Applied Thermal Engineering 105 (2016) 209–216

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research Paper

An experimental study of the latent functionally thermal fluid with micro-encapsulated phase change material particles flowing in microchannels

Yan Wang[a,*], Zhenqian Chen[b], Xiang Ling[a,*]

[a] Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing Tech University, Nanjing 211816, China

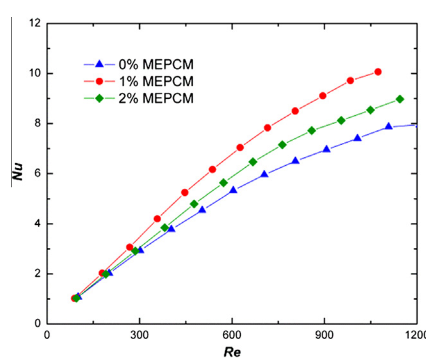
[b] School of Energy and Environment, Southeast University, Nanjing 210096, China

HIGHLIGHTS

- The experiments of latent fluid flowing in parallel microchannels were conducted.
- The performance of water with well dispersed micro-encapsulated phase change material particles was examined.
- The Nusselt number of MEPCM slurry could achieve 1.36 times as that of pure water.

GRAPHICAL ABSTRACT

Fig. 1. Relationship between *Nu* and *Re* for MEPCM slurry with various particle volume fractions. The interrupt of the well dispersed particles would destroy the thermal boundary layer and reduces its thickness, resulting in large Nusselt number for the suspension with 2% volume fraction of MEPCM. Large amount of heat could be absorbed and transferred rapidly during MEPCM melting process, which would result in remarkable increase of Nusselt number. The heat transfer performance of latent thermal fluid would be enhanced as 1.34 times of that of pure water. With smaller particle volume fraction (1% in this context), phase change occurs at lower temperature and more intensive heat flux is required for higher concentration suspension to induce the phase change occurrence, which is useful for application of the thermal management design.



ARTICLE INFO

Article history:
Received 28 March 2016
Revised 19 May 2016
Accepted 26 May 2016
Available online 27 May 2016

Keywords:
Micro-encapsulated phase change material
Microchannels
Visualized experiment
Heat transfer enhancement

ABSTRACT

Phase change material holds a good promise as a media of thermal energy storage and intensive heat flux removal. In this context, experiments were conducted to investigate the hydrodynamic and thermodynamic properties of a latent thermal fluid, which consisted of water and well dispersed micro-encapsulated phase change material (MEPCM) particles, flowing in parallel microchannels. It is suggested that MEPCM particles loading induces much higher pressure drop, which is very sensitive to temperature. Compared against water, the heat transfer performance of MEPCM slurry performs much better owing to particles aggregation, collision and micro-convective around the particles. Besides these, latent heat absorbed during phase change process makes the key contribution. It is found that with melting occurrence, Nusselt number of the slurry with only 2% MEPCM particles would

* Corresponding authors.
E-mail addresses: ywang@njtech.edu.cn (Y. Wang), xling@njtech.edu.cn (X. Ling).

http://dx.doi.org/10.1016/j.applthermaleng.2016.05.159
1359-4311/

increase remarkably and achieves 1.36 times as that of pure water, which is very benefit to the thermal management system.

1. Introduction

Microscale devices have been widely used in industrial and scientific applications, which will generate extremely high heat flux even thermal overload [1–3], and for this reason, novel thermal management devices with higher heat transfer efficiency is required. Meanwhile, discrepancy comes out between the energy supply and demand in heating energy applications, such as discontinuity of energy supply and asynchrony between energy supply and usage, thermal energy storage plays a key role in the area of solar energy collectors [4,5], building heating/cooling systems [6], power and industry waste heat recovery [7] and so on. Techniques to promote enhancing heat transfer in microchannels or large heat capacity with continuous energy supply management are desired.

The latent functionally thermal fluid, which consists of base fluid and well dispersed MEPCM particles, holds tremendous promise in energy utilization field and attracts more and more interests. It serves for both high heat transfer efficiency and large energy storage density due to adsorbing/releasing latent heat during phase change process [8].

It has been an explosion of study of the preparation and thermal properties of MEPCM recently. Sari [9] prepared microcapsules containing paraffin eutectic mixtures and poly (methyl methacrylate) shells for thermal energy storage. A new shape-stabilized phase change material was developed by Barreneche et al. [10] for acoustic and thermal comfort in buildings. Fatty acid mixture was also microencapsulated by Özonur et al. [11] and Mei [12] for its high latent heat storage capacity at low melting point applied in building energy storage. Qiu et al. [13] investigated thermal properties of microencapsulated *n*-octadecane with different methylmethacrylate-based copolymer shells as phase change materials for thermal energy storage.

Besides the investigation of preparation and thermal properties of MEPCM itself, a large amount of experimental work has been dedicated to study the performance characteristics of MEPCM slurries. Bechiri and Mansouri [14] studied thermal energy storage system consisting of several flat slabs with PCM and analyzed total heat transmitted to the phase change material. Through the simulation results, the thermal energy carried by the fluid at the duct inlet enhances with Reynolds number increases, resulting in smaller melting time. Pomianowski et al. [15] reviewed various technologies with PCM for building applications to improve indoor environment, increase thermal inertia and decrease energy use for building operation and concluded that the proper thermal properties of PCMs and their composites, such as, thermal conductivity and specific heat capacity had to be determined as a function of temperature and the climatic condition also had to be taken into account to correctly determine dynamic performance and potential for the whole energy storage system. Delgado et al. [16,17] observed the behavior of MEPCM slurry and studied the influence of mass fraction on the thermal rheological characterization via experiments and found out that rupture of PCM particles would appear after being pumped with 10,000 solidification-melting cycles. Kousksou et al. [18] studied phase behavior and heat transfer characteristics of phase change material dispersed inside an emulsion experimentally by Differential Scanning Calorimeter and found that the effect of the heating rate needed to be considered to characterize with accuracy of the thermal behavior of simple or mixed phase change emulsions. The experimental results [19] of *n*-octadecane with CuO nanoparticle suspensions revealed that the nanoparticles loading had a positive effect on raising the thermal conductivity of the PCM/nanoparticle composite and augmenting heat transfer rate.

The MEPCM particle dispersed in the fluid can interrupt the flow and form the micro-convective, resulting in the heat transfer performance enhanced. Furthermore, the latent heat can be absorbed during melting process, which may prove to be more thermally effective and relevant to future thermal energy storage and electronics cooling systems. However, particle clustering and large particle loadings are expected to lead to remarkable viscosity increases, resulting in unavoidable large pressure drop, thus rendering usefulness of nanofluids questionable. Significant pressure drops have been found via the pioneer work with particles dispersion in the fluid. Experiments conducted by Wang et al. [20] and Das et al. [21] showed that the particle volume fraction played a critical role on effective viscosity of nanoparticle suspension. Gudipaty et al. [22] observed the cluster formation and growth in microchannel flow of dilute particle suspensions via experiments and indicated that the clusters could be formed mostly at the inlet and outlet regions and the total cluster area grown in the microchannel had a linear relationship with time. Based on reviewing the experimental and numerical studies of heat transfer in microchannels by Rosa [23], it was concluded that for single phase fluid flowing in single microchannel, available correlations for macro-channels could give reliable predictions at the micro-scale with scaling effects considered negligible, while for parallel channels, it was still lack of available correlation and accurate experimental studies.

With this communication, despite its many advantages, it's still a challenge to understand and reveal the mechanism of MEPCM slurry flowing in the microchannel clearly. The studies of convective heat transfer of particle slurry in microchannels combined with phase change is inefficient, although relevant experiments have extended knowledge pertinent to pure fluid flowing and heat transfer behavior. Therefore in this paper, we reported on an experiment of heat transfer enhancement scheme with MEPCM slurry flowing in microchannels to investigate the hydrodynamic and thermodynamic properties.

2. Experimental apparatus and method

2.1. Experimental apparatus

The microchannel was manufactured as Fig. 1. There were 10 parallel microchannels with rectangular cross-section in the stainless steel plate and the dimensions of a single channel were 0.35 mm in width, 0.35 mm in depth and 440 mm in length, to make sure the fluid flowing can get fully developed state. The microchannel block was covered by a quartz glass plate to observe the fluid flowing behavior, and a heating block made of aluminum alloy was positioned behind the microchannel. Asbestos was applied surrounding the heating block to reduce the heat loss to ambient, in which way heat could be transferred perpendicularly to the microchannels through the steel plate. The temperatures were measured in the longitudinal dimension to get accurate heat flux transferred to the fluid.

A schematic and photograph of the test section designed for fluid flow confined in microchannels were shown in Figs. 2 and 3