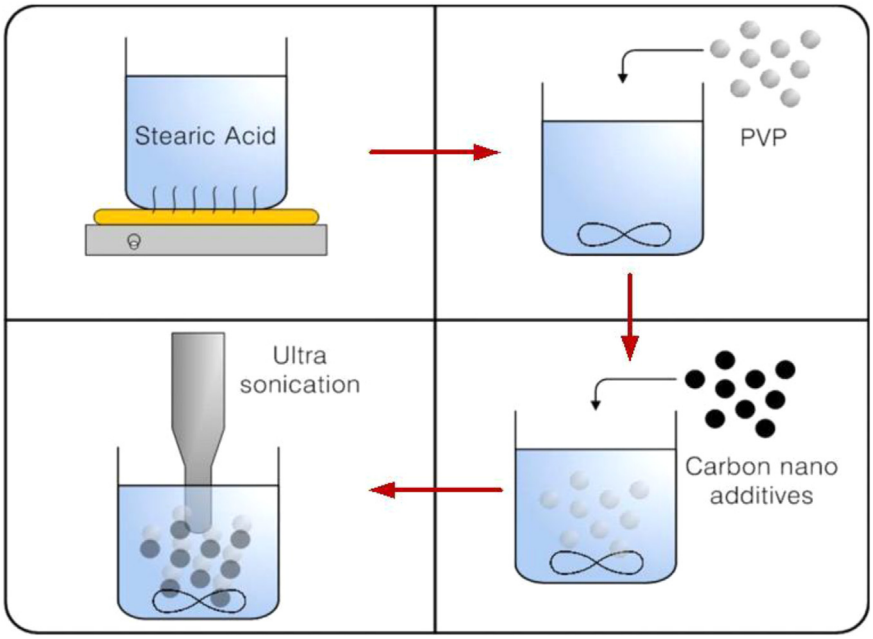

Fig. 1 – Manufacturing procedure for PCMs.