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Graphene based Phase change material (GPCM) melting process in a square enclosure and enhanced potential for thermal energy storage

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The growth of electronic components usage and their thermal control is a significant problem to do research. The relevant use of phase change materials have gained major role to design a thermal energy storage system. A square enclosure of dimensions 25 mm x25mm is filled with a graphene-based phase change material (GPCM) and its melting process is studied numerically using finite volume method (FVM). Graphene nano particles are dispersed at volumetric concentrations of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% in the paraffin wax and their temperature dependent thermophysical properties are calculated using standard correlations. The enclosure is heated from bottom surface and side walls are remains as adiabatic. The initial temperature of GPCM is considered as 300.15 K and bottom wall supplies heat at 330.15 K. The enthalpy porosity method is employed to solve natural convection coupled to solid-liquid interface melting of GPCM. During melting the phase change material (GPCM) is considered as incompressible and viscous dissipation is neglected. The use of 2D, pressure based, unsteady and PCM filled computational grid is ascertained by comparing liquid fraction results with previously published results. The streamlines, isotherms and solid-liquid interface results of all phase change materials have been presented at various stages. The complete solid-liquid interface visualization during melting and temperature distribution at various locations in the square enclosure is presented at different melting stages. Moreover, the effect of volumetric concentrations on melting of GPCM thermal energy storage system is analysed.

Keywords: Phase change material, Graphene nanoparticle, volumetric concentration, Natural convection, CFD.

1. Introduction

The thermal management of electronic devices is a substantial phenomenon in the current scenario. There are several ways to achieve the objective by means of extended surfaces, heat pipes using conventional fluids. The effective thermal conductivity of conventional fluid is enhanced by adopting nanotechnology. The rapid growth of electronic devices in the society needs enough developments for clean and sustainable environment. A large quantity of electronic components in a particular device emits heat energy continuously and it is resulting in higher temperature than its working condition. This excess heat energy can be stored by latent heat thermal energy storage system (LHTESS). Phase change material (PCM) and its characteristics are enough suitable for LHTESS. It is revealed from previous studies that the effective thermo physical properties of PCM should be enhanced for the application of LHTESS. In this regard, several methodologies have been proposed as a part of PCMs properties enhancement and this research gap not fulfilled yet.

The overall performance of LHTESS is mainly depends on effective thermal conductivity of PCM. Moreover, the time required for melting and solidification of PCM is an essential parameter while using in LHTESS. The various LHTESS geometric configurations are also have influence on the melting /solidification time, energy stored in PCM. These configurations will affect heat transfer mechanisms both conduction and convection. In the present work, the effective thermo physical properties of PCM are enhanced using graphene nanoparticles. These properties are calculated using standard correlations available in the literature.

2. Methodology

The computational domain for present comparative study i.e., a square enclosure of dimension 25 mm is modelled using FLUENT version 15.0 has shown in Figure 1. Near the walls of enclosure the mesh is refined and appropriate boundary conditions are imposed on surfaces of computational domain. The assumptions made in the current numerical study as follows.

(a) Two dimensional, unsteady and Pressure based solver
(b) Melting flow is laminar, Newtonian and incompressible
(c) Neglect viscous dissipation

The effect of mushy zone constant (A_{mushy}) is set to 10^6. The thermophysical properties of PCM (Paraffin wax) and GPCM are of temperature dependent and these are inserted into FLUENT material data base using user defined functions (UDF). The convergence criteria is set to 10^{-3} for mass conservation and 10^{-6} for both momentum and energy conservation. Various surface monitors are created to extract the computational data during calculation. The time step is considered as 0.1s to study the melting of PCM and 200 iterations are performed for converged solution. First, the validation of PCM filled square enclosure results are validated with previously published results is presented in Figure 2. Further, different GPCMs simulations are carried out for melting in square enclosure and their results are presented interms of streamlines, isotherms and solid-liquid interfaces.

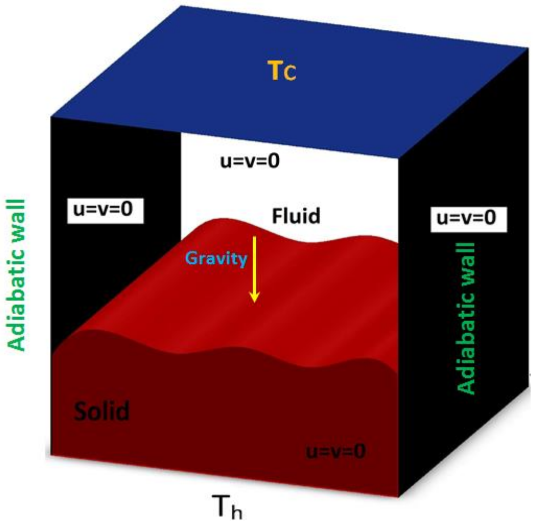

Fig.1. PCM filled square enclosure

3. Results and Discussion

The effect of graphene nanoparticle volume concentration on phase change material melting process in a bottom heated square enclosure is examined. In this study the square enclosure filled by solid PCM initially at 300.15K temperature and its temperature dependent thermophysical properties are inserted using UDF. Numerical simulations are conducted for computationally converged mesh of cells 5500 and 0.1s time step with 200 iterations. The melting process of both PCM and GPCMs are studied and their liquid fraction, streamline and isotherm contours at various time levels have been presented. Further, the time required for melting of PCM and GPCMs comparison has been shown in Figure 3. The solid-liquid interface contours of GPCM 2.0vol % has been shown in Figure 4. The phase change process inside enclosure is traced by creating isosurface in the x-direction. The variation of GPCM 2.0vol % temperature in the x-direction within the square enclosure at various locations is presented in Figure 5.

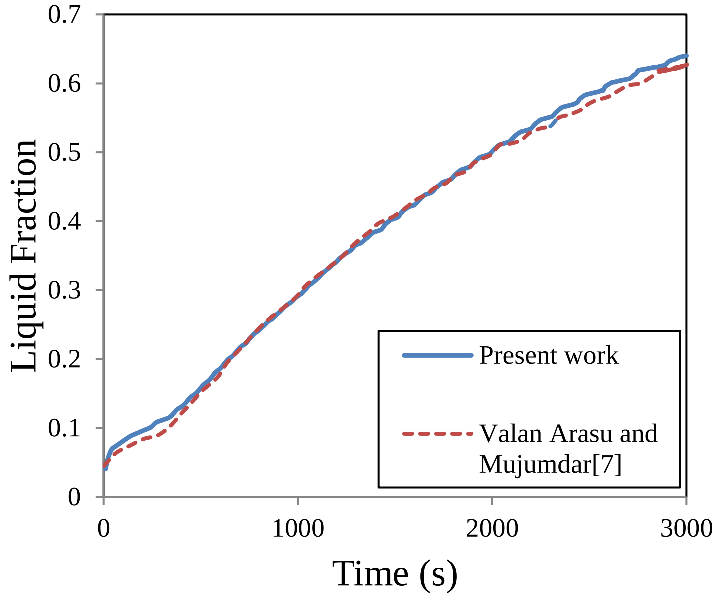

Fig.2. Comparison of predicted liquid fraction

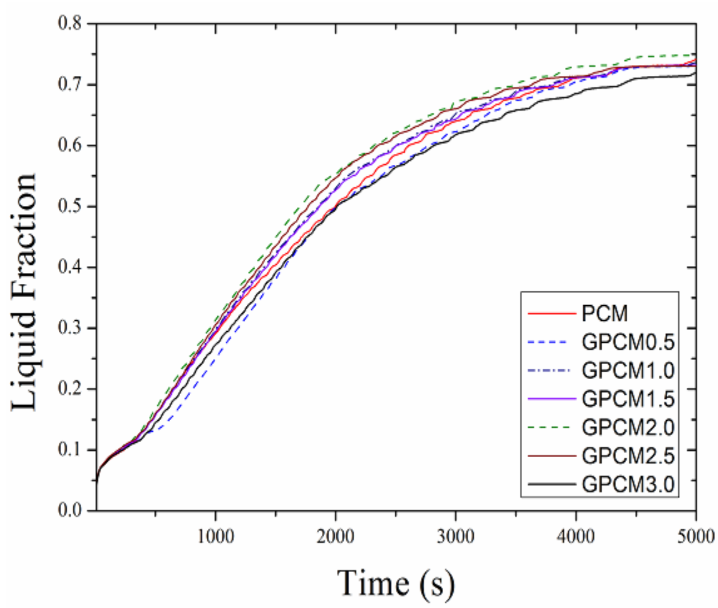

Fig.3. Effect of Graphene nanoparticle vol% on Liquid fraction

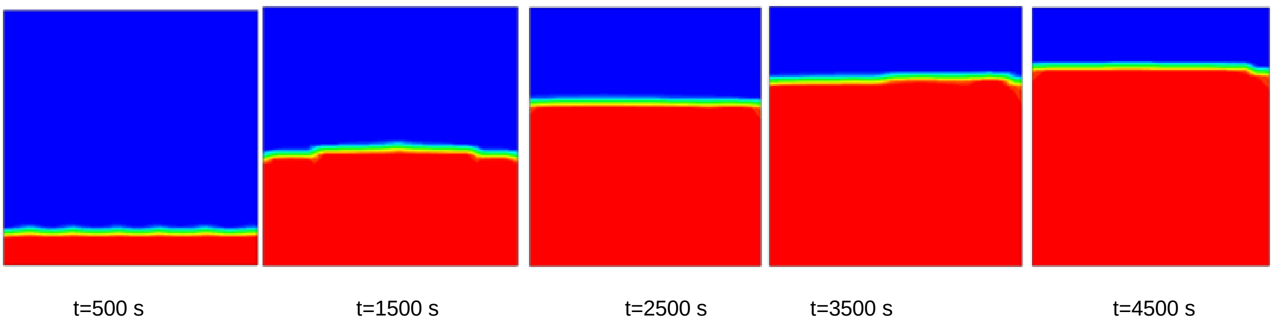

Fig.4(a). GPCM 2.0 vol% liquid-solid interface in bottom heated square enclosure(Liquid Fraction)

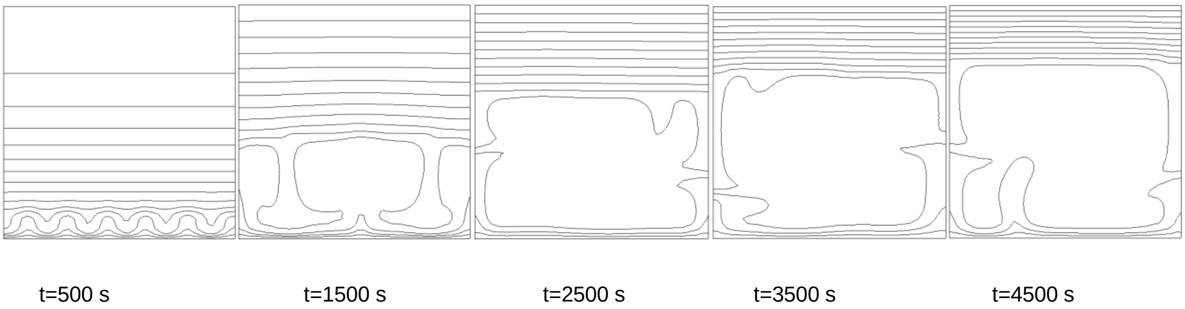

Fig.4(b). GPCM 2.0 vol% liquid-solid interface in bottom heated square enclosure (Temperature Contour)

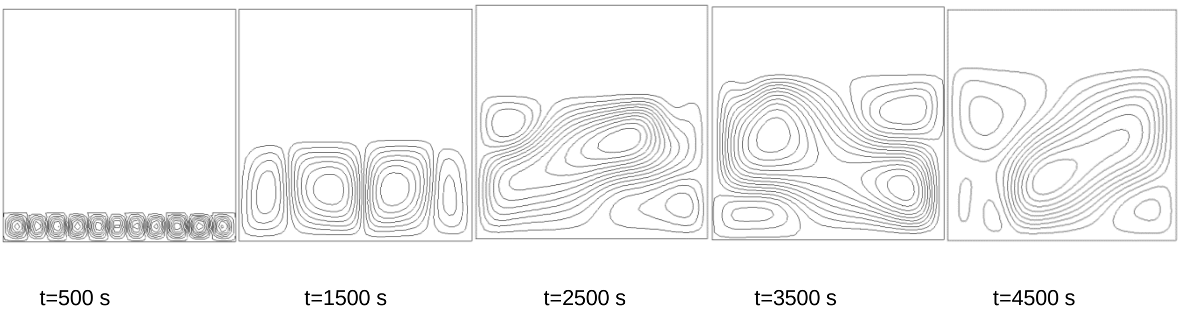

Fig.4(c). GPCM 2.0 vol% liquid-solid interface in bottom heated square enclosure (Streamlines contour)

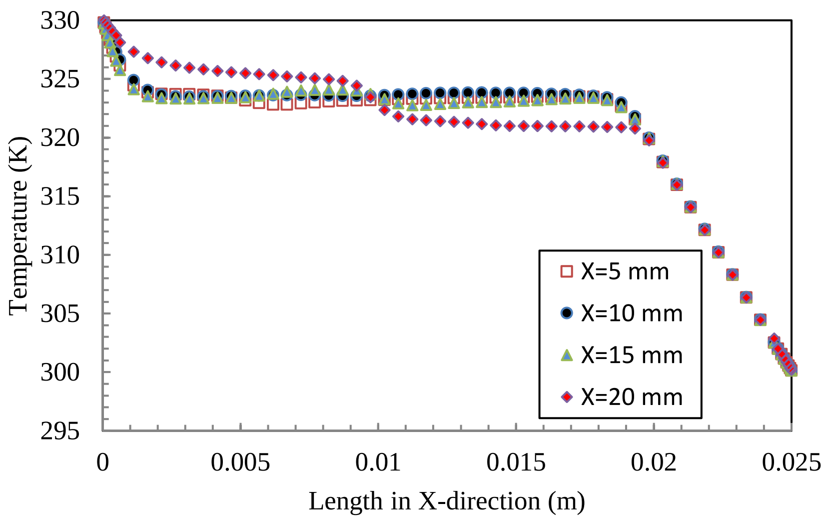

Fig.5. Variation of GPCM 2.0 vol% temperature distribution inside a bottom heated square enclosure

4. Conclusions

In present work graphene based phase change materials (GPCM) are filled in a bottom heated square enclosure. The enthalpy porosity method is employed to solve natural convection coupled to solid-liquid interface melting of GPCM and simulations are carried out using finite volume method (FVM). The effect of graphene nanoparticle volume concentration on melting time and energy stored by PCM has been investigated at appropriate boundary conditions. The simulation results are presented interms of isotherms, streamlines and solid-liquid interfaces at various time intervals. The contours obtained at various time intervals corroborated to melting of PCM in the square enclosure. It is observed from the simulations that the influence of graphene nanoparticle concentration on melting time rate and energy storage is significant. It is perceived from literature that the effective thermal conductivity of paraffin wax can be enhanced by dispersing nanoparticles at low volume concentrations. Thus optimum PCM can be used to design effective latent heat storage system for maintaining electronic devices in the limiting temperature and also in solar technology.

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