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RADIATIVE EFFECTS DUE TO NATURAL CONVECTION BETWEEN HEATED INCLINED PLATES WITH MAGNETIC FIELD

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1. ABSTRACT

We analyze the study of the radiation effects due to natural convection with magnetic field between heated inclined plates. Neglecting the induced electric field the equations governing the motion, temperature and concentration are solved by simple perturbation method. The expressions for velocity, temperature and concentration are evaluated and represented through graphs.

Key words: *Magnetic Field, Radiation Effects, Soret effect.*

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2. INTRODUCTION

The phenomenon of free convection arises in a fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. The study of hydromagnetic free convection flow finds applications in science and engineering. Gebhart [7] and Gebhart and Mollendorf [8] have shown that viscous dissipative heat is important when the free convective flow field is of extreme size or the flow is at extremely low temperature or in a high gravity field. Singh and Sacheti [22] followed the study by Soundalgekar and Hiremath [23] which looked at the flow past an impulsively started infinite isothermal vertical plate in a dissipative fluid. Azzam [3] reported a study on the radiation effects on the magnetohydrodynamic (MHD) mixed free-forced convection flow past a semi-infinite moving vertical plate for high temperature differences. A few other works of interest in this area include Kim [11], Makinde [13] and Ogulu and Prakash [16].The object of this study is to consider unsteady hydromagnetic free convection flow for a dissipative and radiating fluid applying a simple perturbation technique. Chamka [5] studied convective heat and mass transfer characteristics on infinite vertical permeable moving plate.

Separation process of components of a fluid mixture, wherein one of the components is present in extremely small proportion, is of much interest due to their various applications in science and technology. Nield and Bejan [15] and Bejan and Kraus [4] performed detailed reviews of the subject including exhaustive lists of references. Few studies are found when the porous medium is thermally stratified i.e. the ambient temperature is not uniform and it varies linearly in the stream-wise direction. Rees and Lage [19], Takhar and Pop [24] and Tewari and Singh [25] analytically analyzed free convection from a vertical plate immersed in a thermally stratified porous medium under boundary layer assumptions. On the other hand, Angirasa and Peterson [2] and Kumar and Singh [12] numerically investigated the natural convection process in a thermally stratified porous medium.

Groot and Mazur [9] showed that if separation due to thermal diffusion occurred, it might even render an unstable system to a stable one. Sharma et al. [20 & 21] studied the problem of baro-diffusion in a binary mixture of compressible viscous fluids set in motion due to an infinite disk rotation. Hurle and Jake man [10] discussed the effect of a temperature gradient on diffusion of a binary mixture. In all these investigations, it has been found that an increase in the pressure gradient or the temperature gradient or both could enhance the separation process.Ferdows et al. [6] investigate numerically the thermal radiation interaction with convection in a boundary layer flow at a vertical plate with variable suction. In the present paper we investigate the thermal radiation interaction on an absorbing emitting fluid permitted by a transversely applied magnetic field past a moving vertical porous plate embedded in a porousmedium with time dependent suction and temperature.

Maleque and Alam [14] numerically studied free convection and mass transfer characteristics for a unsteady magneto hydrodynamic flow of an electrically conducting viscous incompressible fluid past an infinite vertical porous plate with Dufour and Soret effects. Alam et al. [1] numerically studied Dufour and Soret effects on

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combined free-forced convective and mass transfer flow past a semi infinite vertical flat plate under the influence of transversely applied magnetic field. Raju et al.[18] discussed Soret effects due to natural convection between heated inclined plates with magnetic field. The Soret effect, for instance, has been utilized for isotope separation and in mixtures between gases with very light molecular weight (H_2, He). Therefore, the main objective of this paper is to study the Soret effects due to natural convection between heated inclined parallel plates with magnetic field. In this work, a binary mixture of incompressible viscous thermally and electrically conducting fluids sheared between two inclined parallel plates in presence of a constant uniform transverse magnetic field has been considered in this paper. Using the expressions for velocity and temperature distribution as derived by Osterle and Young [17], the effect of magnetic field on the concentration distribution of the rarer component of a binary fluid mixture has been investigated.

3. FORMULATION OF THE PROBLEM

The binary fluid mixture of thermally and electrically conducting viscous incompressible fluids is sheared between two infinitely wide inclined plates at y = -d and y = d separated by distance 2d. The plates are maintained at uniform temperature T_1 which exceeds the ambient temperature T_o ($T_o < T_1$). A transverse magnetic field of uniform strength is applied perpendicular to the plates. The flow of the fluid due to buoyancy force is in the direction parallel to the plates and is of magnitude 'u', hence, it is considered to be symmetric about the origin. The induced magnetic field is of the order of the product of magnetic Reynolds number and imposed magnetic field. As the fully developed natural convection flow of a fluid with very small electrical conductivity is considered here, it is the case of low magnetic Reynolds number and hence the induced magnetic field due to the weak applied magnetic field may be neglected. In fully developed flow, the pressure distribution must be hydrostatic, hence

$$\frac{\partial p}{\partial x} = -\rho_0 g \tag{1}$$

In this case, the density (ρ) varies slightly from point to point because of the variation in temperature T and can be expressed as

$$\rho = \rho_0\left[1-\beta\left(T-T_0\right)\right] \tag{2}$$

which is well known Boussinesq approximation, where

$$\beta = -\frac{1}{\rho}\left(\frac{\partial p}{\partial T}\right)_{\rho} \tag{3}$$

$$\upsilon\frac{\partial^2 u}{\partial y^2} + \beta g(T-T_0)\sin\psi - \left(\frac{\sigma B_0^{\,2}}{\rho}\right)u = 0 \tag{4}$$

$$k\frac{\partial^2 T}{\partial y^2} + \rho\upsilon\left(\frac{\partial u}{\partial y}\right)^2 - \sigma B_0^{\,2}u^2 - \frac{\partial q_r^{'}}{\partial y} = 0 \tag{5}$$

$$\frac{\partial}{\partial y}\left(\frac{\partial C_1}{\partial y} + S_T C_1\frac{\partial T}{\partial y}\right) = 0 \tag{6}$$

$$\frac{\partial q_r}{\partial y} = 4\alpha^2(T-T_0) \tag{7}$$

The corresponding the boundary conditions

$$u = 0, T = T_1, C = C_1 \text{ at } y = d \tag{8}$$

$$\frac{du}{dy} = 0, \frac{dT}{dy} = 0, \frac{dC}{dy} = 0 \quad \text{at} \quad y = 0 \tag{9}$$

The equation of continuity suggests that

$$u = u(y) \tag{10}$$

By using (11) and the following non dimensional parameters

$$U=\frac{\upsilon u}{g\beta d^2\left(T_1-T_0\right)},\theta=\frac{T-T_0}{T_1-T_0},\ C_1=CC_0,\ Y=\frac{y}{d},\ M=B_0 d\sqrt{\frac{\sigma}{\rho\upsilon}},\ t_d=S_T(T_1-T_0),$$

$$N=\frac{\rho g^2\beta^2 d^4(T_1-T_0)}{\upsilon k},\quad Ra=\frac{4\alpha^2 d^2}{k} \tag{11}$$

The non dimensional form of equations 4 to 6 are

$$\frac{d^2U}{dY^2}+\theta\sin\psi-M^2U=0 \tag{12}$$

$$\frac{d^2\theta}{dY^2}+N\left(\frac{dU}{dY}\right)^2+M^2NU^2-Ra\theta=0 \tag{13}$$

$$\frac{d}{dY}\left[\frac{dC}{dY}+t_d C\frac{d\theta}{dY}\right]=0 \tag{14}$$

The boundary conditions on velocity, temperature and concentration in terms of dimensionless quantities are

U=0,θ=1andC=1atY=1 (15)

$$\frac{dU}{dY}=0,\frac{d\theta}{dY}=0,\frac{dC}{dY}=0 \text{ at Y=0} \tag{16}$$

4. SOLUTION OF THE PROBLEM

The solution of equations (12) and (13) under the boundary conditions (15) and (16) have been developed by Osterle and Young12, by perturbing the velocity and temperature as

$$U=U_0+\phi N \quad \text{and} \quad \theta=\theta_0+\varepsilon N \tag{17}$$

(i). Zeroth order equations

$$\frac{d^2U_0}{dY^2}+\theta_0\sin\psi-M^2U_0=0 \tag{18}$$

$$\frac{d^2\phi}{dY^2}+\varepsilon\sin\psi-M^2\phi=0 \tag{19}$$

(ii). First order equations

$$\frac{d^2\theta_0}{dY^2}-Ra\theta_0=0 \tag{20}$$

$$\frac{d^2\varepsilon}{dY^2}+M^2{U_0}^2+\left(\frac{dU_0}{dY}\right)^2-\varepsilon Ra=0 \tag{21}$$

The corresponding boundary conditions

$$U_0=0,\phi=0,\theta_0=1,\varepsilon=0 \text{ at Y = 1} \tag{22}$$

$$\frac{dU_0}{dY}=0,\frac{d\phi}{dY}=0,\frac{d\theta_0}{dY}=0,\frac{d\varepsilon}{dY}=0 \quad \text{at Y = 0} \tag{23}$$

Solving Eqs. (18) to (21) under the boundary conditions (22) and (23), it is obtained that

$$U_0=\frac{\sin\psi}{M^2}\left[\sec h\sqrt{Ra}\cosh\sqrt{Ra}\,y-\sec hM\cosh My\right] \tag{24}$$

$$\theta_0=\sec h\sqrt{Ra}\cosh\sqrt{Ra}\,y \tag{25}$$

$$\varepsilon=\frac{\sin^2\psi}{M^2}\Bigg[\sec h\sqrt{Ra}\cosh\sqrt{Ra}Y\Bigg\{\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}+\frac{1}{2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{4M^2-Ra}+\frac{1}{Ra}\Bigg)$$

$$-\frac{\sqrt{Ra}}{M}\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}-\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)+\frac{\sec h^2\sqrt{Ra}}{Ra}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}-\frac{1}{2}\Bigg)$$

$$+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{4M^2-Ra}-\frac{1}{Ra}\Bigg)-\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}+\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)\Bigg\}$$

$$-\Bigg\{\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)Y}{6}+\frac{1}{2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)Y}{4M^2-Ra}+\frac{1}{Ra}\Bigg)$$

$$-\frac{\sqrt{Ra}}{M}\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)Y}{\left(\sqrt{Ra}+M\right)^2-Ra}-\frac{\cosh\left(\sqrt{Ra}-M\right)Y}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)+\frac{\sec h^2\sqrt{Ra}}{Ra}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)Y}{6}-\frac{1}{2}\Bigg)$$

$$+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)Y}{4M^2-Ra}-\frac{1}{Ra}\Bigg)-\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)Y}{\left(\sqrt{Ra}+M\right)^2-Ra}+\frac{\cosh\left(\sqrt{Ra}-M\right)Y}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)\Bigg\}\Bigg] \qquad (26)$$

$$\phi=\frac{\sin^3\psi}{M^2}\Bigg[\sec hM\cosh MY\Bigg(\frac{1}{Ra-M^2}\Bigg\{\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}+\frac{1}{2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{4M^2-Ra}+\frac{1}{Ra}\Bigg)$$

$$-\frac{\sqrt{Ra}}{M}\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}-\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)+\frac{\sec h^2\sqrt{Ra}}{Ra}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}-\frac{1}{2}\Bigg)$$

$$+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{4M^2-Ra}-\frac{1}{Ra}\Bigg)-\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}+\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)\Bigg\}$$

$$-\Bigg\{\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6\left(4Ra-M^2\right)}-\frac{1}{2M^2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{3M^2\left(4M^2-Ra\right)}-\frac{1}{RaM^2}\Bigg)$$

$$-\frac{\sqrt{Ra}}{M}\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\left(\sqrt{Ra}+M\right)^2-M^2\right)\left(\left(\sqrt{Ra}+M\right)^2-Ra\right)}-\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\left(\sqrt{Ra}-M\right)^2-M^2\right)\left(\left(\sqrt{Ra}-M\right)^2-Ra\right)}\Bigg)$$

$$+\frac{\sec h^2\sqrt{Ra}}{Ra}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6\left(4Ra-M^2\right)}+\frac{1}{2M^2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{3M^2\left(4M^2-Ra\right)}+\frac{1}{RaM^2}\Bigg)$$

$$-\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\left(\sqrt{Ra}+M\right)^2-M^2\right)\left(\left(\sqrt{Ra}+M\right)^2-Ra\right)}+\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\left(\sqrt{Ra}-M\right)^2-M^2\right)\left(\left(\sqrt{Ra}-M\right)^2-Ra\right)}\Bigg)\Bigg\}\Bigg)$$

$$-\Bigg\{\frac{\sec h\sqrt{Ra}\cosh\sqrt{Ra}Y}{Ra-M^2}\Bigg(\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}+\frac{1}{2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{\left(4M^2-Ra\right)}+\frac{1}{Ra}\Bigg)$$

$$-\frac{\sqrt{Ra}}{M}\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}-\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)+\frac{\sec h^2\sqrt{Ra}}{Ra}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)}{6}-\frac{1}{2}\Bigg)$$

$$+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)}{4M^2-Ra}-\frac{1}{Ra}\Bigg)-\sec h\sqrt{Ra}\sec hM\Bigg(\frac{\cosh\left(\sqrt{Ra}+M\right)}{\left(\sqrt{Ra}+M\right)^2-Ra}+\frac{\cosh\left(\sqrt{Ra}-M\right)}{\left(\sqrt{Ra}-M\right)^2-Ra}\Bigg)\Bigg\}-$$

$$\Bigg\{\frac{\sec h^2\sqrt{Ra}}{M^2}\Bigg(\frac{\cosh\left(2\sqrt{Ra}\right)Y}{6\left(4Ra-M^2\right)}-\frac{1}{2M^2}\Bigg)+\frac{\sec h^2 M}{2}\Bigg(\frac{\cosh(2M)Y}{3M^2\left(4M^2-Ra\right)}-\frac{1}{RaM^2}\Bigg)$$

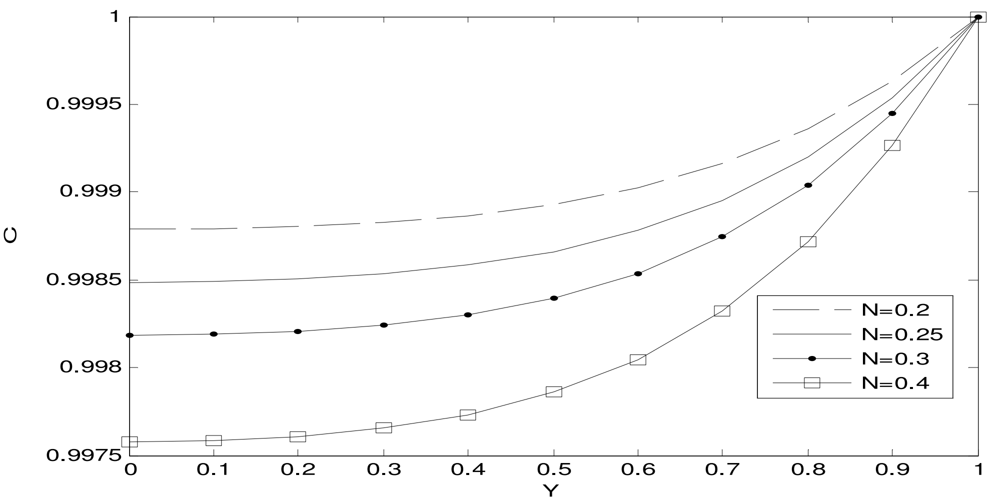
$$-\frac{\sqrt{Ra}}{M}\operatorname{sec}h\sqrt{Ra}\operatorname{sec}hM\left(\frac{\cosh\left(\sqrt{Ra}+M\right)Y}{\left(\left(\sqrt{Ra}+M\right)^{2}-M^{2}\right)\left(\left(\sqrt{Ra}+M\right)^{2}-Ra\right)}-\frac{\cosh\left(\sqrt{Ra}-M\right)Y}{\left(\left(\sqrt{Ra}-M\right)^{2}-M^{2}\right)\left(\left(\sqrt{Ra}-M\right)^{2}-Ra\right)}\right)$$

$$+\frac{\operatorname{sec}h^{2}\sqrt{Ra}}{Ra}\left(\frac{\cosh\left(2\sqrt{Ra}\right)Y}{6\left(4Ra-M^{2}\right)}+\frac{1}{2M^{2}}\right)+\frac{\operatorname{sec}h^{2}M}{2}\left(\frac{\cosh\left(2M\right)Y}{3M^{2}\left(4M^{2}-Ra\right)}+\frac{1}{RaM^{2}}\right)$$

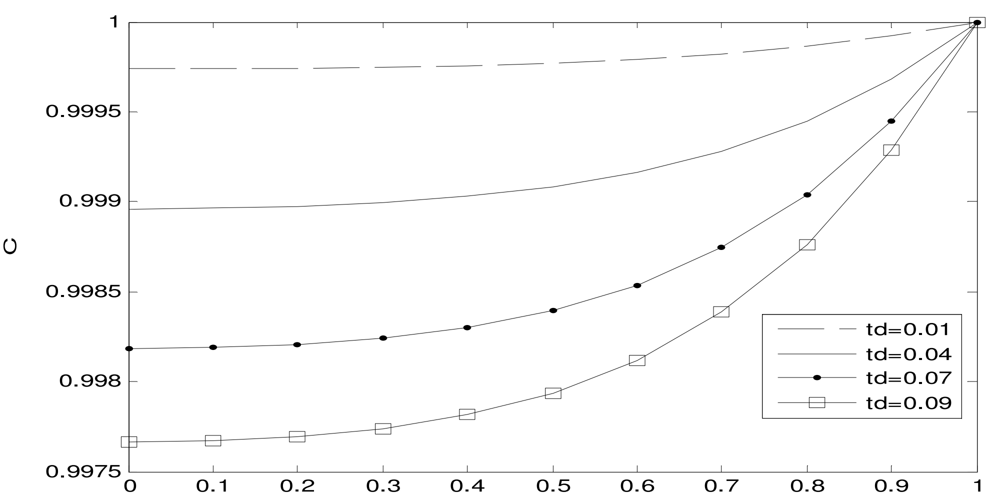
$$\left.\left.\left.\left.-\operatorname{sec}h\sqrt{Ra}\operatorname{sec}hM\left(\frac{\cosh\left(\sqrt{Ra}+M\right)Y}{\left(\left(\sqrt{Ra}+M\right)^{2}-M^{2}\right)\left(\left(\sqrt{Ra}+M\right)^{2}-Ra\right)}+\frac{\cosh\left(\sqrt{Ra}-M\right)Y}{\left(\left(\sqrt{Ra}-M\right)^{2}-M^{2}\right)\left(\left(\sqrt{Ra}-M\right)^{2}-Ra\right)}\right)\right\}\right)\right)\right] \quad (27)$$

Using the above expressions for under the boundary conditions the concentration function

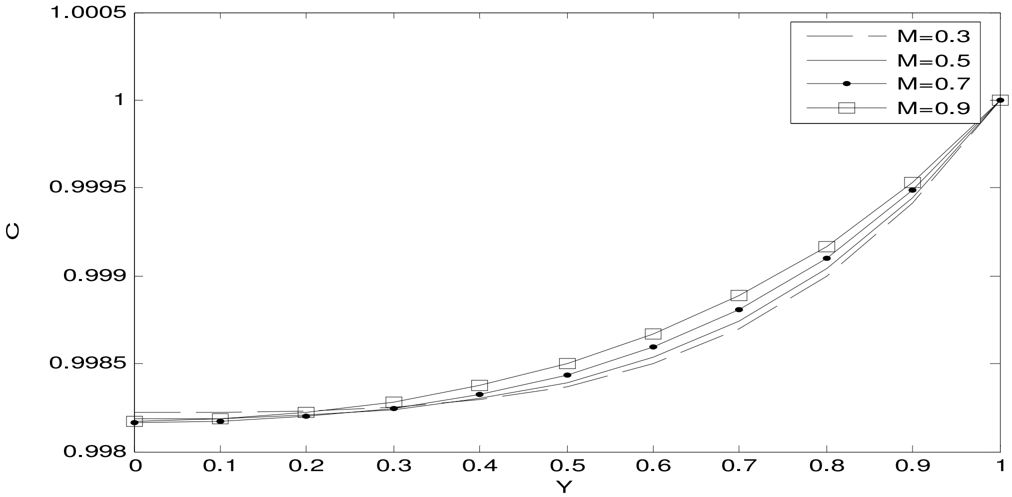
$$C = e^{td\,(1-\theta)} \quad (28)$$



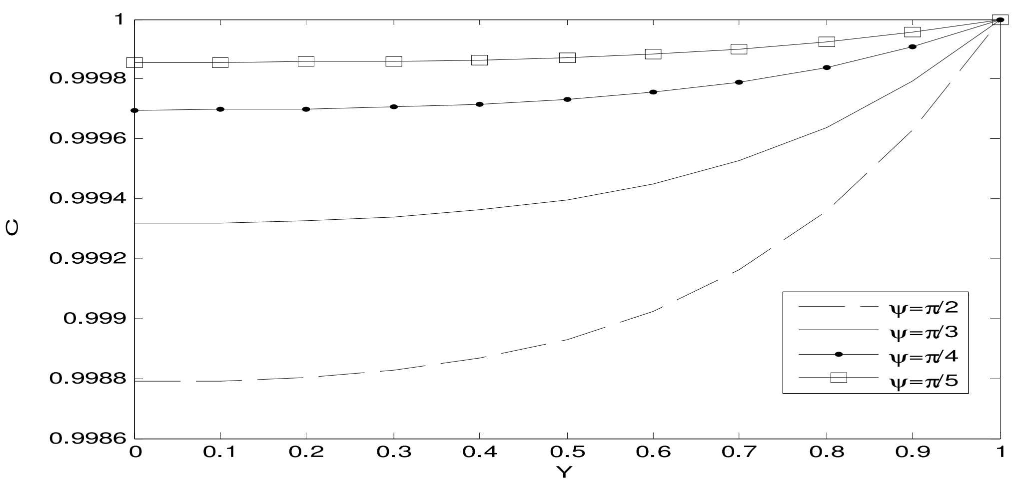
Fig(1): Graph of concentration profiles for different values of the dimensionless number measuring the buoyancy force ‘N’.



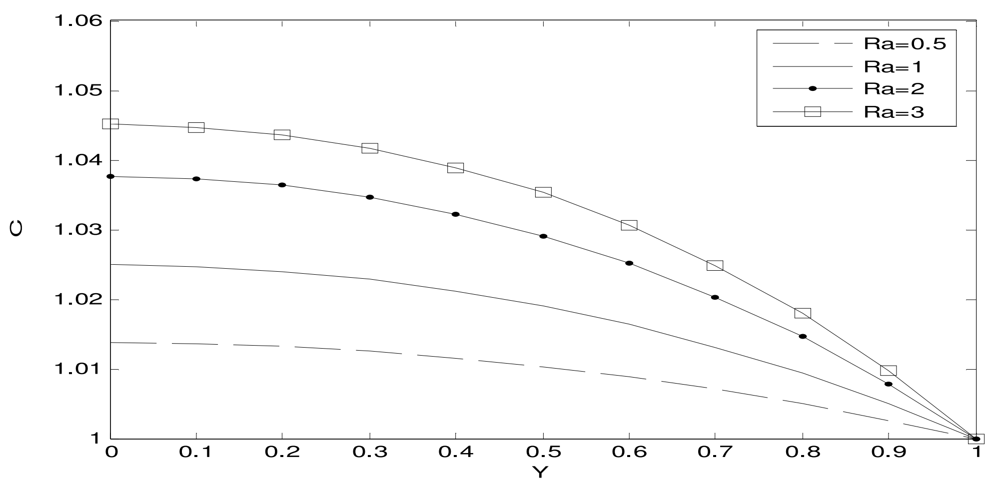
Fig(2): Graph of concentration profiles for different values of thermal diffusion number td.



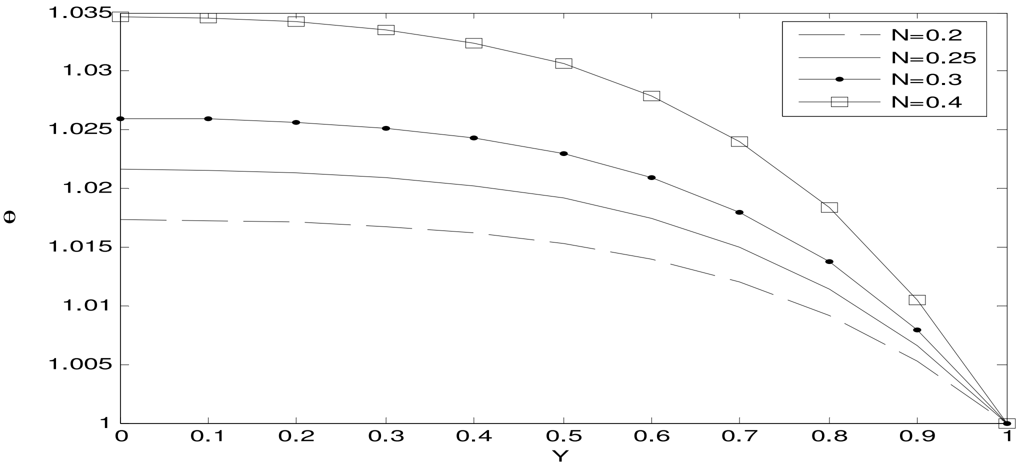
Fig(3): Graph of concentration profiles for different values of Hartmann number 'M'.



Fig(4): Graph of concentration profiles for different values of the angles that the plates make the horizontal ψ .



Fig(5): Graph of concentration profiles for different values of Radiation Parameter 'Ra'.



Fig(6): Graph of temperature profiles for different values of the dimensionless number measuring the buoyancy force 'N'.

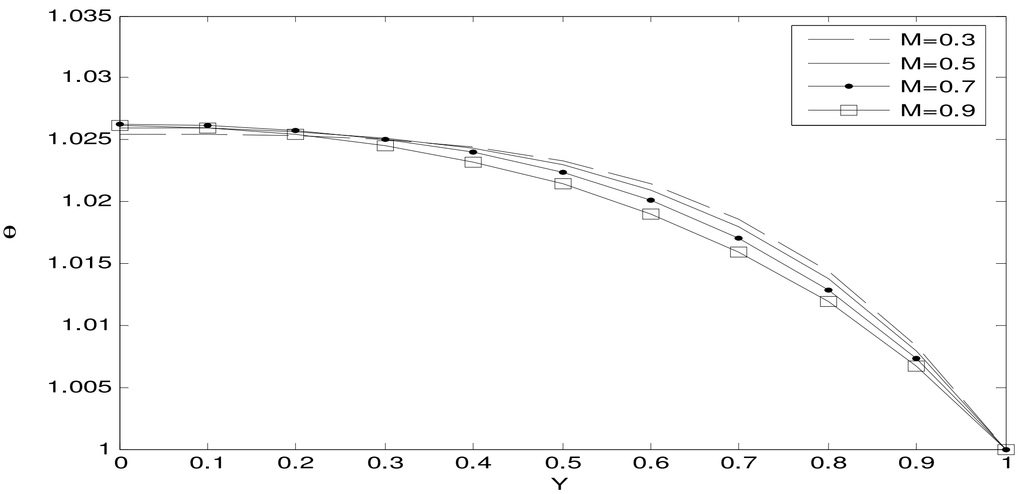
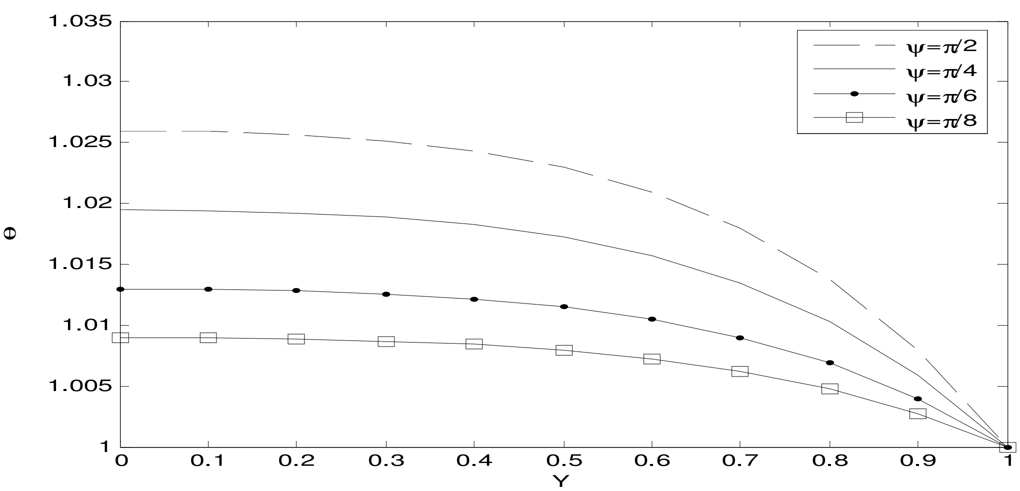


Fig (7): Graph of temperature profiles for different values of 'M'.



Fig(8): Graph of temperature profiles for different values of 'ψ'.

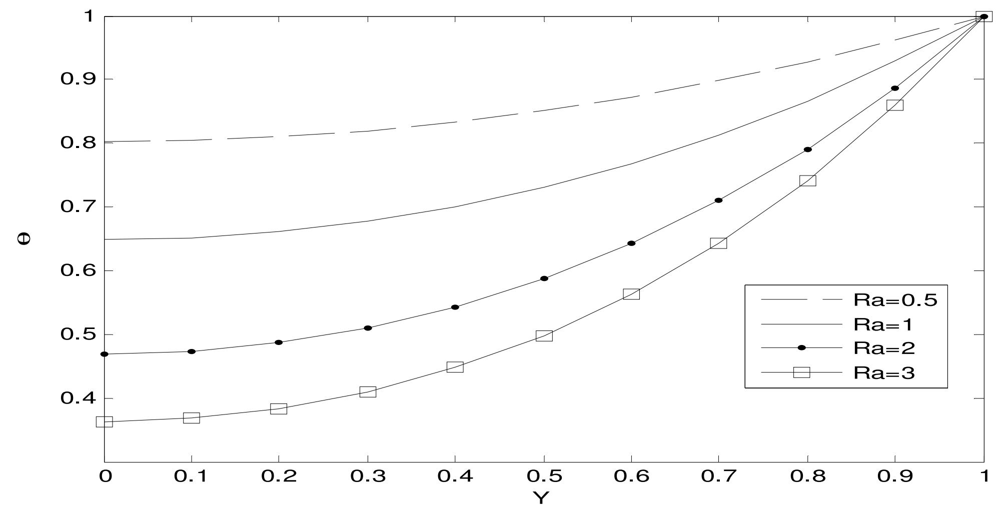


Fig (9): Graph of temperature profiles for different values of Radiation Parameter 'Ra'.

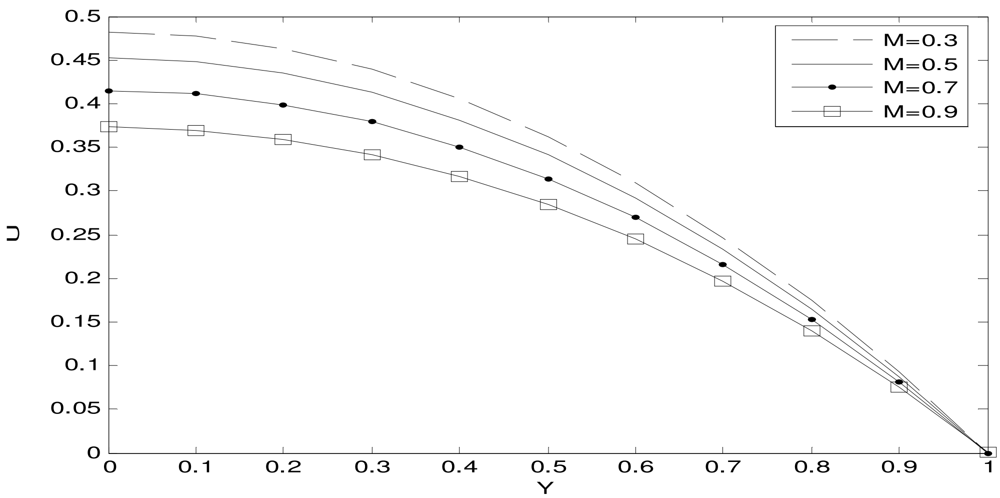


Fig (10): Graph of velocity profiles for different values of 'M' of ψ

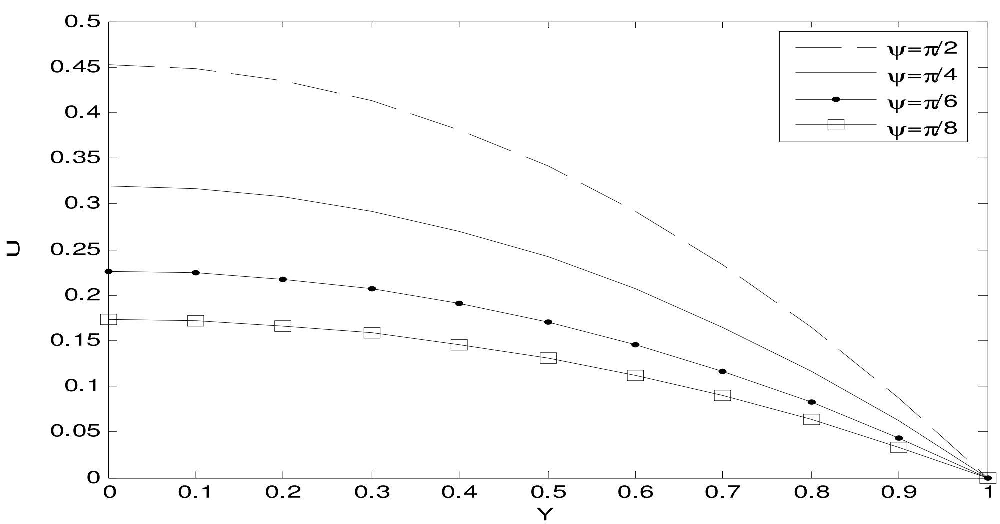


Fig (11): Graph of velocity profiles for different values of ψ

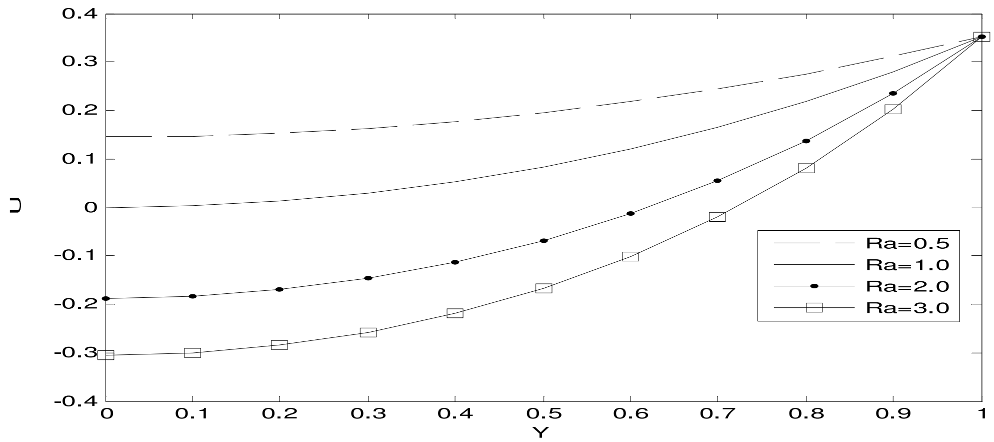


Fig (12): Graph of velocity profiles for different values of Radiation Parameter 'Ra'

5. RESULTS AND DISCUSSION

Numerical computations have been carried out for different values of Hartmann number (M), thermal diffusion number (td), the buoyancy force parameter (N) and the inclination angle (ψ). With the above mentioned flow parameters, the results are displayed in Figures 1-12 in terms of the concentration, temperature and velocity profiles. As the problem is carried out for the case of higher viscous force in compare to inertia force, the values of M are taken very small which results low intensity of magnetic field in the fluid flow as well as heat and mass transfer characteristics. Besides the values of td is chosen arbitrarily.

Figure 1 displays the concentration profiles for different values of N. From this figure, it is seen that rate of species separation decrease with the increase of N for fixed values of M = 0.5, td = 0.07, $Ra \to 0$ and ψ = π/2. Similar effect has been observed in Figure 2 for different values of td and fixed values of M = 0.5, N = 0.3, $Ra \to 0$ and ψ = π/2. This suggests that the rate of separation of species can be enhanced by decreasing the temperature difference between the plates. In Figure 3, concentration profiles are shown for various values of M with fixed values of N = 0.3, ψ = π/2, $Ra \to 0$ and td = 0.07. Interestingly, it is found in this figure that the rate of species separation enhances by the increase of magnetic field near the plates but reverse action takes place in the central part of the plates. As the magnetic field retards the fluid flow, the rarer and lighter components of the binary mixture increase in the central part of the plates with the decreasing strength of the magnetic field. Moreover, variations in concentration profiles with ψ are shown in Figure 4. From this figure, it is noticed that the concentration decreases with the increase of ψ. In Figure 5 in concentration profile are displayed for different values of Ra with fixed values of M = 0.5, ψ = π/2, N=0.3 and td = 0.07.From this figure, it is observed that the concentration increase with the decrease of Ra , In Figure 6 in temperature profiles are displayed for different values of N with fixed values of M = 0.5, ψ = π/2, $Ra \to 0$ and td = 0.07. From this figure, it is observed that the increase of N leads to the increase of temperature indicating that the rate of separation of species decreases with the increase of N. In Figure 7, the effects of magnetic field parameter M on temperature are shown. From this figure, we see that temperature decreases with the increase of M near the plates, but reverse action takes place at the centre. In Figure 8, variations of temperature are shown with the variation of ψ. From this figure, we observe that temperature increases with the increase of ψ. In figure 9 variations of temperature are shown with the variation of Ra . From this figure, we observe that temperature increases with the decrease of Ra .

Finally, the influences of M, ψ and Ra on velocity are shown in Figures 10 and 12 respectively. It is seen in Figure 10 that velocity decreases as M increases where as velocity increases with the increase of ψ for fixed values of N = 0.3, M = 0.5, $Ra \to 0$ and td = 0.07 as shown in Figure 11.It is seen in figure 12 that velocity increases as Ra decrease for fixed values of N=0.3, M=0.5 and ψ = π/2.

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