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Numerical Study of Double-diffusive Natural Convection in a Window Shaped Cavity Containing Multiple Obstacles Filled with Nanofluid

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Abstract

In the present study, double-diffusive natural convection flow inside a window shaped cavity containing multiple obstacles filled with nanofluid is studied numerically. Water base nanofluid containing various nanoparticles including Ag, Cu and $Al_2O_3$are considered as working fluid. The left and right inclined walls of the cavity are maintained at a relatively low temperature and low concentration while the vertical walls are adiabatic and impermeable. The non-uniform temperature and concentration are imposed along the bottom wall of the cavity. The governing equations are transformed to the dimensionless form and solved numerically using Galerkin weighted residual technique of finite element method. The influence of pertinent parameters such as thermal Rayleigh number, and Lewis number and volume fraction of nanoparticles on the heat and mass transfer and fluid flow is studied. The results are obtained in terms of streamlines, isotherms, isoconcentrations, average Nusselt number and average Sherwood number for the considered parameters and it is observed that the flow pattern, temperature and concentration fields are affected by the variation of the parameters.

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Keywords: Double-diffusive; Natural convection; Nanofluid; Window shaped cavity

1. Introduction

Double-diffusive natural convection is of a great importance in industrial and energy perspectives and an extensive research have been performed on this topic by many researchers [1,2]. Double-diffusive natural convection is refereed to buoyancy driven flows by both temperature and concentration gradients. Double-diffusive natural convection occurs in a wide range of applications such as in chemical process, crystal growth, solidification, food processing and migration of impurities in non-isothermal material processing applications. Ostrach [3] and Viskanta et al. [4] have reported complete reviews on the subject.

Enhancement of heat transfer in cavities is important from industrial and energy perspectives. The low thermal conductivity of convectional working fluids like water is a limitation in enhancing the performance of thermal systems. The technique to enhance thermal properties of the working fluid is using nanoscale particles in the working fluid, known as nanofluid. Khanafer et al. [2] have used this fluid in order to enhance the heat transfer in modern technology. Sheikhzadeh et al. [5] have studied effects of walls temperature variation on double diffusive natural convection of

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Al_2O_3-water nanofluid in an enclosure. Esfahani and Bordbar [6] have investigated double diffusive natural convection heat transfer enhancement in a square enclosure using nanofluids. Teamah [7] has done numerical simulation on double-diffusive natural convection in an inclined rectangular enclosure with magnetic field and heat source. Bejan [8] has conducted mass and heat transfer by natural convection in a vertical cavity. Kamotani [9] has examined an experimental work on natural convection in shallow enclosures with horizontal temperature and concentration gradients. Mamou et al. [10] have studied double-diffusive convection in an inclined porous enclosure and used Galerkin finite element formulations.

Many authors have recently analyzed heat transfer in enclosures with partitions, fins and block which manipulates the convective flow phenomenon. A body can be used as a control element for heat transfer and fluid flow which is investigated by Varol et al. [11]. Amine et al. [12] investigated the thermal convection around obstacles with different configurations. Ha et al. [13] tested the different boundary conditions for the inserted body to the enclosure. They reported that the presence of the body obstructs the flow and temperature fields. Oztop et al. [14] analyzed the effects of the location of the insulated body for partially heated enclosure. Chowdhury et al. [15] have analyzed MHD natural convection in a porous equilateral triangular enclosure with a heated square body in the presence of heat generation.

Heat and mass transfer in a window shaped cavity containing multiple obstacles can be a simple model of many engineering applications. Although many studies have reported on double-diffusive natural convection in regular shaped cavities (triangular, rectangular, trapezoidal), studies in irregular shaped cavities like window shaped cavity filled with nanofluid are very limited. The aim of the present study is to investigate the flow pattern, heat and mass transfer in a window shaped cavity filled with nanofluid and containing obstacles exposed to both temperature and concentration gradients. Double-diffusive conditions is maintained by taking the bottom wall as heated wall and the source for solute concentration, the left and right inclined walls are cold and lower concentration. The vertical walls and the walls of square obstacles are kept adiabatic and impermeable.

Nomenclature

c	concentration $[molm^{-3}]$
C	dimensionless concentration
Cp	specific heat $[Jkg^{-1}K^{-1}]$
D	mass diffusivity $[m^2/s]$
g	gravity acceleration $[m/s^2]$
k	thermal conductivity $[Wm^{-1}K^{-1}]$
b	base of the cavity $[m]$
H	height of the cavity$[m]$
N	buoyancy ratio, $\beta_S \nabla_c / \beta_T \nabla T$
p	fluid pressure $[Pa]$
P	dimensionless fluid pressure
u, v	x,y component of velocity $[ms^{-1}]$
U, V	x, y component of dimensionless velocity
T	Temperature $[K]$

Greek Letters

β_S	volumetric coefficient of solutal expansion $[m^3kg^{-1}]$
λ	dimensionless heat generation parameter
μ	dynamic viscosity $[kgm^{-1}s^{-1}]$
θ	dimensionless temperature
ν	kinematic viscosity $[m^2s^{-1}]$
ρ	density $[kgm^{-3}]$
ϕ	nanoparticle volume fraction

Subscript

c	cold
h	hot
f	fluid
p	nanoparticle
nf	nanofluid

2. Governing Equations

Fig. 1 shows the schematic diagram of window shaped cavity containing three square shaped obstacles s_1, s_2 and s_3 subjected to the non-dimensional boundary conditions. The bottom wall of the cavity is heated non-uniformly at temperature T_h, the top left and right inclined wall of the cavity is cold at temperature T_c. The left and right vertical walls and the walls of obstacles are adiabatic. The concentration c_h,is higher at bottom wall, lower c_c, at top left and right inclined walls, and the vertical walls and obstacles body walls are impermeable. The working fluid consider in the system is water based Ag, Cu and Al_2O_3 nanofluid. The properties of water and considering nanoparticles are