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ORIGINAL ARTICLE

Numerical simulation of double-diffusive natural convective flow in an inclined rectangular enclosure in the presence of magnetic field and heat source, part A: Effect of Rayleigh number and inclination angle

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Abstract Double-diffusive convective flow in an inclined rectangular enclosure with the shortest sides being insulated and impermeable is investigated numerically. Constant temperatures and concentration are imposed along the longest sides of the enclosure. In addition, a uniform magnetic field is applied in a horizontal direction. Laminar regime is considered under steady state condition. The transport equations for continuity, momentum, energy and species transfer are solved using the finite volume technique. The validity of the numerical code used is ascertained and good agreement was found with published results. The numerical results are reported for the effect of thermal Rayleigh number on the contours of streamline, temperature, and concentration. In addition, results for the average Nusselt and Sherwood numbers are presented and discussed for various parametric conditions. This study was done for constant Prandtl number, Pr = 0.7, aspect ratio, A = 2, Lewis number, Le = 2, the buoyancy ratio, N = 1, Hartmann number, Ha = 10 and the dimensionless

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heat generation, $\Phi = 1$. Computations are carried out for Ra_T ranging from 10^3 to $5 * 10^5$ and inclination angle range of $0° \leqslant \gamma \leqslant 180°$.

Nomenclature

A	aspect ratio, H/L
B	magnetic induction, $Tesla = N/Am^2$
C	vapor concentration
c_h	concentrations at the left wall of the cavity
c_l	concentrations at the right wall of the cavity
C	dimensionless vapor concentration, $C = (c - c_l)/(c_h - c_l)$
C_p	specific heat at constant pressure
D	mass diffusivity
g	acceleration of gravity
h	heat transfer coefficient
h_s	solutal transfer coefficient
H	cavity height
k	fluid thermal conductivity
L	cavity width
Le	Lewis number, $Le = \alpha/D$
N	buoyancy ratio
Nu	average Nusselt number, $Nu = hL/k$
Nu_i	local Nusselt number
p	pressure
P	dimensionless pressure, $P = pL^2/\rho^*\alpha^2$
Pr	Prandtl number, $Pr = \nu/\alpha$
Q_o	heat generation or absorption coefficient, W/m^3 °C
Ra_S	solutal Rayleigh number, $Ra_S = Gr_S$ Pr
Ra_T	thermal Rayleigh number, $Ra_T = Gr_T$ Pr
Sh	average *Sherwood* number, $Sh = h_s L/D$
Sh_i	local Sherwood number
T	local temperature
T_c	cold wall temperature
T_h	hot wall temperature
ΔT	temperature difference
u	velocity components in x direction
v	velocity components in y direction
U	dimensionless velocity component in X direction
V	dimensionless velocity component in Y direction
x, y	dimensional coordinates
X, Y	dimensionless coordinates

Greek symbols

α	thermal diffusivity
β_T	coefficient of thermal expansion
β_S	coefficient of solutal expansion
Φ	dimensionless heat generation or absorption
θ	dimensionless temperature, $(T - T_c)/(T_h - T_c)$
μ	dynamic viscosity
ν	kinematics viscosity
ρ	local fluid density
ρ_o	fluid density at the bottom surface
ρ^*	dimensionless density, $NC - \theta$
ψ	dimensionless stream function
ψ_{max}	maximum dimensionless stream function
γ	inclination angle
σ	electrical conductivity

1. Introduction

Natural convection is of a great importance in many industrial applications. Application of natural convection in engineering can be found in the solar collectors, furnaces, building heating and cooling system, heat exchangers, and so on. Buoyancy-induced flow and heat transfer in enclosures have received considerable attention by many researches both experimentally and numerically. A good review was reported by de Vahl Davis [1].

Natural convection heat transfer induced by internal heat generation has recently received considerable attention because of numerous applications in geophysics and energy-related engineering problems. Such applications include heat removal from nuclear fuel debris, underground disposal of radioactive waste materials, storage of foodstuff, and exothermic chemical reactions in packed-bed reactor. Acharya and Goldstein [2] studied numerically a complicated inclined cavity with inner heat generation. Two Rayleigh numbers were introduced; internal Rayleigh number Ra_I which is based on the rate of heat generation and external Rayleigh number Ra_E which is based on the temperature difference. The study covered a range for Ra_I from 10^4 to 10^7, Ra_E from 10^3 to 10^6 and cavity inclination angle from 30° to 90°.

Also, Rahman and Sharif [3] studied numerically the same geometry with heated bottom and cooled top surfaces and insulated sides. In their study, both Ra_I and Ra_E were 2×10^5 and the aspect ratio ranged from 0.25 to 4. They found that for $Ra_E/Ra_I > 1$, the convective flow and heat transfer were almost the same as that in a cavity without internal heat generating fluid and they observed similar results as in Acharya and Goldstein [2].

Heat transfer in partially divided enclosures has received attention primarily due to its many applications such as the design of energy efficient building, reduction of heat loss from flat plate solar collectors, natural gas storage tanks, crystal manufacturing and metal solidification processes. AlAmiri et al. [4] studied numerically buoyancy-induced heat transfer in a partially divided square enclosure with protruding isothermal heater. Their study covered Rayleigh number in the range of $10^4 \leqslant Ra \leqslant 5 * 10^7$. Various pertinent parameters such as Rayleigh number, height of the heater, heater width,