Case Studies in Thermal Engineering 12 (2018) 312–318

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite

Magnetically stirring enhanced thermal performance of phase change material

Dao-Yu Sun[1], Si-Xin Yan[1], Zhi-Zhu He*

Vehicle Engineering, College of Engineering, China Agricultural University, Beijing 100083, China

ARTICLE INFO

Keywords:
Phase change material
Magnetically stirring
Heat transfer
Energy storage technology

ABSTRACT

Here we report an active method to enhance the thermal performance of phase change material (PCM) based on magnetically-stirring method. The magnetic bead with small size embedded in the container filled with octadecanol, is driven to rotate by rotating magnetic field, and induce the forced convective heat transfer of the liquid octadecanol. We investigate the impact of rotating magnetic velocity, magnetic bead size, the distance between magnetic bead and rotating permanent magnet on the surface temperature of the simulated heating plate. The experimental results indicated that magnetically stirring obviously improve the heat transfer from liquid phase to solid phase of octadecanol and make simulated heat source keep a lower and smoother temperature platform. We also find that the best condition point could be determined by matching the rotation velocity for the given size of magnetic bead. These results are expected to provide insights into the design and optimization of latent heat thermal energy storage systems.

1. Introduction

The phase change materials (PCM) based energy storage technology, which are used in latent heat energy storage and aimed to bridge the gap between energy supply and its demand, has been widely applicated in various areas to improve the performance and reliability of the energy system, such as solar energy utilization [1], vehicle component thermal buffering [2], building temperature adjusting [3,4], and electronic component thermal protection [5,6]. The thermal energy transfer occurs when PCM transfer during melting from solid to liquid for absorbing heat, or solidification from liquid to solid for releasing heat, which keeps a nearly constant temperature. The latent heat of PCM is much larger than the sensible heat of conventional material like water, which thus has an attractive advantage of high thermal storage density with small temperature variations. However, most of PCMs have low thermal conductivity, with the exception of metallic-based PCM [7], such as 0.1–0.7 W/m °C for organic materials and 0.5–1.5 W/m °C for salt hydrates [8], which drastically affects the thermal performance during heat exchange process.

Different categories have been developed to enhance thermal performance of PCM, which are mainly divided into two kinds, including methods for improving thermal conductivity of PCM and heat transfer path optimization through structure design of container filled with PCM. The principle of the former is to disperse nanoparticles or impregnate porous materials with high thermal conductivity into PCM [9–12]. The research of Zeng et al [13]. has indicated that the thermal conductivity of PCM composites (about 2.86 W/m °C) with 11.9 vol% of copper nanowires is nine times higher than that of the pure tetradecanol (about 0.32 W/m °C). The study from Siahpush et al [14]. showed that the effective thermal conductivity of eicosane could increase from 0.423 W/m °C to 3.06 W/m °C through filling with copper porous foam of 95% porosity. The other additives include expanded graphite, metal oxide

* Correspondence to: China Agricultural University, 17 Qinghua Donglu, Beijing 100083, China.
E-mail address: zzhe@cau.edu.cn (Z.-Z. He).
[1] Dao-Yu Sun and Si-Xin Yan contribute equally to this research.

https://doi.org/10.1016/j.csite.2018.05.001
Received 15 December 2017; Received in revised form 7 April 2018; Accepted 3 May 2018
Available online 05 May 2018
2214-157X/

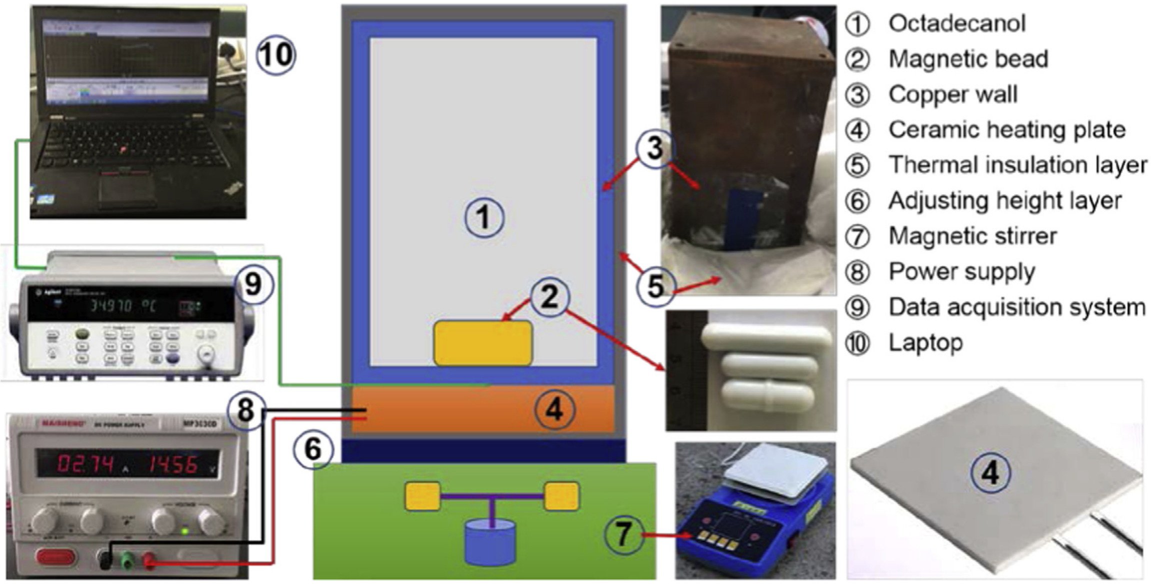

Fig. 1. The scheme diagram of experiment setup.

(such as CuO and TiO_2 [15,16]), metal particles, carbon nanotubes, and so on. The main problem of this method is the compatibility between PCM and the additive. Such as, nanoparticles coagulation may occur after many times repeat of melting-freezing process. Another enhancement method is to embed the fin structure with high thermal conductivity (such as aluminum and copper) into PCM container, which increase the heat transfer area between PCM and heat sink to improve the thermal performance of PCM. Heat pipe is also applied to accelerate heat transfer between PCM and heat sink. Such methods may reduce the PCM volume but weaken the thermal storage density of PCM [8,17,18]. In order to further improve thermal performance of PCM, the active method has also been reported by several researchers, such as the external magnetic field combined nanoparticle for heat transfer enhancement [19], while the effect of magnetic field below 1 T on "weak-magnetic" materials is small [20]. However, the external magnetic field has more obvious effect on the phase process of alloy PCM [21–23].

This paper is aimed to develop and evaluate an active method to enhance the performance of heat transfer between PCM and heat sink based on magnetically stirring. The magnetic bead embedded in the Octadecanol container, is applied to induce liquid Octadecanol from natural convection to forced convective heat transfer through external rotating permanent magnet driven by micro motor with less 1 W power supply. We discuss in detail the impact of rotation velocity, size of magnetic bead, the distance between magnetic bead and rotating permanent magnet on the enhanced thermal performance of PCM.

2. Experimental method

The schematic diagram of experimental setup is shown in Fig. 1. A rectangular-shaped prototype heat storage copper-container with outer dimensions of 68 mm × 68 mm × 105 mm and wall the thickness 5 mm. Octadecanol (purchased from Shanghai Macklin Biochemical Co., Ltd) is chosen here as the PCM and enclosed in the copper-container with the fixed volume about 357 mL. The melting point of octadecanol is about 55.6 °C, and its volumetric latent heat is 214.3 MJ/m^3, the density about 894 kg/m^3 for solid phase, and the thermal conductivity about 0.273 W/m °C for solid phase and 0.175 W/m °C for liquid phase [24]. The ceramic heating plate with the size 50 mm × 50 mm × 2 mm is used as the simulated heat sink, which is supplied by DC-power. The copper-container and heating plate are compressed tightly and its contacted surface smeared with the silicone grease for reducing the thermal contact resistance. Two T-type thermocouples are placed at the center of the contacted interface between copper-container and heating plate to monitor the temperature of heating plate surface. The temperatures data are acquired by Keysight 34970A data acquisition and saved in laptop. The whole copper-container and heating plate are packaged with the thermal insulation material of asbestos to eliminate the heat transfer from environment.

The rod-like magnetic bead composed of permanent magnet is packaged with polytetrafluoroethylene. There are three sizes of magnetic bead considered here, corresponding to No. 1 with radius 4.5 mm and length 27 mm, No. 2 with radius 3 mm and length 30 mm, and No. 3 with radius 3 mm and length 40 mm, respectively. The maximum volume of beads is 1.72 mL, which could be ignored compared with the PCM volume of 357 mL. The magnetic bead is placed on the bottom of copper-container shown in Fig. 1. In order to drive the magnetic bead rotation, a commercial electromagnetic stirrer (version of ZHCL-BS from Beijing Shijihuake Experimental facility Co., Ltd) is used to generate rotating magnetic field through rotating permanent magnet driven by micro motor (3 V/0.12 A), which only need less 1 W power supply. Thus, the magnetic bead rotation is controlled by adjusting rotation rate of micro motor. In order to investigate the impact of magnetic field intensity from rotating permanent magnet on the rotation of magnetic bead, there is an adjusting-height layer placed between copper-container and electromagnetic stirrer shown in Fig. 1. The T-