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Thermal Modeling of Melting of Nano based Phase Change Material for Improvement of Thermal Energy Storage

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Abstract

A two dimensional numerical model is developed for melting of a nano based phase change material (PCM) such as n-octadecane with CuO nanoparticle in a square cavity. The governing equations are discretized using Finite Volume Method (FVM). The flow equations are solved using SIMPLER algorithm. Tri-Diagonal Matrix Algorithm (TDMA) is used to solve the corresponding algebraic equations. Enthalpy porosity technique is used to capture the position of the moving melt front. The melting of nano based phase change material with varying volume fractions of nanoparticles is studied to investigate the heat transfer enhancement during the melting process through dispersion of nanoparticles. The effect of some significant parameters, namely melting front progression, volume fraction of nanoparticle, heated left wall temperature, heat transfer rate and melting time are studied. The results obtained are represented graphically to study the nature and behavior of the parameters when are presented in terms of temperature, velocity profiles, moving interface position and solid fraction. Finally, it is concluded that addition of nanoparticles enhances the thermal conductivity as compared to conventional phase change material, resulting in a relatively higher heat transfer and a faster melting rate. In addition, with the rise in heat transfer rate of the nanofluid the melting time eventually decreased as the volume fraction of nanoparticles increased. Increase in difference between the melting temperature and the hot wall temperature fastened the melting process of the nano based PCM.

Keywords: Phase change material; Nanoparticle; Enthalpy method; Melting

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1. Introduction

A number of experimental, analytical and numerical results have come forward for solid-liquid phase change problems [1-4] in the last few decades because of its growing demand and interest in the engineering field of Latent Heat Thermal Energy Storage (LHTES). In this technique the latent heat is stored during the melting process and releases the same when required during the freezing process. The ability of PCM to provide high-energy storage density and isothermal behaviour have brought them into force for applications in areas such as storage of food, temperature control inside buildings and refrigeration and air-conditioning applications [5-8].

As the PCMs have low thermal conductivity, hence many studies such as enhanced heat flux [9], inserting fins [10], and addition of nanoparticle [11] are found in the literature to enhance the thermal conductivity. Technical grade paraffins which are mixture of many hydrocarbons are used for latent heat storage instead of pure paraffin waxes which are very expensive. n-octadecane is a commercial paraffin wax used extensively for heat storage applications [12].

After a critical study of the literature, it is observed that no detailed model is available to study the effect of embedding nanoparticle in a PCM as a thermal conductivity enhancer to improve the thermal energy storage which has now-a-days a great demand. Further an elaborative analysis of role of nanoparticle in the heat transfer enhancement in particularly natural convection is not focused. The aim of this computational study is to investigate the natural convection effect using Copper oxide and n-octadecane Paraffin as nanofluid in an enclosure. A parametric study like the effect of volume fraction of nanoparticle on the melting rate of PCM is studied.

Nomenclature

t	Time
u	x-velocity
v	y-velocity
P	Pressure
T	Temperature
g	Acceleration due to gravity
S_x	Source term for x-momentum equation
S_y	Source term for y-momentum equation
H	Total Enthalpy
S_h	Source term for energy equation
S_c	Source term for discretization equation
C_p	Specific heat at constant pressure
K	Thermal Conductivity
f	Melt fraction during phase change
C	Morphology constant
B	Computational constant
L	Latent heat of fusion
b	Empirically determined constant
a	Coefficients in the discretization equation

Greek Symbols

ϕ	Volumefraction
ρ	Density
μ	Dynamic viscosity
β	Volumetric coefficient of thermal expansion
λ	Under-relaxation factor

Subscripts

ref	Reference value
s	Solid
0	Stagnant
d	Thermal dispersion
p	Control volume
h	Heated wall conditions
m	Melting point
c	Cold wall conditions

Superscripts

n	Iteration counter

Abbreviations

PCM	Phase Change Material
nf	Nanofluid
FVM	Finite Volume Method
TDMA	Tri Diagonal Matrix Algorithm
TES	Thermal Energy Storage
SIMPLER	Semi Implicit Method for Pressure Linked Equation-Revised