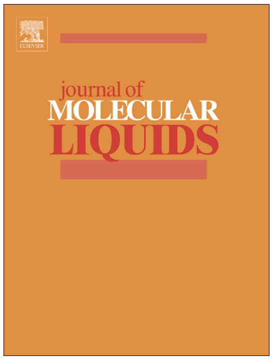

Influence of adding nanoparticles on solidification in a heat storage system considering radiation effect

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Influence of adding nanoparticles on solidification in a heat storage system considering radiation effect

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Abstract

In this attempt, nanoparticle enhanced PCM is employed to enhance solidification rate. To augment low thermal conductivity of H_2O, CuO nanoparticles were dispersed in it. Also Brownian motion impact was involved in properties of NEPCM. Graphs are obtained via FEM and displayed the impacts of radiation, length of fin and nanoparticles' size. Outputs display that selecting $d_p = 40nm$ leads to the fastest discharging. Discharging time reduces with increase of thermal radiation.

Keywords: Nanoparticle; FEM; Mesh refinement; Thermal radiation; Thermal Energy Storage; Solidification.

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Nomenclature

NEPCM	Nano-Enhanced PCM	***Greek symbols***	
C_p	Heat Capacity	α	Thermal diffusivity $[m^2/s]$
FEM	Finite element method	ρ	Fluid density
L_f	Latent Heat of Fusion	ϕ	Concentration of NEPCM
k	Thermal conductivity	***Subscripts***	
PCM	Phase change Material	f	water
Rd	Radiation parameter	nf	NEPCM
		p	CuO

1. Introduction

Heat storage system has two mechanisms: melting and solidification. Researchers investigated about various ways of accelerating discharge process. Using nanoparticles can help this process. Hayat et al. [1] investigated optimal analysis of three dimensional nanoparticle flows in existence of heated surface. Hashim et al. [2] demonstrated transient MHD flow of nanoparticles. They considered non-uniform thermal conductivity. Sheikholeslami et al. [3] illustrated the expedition of solidification with magnetic force and nanoparticles. Kefayati and Tang [4] reported the LBM simulation for viscoplastic fluid forced convection. Sheikholeslami [5] displayed discharging of NEPCM with new numerical method with adaptive grid. Rashid et al. [6] demonstrated the transportation of copper nanoparticles over a sheet with non-uniform temperature. Sheikholeslami et al. [7] described the radiation impact on discharging rate considering CuO nanoparticles. They proved that radiation make discharge rate to enhance. Cheng and Zhai [8] investigated impact of multiple PCMs on efficiency of cold storage system. Ramzan et al. [9] illustrated Cattaneo heat flux impact on 3 dimensional MHD flow. Nadeem et al. [10] demonstrated nonlinear heating influences on fluid movement in existence of heat flux. Sheikholeslami [11] simulated magnetic forces impact on NEPCM treatment through a thermal energy storage enclosure. Hashim et al. [12] demonstrated homogeneous reaction impact on non-Newtonian fluid flow. They presented dual solutions for their problem. Sheikholeslami [13] analyzed performance of LHTESS in presence of NEPCM. They proved that nanoparticles can help solidification. Qi et al. [14] studied a heat exchanger performance in presence of nanofluid. They presented stability of nanofluid in this work. Improving heat transfer was the final goal of several articles [15-50].

In present attempt, NEPCMs act as working fluid during transient discharge. Powerful numerical method has been used to display the impacts of concentration of nanofluid, d_p, length of the fin.

2. Problem formulation

Fig. 1 illustrates heat storage configuration and boundary conditions. Working fluid is NEPCM. Table 1 illustrates the properties of NEPCM. Storage is full of CuO-water. Characteristics are included in table 1.

3. Governing Equations

Discharging of NEPCM can present with:

$$\left(\rho C_p\right)_{nf}\frac{dT}{dt}=\nabla\left(k_{nf}\nabla T\right)+L_{nf}\frac{dS}{dt}-\frac{\partial q_r}{\partial y},\qquad (1)$$

$$\left[q_r=-\frac{4\sigma_e}{3\beta_R}\frac{\partial T^4}{\partial y},\ T^4\cong 4T_0^3T-3T_0^4, Rd=4\sigma_e T_0^3/\left(\beta_R k_f\right)\right]$$

$$\begin{cases} S=(-T+T_0/2+T_m)\left(T_0\right)^{-1} & -T_0<T-T_m<T_0 \\ S=1 & T<T_m-T_0 \\ S=0 & T>T_m+T_0 \end{cases}\qquad (2)$$

$\left(\rho L\right)_{nf}$, ρ_{nf} ,$\left(\rho C_p\right)_{nf}$ and $\left(k\right)_{nf}$ of NEPCM are:

$$\left(\rho L\right)_{nf}=\left(\rho L\right)_f(1-\phi)\qquad (3)$$

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

$$\left(\rho C_p\right)_{nf}=\left(\rho C_p\right)_f(1-\phi)+\left(\rho C_p\right)_p\phi\qquad (5)$$

$$g'\left(d_p,T,\phi\right)=Ln\left(T\right)\left(a_2Ln\left(d_p\right)+a_5Ln\left(d_p\right)^2+a_1+a_3Ln\left(\phi\right)+a_4Ln\left(d_p\right)Ln\left(\phi\right)\right)$$
$$+\left(a_{10}Ln\left(d_p\right)^2+a_7Ln\left(d_p\right)+a_6+Ln\left(d_p\right)a_9Ln\left(\phi\right)+a_8Ln\left(\phi\right)\right)$$
$$,-d_p/k_{p,eff}+4\times10^{-8}=-d_p/k_p,$$
$$\frac{k_{nf}}{k_f}=1-3\frac{\left(-k_p/k_f+1\right)\phi}{\left(k_p/k_f+2\right)+\left(1-k_p/k_f\right)\phi}+10^4\times g'(d_p,T,\phi)\rho_f\phi(5)\sqrt{\frac{\kappa_b T}{\rho_p d_p}}c_{p,f}$$

Table 2 depicts the required variables.

T_{ave} and E_{total} are:

$$T_{ave}=\frac{\int TdA}{\int dA}\qquad (7)$$

$$E_{total}=\int(\left(\rho C_p\right)_{nf}T+s\left(\rho L\right)_{nf})dV\qquad (8)$$

4. Simulation and validation

In current method, mesh refinement was considered. Newton-Raphson and implicit methods were employed for solve final equations and unsteady terms, respectively. Current code has been verified with previous experimental article ([51]) (as depicted in Fig. 2). Fig. 3 demonstrates the adaptive mesh.

5. Results and discussion

In current attempt, NEPCM conduction heat transfer in solidification process is investigated via FEM. In order to accelerate this process CuO nanoparticles with various size has been employed. Influences of length of the fin $\left(L = 0.5 to\ 1.5\right)$, nanofluid volume fraction $\left(\phi = 0\ to\ 0.04\right)$, diameter of nanoparticles $\left(d_p = 30, 40, 50 nm\ \right)$ and radiation parameter $\left(Rd\ = 0 to 1\ \right)$ on solidification process are depicted.

Figs. 4 and 5 display the effect of dispersing nanoparticles into base fluid. Current figure displayed that adding CuO to water has vital effect on solidification. As illustrated in current figure, discharging becomes faster with using NEPCM. Moreover, roles of ϕ becomes more essential in greater time.

Fig. 6 demonstrates the impact of fin length on S and T contours. Cold penetration deepness is augmented by using longer fins; discharging rate is greater for longer fins. At start of process, T_{ave} is maximum and S_{ave} is minimum. Figs. 7 and 8 demonstrate the role of Rd on phase change process. Graphs revel that the most uniform phase changes process for higher Rd . As Rd enhances, discharging process has been finished in shorter time.

Figs. 9 and 10 depict the impact of d_p on solidification. Fig. 11 depicts the roles of *Rd* and d_p on T_{ave}, S_{ave}, total energy. As Rd rises, discharging process takes shorter time. This figure displays that discharging rate has difference treatment when d_p enhances. The best rate is obtain for $d_p = 40nm$. Radiation can help solidification. Energy storage reduces with rise of Rd.

Eq. (9) belongs the solidification time. Influences of Rd, d_p and L on *Time* were illustrated in Fig. 12.

$$\begin{gathered}Time = 8.86 - 6.82L - 0.52Rd + 0.39d_p \\ +0.17(Rd)(L) + 0.054(L)(d_p) - 0.021(Rd)(d_p) \\ +1.4(L)^2 + 1.84(d_p)^2\end{gathered} \tag{9}$$

As radiation paramter increases, solidification process accelerated. Increasing fin length leads to accelaerate solidification rate. Morever full discharging time decreases with rise of Rd and L . Highest value of S_{ave} occurs when $d_p = 40nm$.

6. Conclusion

In current paper, powerful method with grid refinement has been used to simulate discharging process of NEPCM. Fins and nanoparticles are selected as passive ways to help solidification. Impacts of fin length, nanoparticles' size and radiation parameter on discharging rate are demonstrated. Graphs illustrate that utilizing $d_p = 40nm$ leads to highest efficiency. Discharging rate augments with rise of *Rd*. Acceleration in solidification can be seen with rise of fin length.

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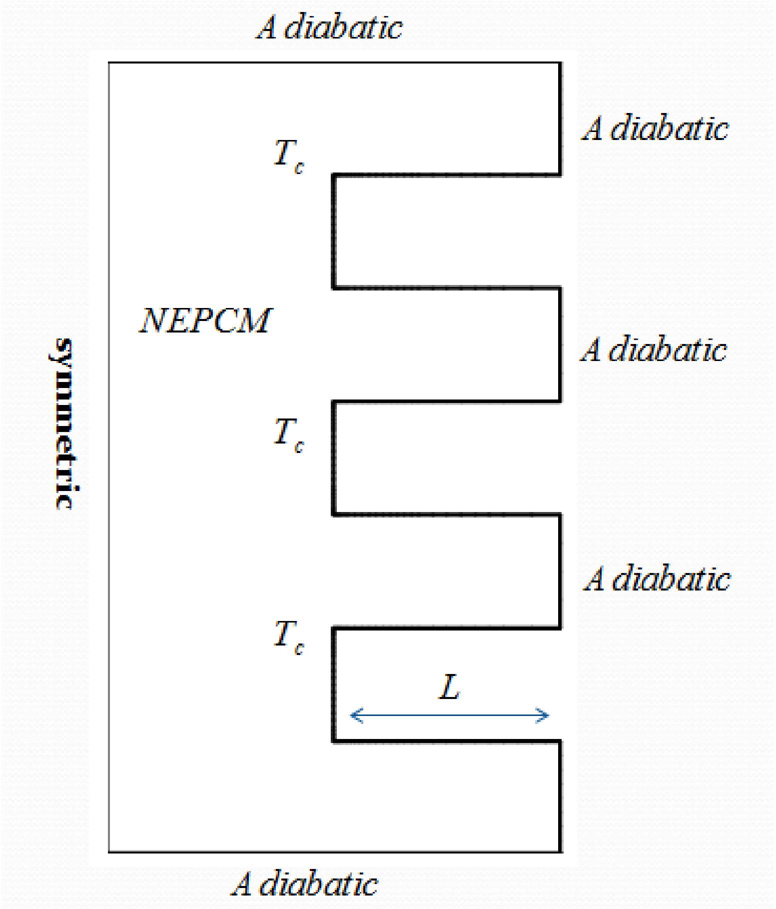


Fig. 1. Geometry of heat storage

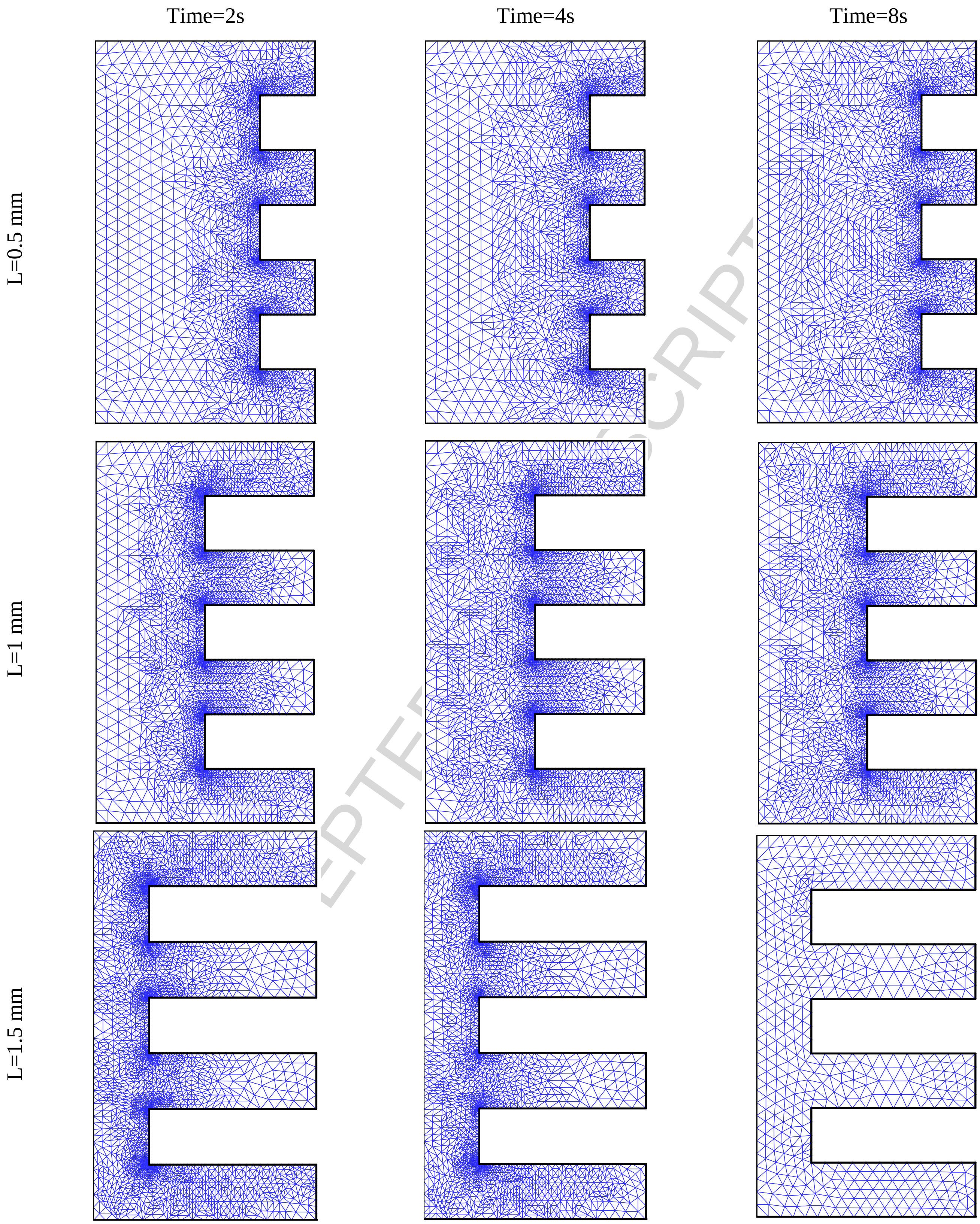


Fig. 2. Sample of grid at $\phi = 0.04, Rd = 0, d_p = 40nm$

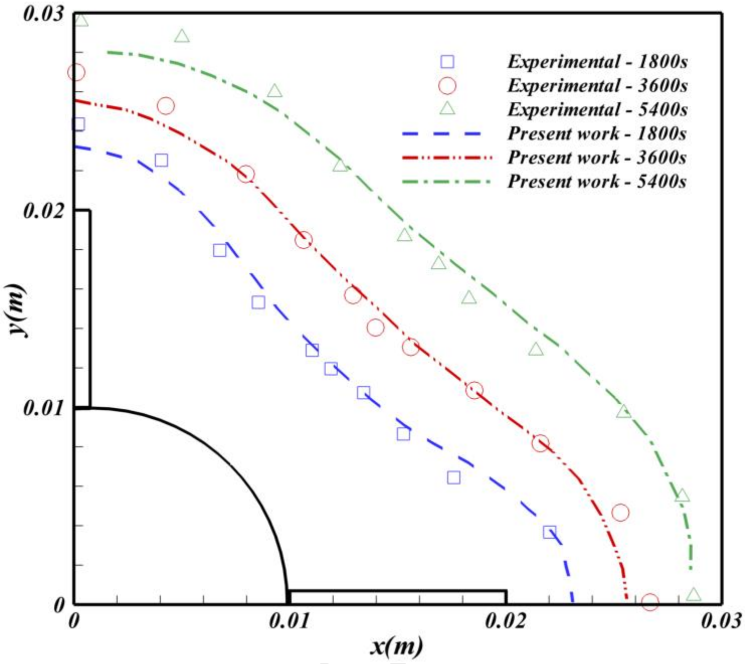
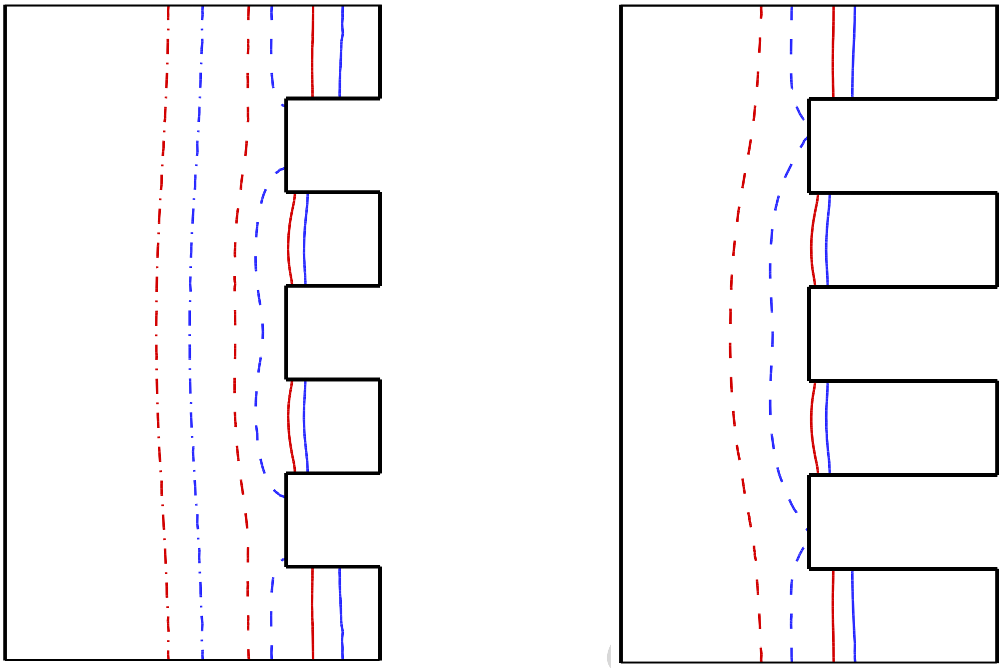


Fig. 3. Verification of FEM code [51].



L=0.5mm

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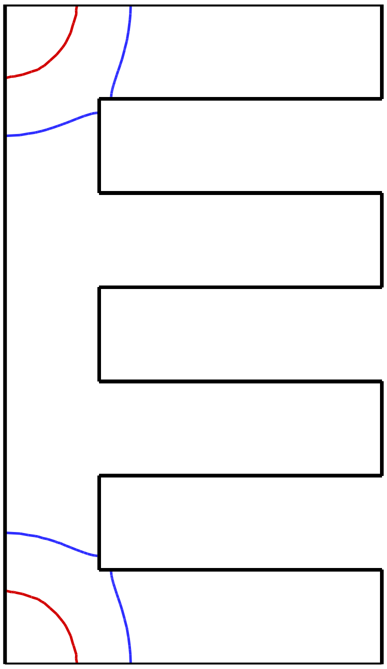


L=1.5mm

Fig. 4. Impact of nanofluid concentration on phase change process (blue ($\phi = 0$), red ($\phi = 0.04$))at various times (Time=2s$(-)$, Time=4s$(--)$, Time=8s$(-\cdot-)$)when $Rd = 0, d_p = 30nm$

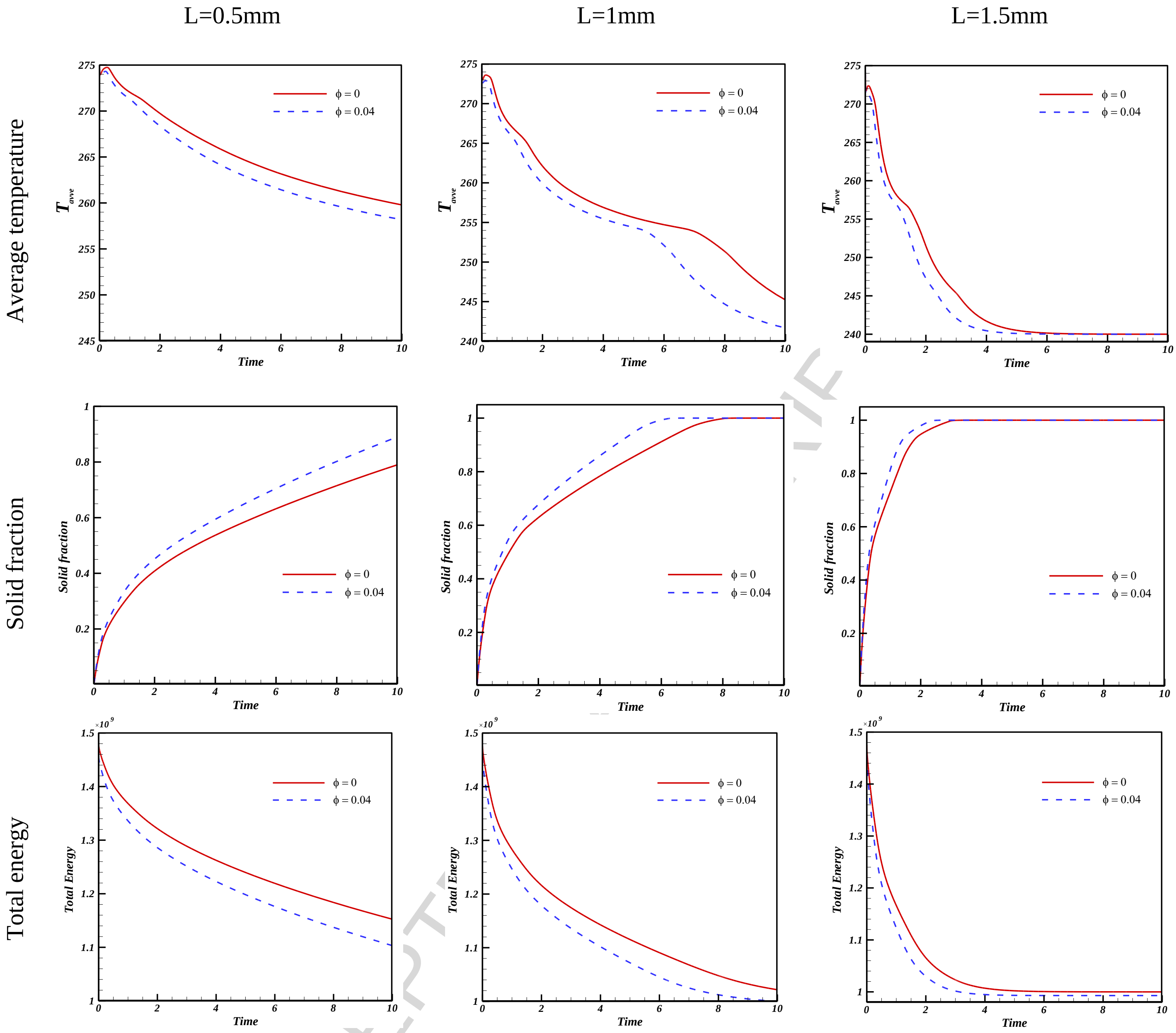
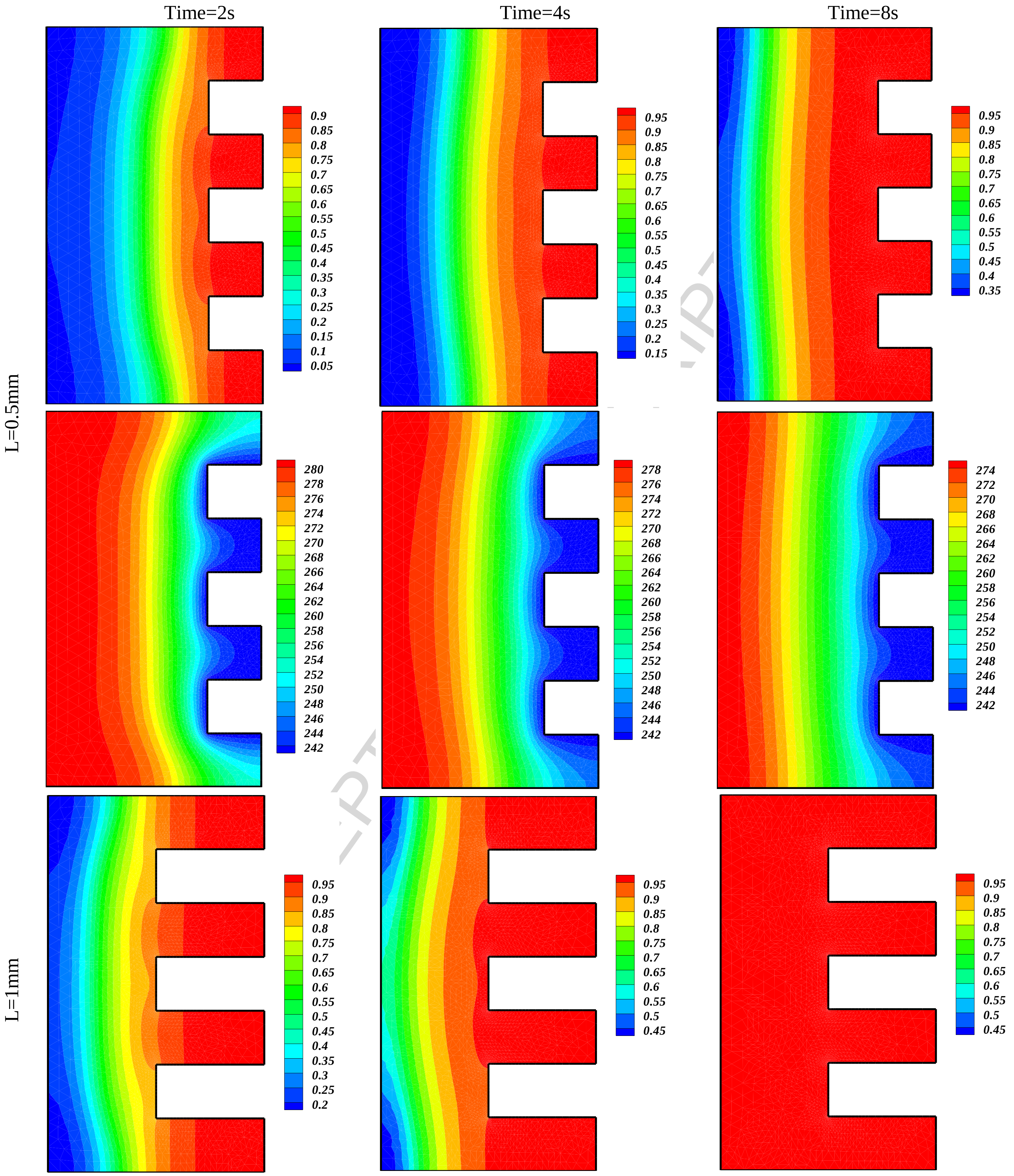


Fig. 5. Impacts of ϕ on T_{ave} , Solid fraction, total energy at $Rd = 0, d_p = 40nm$


Time=2s
Time=4s
Time=8s
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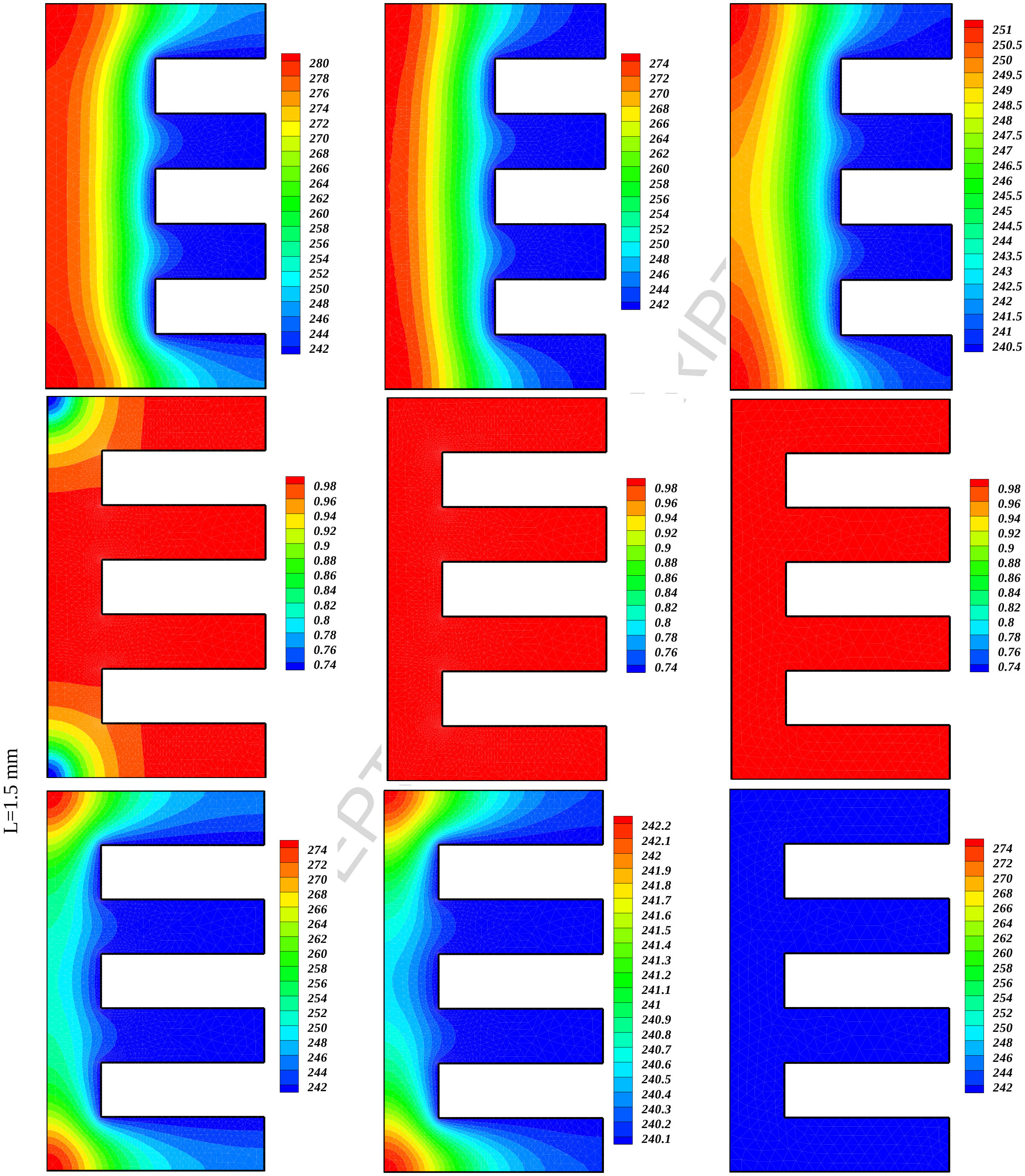


Fig. 6. Temperature (bottom) and solid fraction (up) contours during solidification at $\phi = 0.04, Rd = 0, d_p = 40nm$

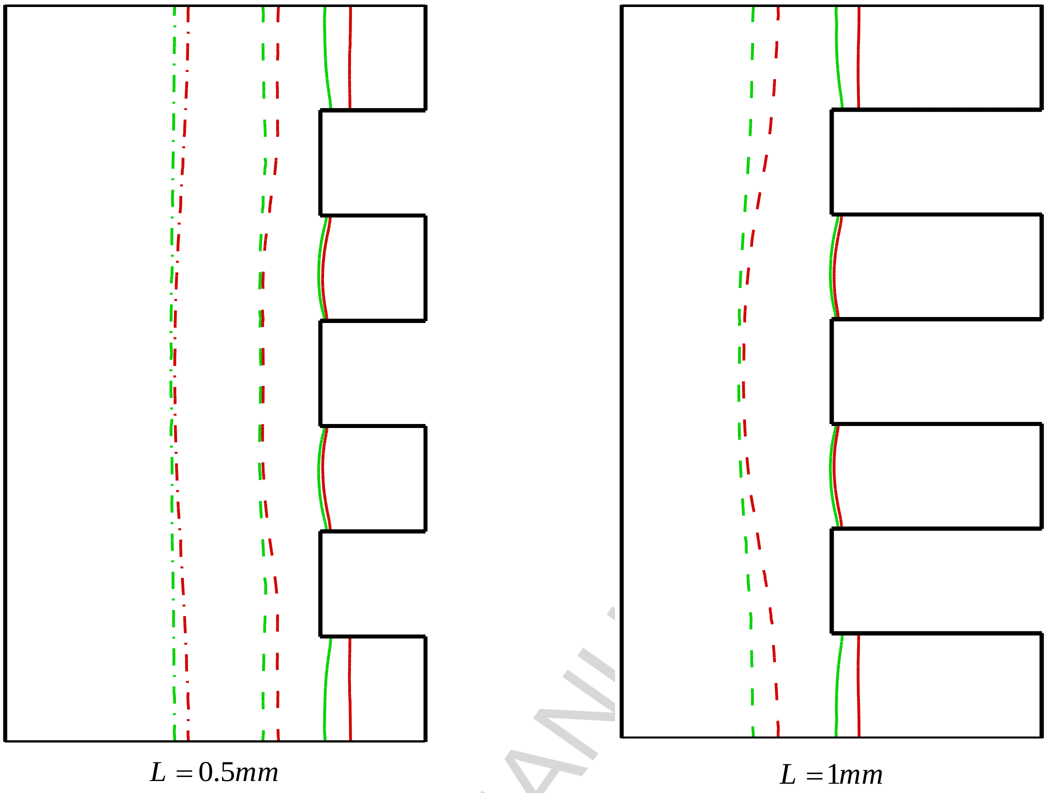
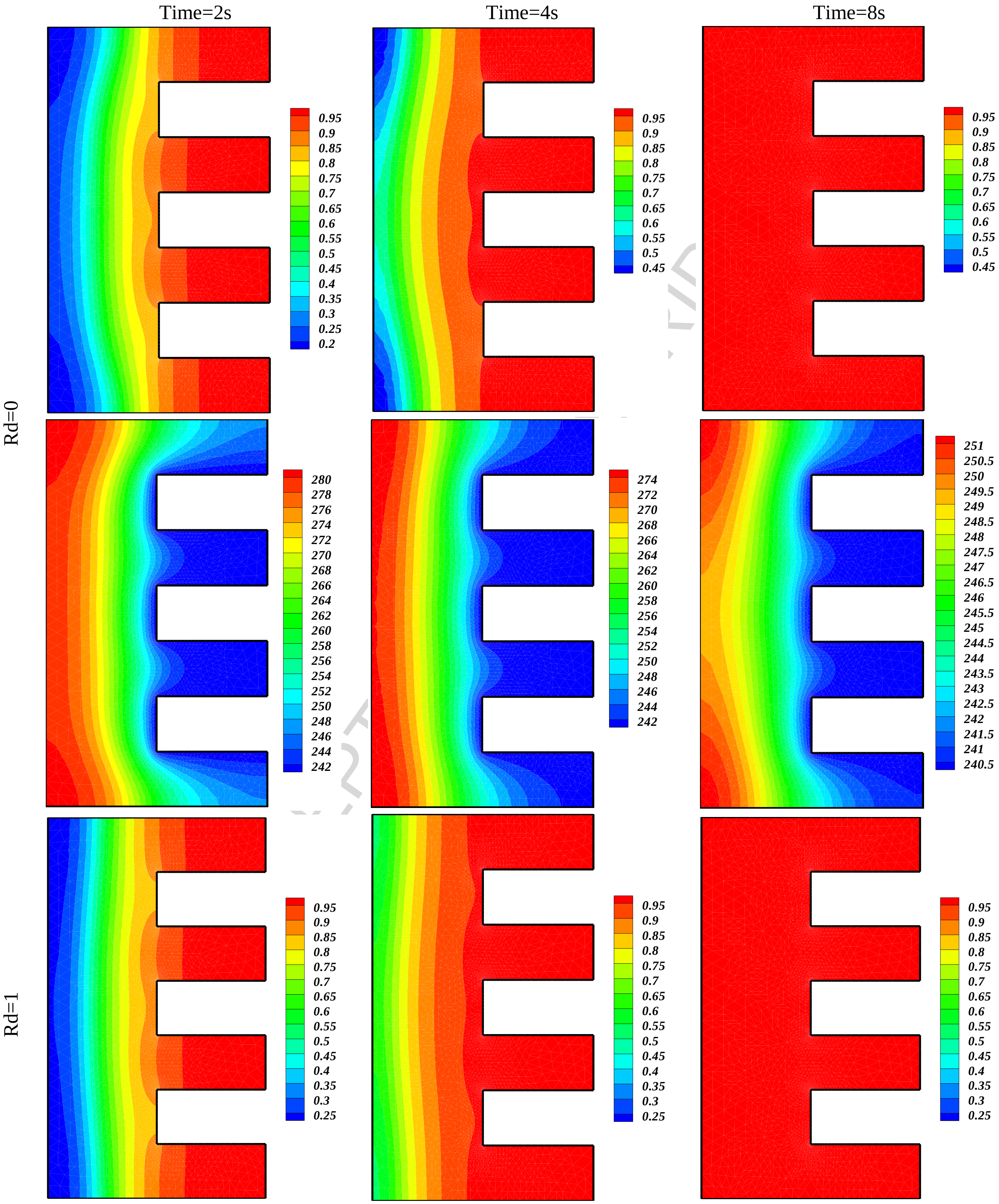


Fig. 7. Impact of Rd on solidification front (red ($Rd = 0$), green ($Rd = 1$)) at various times (Time=2s$(-)$, Time=4s$(--)$, Time=8s$(-\cdot-)$) at $d_p = 40nm, \phi = 0.04$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Rd=1
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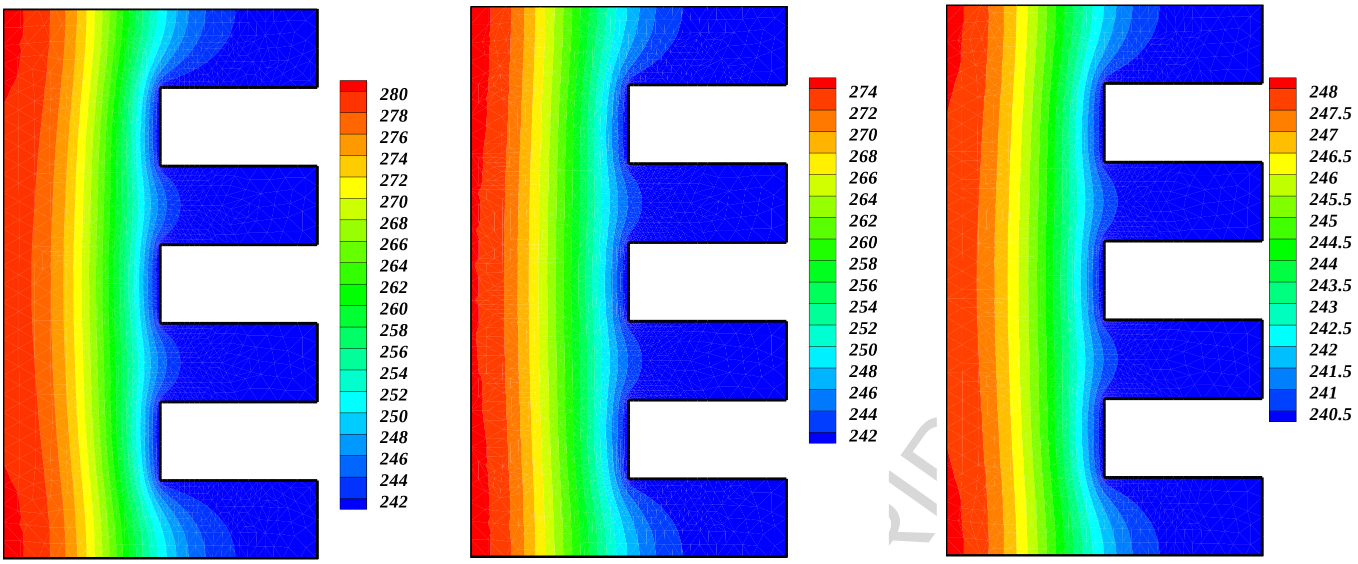


Fig. 8. Temperature and solid fraction contours for various Rd at $\phi = 0.04, Rd = 0, L = 1mm$

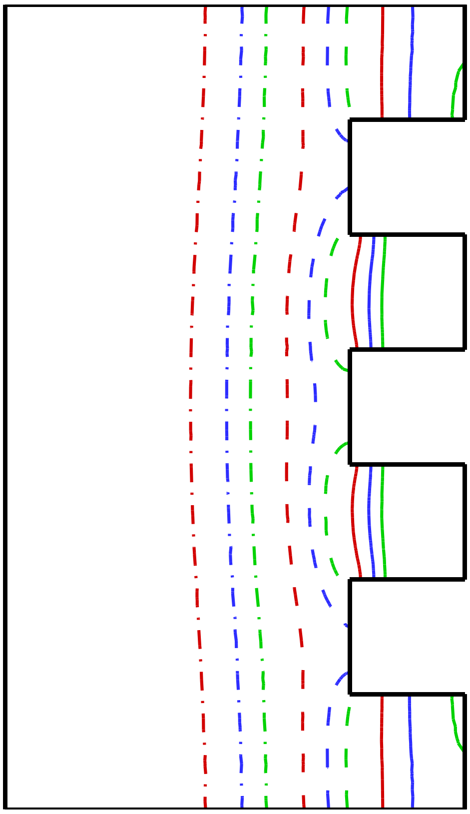
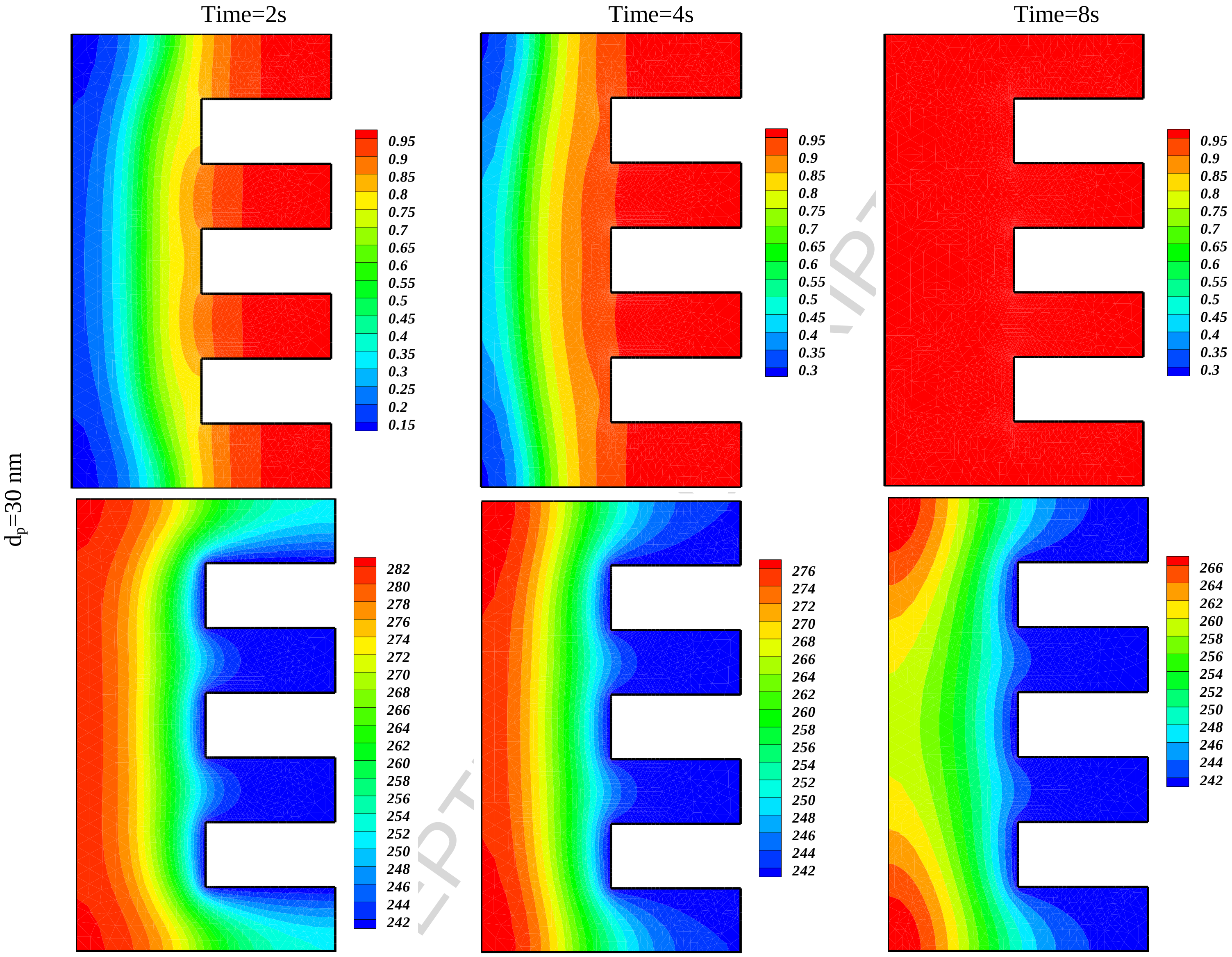


Fig. 9. Impacts of d_p on discharging front (blue ($d_p = 30nm$), red ($d_p = 40nm$), green ($d_p = 50nm$)) at various times (Time=2s$(-)$, Time=4s$(--)$, Time=8s$(-\cdot-)$)when $Rd = 0, \phi = 0.04, L = 0.5mm$


Time=2s
Time=4s
Time=8s
d_p=30 nm
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0.85
0.8
0.75
0.7
0.65
0.6
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0.45
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0.35
0.3
0.25
0.2
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0.9
0.85
0.8
0.75
0.7
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0.55
0.5
0.45
0.4
0.35
0.3
0.95
0.9
0.85
0.8
0.75
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0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
282
280
278
276
274
272
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264
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260
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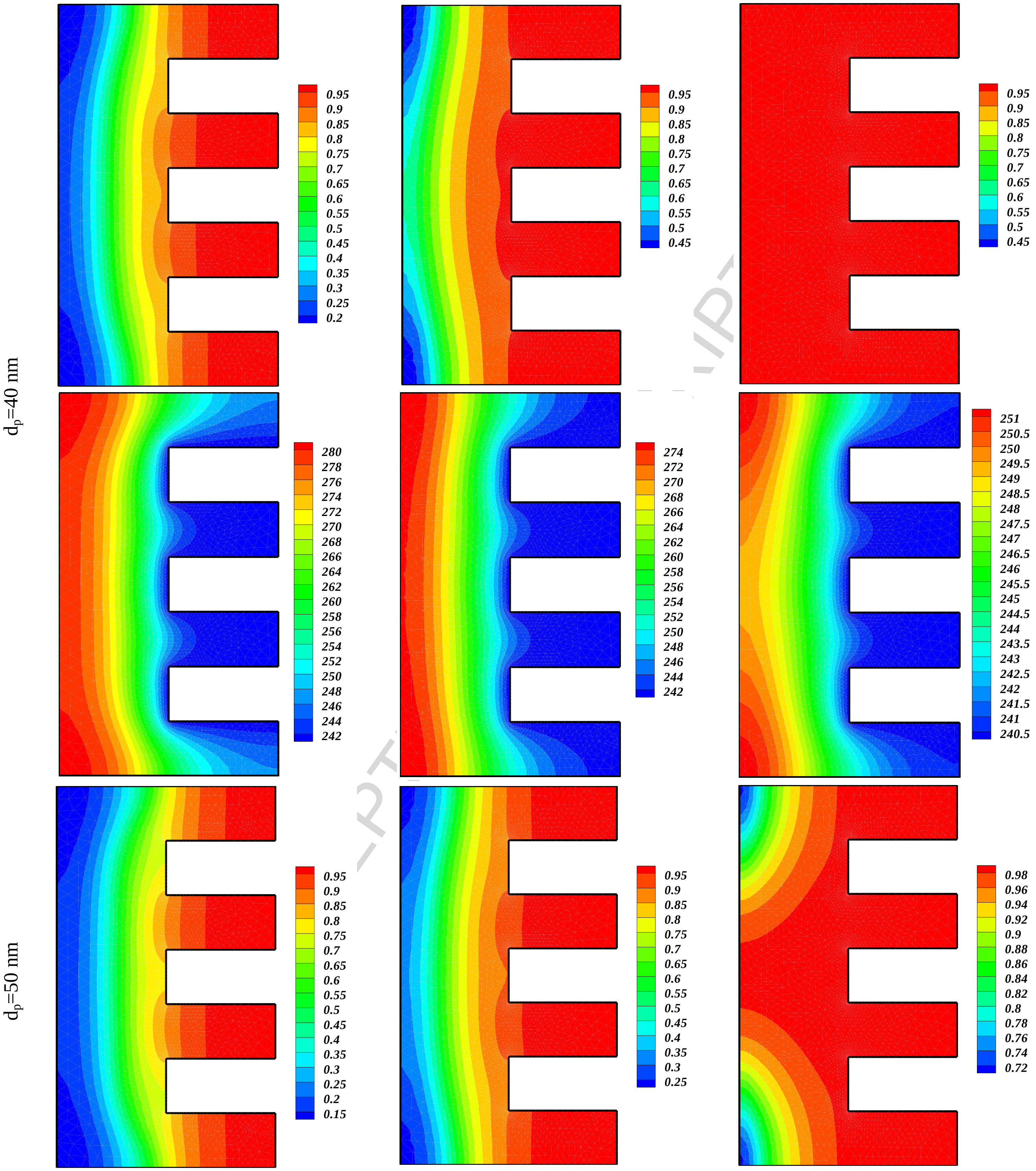
244
242



d$_p$=40 nm
d$_p$=50 nm
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.95
0.9
0.85
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0.75
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0.95
0.9
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0.65
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0.5
0.45
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0.35
0.3
0.25
0.2
0.15
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.78
0.76
0.74
0.72

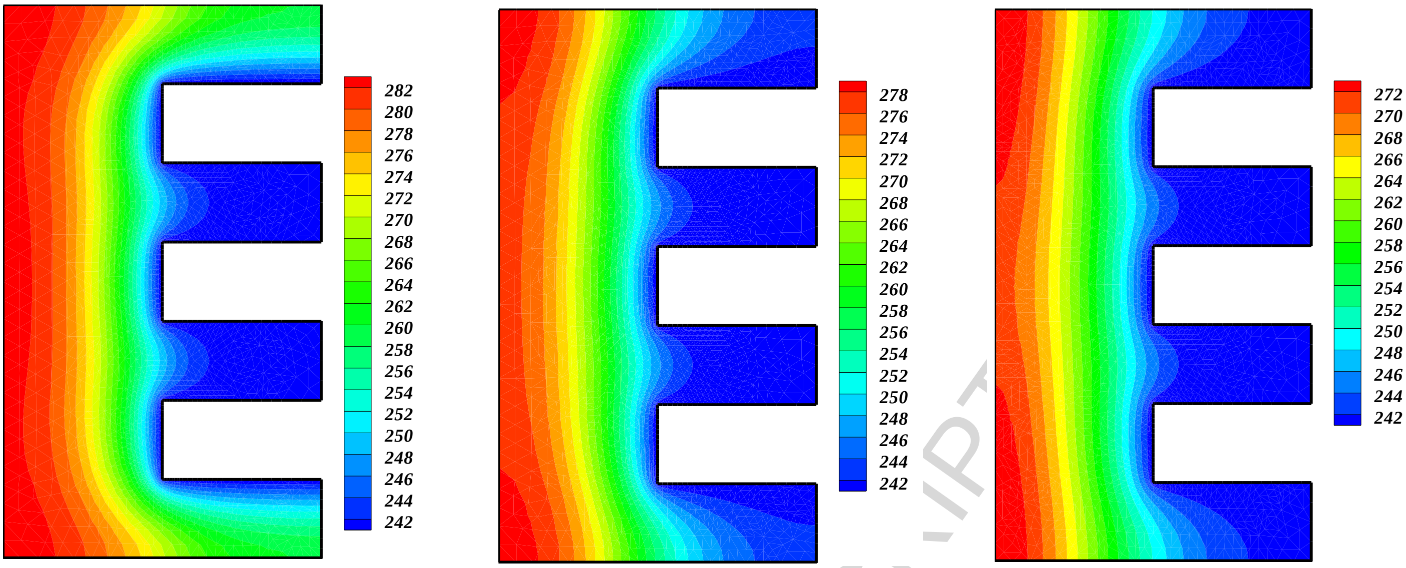


Fig. 10. Temperature (bottom) and solid fraction (up) contours for various d_p at $\phi = 0.04, Rd = 0, L = 1mm$

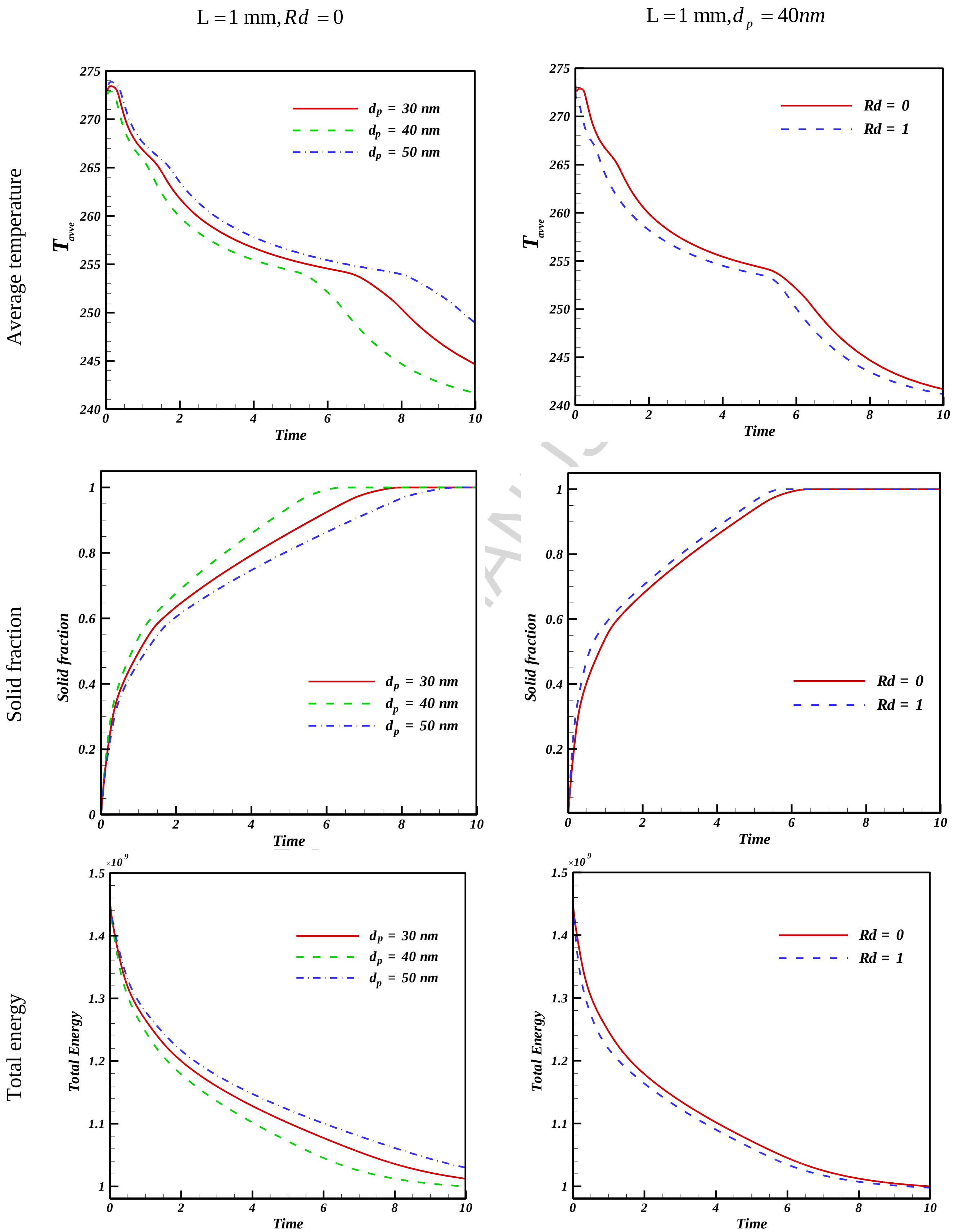
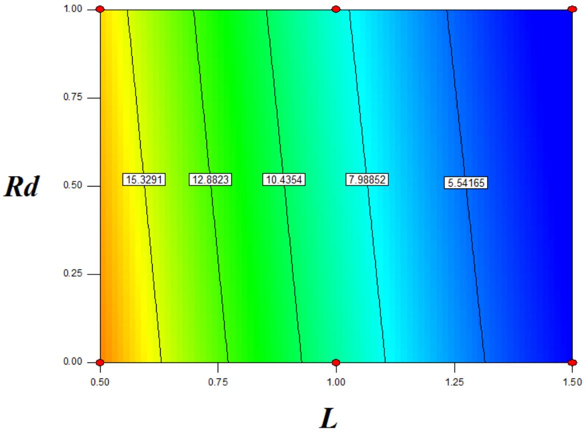
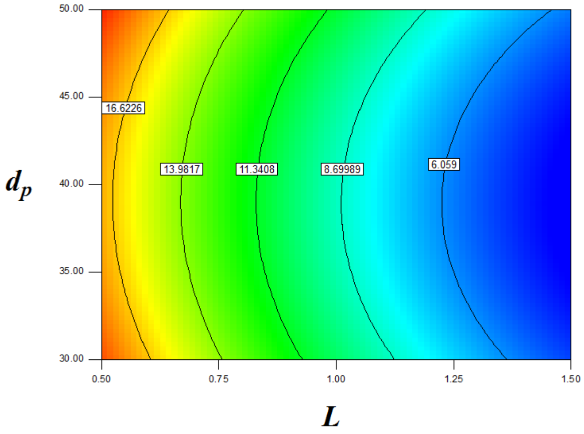


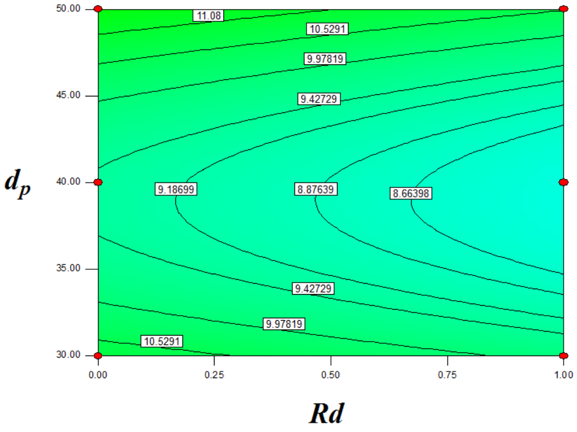
Fig. 11. Influences of Rd and d_p on T_{ave} , Solid fraction, total energy when $\phi = 0.04$



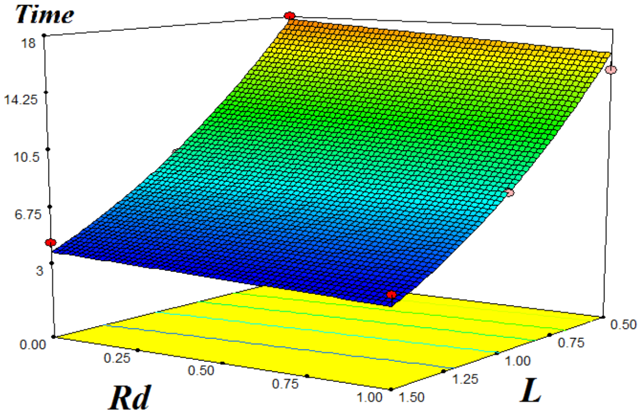
$d_p = 40nm$



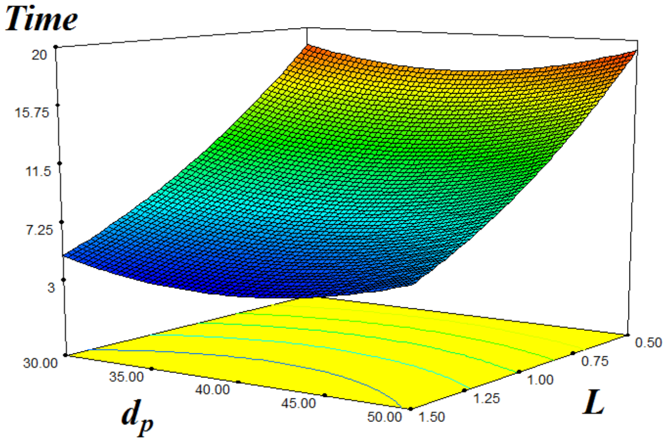
$Rd = 0.5$



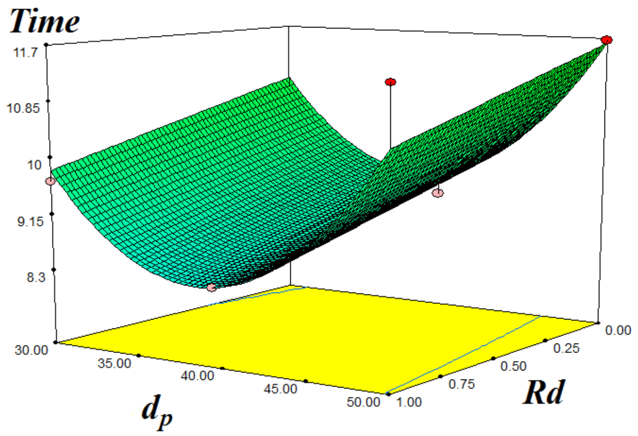
$L = 1mm$



$d_p = 40nm$



$Rd = 0.5$



$L = 1mm$

Fig. 12. Discharging time for different Rd, L, d_p

Table1. Pure PCM and nanoparticles' properties

Property	PCM	Nanoparticles
$\rho[kg/m^3]$	997	6500
$C_p[j/kg\ K]$	4179	540
$k[w/mK]$	0.6	18
$L_f[j/kg]$	335000	-

Table2. Related parameters for $CuO-Water$ nanofluids

Coefficient values	$CuO-Water$
a_1	-26.593310846
a_2	-0.403818333
a_3	-33.3516805
a_4	-1.915825591
a_5	6.42185846658E-02
a_6	48.40336955
a_7	-9.787756683
a_8	190.245610009
a_9	10.9285386565
a_{10}	-0.72009983664

Highlights

> Solidification of NEPCM under the radiation effect is investigated.

> FEM was applied for simulation.

> Dispersing CuO can enhance the discharge rate.

> Considering radiation can detract the solidification time.