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Solidification heat transfer of nanofluid in existence of thermal radiation by means of FEM

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ABSTRACT

In this research, nanofluid unsteady heat transfer process (solidification) under the impact of thermal radiation is reported. In order to simulate this problem, Finite element method with adaptive mesh is employed. CuO-water nanofluid is utilized and Brownian motion effect on thermal conductivity is taken into consideration. Total energy, average temperature, isotherm and solid fraction contours are reported as results. Results demonstrate that total energy reduces with increase of radiation parameter and solidification process is completed in lower time in presence of thermal radiation. Also, it can be understand that using Nano-enhanced phase change material (NEPCM) instead of pure PCM leads to higher heat transfer rate.

1. Introduction

Thermal energy storage systems have two essential aspects: energy storage density and high heat transfer performance. Nanotechnology can be helpful to enhance the performance of melting and solidification of phase change materials. Khan et al. [1] investigated melting heat transfer effect on unsteady Falkner-Skan flow of Carreau nanofluid over a wedge. Hayat et al. [2] reported the mixed convection of nanofluid in existence of nonlinear thermal radiation. Shivakumara et al. [3] investigated instability of nanofluid in a porous media. They used Oldroyd-B nanofluid as working fluid. Sheikholeslami and Shehzad [4] utilized the non-equilibrium model for porous media in order to find the hydrothermal behavior of nanofluid. Wang et al. [5] reported the melting process in pipe with internal fins.

Khan et al. [6] simulated the convective heat transfer of nanofluid over a porous plate. They considered thermo-diffusion effect on nanofluid behavior. Tipole et al. [7] demonstrated the impact of Lorentz forces on energy consumption in a vapor compression system. Hayat et al. [8] investigated nanofluid flow over a nonlinear starching plate due to magnetic field.

Garoosi et al. [9] utilized nanofluid for cooling process. Sheikholeslami and Seyednezhad [10] studied the free convection of nanofluid in existence of electric field. They utilized innovative numerical method for simulation. Khan et al. [11] reported the chemical reaction influences on fluid flow in a channel in existence of magnetic field. Sheikholeslami and Rokni [12] simulated the radiation effect on nanofluid free convection in a porous media. They considered variable electric field. Sheremet et al. [13] depicted the convective motion of ferrofluid inside a rotating cavity. Muhammad et al. [14] presented the new model for Darcy-Forchheimer three-dimensional flow of nanofluid. They considered convective boundary condition. Chamkha [15] utilized the two phase model for convective flow in a porous media. Safaei et al. [16] studied the nano-sized particle erosion in a curved pipe. They utilized Two-Phase Discrete Phase Model for simulation. Different publications have been published about NEPCM [17–26].

In this paper, impacts of using NEPCM on solidification rate have been demonstrated. This unsteady problem is simulated via FEM. Roles of nanofluid volume fraction, diameter of nanoparticles, number of undulations and amplitude are illustrated.

2. Problem statement

Fig. 1(a) depicts the geometry of the present study. The gap between inner circular wall and outer sinusoidal wall filled with

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Nomenclature

PCM	phase change material
L_f	latent heat of fusion [J/kg]
C_p	heat capacity [J/kg K]
NEPCM	nano-enhanced PCM
k	thermal conductivity
LHTESS	latent heat thermal energy storage system

Greek symbols

α	thermal diffusivity [m^2/s]
ρ	fluid density
ϕ	nanoparticle volume fraction

Subscripts

f	base fluid
nf	nanofluid
p	particle

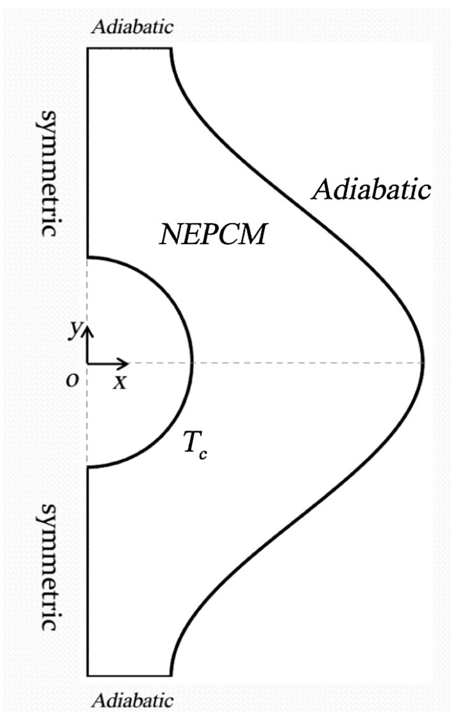

Fig. 1. Two-dimensional view of LHTESS.

Table 1
The physical properties of water as PCM, CuO as nanoparticles.

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

Table 2
The coefficient values of $CuO - Water$ 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

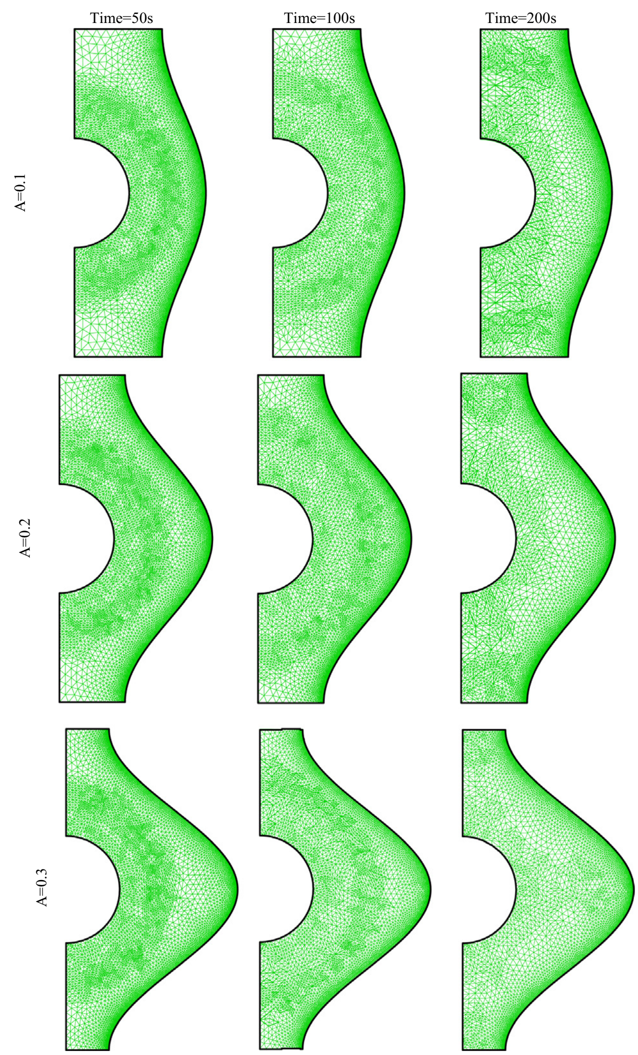

Fig. 2. Adaptive mesh refinement procedure when $\phi = 0.04$, $d_p = 30$ nm, $Rd = 0$.

NEPCM. Properties of PCM and CuO are depicted in Table 1. Fig. 1 (b) shows 2D geometry and boundary conditions. The initial temperature of NEPCM is equal to 278 K and temperature of cold wall is 240 K.

3. Governing equations

Unsteady solidification process has following equations: