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Transient thermal energy storage in partitioned enclosures packed with microencapsulated phase change materials

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A R T I C L E I N F O

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A B S T R A C T

In this work, transient characteristics of thermal energy storage in partitioned enclosures filled with microencapsulated phase change material (MEPCM) particles were examined experimentally and numerically. The enclosure is partitioned with aspect ratio λ and packed with different MEPCMs with melting temperatures about $T_M = 28$ °C and 37 °C. The top and bottom surfaces of the partitioned enclosure are, respectively, maintained at hot and cold temperatures, while the other surfaces are kept thermally insulated. The results showed that at the initial transient, the net energy storage in partitioned enclosure, Q_{net}, increases with the time. Finally, the Q_{net} approaches quickly the steady state. Additionally, higher dimensionless accumulated energy through the hot wall Q_h and cold wall Q_c are found for a case with higher hot wall temperature T_h. that the faster melting is experienced for the system with higher Stefan number and the subcooling number is the main parameter to dominate the thermal latent heat storage of the MEPCM system. In addition, better net energy storage is noted for a partitioned enclosure with a smaller aspect ratio.

1. Introduction

Phase change material can effectively store or release latent heat during melting or solidification of phase change process, respectively, and maintain the system temperature being at melting temperature. Therefore, it is very potential and widely used for the materials for energy storage and environmental temperature control [1–3].

Addition of MEPCM in working fluid is considered to be a potential heat transfer enhancement cooling fluid. The laminar convective heat transfer in circular pipes with MEPCM suspensions was investigated experimentally by Goel et al. [4]. Measured data showed that use of phase change material suspensions can reduce the rise in wall temperature by up to 50% as compared to a pure fluid for the same non-dimensional parameters. Additionally, they indicated that the most dominant parameter affecting the heat transfer was the bulk Stefan number. The forced convective heat transfer enhancement of MEPCM slurries flowing through a circular duct with constant heat flux was numerically examined by Hu and Zhang [5] using an effective specific heat capacity model. They concluded the conventional heat transfer correlations for pure fluids are not suitable for accurately describing the heat transfer with MEPCM suspensions. Ho et al. [6] performed an experimental study to examine the cooling performance of a minichannel heat sink using water-based suspensions of alumina nanoparticles (nanofluid), and/or microencapsulated phase change material (MEPCM) particles. In their work, the experimental data for the various effectivenesses of using the water-based suspensions formulated in the minichannel sink were found well correlated with the relevant dimensionless parameters in general forms. Numerical model of laminar forced convection heat transfer for microencapsulated phase change material suspensions with constant heat flux was developed by Liu et al. [7]. They presented tube cross section effects on the heat transfer enhancement.

Characteristics of fluid flow and heat transfer in a rectangular enclosure packed with MEPCMs were investigated numerically by Sabbah et al. [8]. Predicted results disclosed considerable heat transfer enhancement (up to 80%) at the considered operating conditions. This enhancement is due to the MEPCM latent heat. Zhangi et al. [9] established a rectangular heat storage tank to examine the performance of natural convection of working fluids, by which the performance of the MEPCM was assessed. The results showed that the MEPCM improved the natural convection heat transfer performance.

An experimental study on heat transfer characteristics in a vertical square enclosure with a solid–liquid phase-change material dispersed with nanoparticles Al_2O_3 nanoparticles as the nano-PCM was carried

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Nomenclature

A	cross section area (m^2)
c	specific heat (J/kg K)
Fo	Fourier number, $\alpha_m\tau/H^2$
H	height of enclosure (m)
h_{LS}	latent heat (J/kg)
k	thermal conductivity (W/mK)
L	width of enclosure
q''	heat flux (W/m^2)
Q	accumulated energy (J)
Sb_i	subcooling parameter, $(T_M - T_c) / (T_h - T_M)$; $i = 1$ for upper, $i = 2$ for lower
Ste_i	Stefan number, $c_{p,m}\,(T_h - T_M) / h_{LS;}$ $i = 1$ for upper, $i = 2$ for lower
T	temperature (°C)
α	thermal diffusivity (m^2/s)
ρ	density (kg/m^3)
τ	time (s)
λ	aspect ratio, H_1/H_2

Subscripts

c	cold wall
h	hot wall
i	layer of enclosure, $i = 1$ for upper, 2 for lower
M	melting point
net	net
o	total

out by Ho and Gao [10]. They indicated that natural convection heat transfer into the melted region of the enclosure tends to degrade significantly with increasing mass fraction of nanoparticles dispersed in the nano-PCM, as compared with that of pure PCM. The transient characteristics of energy storage across a square enclosure filled with MEPCM particles were investigated by Ho et al. [11]. The results disclosed that the faster melting is experienced for the system with higher Stefan number and the subcooling number is the main parameter to dominate the thermal latent heat storage of the MEPCM system. Recently, the unsteady characteristics of energy storage in an enclosure packed with microencapsulated phase change material (MPCM) particles were examined by Ho et al. [12]. They showed that the faster melting is experienced for the system with higher Stefan number and the subcooling number is the main parameter to dominate the thermal latent heat storage of the MEPCM system.

Although the above studies investigated the heat transfer characteristics in enclosures filled with MEPCMs, to the best of the authors' knowledge, few studies in the literature systematically describe the unsteady thermal energy storage in partitioned enclosures filled with different MEPCMs. This motivates the present study.

2. Experimental study

As illustrated in Fig. 1(b), the experimental setup mainly consists of test cell, resistive electrical heaters, insulation material, MEPCM, power supply, thermocouples, and the data acquisition system. The test cell of the enclosure, having interior dimensions of 32 mm × 100 mm × 100 mm, was fabricated with Acrylic. The enclosure was partitioned with an aluminium plate of 2.0 mm thickness. The upper and lower enclosures were packed with different MEPCM particles with melting temperatures T_{M1} and T_{M2}, respectively. The hot wall (top wall) is heated by an electrical foil heater made of flat strip Nichrome wires with feedback of the deviation of the hot wall temperature from the desired value to achieve the isothermal condition of hot wall. The cold wall with flow channels circulated with temperature-controlled fluid from a thermostat was maintained at cold temperature. The external surfaces of the test cell were insulated by a polyethylene material of 60 mm thickness to reduce heat losses to the surroundings. Nine T-type thermocouples were installed in the test cell at various locations to monitor the temperature variations. The thermocouple data were recorded by a data acquisition system. It takes about 4–5 h for the system to reach steady state.

The MEPCM particles packed within the partitioned enclosure were purchased from Microtek Laboratories, Inc. (Germany) with products' number MPCM28D and MPCM37D. The core PCM of MEPCM particles is n-octadecane with melting point of 28 °C and 37 °C, respectively, while their mean particle sizes are in the range of 17–20 μm. The thermophysical properties of the MPCM28D and MPCM37D including density and thermal conductivity were measured as a function of temperature. Density was measured using a hydrometer (Tomei Co. Ltd., Japan) which has a measuring accuracy of within ± 5×10^{-4} kg/m^3. The thermal conductivity was measured by the thermal analyzer (Decagon devises KD2-Pro) with a standard deviation of ± 5%.

In this work, the melting point, latent heat of fusion and specific heat capacity were determined on a differential scanning calorimeter

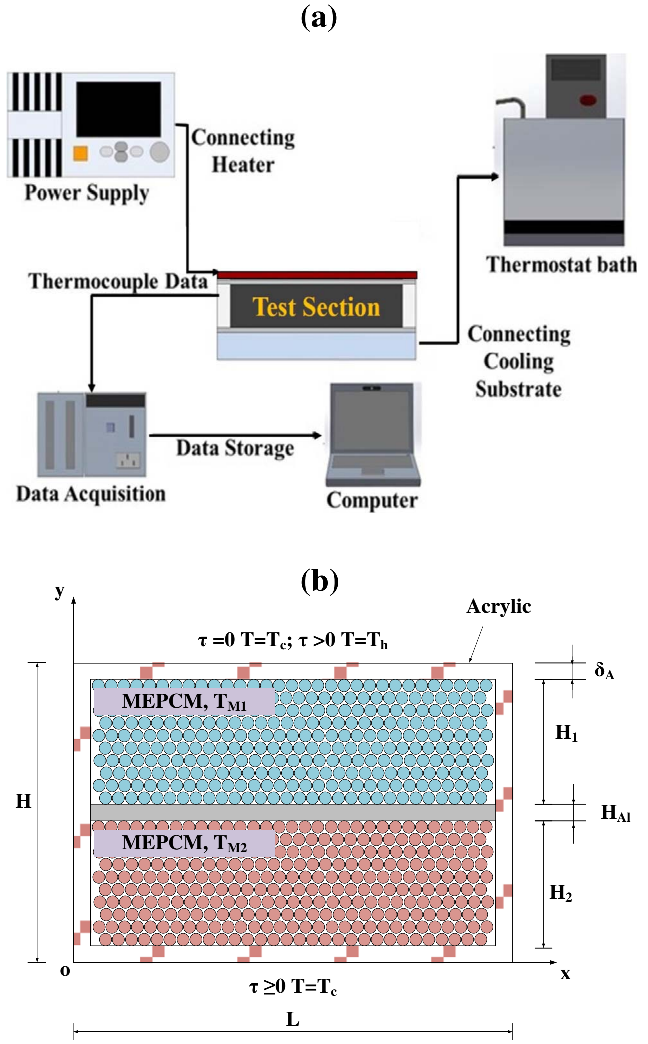

Fig. 1. Schematic diagrams of (a) the experimental system and (b) numerical modelling.