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Novel insight and numerical analysis of convective heat transfer enhancement with microencapsulated phase change material slurries: laminar flow in a circular tube with constant heat flux

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Abstract

This paper presents a novel insight for the forced convective heat transfer enhancement of microencapsulated phase change material slurries flowing through a circular tube with constant heat flux. The influence of various factors is analyzed in detail by using an effective specific heat capacity model, validated with the results available in the literature. It is found that the conventional Nusselt number correlations for internal flow of single phase fluids are not suitable for accurately describing the heat transfer enhancement with microencapsulated phase change material suspensions, and a modification is introduced that enables evaluation for the convective heat transfer of internal flows. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Microencapsulated phase change material slurries; Microcapsule; Heat transfer enhancement; Energy storage

1. Introduction

Recently, a new technique has been proposed for utilizing phase change materials (PCM) in energy storage systems, heat exchangers and thermal control systems [1–3] where the PCM is microencapsulated and suspended in a conventional single-phase heat transfer fluid to form phase change slurries. Such slurries have large apparent specific heats during the phase change period, which enhances the heat transfer rate between the fluid and the tube wall. The slurry can serve not only as the thermal storage media but also as the heat transfer fluid, and hence, could have many potentially important applications in the fields of heating, ventilation and air-conditioning (HVAC), refrigeration and heat exchangers, etc.

The flow and heat transfer characteristics of phase change slurries have been investigated in various theoretical and experimental studies [1–9]. The results showed that the phase change slurries enhanced the convective heat transfer with small increases in the pressure drop for some conditions [2,3,8]. The fluid could be analyzed as Newtonian when the microcapsule volumetric concentration was less than 25% [1]. The Nusselt number for the phase change slurry was from 1.5 to 4 times higher than for single-phase flow under ideal conditions [1]. Experimental results for the dimensionless wall temperature with constant wall heat flux were 45% less than the ideal theoretical prediction because the slurry inlet temperature was less than the PCM phase change temperature and the phase change process occurred over a finite temperature range [4,6]. The dominant parameters affecting the heat transfer enhancement of the phase change slurry were the bulk Stefan number, the volumetric concentration of the microcapsules, the dimensionless initial degree of subcooling, the dimensionless phase change temperature range and the microcapsule diameter. The microcapsule

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Nomenclature

c	volumetric concentration of microcapsules
c_m	mass concentration of microcapsules
c_p	specific heat, kJ kg^{-1} K^{-1}
d_p	microcapsule diameter, m
h	convective heat transfer coefficient, W m^{-2} K^{-1}
h_{fs}	heat of fusion for phase change material, kJ kg^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
k_e	effective thermal conductivity of slurry, W m^{-1}K^{-1}
ML	dimensionless initial supercooling, $(T_1 - T_i)/(q''_w r_0/k_b)$,
Mr	dimensionless phase change temperature range, $(T_2 - T_1)/(q''_w r_0/k_b)$
Nu	conventional Nusselt number
Nu^*	modified Nusselt number
q''_w	wall heat flux, W m^{-2}
Pe	Peclet number
Pr	Prandtl number
Re	Reynolds number
r	radial coordinate, m
r_0	duct radius, m
r_1	dimensionless radial coordinate, r/r_0
Ste	Stefan number, $(c_{p,b0} \cdot q''_w r_0/k_b)/(c_m \cdot h_{fs})$
T	temperature, °C
T_1	lower phase change temperature limit, °C
T_2	upper phase change temperature limit, °C
T_i	slurry inlet temperature, °C
u	axial velocity, m s^{-1}
v	radial velocity, m s^{-1}
x	axial coordinate, m
x_1	dimensionless axial coordinate, x/r_0

Greek symbols

α	thermal diffusivity, m^2 s^{-1}
β	included angle between fluid velocity and temperature gradient velocity
θ	dimensionless temperature
ϕ	dimensionless temperature
μ	dynamic viscosity, N s m^{-2}
ν	kinematic viscosity, m^2 s^{-1}
η	degree of heat transfer enhancement, $\eta = h_m{}^*/(h_m{}^*)_{single}$

Subscripts

b	bulk fluid (slurry)
b0	slurry without phase change
bp	slurry with phase change
l	liquid
m	mean
s	solid
f	bulk fluid
p	microcapsule particles
w	wall
x	local

crust, the form of the PCM specific heat function, the specific heat ratio, $c_m \cdot c_{p,s}/c_{p,b0}$, and the thermal conductivity ratio, k_p/k_f had little effect on the heat transfer characteristics [1,4,6,8,9].

Previous researches suggested that the heat transfer enhancement in phase change slurries is caused by the phase change in the microcapsules and the increased effective thermal conductivity of the slurry. However, the heat transfer enhancement mechanism is not well understood and the effects of various factors on the heat transfer enhancement have not been analyzed quantitatively. Moreover, for internal flow of a phase change slurry, the current analysis shows that, the conventional Nusselt number is not suitable for accurately describing the heat transfer enhancement because the heat transfer rates depend not only on the convective heat transfer coefficient but also on the temperature difference in a very non-linear way, since the apparent specific heat of the slurry is closely related to the bulk temperature during the phase change.

As analyzed and emphasized in [10,11] for enhancing the forced convective heat transfer, not only to increase Reynolds and/or Prandtl number as usual, it would be also, as a new way to develop new technology to increase the fullness of dimensionless velocity and/or temperature profiles, and to increase the included angle between the dimensionless velocity and temperature gradient vectors. In fact, for fluids with variable thermal physical properties, the variable specific heat induced by phase change could strongly affect the convective heat transfer rate. This paper analyses the forced convective heat transfer enhancement with microcapsulated phase change slurries for laminar flow in a tube with constant heat flux. The conventional Nusselt number definition for internal flow is modified, here, so that it can describe such degree of heat transfer enhancement more concisely.

2. Theoretical analysis for enhancing forced convective heat transfer

It is seen from Fig. 1 that, for phase change material slurries the conventional local Nusselt number [12], Nu_x, is smaller than that of single phase fluid around

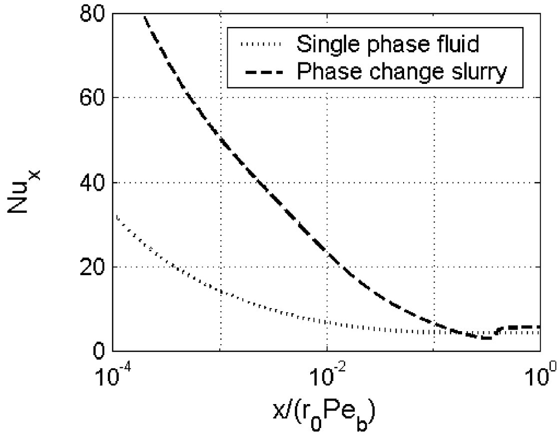


Fig. 1. Variation of the local conventional Nusselt number with position ($Ste = 1.0$, $Mr = 0.07$, $ML = 0$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm, $Re_b = 200$, Sine curve case).

$x/(r_0 Pe_b) = 0.5$ although the convective heat transfer of phase change material enhances in this region compared with that of single phase fluid. This implies that the conventional Nusselt number correlations cannot accurately describe that of phase change material slurries whose apparent specific heat is strongly temperature-dependent.

It is modified to define the local Nusselt number, Nu_x^*, for internal flow:

$$Nu^* = \frac{h^* \cdot L_c}{k_b} = \frac{q''_w}{T_w - T_i} \cdot \frac{2r_0}{k_b}, \tag{1}$$

where L_c being the characteristic length, and usually, take $L_c = 2r_0$. Then, Fig. 1 can be reproduced to that in Fig. 2.

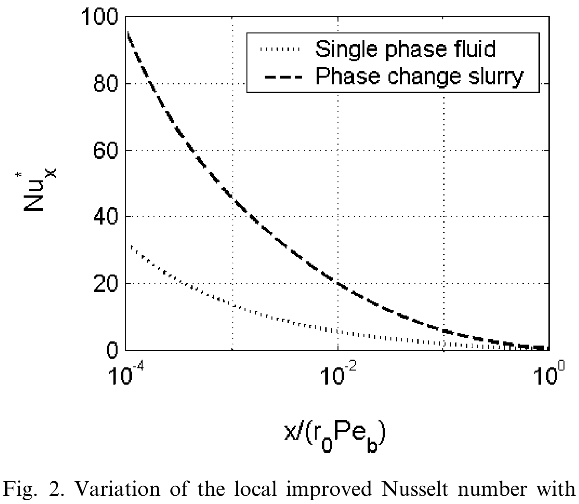


Fig. 2. Variation of the local improved Nusselt number with position ($Ste = 1.0$, $Mr = 0.07$, $ML = 0$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm, $Re_b = 200$, sine curve case).

Considering the energy equation for steady two-dimensional boundary layer flow in a circular duct with solid–liquid phase change, we have,

$$\rho_b c_{p,b}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial r}\right) = \frac{1}{r}\frac{\partial}{\partial r}\left(r \cdot k_e \frac{\partial T}{\partial r}\right). \tag{2}$$

Integrating Eq. (2) over the thermal boundary layer thickness yields

$$\int_{r_0-\delta_t}^{r_0} \rho_b c_{p,b} r\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial r}\right) dr = \int_{r_0-\delta_t}^{r_0} \frac{\partial}{\partial r}\left(rk_e\frac{\partial T}{\partial r}\right) dr. \tag{3}$$

Defining the dimensionless parameters

$$r_1 = \frac{r}{r_0}, \quad x_1 = \frac{x}{r_0}, \quad u_1 = \frac{u}{u_m}, \quad v_1 = \frac{v}{v_m},$$
$$c_p^* = \frac{c_{p,b}}{c_{p,b0}}, \quad \phi = \frac{T - T_i}{T_w - T_i},$$

gives the approximate dimensionless equation as

$$Re_b Pr_{b0} \int_{1-(\delta/r_0)}^{1} r_1 \cdot c_p{}^* \cdot \left(u_1\frac{\partial \phi}{\partial x_1} + v_1\frac{\partial \phi}{\partial r_1}\right) dr_1 = Nu_x{}^*. \tag{4}$$

Eq. (4) can be rewritten in vector form as

$$Re_b Pr_{b0} \int_{1-(\delta/r_0)}^{1} r_1 \cdot c_p{}^* \cdot \left(\vec{U}_1 \cdot \overrightarrow{\nabla\phi}\right) dr_1 = Nu_x{}^*, \tag{5}$$

where

$$Nu_x^* = \frac{2r_0 q''_w}{k_b(T_w - T_i)}, \quad Re_b = \frac{2r_0 u_m}{\nu_b},$$
$$Pr_{b0} = \frac{\nu_b}{\alpha_{b0}} = \frac{\rho_b c_{p,b0} \nu_b}{k_b}.$$

Analysis of Eq. (5) shows that

$$Nu_x^* = f\left(Re_b, Pr_{b0}, c_p{}^*, \vec{U}_1 \cdot \overrightarrow{\nabla\phi}\right). \tag{6}$$

So, to enhance the convective heat transfer for internal flow of phase change slurries, we can increase Re_b or/and Pr_{b0}, increase $c_p{}^*$, increase the uniformity of velocity profile U_1, increase the dimensionless temperature gradient $\nabla\phi$, and/or change the included angle, β, between the dimensionless velocity vector and the dimensionless temperature gradient vector (either decrease β if $0 \leqslant \beta \leqslant 90°$, or increase β if $90° < \beta \leqslant 180°$). However, these factors are not all independent, for example, the change of Re_b, Pr_{b0} or $c_p{}^*$ will change the value of $\vec{U}_1 \cdot \overrightarrow{\nabla\phi}$.

3. A model proposed for prediction

The following assumptions are made to simplify the formulation:

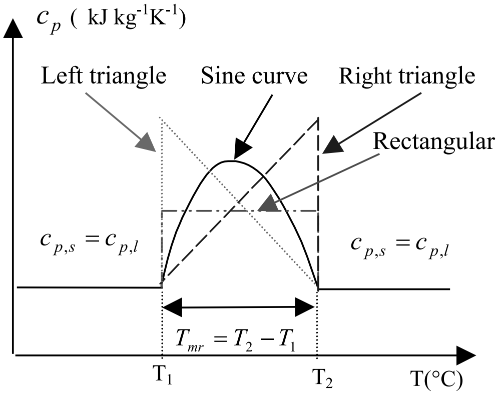


Fig. 3. Variation of microcapsule specific heat with temperature.

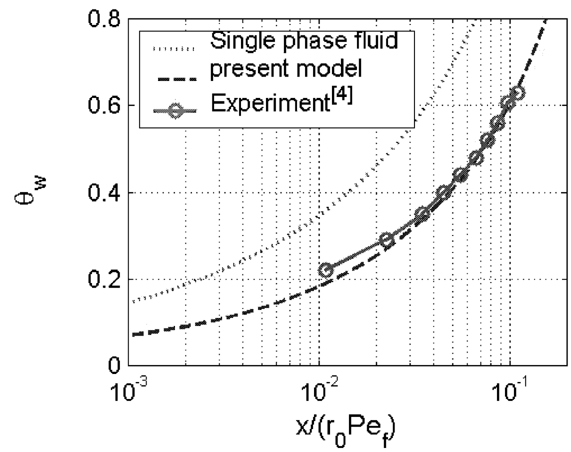


Fig. 4. Comparison of the numerical results with those of experiments [4] ($Ste = 1.0$, $Mr = 0.4$, $ML = -0.33$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm, $Re_b = 200$, rectangular case).

(1) The slurry flows in a circular duct, and the flow is fully developed laminar flow.
(2) The slurry inlet temperature, T_i, is not higher than the upper phase change temperature limit, T_2 (Fig. 3).
(3) The volumetric concentration of the microcapsules is less than 25% so that the flow can be analyzed as a Newtonian fluid [1].
(4) The microcapsules are uniformly distributed in the slurry.
(5) Viscous dissipation and axial conduction are small to be neglected.
(6) No other internal heat sources exist in the flow, except the heat of fusion for phase change materials suspension.
(7) The thermophysical properties are assumed to be constant except especially for the specific heat, which is strongly temperature-dependent as to take account of the heat of fusion, h_{fs}, for phase-charge material suspension. Four different specific heat functions have been considered in the present work, which are shown in Fig. 3.
(8) The effect of the microparticles free layer nearby the wall is to be neglected.
(9) The interfacial thermal resistance for the microcapsules is small to be neglected.

Then, the energy equation for the phase change slurry can be written as:

$$\rho_b c_{p,b} u \frac{\partial T}{\partial x} = \frac{1}{r}\frac{\partial}{\partial r}\left(r \cdot k_e \frac{\partial T}{\partial r}\right) \tag{7}$$

with corresponding boundary conditions:

$$T|_{x=0} = T_i, \quad \left.\frac{\partial T}{\partial r}\right|_{r=0} = 0, \quad \left.\frac{\partial T}{\partial r}\right|_{r=r_0} = \frac{q''_w}{k_{e,w}} \tag{8}$$

The laminar velocity profile is given by

$$u = 2u_m\left[1 - \left(\frac{r}{r_0}\right)^2\right]. \tag{9}$$

The effective thermal conductivity of the slurry can be written as [1]

$$k_e = f \cdot k_b, \tag{10}$$

where k_b and f are defined by

$$k_b = k_f \cdot \frac{2 + k_p/k_f + 2c(k_p/k_f - 1)}{2 + k_p/k_f - c(k_p/k_f - 1)}, \tag{10a}$$

$$f = 1 + BcPe_p^m = 1 + Bc8^m\left[Pe_f\left(\frac{r_p}{r_0}\right)^2\right]^m r_1^m,$$

$$\begin{aligned} &B = 3.0, \quad m = 1.5, \quad Pe_p < 0.67, \\ &B = 1.8, \quad m = 0.18, \quad 0.67 \leqslant Pe_p \leqslant 250, \\ &B = 3.0, \quad m = \frac{1}{11}, \quad Pe_p > 250. \end{aligned} \tag{10b}$$

The dynamic viscosity of the slurry may be calculated from [1]

$$\frac{\mu_b}{\mu_f} = \left(1 - c - 1.16c^2\right)^{-2.5}. \tag{11}$$

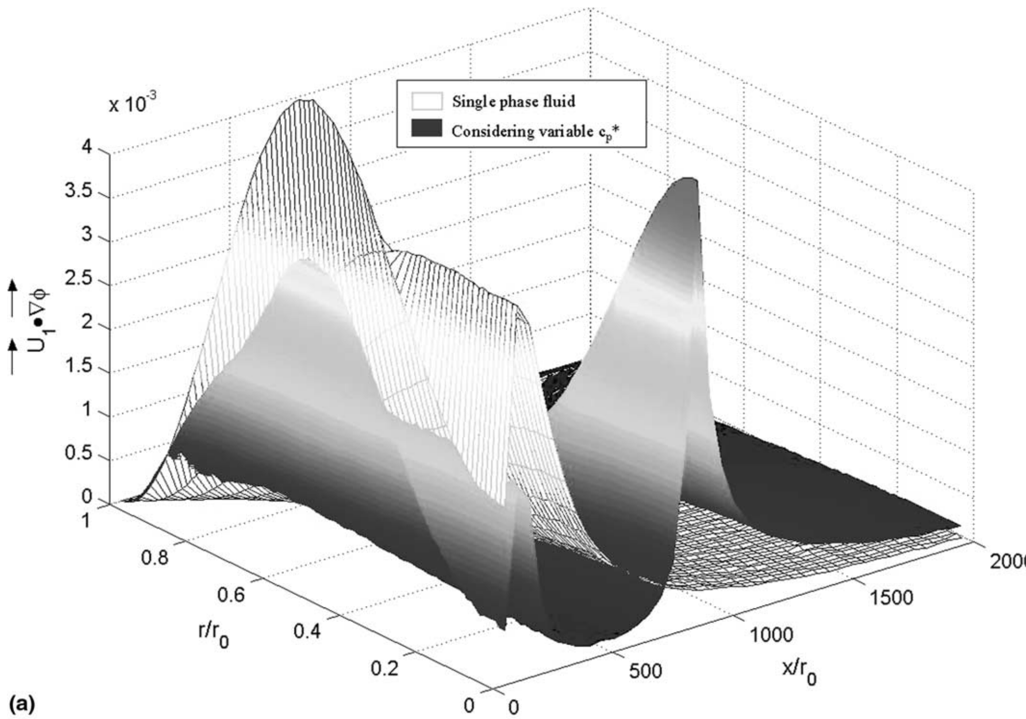
With the dimensionless specific heat $c_p{}^* = (c_{p,b})/(c_{p,b0})$ and defining the dimensionless temperature $\theta = (T - T_i)/(q''_w r_0/k_b)$, the dimensionless energy equation and boundary conditions are taken as

$$Re_b Pr_{b0} c_p{}^*\left(1 - r_1^2\right)\frac{\partial \theta}{\partial x_1} = f\frac{\partial^2\theta}{\partial r_1^2} + \left(\frac{f}{r_1} + \frac{\partial f}{\partial r_1}\right)\frac{\partial \theta}{\partial r_1}, \tag{12}$$

$$\theta_{0,j} = 0, \quad \left.\frac{\partial \theta}{\partial r_1}\right|_{r_1=0} = 0, \quad \left.\frac{\partial \theta}{\partial r_1}\right|_{r_1=1} = \frac{1}{f_w}, \tag{13}$$

where

$$Ste = \frac{c_{p,b0} \cdot q''_w r_0/k_b}{c_m \cdot h_{fs}}, \quad ML = \frac{T_1 - T_i}{q''_w r_0/k_b}, \quad Mr = \frac{T_2 - T_1}{q''_w r_0/k_b}.$$



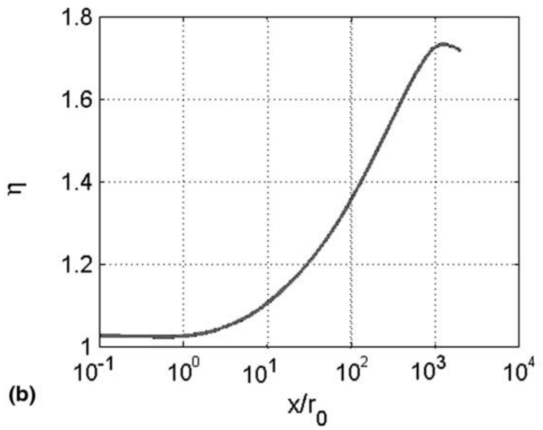


Fig. 5. Effect of $c_p{}^*$ on the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ and the heat transfer enhancement: (a) $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$; (b) heat transfer enhancement. ($Ste = 1.0$, $ML = 0.07$, $Mr = 0.4$, $c = 0.1$, $Re_b = 200$, sine curve case).

When

$$\theta < ML \quad \text{or} \quad \theta > (ML + Mr), \quad c_p{}^* = 1.$$

When

$$ML \leqslant \theta \leqslant (ML + Mr)$$

$$c_p{}^* = \begin{cases} 1 - c_m \cdot \frac{c_{p,s}}{c_{p,b0}} + \frac{1}{Ste \cdot Mr} & \text{(Rectangular case)} \\ 1 + 2\left(\frac{1}{Ste \cdot Mr} - \frac{c_m \cdot c_{p,s}}{c_{p,b0}}\right) \cdot \left(1 + \frac{ML - \theta}{Mr}\right) & \text{(Left triangle case)} \\ 1 + 2\left(\frac{1}{Ste \cdot Mr} - \frac{c_m \cdot c_{p,s}}{c_{p,b0}}\right) \cdot \frac{\theta - ML}{Mr} & \text{(Right triangle case)} \\ 1 + \frac{\pi}{2} \cdot \left(\frac{1}{Ste \cdot Mr} - c_m \cdot \frac{c_{p,s}}{c_{p,b0}}\right) \cdot \sin\left(\pi \cdot \frac{\theta - ML}{Mr}\right) & \text{(Sine curve case).} \end{cases}$$

Eq. (12) was solved by converting it into a finite difference form, using central differences in the radial direction and forward differences in the axial direction. A number of numerical tests were performed with different grid sizes to validate the numerical convergence of the algorithm. The final dimensionless grid size for x_1 and r_1 in the solution procedure are 0.025 and 0.0125, respectively.

The proposed model is checked numerically well with the analytical local Nusselt numbers for fully developed internal flow without phase change material suspensions, i.e. $Nu = 4.36$, for the constant wall temperature boundary condition. The relative errors between them are less than 0.4%.

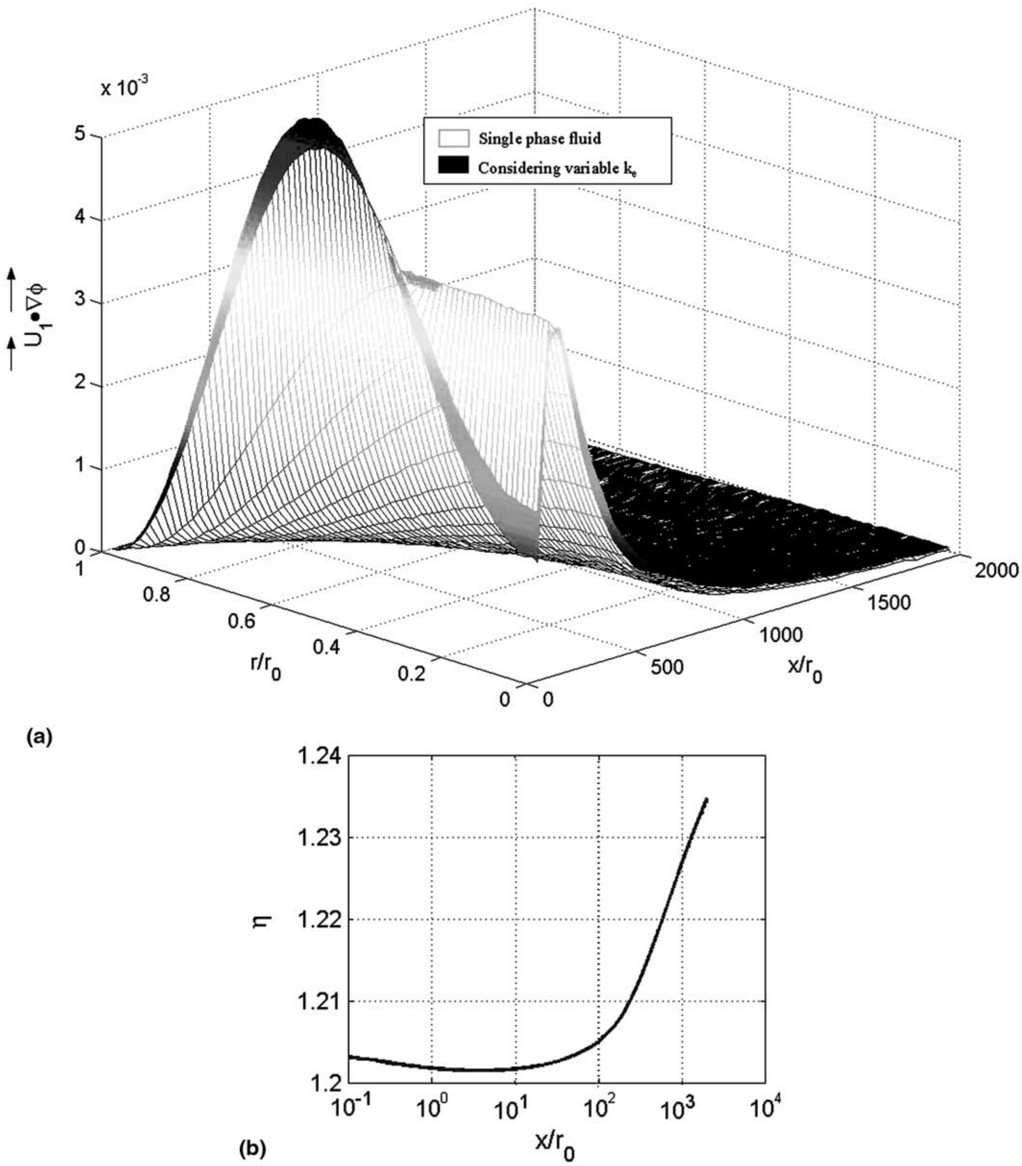


Fig. 6. Effect of k_e on the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ and the heat transfer enhancement. (a) $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$; (b) heat transfer enhancement. ($c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm, $Re_b = 200$).

For phase change slurries, the present numerical results are validated with the experimental results [4], the relative discrepancies are less than 6%.

4. Simulating results and discussion

4.1. Effect of variable c_p^* due to phase change on the heat transfer enhancement

Fig. 5 shows the effect of variable c_p^* due to phase change on the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ and on the degree of heat transfer enhancement, η. As shown in Fig. 5(a), the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ with phase change is less than that of single-phase fluid, and thus reduces the heat transfer rate. However, increased c_p^* due to phase change greatly enhances the heat transfer. The degree of heat transfer enhancement, η, in Fig. 5(b) reflects the combined influence of c_p^* and $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$.

4.2. Effect of k_e on heat transfer enhancement

Fig. 6 shows the effect of the effective slurry thermal conductivity, k_e, on the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ and the heat

Table 1
Physical properties of the microcapsules and the fluid [4]

	Density (kg m^{-3})	Specific heat (J kg^{-1} K^{-1})	Thermal conductivity (W m^{-1} K^{-1})	Kinematic viscosity (m^2 s^{-1})
Water	997	4180	0.606	9.07×10^{-7}
Microcapsule	946. 4	1973.1	0.150	–

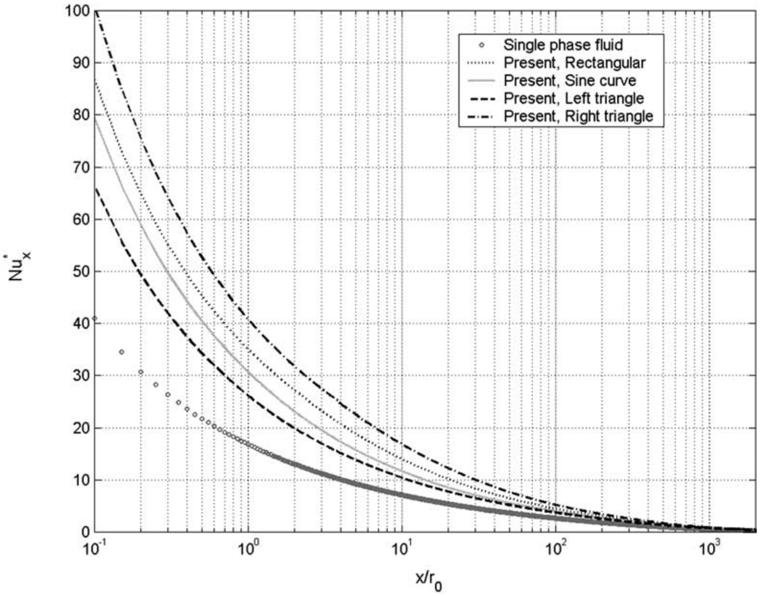


Fig. 7. Effect of specific heat functions on the heat transfer process ($Ste = 1.0$, $Mr = 0.4$, $ML = -0.33$, $c = 0.1$, $Re_b = 200$, $r_p = 50$ μm, $r_0 = 1.57$ mm).

transfer enhancement induced by adulterating the micro-particles without phase change. As shown in Fig. 6, $h_m{}^*$ is enhanced since the value of $\overrightarrow{U}_1 \cdot \overrightarrow{\nabla\phi}$ in the thermal boundary layer increased compared with that in a single phase fluid. Therefore, k_e influences the value of $Nu_x{}^*$ in Eq. (5) by changing the temperature distribution in the slurry.

4.3. Sensitivity analysis of each factor on the heat transfer enhancement

When the wall heat flux is constant, defining the dimensionless parameter $\theta = (T - T_i)/(q''_w r_0/k_b)$, ϕ can be written as $\phi = (\theta/\theta_w)$, simulations on convective heat transfer enhancement of microencapsulated phase change material slurries with constant heat flux are made from Eqs. (6), (10), (12), (13) and $c_p{}^*$ function in Section 3. The physical properties of the microcapsules and the fluid used in the numerical calculation are listed in Table 1.

As shown in Fig. 7, the differences between $Nu_x{}^*$ with different specific heat functions decreased with increasing x/r_0, and can be neglected for $x/r_0 \geqslant 500$. This implies that the exact nature of the phase change process is more important in modeling the heat transfer behavior of thermal entry region. It is necessary to know not only

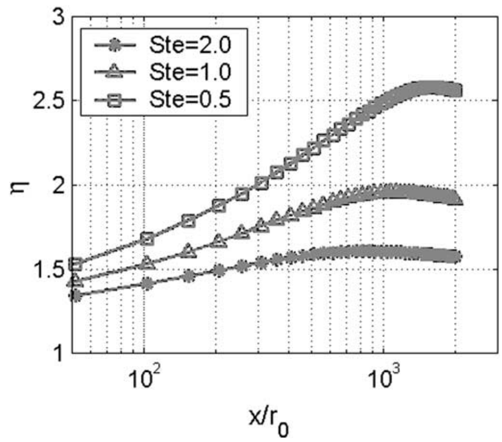


Fig. 8. Effect of Ste on the heat transfer enhancement ($ML = 0.07$, $Mr = 0.4$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm and $Re_b = 200$, sine curve case).

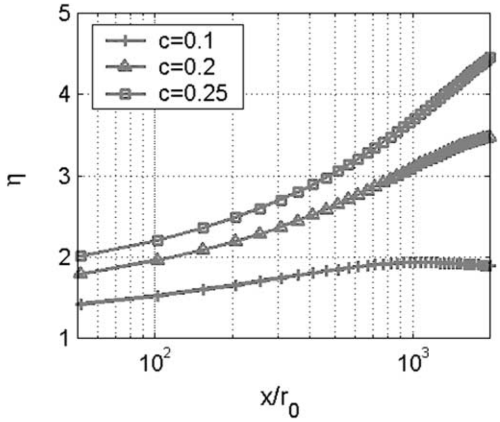


Fig. 9. Effect of c on the heat transfer enhancement ($q''_w = 2$ kW, $h_{fs} = 230$ kJ kg^{-1}, $ML = 0.07$, $Mr = 0.4$, $r_p = 50$ μm, $r_0 = 1.57$ mm, $Re_b = 200$, sine curve case).

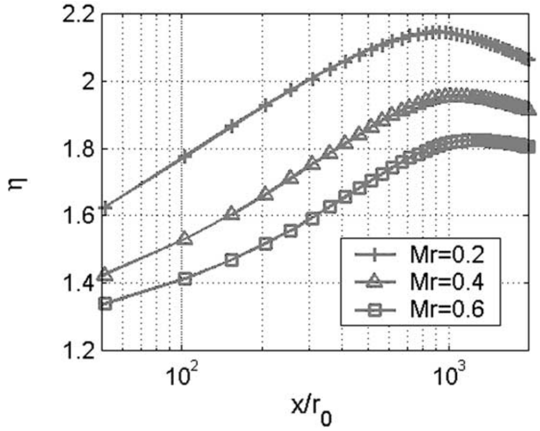


Fig. 11. Effect of Mr on the heat transfer enhancement ($Ste = 1.0$, $ML = 0.07$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm and $Re_b = 200$, sine curve case).

the latent heat of melting (fusion) and the phase change temperature range accurately, but also the exact specific heat curve shape so that the relevant nondimensional specific heat can be evaluated.

Figs. 8–13 show the influences of the dimensionless parameters Ste, ML, Mr, d_p, c (volumetric concentration of microcapsules) and Re_b on heat transfer enhancement with the microcapsule specific heat curve being sine curve during the phase change process.

As shown in Fig. 8, Ste is an important parameter that strongly affects the heat transfer enhancement in the phase change slurry. For $Ste = 0.5$, $h_m{}^*$ for the phase change slurry is 1.5–2.6 times that of a single-phase fluid. From Fig. 9, the volumetric concentration of the microcapsules, c, is another important parameter influencing the heat transfer enhancement in the phase change slurries, since c affects not only the value of $c_p{}^*$ but also the value of $k_e \cdot h_m{}^*$ for the phase change slurry with $c = 0.25$ will be 2.0–4.5 times that of the single-phase fluid for some x/r_0.

As shown in Figs. 10–12, the initial subcooling, ML, the phase change temperature range, Mr, and the particle diameter, d_p, all affect the heat transfer, but the effect is less than that of Ste. $h_m{}^*$ increases with decreasing ML. Mr affects not only the value of $c_p{}^*$ but also the phase change temperature range over which the phase change occurs in the microcapsules. In addition, $h_m{}^*$ increases with increasing d_p. Of course, as shown in

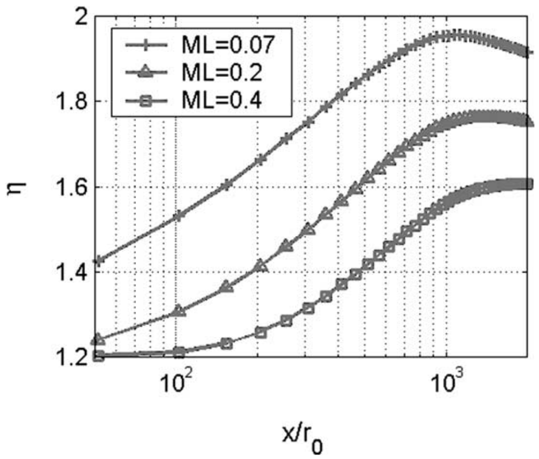


Fig. 10. Effect of ML on the heat transfer enhancement ($Ste = 1.0$, $Mr = 0.4$, $c = 0.1$, $r_p = 50$ μm, $r_0 = 1.57$ mm and $Re_b = 200$, sine curve case).

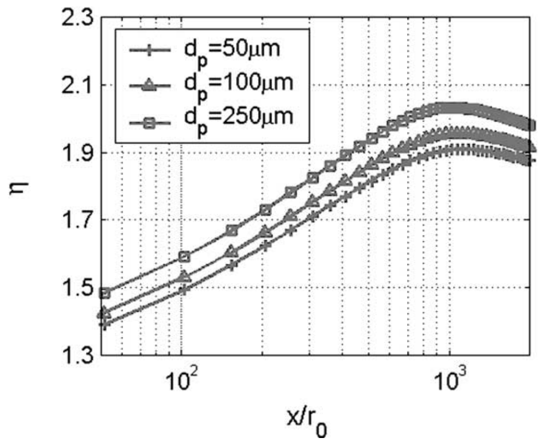


Fig. 12. Effect of d_p on the heat transfer enhancement ($Ste = 1.0$, $ML = 0.07$, $Mr = 0.4$, $c = 0.1$, $r_0 = 1.57$ mm and $Re_b = 200$, sine curve case).

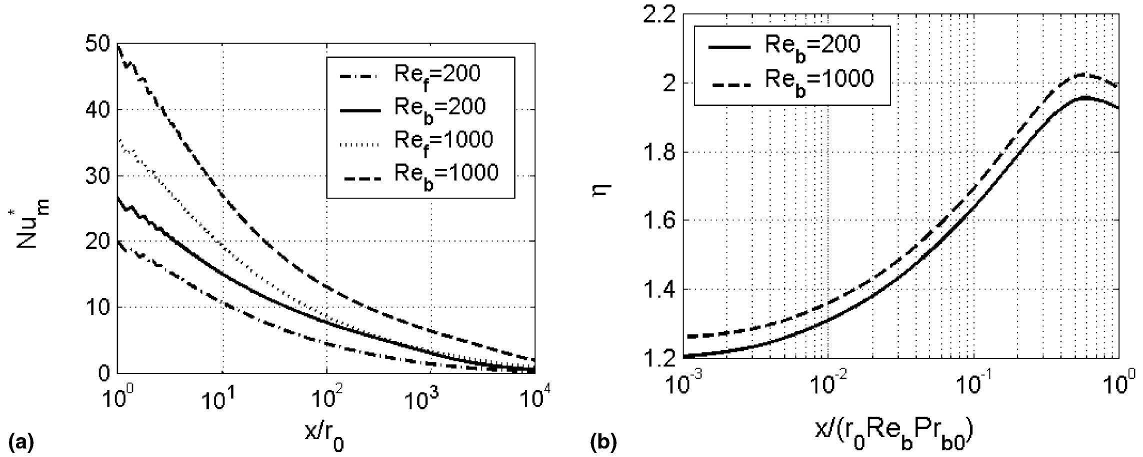


Fig. 13. Effect of Re on the heat transfer enhancement. (a) The mean improved Nusselt number; (b) The heat transfer enhancement degree ($Ste = 1.0$, $ML = 0.07$, $Mr = 0.4$, $c = 0.1$, $r_p = 50$ μm and $r_0 = 1.57$ mm, sine curve case).

Fig. 13, $Nu_m{}^*$ increases with increasing Re for the same heat transfer fluid, and the degree of heat transfer enhancement, η, increases with increasing Re_b at the same $x/(r_0 Re_b Pr_{b0})$.

Figs. 8–13 illustrate clearly that the degree of heat transfer enhancement in the thermally fully developed region is much larger than in the thermal entry region because in a single-phase fluid, the heat transfer is stronger in the entry region than in the thermally developed region.

5. Conclusions

A model is proposed for predicting the forced convective heat transfer characteristics of laminar flow with microencapsulated phase change material in a circular tube under constant wall heat flux, which checks well with experimental data reported in [4].

The predicting results by numerical simulation with the proposed model are shown, respectively, in Figs. 3–13, from which main conclusions can be drawn below:

(1) The exact nature of the phase change process strongly affects the degree of convective heat transfer enhancement.
(2) Ste and c are the most important parameters influencing the heat transfer enhancement of phase change slurries. However, ML, Mr and d_p also influence the degree of heat transfer enhancement. The enhancement increases with decreasing ML and/or Mr, and increase with increasing d_p. Therefore, the degree of enhancement in a small-diameter tube may be better than that in a large pipe for a given phase change slurry.
(3) The degree of heat transfer enhancement in the thermally fully developed region is much greater than that in the thermal entry region.
(4) Increasing Re_b can increase the heat transfer significantly for the given fluid too.

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