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ORIGINAL ARTICLE

Magnetohydrodynamic double diffusive natural convection in trapezoidal cavities

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Abstract A numerical work has been carried out to study the effects of magnetic field on double diffusive natural convection in a trapezoidal enclosure. Both inclined walls and bottom wall were kept at constant temperature and concentration where the bottom wall temperature and concentration are higher than those of the inclined walls. Top wall of the cavity is adiabatic and impermeable. The trapezoidal enclosure is subjected to a horizontal magnetic field. To investigate the effects, finite volume method is used to solve the governing equations for different parameters such as Grashof number, inclination angle of inclined wall of the enclosure, Hartmann number and buoyancy ratio. The numerical results are reported for the effect of studied parameters on the contours of streamline, temperature, and concentration. In addition, results for both local and average Nusselt and Sherwood numbers are presented and discussed for various parametric conditions. This study is done for constant Prandtl number, $Pr = 0.7$; aspect ratio = 1 and Lewis number, $Le = 2$. The studied range of Grashof number is from $Gr = 10^3$ to 10^6, inclination angle from 0° to 75°, Hartmann number from 0 to 15 and buoyancy ratio from -2 to 2 which covers the double diffusive range in the cases of aiding and opposing flows. It is found that heat and mass transfer decreased as φ increases from 0° to 75°. Also heat and mass transfer decreased as Hartman number increased from 0 to 15. Finally, the predicted results for both average Nusselt and Sherwood numbers were correlated in terms of the studied parameters.

1. Introduction

Double diffusive natural convection heat transfer has an essential role in modern life. Application of double diffusive natural convection heat transfer is common in many engineering fields such as, drying processes, printing, building heating and cooling, solar collector, and heat exchangers. In most of these applications, convective heat and mass transfer are investigated, and the cavities are of various shapes including triangular, rectangular, trapezoidal, sinusoidal or ellipsoidal. Magnetic field is also an important control parameter for convective heat and mass transfer in pipes, ducts and cavities.

Basak et al. [1,2] investigated the natural convection in a trapezoidal enclosure filled with porous matrix by applying

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Nomenclature

B	magnetic induction, Tesla $= \mathrm{N/Am^2}$
c_h	high concentrations at the bottom wall of the cavity
c_c	low concentrations at the left and right walls of the cavity
C	dimensionless concentration, $C = (c - c_c)/(c_h - c_c)$
C_p	specific heat at constant pressure
D	mass diffusivity
g	acceleration of gravity
Gr_s	solutal Grashof number
Gr	thermal Grashof number
h	heat transfer coefficient
h_s	solutal heat transfer coefficient
H	cavity height
k	fluid thermal conductivity
L	bottom wall of the cavity length
Le	Lewis number, $Le = \alpha/D$
N	buoyancy ratio
Nu	average Nusselt number, $Nu = hL/k$
p	pressure
P	dimensionless pressure, $P = pL^2/\rho^*\alpha^2$
Pr	Prandtl number, $Pr = \nu/\alpha$
Ra_s	solutal Rayleigh number
Ra	thermal Rayleigh number
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
θ	dimensionless temperature, $(T - T_c)/(T_h - T_c)$
ϕ	trapezoidal inclination angle
μ	dynamic viscosity
ν	kinematics viscosity
ρ	local fluid density
ρ^*	dimensionless density, $NC\text{-}\ \theta$

finite element method. In their investigation, they studied the effect of uniform and non-uniform heating of bottom wall where the two vertical walls were maintained at constant cold temperature and top wall is well insulated. They also investigated natural convection in trapezoidal enclosures for uniformly heated bottom wall, and linearly heated vertical wall (s) with insulated top wall by using finite element method. Basak et al. [3] extended their work to various inclination angle for the trapezoidal. A study on natural convection on a trapezoidal porous enclosure has been carried out by Baytas and Pop [4]. They solved the problem by finite-difference method with boundary conditions as top enclosure being cooled, bottom cylindrical surfaces being heated and the remaining two non-parallel plane sidewalls of enclosure being adiabatic. In trapezoidal geometries, numerical studies are widely available, such as those by Dong and Ebadian [5] and Boussaid et al. [6,7] in the laminar-flow regime and by Van der Eyden et al. [8] in the turbulent flow regime. Kumar and Kumar [9] studied the coupled non-linear partial differential equations governing the natural convection from an isothermal wall of a trapezoidal porous enclosure by using finite element method. Kumar [10] studied thermal analysis to investigate the natural convection for a trapezoidal absorber plate and compared the results with the rectangular enclosure. Authors found that the convective heat transfer coefficient for rectangular enclosure is 31–35% lower. Iyican and Bayazitoglu [11] investigated natural convective flow and heat transfer within a trapezoidal enclosure with parallel cylindrical top and bottom walls at different temperatures and plane adiabatic side walls. Karyakin [12] reported two-dimensional laminar natural convection in enclosures of arbitrary cross-section. This study reported on transient natural convection in an isosceles trapezoidal cavity. Fundamental studies on natural convection in trapezoidal enclosures of various forms (including triangular ones as a special case) have been presented by Perić [13], Hasanuzzaman [14] and Hoogendoorn [15] and Varol et al. [16] analyzed numerically the entropy in a right-angle trapezoidal enclosure filled with a porous medium bounded by a solid vertical wall. Authors used finite difference technique in their work at different values of thermal conductivity and solid wall thickness. Kimura and Bejan [17] proposed heatlines for visualization of convective heat transfer through an extension of heat flux line concept to include the advection terms. A smaller number of studies have considered the trapezoidal geometry, which is encountered in several practical applications, such as attic spaces in buildings [18]. Other related works with trapezoidal enclosure can be found in the literature as [19–21]. Teamah [22] studied double diffusive in symmetrical trapezoidal enclosure, and the work is extended for different values of Grashof number and aspect ratio as further reported in [23].

Basak et al. [24] studied numerically the natural convection flows in a square cavity filled with a porous matrix for various boundary conditions and wide range of parameters. The stability of the flow in confined rectangular enclosures has also received considerable attention in recent years [25]. Teamah [26,27] studied double diffusive flow in a rectangular cavity in the presence of magnetic field and inner heat source. Teamah et al. [28–30] extended the previous work by studying the inclined cavity. Recently Teamah and El-Maghlany [31] studied the effect of magnetic field on heat transfer in a rectangular cavity filled with nano-fluid. Further work is done by Khairat and Teamah [32], and they studied the hydromagnetic mixed convection double diffusive in a lid driven square cavity numerically. Oztop et al. [33] numerically

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