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Heat transfer simulation of heat storage unit with nanoparticles and fins through a heat exchanger

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A B S T R A C T

The current article investigates the impact of using fins and nano sized materials on performance of discharging system. Various shapes for nanoparticle have been considered. Cold fluid flows in both inner and outer layers and middle layer is full of PCM. To make a careful choice of designing heat storage based on uniform solidification, two factor has been examined; length of fins and shape factor. Temperature and solid fraction distributions were reported at various time steps. The homogeneous model for nanofluid has been extended by incorporating various shapes of CuO nanoparticles. The mathematical model has been offered in the form of PDE's, which were solved using Galerkin FEM. It can be observed that the employing nanofluid augments the discharging rate and best performance is obtained for platelet shape.

1. Introduction

Heat storage unit is a way that assets thermal energy in a storage medium. Among various types of ways, latent heat TES unit generally possess greater heat storage capacity. To advance the performance of such systems, nanoparticles can be PCM and enclosure can be equipped with fins. Abidi et al. [1] scrutinized discharging of PCM inside a triplex pipe. Their enclosure was included external and internal fins. Li and Zhai [2] designed a set up for phase change process by involving solar collector. They also verified their data with theoretical solutions. Sheikholeslami and Mahian [3] carried out a FEM simulation for transient heat conduction of NEPCM. They applied magnetic field to control the discharging rate. Andraka et al. [4] reported various applications of PCMs which is mixed with nanoparticles. Cheng and Zhai [5] scrutinized multiple PCMs application for cold storage. They tried to boost the efficiency. Sheikholeslami et al. [6] suggested the new shape of fins for heat storage to enhance the rate of solidification. They found that solid front is affected by dispersed nanoparticles. Saikia et al. [7] analyzed the cooling of house with PCM in view of thermodynamic. Zeng et al. [8] investigated charging of PCM inside a cylinder which is heated from bottom. They presented experimental results in existence of nanoparticles. Ahmed et al. [9] described the viscous dissipation impact on radiation over a plate using nanofluid. They assumed squeezing flow with using CNT nanoparticles. Sheikholeslami et al. [10] displayed the radiation effect on discharge of NEPCM in a heat storage enclosure. Usman et al. [11] illustrated the behaviors of various nanoparticles in a duct with converging walls. Recently, several publications have been related to heat transfer in thermal systems [12–30].

From literatures, we can see that researchers were tried to improve discharging and charging rate of PCM in common heat exchanger. Furthermore, few articles focus of NEPCM effect in appearance of extended surface. In this research, FEM is employed to model new shape of heat storage with Y shaped fin and NEPCM. Temperature and solid fraction distributions with various shapes

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Nomenclature

k	Thermal conductivity
C_p	Heat capacity
NEPCM	Nanoparticle-Enhanced PCM
m	Shape factor
L_f	Latent heat of solidification
PCM	Phase change material
S	Solid fraction
TES	Thermal energy storage

Greek symbols

ϕ	Concentration of nanofluid
α	Thermal diffusivity
ρ	Fluid density

Subscripts

nf	NEPCM
f	PCM
p	solid

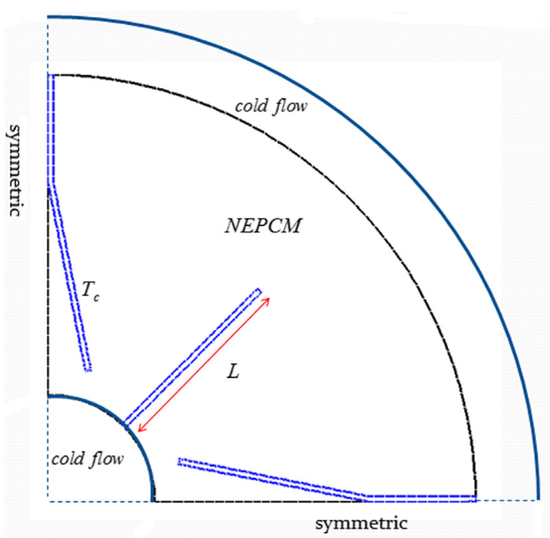

Fig. 1. Geometry with metallic fins.

of nanoparticle and length of fins were reported at various time steps.

2. Problem statement

The schematic vision of the designed heat storage in current article was demonstrated in Fig. 1. We considered the domain as

Table 1
Characteristics of CuO nanoparticle and H_2O.

Property	L_f[j/kg]	k[w/mK]	C_p[j/kg K]	ρ[kg/m^3]
PCM	335,000	0.6	4179	997
CuO	–	*18*	*540*	*6500*

Table 2
Various shapes of nanoparticles.

Shape	*Brick*	*Cylinder*	*Platelet*	*Spherical*
Shape factor (m)	3.7	4.8	5.7	3

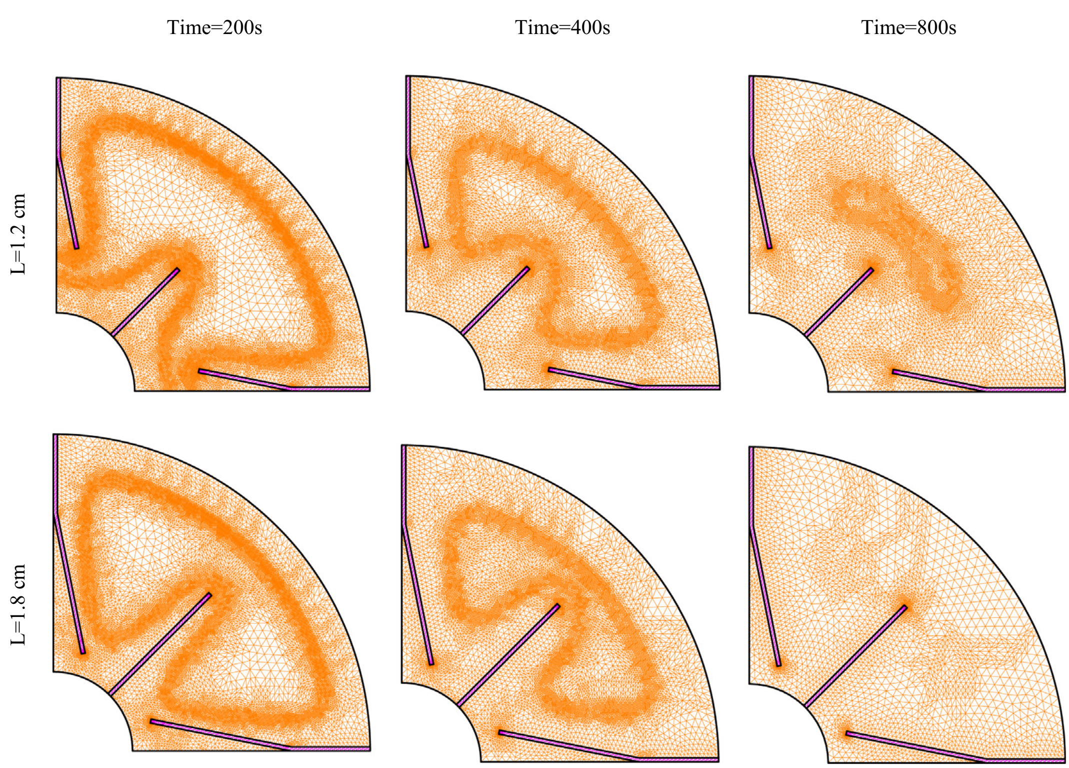

Fig. 2. Sample of grids at various time when $\phi = 0.04, m = 5.7$.

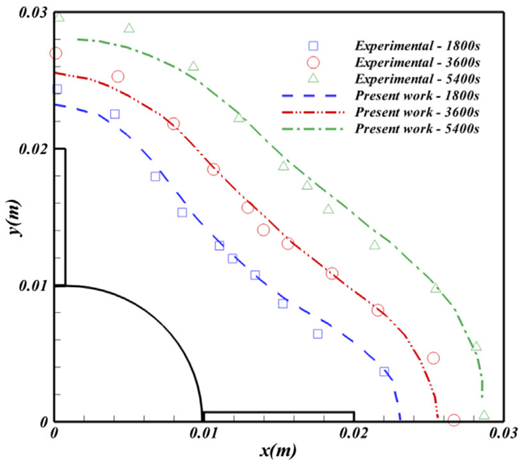

Fig. 3. Testing accuracy of code by comparing with Ref. [31].

2D system. Triplex tube has three layers. In middle layer, NEPCM is used which is mixture of water and CuO nanoparticles with various shapes. Summarized details of materials are illustrated in Tables 1 and 2. The other layer contains cold flow. Y shaped fins are related to outer wall and one radial fin is related to inner wall. Due to symmetric conditions, we just model quarter of whole unit. The length of fin is symbolized by L. Whole domain is considered 278 K at initial time.

3. Governing equations

To simulate solidification of NEPCM, finite element method based on Galerkin method has been adopted. At first all NEPCM has liquid phase and as time passes it start to covert to solid phase. Metallic fins help this process by conduction mechanism. For transient terms, implicit approach is used. In order to more accurate modeling, we used adaptive mesh for current paper. Fig. 2 demon-

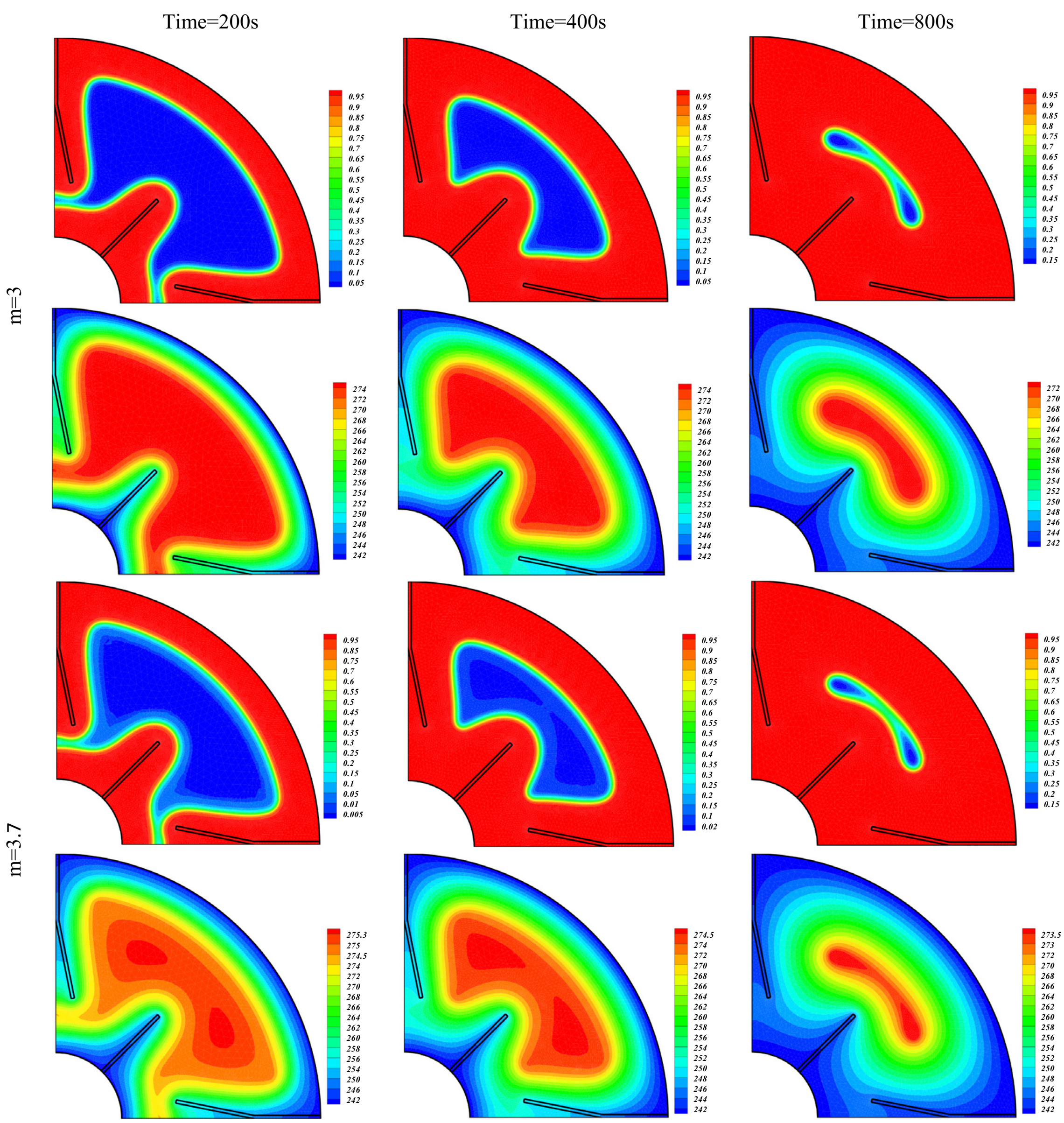

Fig. 4. Presentation of contours at various time at $\phi = 0.04, L = 1.2\,\text{cm}$.

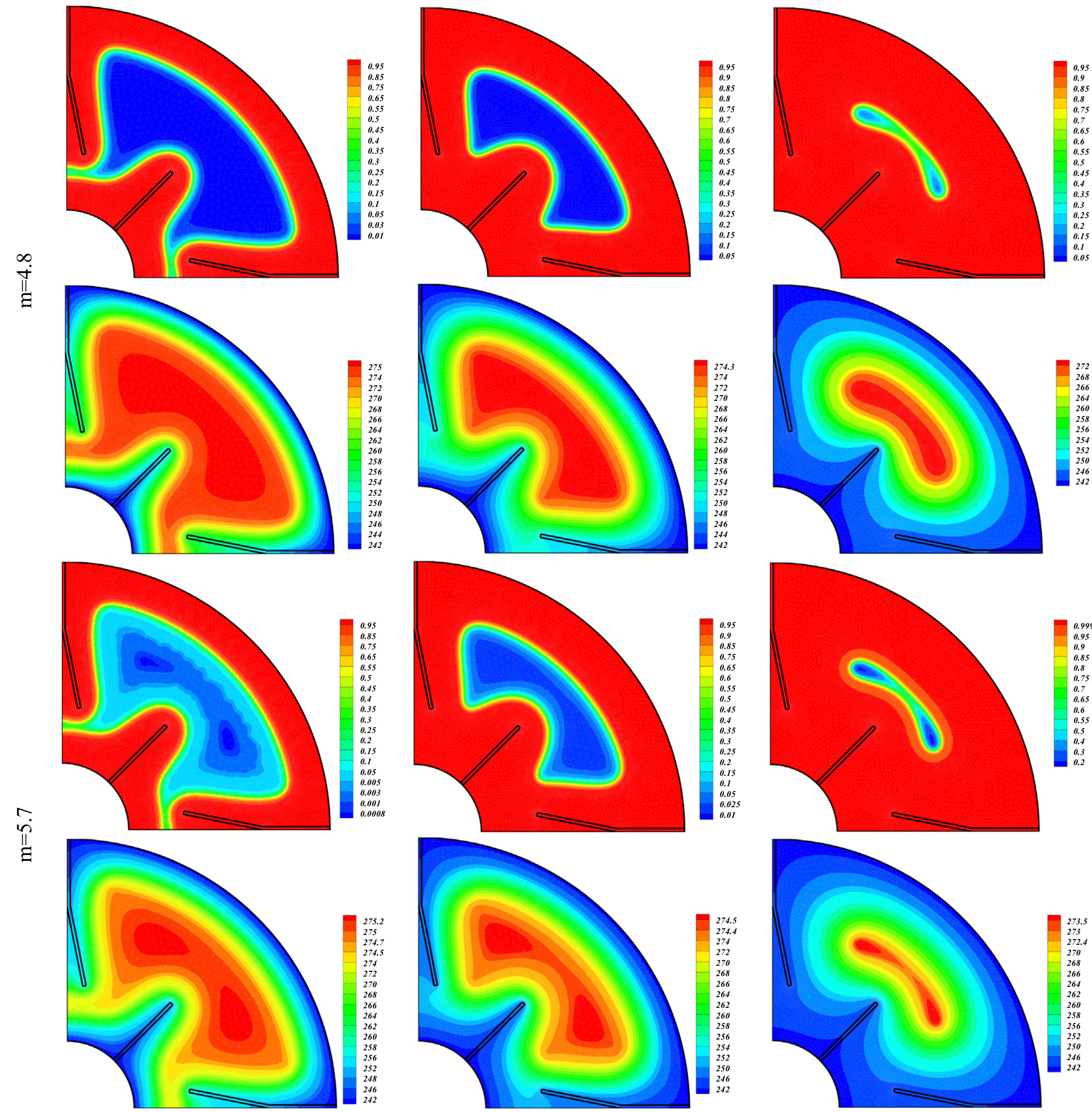

Fig. 4 (*continued*)

strates samples of mesh. Transient presentation of governing equations can be given as:

$$\begin{cases} S = 1 & (T - T_m) < (-T_0) \\ S = 0 & (T - T_m) > (-T_0) \\ S = (T_m + 0.5T_0 - T)/T_0 & (-T_0) < (T - T_m) < T_0 \end{cases} \tag{1}$$

$$(\rho C_p)_{nf} \frac{dT}{dt} = \nabla(k_{nf} \nabla T) + L_{nf} \frac{dS}{dt} \tag{2}$$

$(\rho L)_{nf}$, ρ_{nf}, k_{nf} and $(\rho C_p)_{nf}$ of mixture should be estimated according to below formula:

$$(L\rho)_f = (1-\phi)^{-1} (L\rho)_{nf} \tag{3}$$

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \tag{4}$$

$$\frac{k_{nf}}{k_f} = \frac{-(k_f - k_p)m\phi + (k_p - k_f)\phi + mk_f + k_p + k_f}{mk_f + (k_f - k_p)\phi + k_f + k_p} \tag{5}$$

$$(C_p)_{nf} = \phi\rho_{nf}^{-1}(\rho C_p)_p + (\rho C_p)_f \rho_{nf}^{-1}(1-\phi) \tag{6}$$

In order to better explanation in result section, we defined two important variables; stored energy and temperature of domain:

$$E_{total} = \int (T(\rho C_p)_{nf} + (\rho L)_{nf}(s))dV \tag{7}$$

$$T_{ave} = \frac{\int^T dA}{\int^d A} \tag{8}$$

In order to validate the correctness of the considered problem, our code has been verified with the existing paper (Ref. [31]). The nice agreement between present FEM solutions with the existing published outputs offers validity to the current outcomes (see Fig. 3).

4. Results and discussion

The numerical outputs have been obtained for current problem of solidification acceleration with inserting fins and using nanoparticles. Solidification is mainly influenced by conduction, so we considered the buoyancy effect negligible. Triplex pipe was taken into account to expedite the phase change process. The outer layer connected to Y shaped fins. CuO nanoparticles have been dispersed to pure PCM to boost the thermal behavior. PDEs were solved by applying FEM. The computations were provided for various concentration of nanofluid ($\phi = 0$ to 0.04), shape of particles ($m = 3$ to 5.7) and fin length ($L = 1.2$ to 1.8 cm).

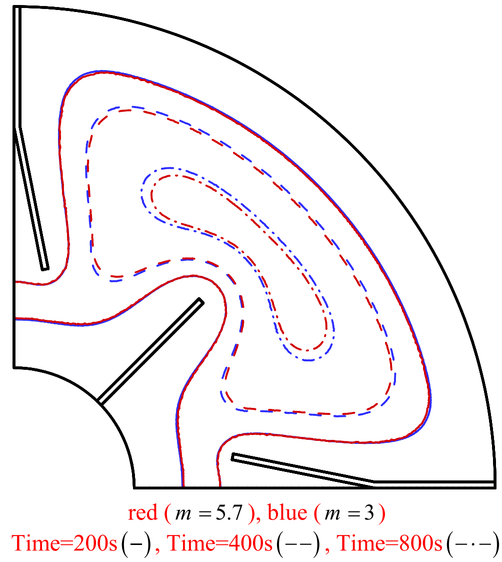

Fig. 6. Solid front changes with various shape factor at $\phi = 0.04$, $L = 1.8$ cm.

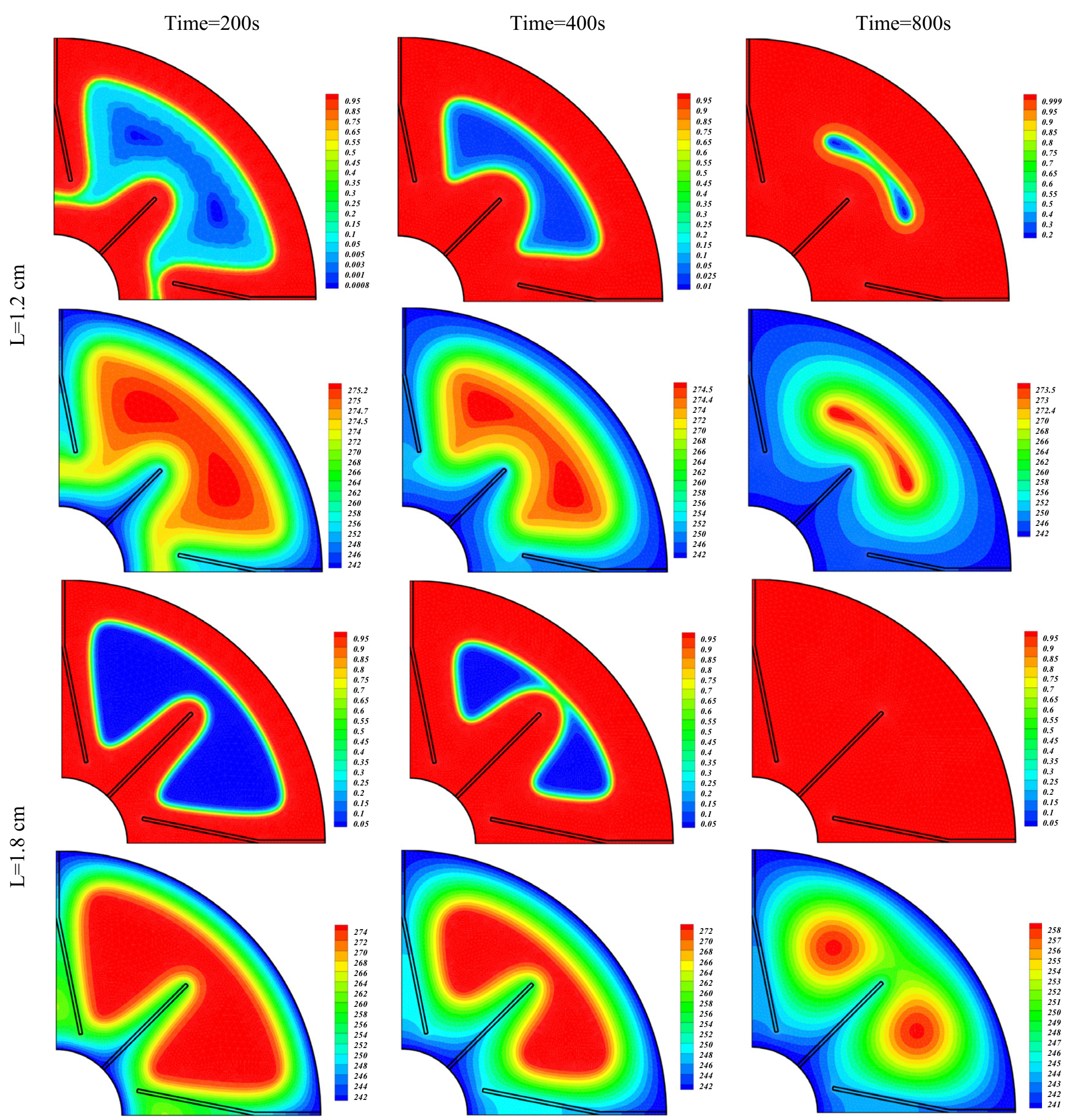

Fig. 5. Presentation of contours at various time at $\phi = 0.04, m = 5.7$.

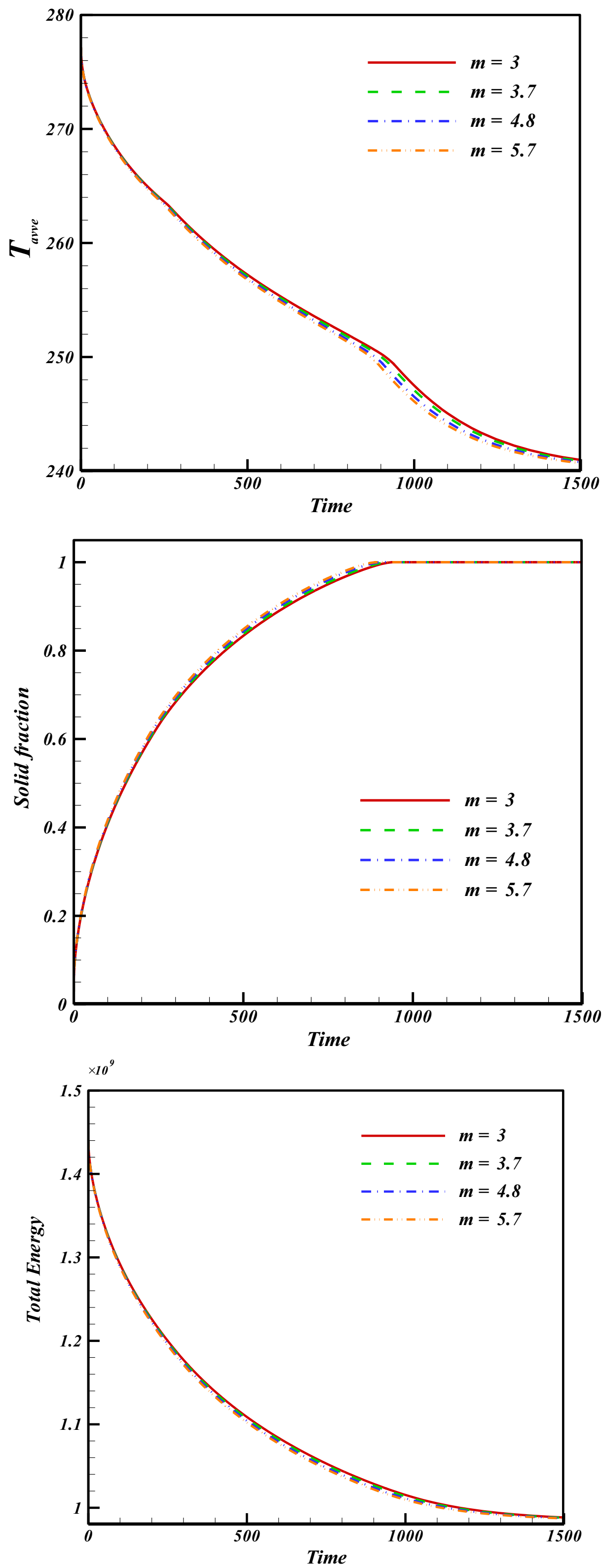

Fig. 7. Changes in important profiles by using various shape at $\phi = 0.04$, $L = 1.2$ cm.

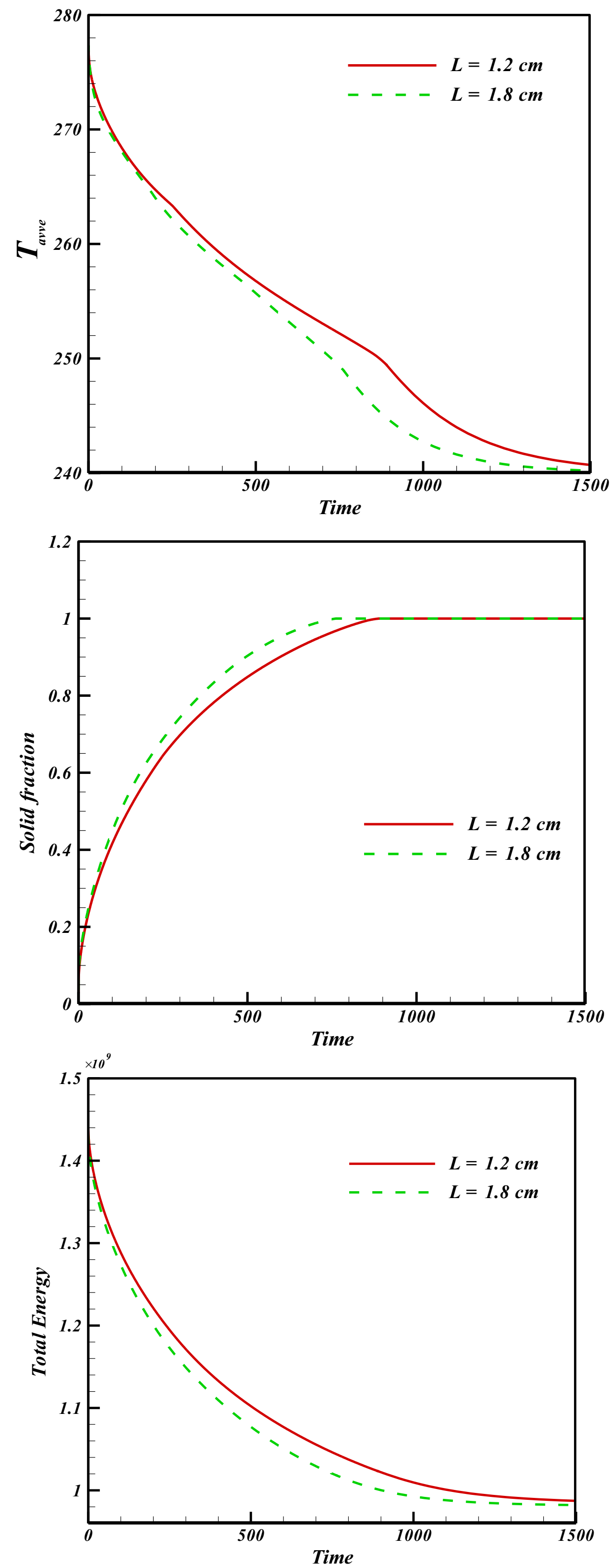

Fig. 8. Changes in important profiles by increasing L at $\phi = 0.04$, $m = 5.7$.

Effects of L and shape factor on T and S distribution were displayed in Figs. 4 and 5. Solid front changes with respect to shape factor, this fact are shown in Fig. 6. Increasing length of fins paves the way to develop solidification. Moreover, choosing nanoparticles with platelet shape provides greater performance and discharging finishes in lower time. The rate of solidification enhances as a result of expanding m, even though there is a reduction in temperature. Variation of T_{ave}, $E_{total}$and solid fraction

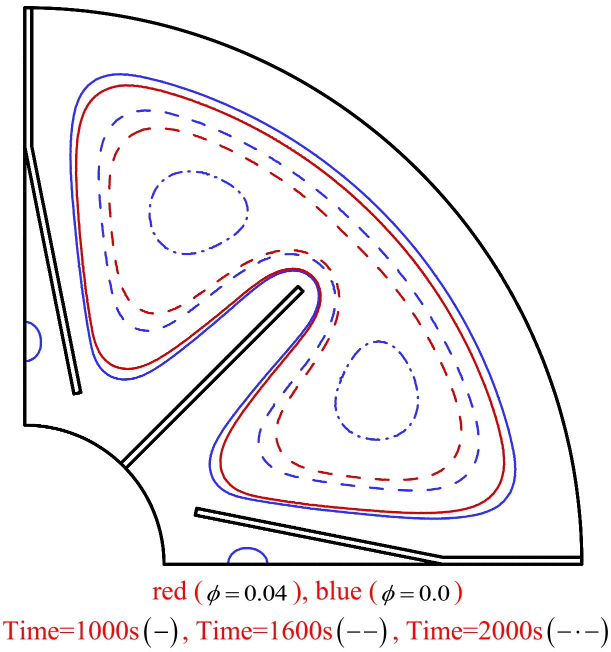

Fig. 9. Solid front changes with dispersing nanoparticle at $m = 5.7,\ L = 1.8$ cm.

with changing active parameters are described in Figs. 7 and 8. Temperature reduces as time passes while solid fraction enhances with progressing time. Rate of discharging is characterized by solid fraction profile and its augments with augmenting L. Contours were also influenced by variances in length of fins as noticed by greater thermal penetration. An increase in shape factor from 3 to 5.7, stronger conduction mode develops and causes better homogenous solidification. This acceleration impact is more sensible for platelet shape CuO nanoparticles. Dispersing nanoparticle has favorable impact on discharging process as shown in Figs. 9 and 10. Solidification is characterized by conduction, so dispersing nanoparticles which can enhance thermal properties makes solidification to be finished in lower time. Temperature declines as ϕ enhances. This impact is as same as energy storage but solid fraction has opposite impact. Discharging time can be calculated with respect to m and L by means of the following formula:

$$Time = 848.97 - 65.8L - 21.46m + 2.94(m)(L) + 0.97m^2 \quad (9)$$

According to Eq. (9), Fig. 11 has been drawn. It is found that time for platelet shape is lower than other shapes, thus selecting such particles boosts the conduction of domain. Furthermore, longer fins can connect more distance with cold temperature. Therefore, lower time can be obtained with rise of L.

5. Conclusion

The main intention of current paper is to simulate solicitation of NEPCM in appearance of metallic fins and nanoparticles. To achieve the governing equations, we assumed single phase model for nanofluid and we neglected buoyancy forces effect on discharging process. Outputs are shown the influences of pertinent parameters. Not only geometric parameters but also shapes of nanoparticles affect this transient process. Introducing nanoparticles results into improve the discharging rate. Make choice of platelet shape lends more homogenous solidification.

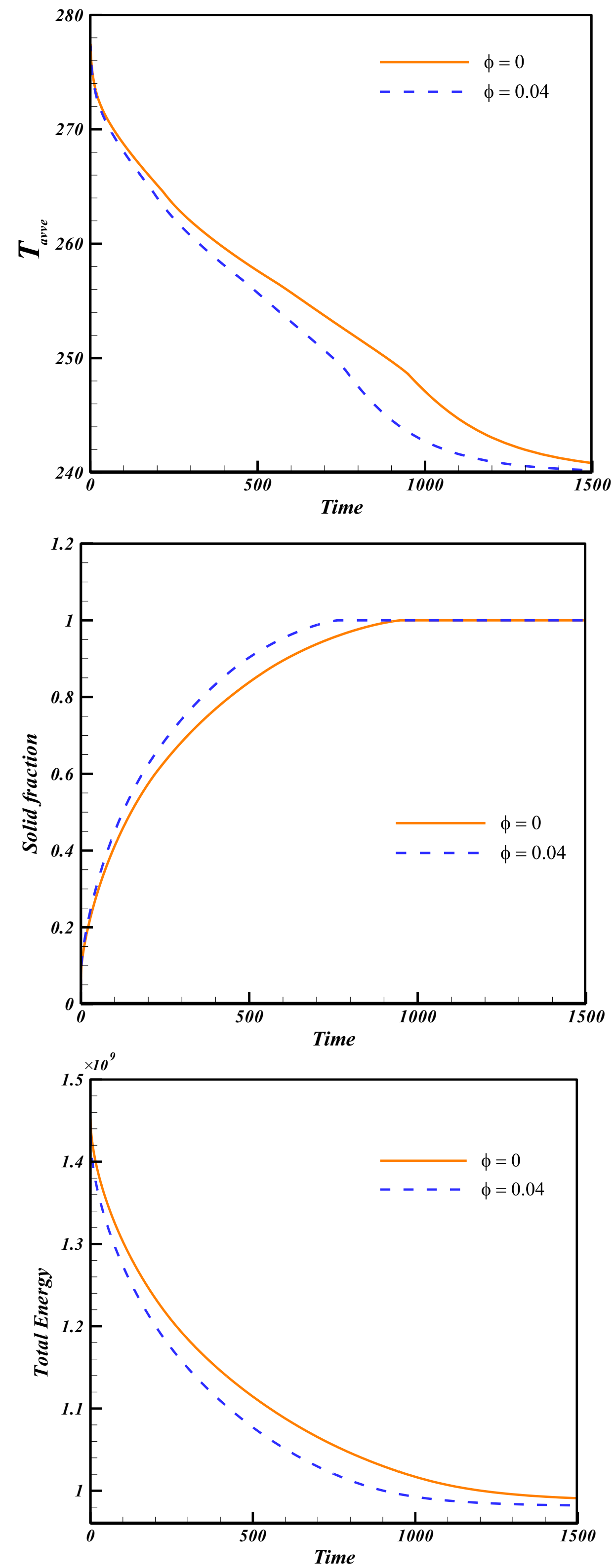

Fig. 10. Changes in important profiles by adding nanoparticles at $m = 5.7,\ L = 1.8$ cm.

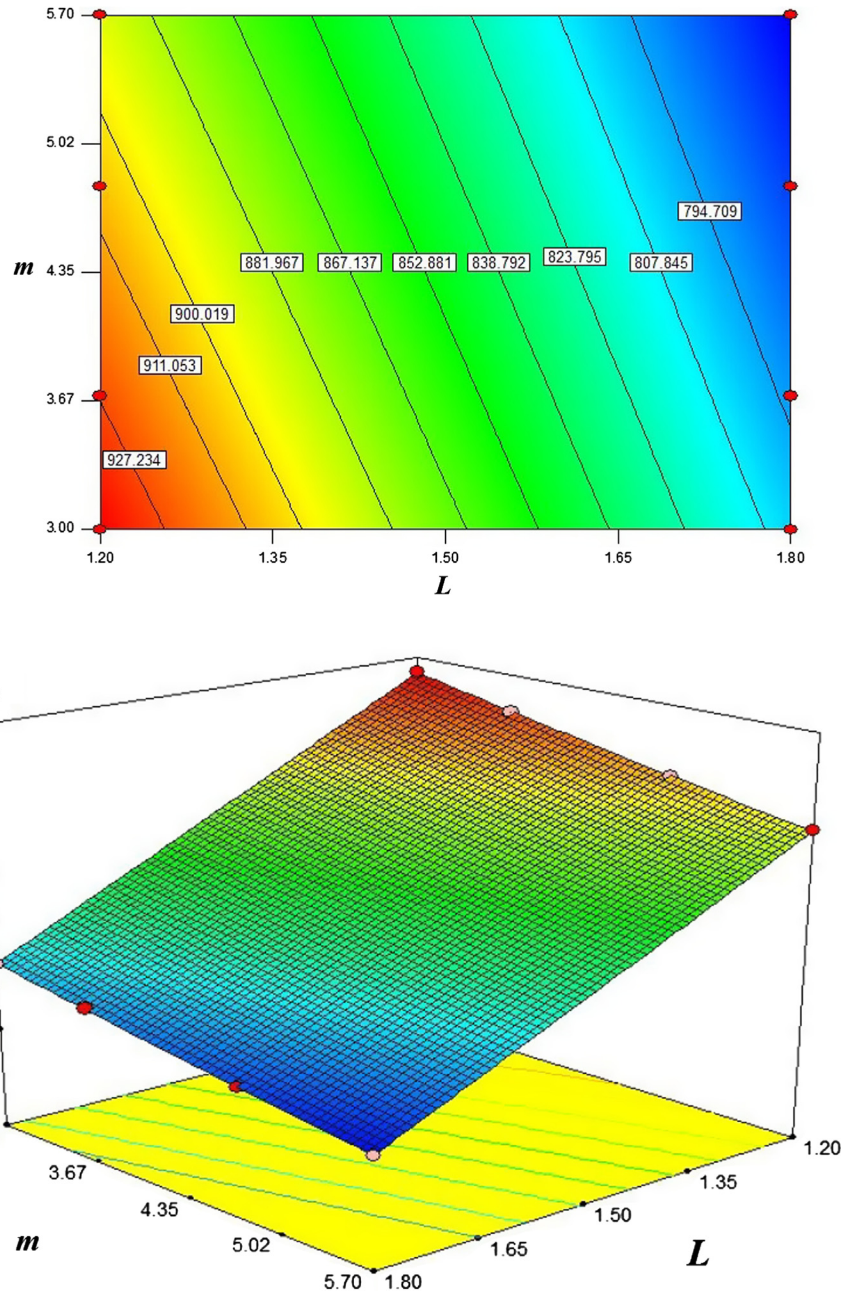

Fig. 11. Impact of m, L on *Time* at $\phi = 0.04$.

Conflict of interest

None declared.

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