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Nanoparticle-enhanced phase change materials (NEPCM) with great potential for improved thermal energy storage ☆

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Abstract

Improved functionality of phase change materials (PCM) through dispersion of nan oparticles is reported. The resulting nanoparticle-enhanced phase change materials (NEPCM) exhibit enhanced thermal conductivity in comparison to the base material. Starting with steady state natural convection within a differentially-heated square cavity that contains a nanofluid (water plus copper nanoparticles), the nanofluid is allowed to undergo solidification. Partly due to increase of thermal conductivity and also lowering of the latent heat of fusion, higher heat release rate of the NEPCM in relation to the conventional PCM is observed. The predicted increase of the heat release rate of the NEPCM is a clear indicator of its great potential for diverse thermal energy storage applications.

Keywords: Nanoparticles; Nanofluids; Phase change; Thermal storage; Natural convection; Freezing

1. Introduction

Utilization of naturally-occurring or fabricated nanoparticles (diameters less than 50 nm) promises to open up a great number of opportunities for new technological innovations in materials synthesis, biotechnology, deep space exploration, design of microfluidic devices, emission control and energy efficiency. Masuda et al. [1] reported on enhanced thermal conductivity of dispersed ultra-fine (nanosize) particles in liquids. Soon thereafter, Choi [2] was the first to coin the term "nanofluids" for this new class of fluids with superior thermal properties. Another opportunity that has been overlooked is the exploitation of the thermal properties of nanomaterials in preparation, tailoring and development of functionality-tested nanoparticle-enhanced phase change materials (NEPCM) through dispersion of nanoparticles. In this communication, early results of an ongoing computational/experimental study that highlights the superiority of NEPCM for thermal energy storage applications are presented.

2. Problem statement

The analysis was carried out in two separate but related stages. Firstly, steady-state buoyancy-driven convection in a differentially-heated cavity containing a nanofluid was studied, very similar to the recent work of Khanafer et al. [3].

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Nomenclature

d_p	diameter of spherical nanoparticles, m
k	thermal conductivity, W/mK
L	latent heat of fusion, J/kg
Ste	Stefan number, i.e. $c_p \Delta T/L$
Greek symbols	
ϕ	volume fraction of solid particles
λ	volume fraction of the nanofluid
τ	freezing time, s
Subscripts	
f	base fluid
nf	nanofluid
s	solid
0	stagnant
1, 2	related to Grashof numbers 10^4 and 10^5, respectively

Consider a differentially-heated square cavity (side H) with adiabatic top and bottom walls, whereas the left and right walls are maintained at constant temperatures, T_H and T_C ($T_C < T_H$), respectively. Gravity acts parallel to the active walls pointing toward the bottom wall. The nanofluid is treated as an incompressible and Newtonian fluid. Thermophysical properties of the nanofluid are assumed to be constant, whereas the density variation in the buoyancy force term is handled by the Boussinesq approximation.

2.1. Governing relations

Considering the nanofluid as a continuous media with thermal equilibrium between the base fluid and the solid nanoparticles, the governing equations are:

Continuity:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

X-momentum equation:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{1}{\rho_{\mathrm{nf}}}\left(-\frac{\partial p}{\partial x} + \mu_{\mathrm{nf}}\nabla^2 u + (\rho\beta)_{\mathrm{nf}}\, g_x(T - T_{\mathrm{ref}})\right), \tag{2}$$

Y-momentum equation:

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = \frac{1}{\rho_{\mathrm{nf}}}\left(-\frac{\partial p}{\partial y} + \mu_{\mathrm{nf}}\nabla^2 v + (\rho\beta)_{\mathrm{nf}}\, g_y(T - T_{\mathrm{ref}})\right), \tag{3}$$

Energy equation:

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{\partial}{\partial x}\left[\frac{(k_{\mathrm{nf0}} + k_{\mathrm{d}})}{(\rho c_{\mathrm{p}})_{\mathrm{nf}}}\frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial y}\left[\frac{(k_{\mathrm{nf0}} + k_{\mathrm{d}})}{(\rho c_{\mathrm{p}})_{\mathrm{nf}}}\frac{\partial T}{\partial y}\right]. \tag{4}$$

The density of the nanofluid is given by:

$$\rho_{\mathrm{nf}} = (1-\phi)\rho_{\mathrm{f}} + \phi\rho_{\mathrm{s}}, \tag{5}$$