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Thermal Diffusion and Hall Effects on MHD Flow Past an Impulsively Started Inclined Plate with Variable Temperature and Mass Diffusion in The Presence of Thermal Radiation

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ABSTRACT
The effects of thermal diffusion and Hall current on unsteady magneto-hydrodynamic (MHD) flow past an impulsively started inclined plate with variable temperature and mass diffusion in the presence of radiation under the influence of uniform magnetic field applied normal to the flow has been carried out. The fluid is considered a gray, absorbing-emitting radiation but a non-scattering porous medium. The governing equations of the flow for this investigation are solved numerically by the Ritz finite element method. The results obtained are discussed with the help of graphs drawn for different flow parameters like thermal Grashof number, mass Grashof number, Prandtl number, Schmidt number, radiation parameter, magnetic parameter, Hall parameter, thermal diffusion parameter and angle of inclination. The numerical data for shearing stresses, Nusselt number and Sherwood number are presented in tables and then discussed.

Keywords: Hall current, magneto-hydrodynamic flow, radiation, thermal diffusion, inclined plate, mass diffusion.

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I. INTRODUCTION

Magneto-hydrodynamic (MHD) is concerned with the flow of conducting fluid in the presence of magnetic field and electric field. MHD flow with heat and mass transfer plays an important role in different areas of science and technology like chemical engineering, mechanical engineering, biological science, petroleum engineering, biomechanics, irrigation engineering and aerospace technology. Some applications of MHD flow are worth mentioning. It can be used in magnetic material processing, glass manufacturing control processes and purification of crude oil. The study of thermal diffusion effects has become increasingly important in engineering applications. For example, thermal diffusion effect has been utilized for isotopes separation in the mixture between gases with very light molecular weight (like hydrogen, helium) and medium molecular weight (like oxygen, ammonia). In the separation of such gases the thermal diffusion effect is found to be of magnitude that cannot be neglected. Further, the study of thermal diffusion, radiation and Hall current is important in describing different fluid models.

Hossian and Takhar [1] presented radiation effects on mixed convection along a isothermal vertical plate. Chamkha [2] investigates the thermal radiation and buoyancy effects on hydro-magnetic flow over an accelerating permeable surface with heat source /sink. Sattar and Maleque [3] studied unsteady MHD natural convection flow along an accelerated porous plate with Hall current and mass transfer in a rotating porous medium. Takhar et. al [4] studied MHD flow over a moving plate in a rotating fluid with magnetic field, Hall currents and free stream velocity. Prakash and Ogulu [5] have studied unsteady two-dimensional flow of a radiating and chemically reacting MHD fluid with time-dependent suction. Mbeledogu and Ogulu [6] have studied heat and mass transfer of an unsteady MHD natural convection flow of a rotating fluid past a vertical porous flat plate in the presence of radiative heat transfer. Sharma et. al [7] presented Hall effect on MHD mixed convective flow of a viscous incompressible fluid past a vertical porous plate, immersed in a porous medium with heat source/sink. Hitesh Kumar [8] studied radiative heat transfer with hydro-magnetic flow and viscous dissipation over a stretching surface in the presence of variable heat flux. Shanker et. al [9] presented radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation/absorption. Swarup et.al [10] investigates the effects of thermal diffusion on MHD free convection flow past a vertical porous plate taking viscous and Darcy resistance terms into account. Reddy and Rao [11] presented radiation and thermal diffusion effects on an unsteady MHD free convection mass transfer flow past an infinite vertical porous plate with Hall current and heat source. Ahmed and Sarma [12] studied MHD transient flow past an impulsively started infinite horizontal porous plate in a rotating system with Hall current. Reddy and Rao [13] studied heat and mass transfer of an unsteady MHD free convection flow over a moving isothermal vertical plate with variable mass diffusion in the presence of radiation. Ramana Reddy et al. [14] have studied MHD free convection heat and mass transfer flow of a viscous fluid past a semi-infinite vertical moving porous plate embedded in a porous medium in the presence of heat generation taking thermal diffusion into account. Reddy and Rao [15] presented the thermal diffusion effect on an unsteady MHD free convective mass transfer flow past a vertical porous plate with Ohmic dissipation by finite element method.

Hence, based on the above investigations and applications, the objective of the present paper is to analyze the effects of thermal diffusion and Hall current on unsteady magneto-hydrodynamic (MHD) flow past an impulsively started inclined plate with variable temperature and mass diffusion in the presence of radiation. The Ritz finite element method has been adopted to solve the dimensionless governing equations of flow, which is more economical from computational point of view. The behavior of the primary and secondary velocities, temperature, concentration, shearing stresses, Nusselt number and Sherwood number have been discussed for variations in the governing parameters.

II. MATHEMATICAL ANALYSIS

A two dimensional unsteady magneto-hydrodynamic (MHD) flow past an impulsively started inclined plate with variable temperature and mass diffusion in the presence of radiation with Hall current is considered. The flow is assumed to be directed in the x' direction, which is taken along the plate and the y' axis is taken normal it. The Hall current gives rise to the Lorentz force in the z' direction, which induces a cross flow in that direction. Consequently, the flow field becomes three dimensional. The z' axis is assumed to be normal to the $x'y'$ plane. A strong magnetic field B_0 is applied normal to the flow. Initially, it has been considered that the plate as well as the fluid is at the same temperature T_∞, the species concentration in the fluid taken as C'_∞. At $t' > 0$, the plate starts moving with velocity u_0 in its own plane in the presence of radiation, temperature of the plate is raised to T_w and the level of concentration near the plate raised linearly with time. The fluid is considered gray, absorbing-emitting radiation but a non-scattering porous medium. With these assumptions and those usually associated with the Boussinesq's approximations, the basic equations relevant to the problem are:

$$\frac{\partial u'}{\partial t'} = g\beta\cos a\left(T - T_\infty\right) + g\beta^*\cos a\left(C' - C'_\infty\right) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2(u' + mw')}{\rho(1+m^2)} \tag{1}$$

$$\frac{\partial w'}{\partial t'} = \nu\frac{\partial^2 w'}{\partial y'^2} + \frac{\sigma B_0^2(mu' - w')}{\rho(1+m^2)} \tag{2}$$

$$\rho C_p\frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y'^2} - \frac{\partial q_r}{\partial y'} \tag{3}$$

$$\frac{\partial C'}{\partial t'} = D_M\frac{\partial^2 C'}{\partial y'^2} + D_T\frac{\partial^2 T'}{\partial y'^2} \tag{4}$$

The corresponding initial and boundary conditions are:

$$\begin{aligned} &u' = 0, w' = 0, T = T_\infty, C' = C'_\infty && \text{for all } y',\ t' \le 0 \\ &u' = u_0, w' = 0, T = T_\infty + (T_w - T_\infty)\frac{u_0^2 t}{\upsilon}, C' = C'_\infty + \left(C'_w - C'_\infty\right)\frac{u_0^2 t}{\upsilon} && \text{at } y' = 0,\ t' > 0 \\ &u' \to 0, w' \to 0, T \to T_\infty, C' \to C'_\infty && \text{as } y' \to \infty \end{aligned} \tag{5}$$

Here, u' is primary velocity of the fluid, w' is secondary velocity of the fluid, g is acceleration due to gravity, $m(=\omega_e\tau_e)$ is the Hall parameter with ω_e is cyclotron frequency of electrons and τ_e is electron collision time, T is temperature of the fluid, C' is species concentration in the fluid, ν is kinematic viscosity of the fluid, ρ is density, C_p is specific heat at constant pressure, k is thermal conductivity of the fluid, D_M is mass diffusion coefficient, β is volumetric coefficient of thermal expansion, β^* is volumetric coefficient of concentration expansion, t is time, T_w is temperature of the plate at $y=0$, $C_w^{'}$ is species concentration at the plate $y=0$, B_0 is strength of the magnetic field, σ is electrical conductivity.

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y'} = -4a^*\sigma(T_\infty^4 - T^4) \tag{6}$$

where a^* is absorption constant. Considering the temperature differences within the flow sufficient small, T^4 can be expressed as the linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about a free stream temperature T_∞ and neglecting the higher-order terms,

$$T^4 \cong 4T_\infty^4 T - 3T_\infty^4 \tag{7}$$

By using equations (6) and (7), equation (3) reduces to

$$\rho C_p \frac{\partial T}{\partial t'} = k\frac{\partial^2 T}{\partial y'^2} + 16a^*\sigma T_\infty^3 (T_\infty - T) \tag{8}$$

It is convenient to introduce the following non-dimensional quantities into the basic equation, initial and boundary conditions in order to make them dimensionless.

$$u = \frac{u'}{u_0}, y = \frac{u_0 y'}{\nu}, t = \frac{u_0^2 t'}{\nu}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, C = \frac{C' - C'_\infty}{C'_w - C'_\infty}, S_c = \frac{\nu}{D_M}, P_r = \frac{\mu C_p}{k}, M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, w = \frac{w'}{u_0},$$

$$\mu = \rho\upsilon, R = \frac{16a^*\sigma\nu^2 T_\infty^3}{k u_0^2}, A = \frac{D_T (T - T_\infty)}{\nu(C_w^{'} - C_\infty^{'})}, G_r = \frac{g\beta\nu(T_w - T_\infty)}{u_0^3}, G_m = \frac{g\beta^*\nu\left(C'_w - C'_\infty\right)}{u_0^3}.$$

After substituting the above non-dimensional quantities into equations (1),(2),(4),(5) and (8), we obtain the governing equations of the flow in non-dimensional form are:

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + G_r \cos\alpha\theta + G_m \cos\alpha C - \frac{M(u + mw)}{(1 + m^2)} \tag{9}$$

$$\frac{\partial w}{\partial t} = \frac{\partial^2 w}{\partial y^2} + \frac{M(mu - w)}{(1 + m^2)} \tag{10}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{P_r}\theta \tag{11}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} + A\frac{\partial^2 \theta}{\partial y^2} \tag{12}$$

where G_r is thermal Grashof number, G_m is mass Grashof number, M is magnetic parameter, m is the Hall parameter, α is angle of inclination, P_r is Prandtl number, R is radiation parameter, S_c is Schmidt number, A is thermal diffusion parameter.
The corresponding boundary conditions in non-dimensional form are:

$$\begin{aligned} &u = 0, w = 0, \theta = 0, C = 0 && \text{for all } y, t \le 0 \\ &u = 1, w = 0, \theta = t, C = t && \text{at } y = 0, t > 0 \\ &u \to 0, w \to 0, \theta \to 0, C \to 0 && \text{as } y \to \infty \end{aligned} \tag{13}$$

III. SOLUTION OF THE PROBLEM

Finite element methods have been employed extensively to solving the boundary value problems by the authors in many challenging heat and mass transfer, biomechanics and metallurgical transport phenomena problems over the past few years. Here, we use the Ritz finite element method to solve the system of partial differential equations $(9)-(12)$ under the boundary conditions given in equation (13). The method entails the following steps.

1. Division of the whole domain into smaller elements of finite dimensions called “finite elements”.
2. Generation of the element equations using variational formulations.
3. Assembly of element equations as obtained in step 2.
4. Imposition of boundary conditions to the equations obtained in step 3.
5. Solution of the assembled algebraic equations.

The assembled equations can be solved by any of the numerical technique viz. Gauss-Seidal iteration method. Here, $y \to \infty$ is taken as $y_{\max} = 10$. An important consideration is that of *shape functions* which are employed to approximate actual functions. For one dimensional and two dimensional problems, the shape factions can be linear/quadratic and higher order. However, the suitability of the shape functions varies from problem to problem. Due to simple and efficient use in computations linear shape functions are used in the present problem. To prove convergence and stability of the Ritz finite element method, the computations are carried out by making a small changes time t and $y-$directions. For these slightly changed values, no significant change was observed in the values of primary velocity (u), secondary velocity (w), temperature (θ) and concentration (C). Hence, the Ritz finite element method is convergent and stable.

SHEARING STRESSES, RATES OF HEAT AND MASS TRANSFER

The shearing stresses at the plate in the x and z directions are given by

$$\tau_x = \left(\frac{\partial u}{\partial y}\right)_{y=0}, \tau_z = \left(\frac{\partial w}{\partial y}\right)_{y=0}$$

The heat and mass transfer rates (Nu and Sh , respectively) are expressed as

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}, Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

III. NUMERICAL RESULTS AND DISCUSSION

The effects of the thermal diffusion and Hall current on unsteady magneto-hydrodynamic (MHD) flow past an impulsively started inclined plate with variable temperature and mass diffusion in the presence of radiation under the influence of uniform magnetic field applied normal to the flow addressed in this study. The Ritz finite element method has been adopted to solve dimensionless governing equations of the flow. The numerical calculation has been carried out for dimensionless primary velocity (u) and secondary velocity (w), temperature (θ), concentration (C), shearing stresses τ_x, τ_z and heat and mass transfer coefficients (Nusselt number (Nu) and Sherwood number (Sh), respectively) for various values of the material parameters. Numerical results are presented in figures and tables. These results show the effect of the material parameters on the quantities mentioned.

Figure 1 depicts the temperature distribution for $P_r = 0.71$, as corresponds to air, $P_r = 1.00$, as corresponds to electrolytic solution and $P_r = 7.00$, as corresponds to water at room temperature and one atmosphere pressure. It is observed an increasing value of the Prandtl number leads to decrease in the temperature field. This is due to the fact that thermal conductivity of the fluid decreases with increasing Prandtl number results a decrease in the thermal boundary layer thickness. The effects of the radiation parameter R on the temperature distribution are presented in figure 2. It is seen that an increase in the radiation parameter decreases the temperature field. Also, from these two figures it can be seen that the temperature is observed to decrease steeply and exponentially away from the plate. Figure 3 displays the effects of time parameter t on the temperature distribution. It can be seen that an increase in the time parameter increases the temperature of the fluid. Figure 4 depicts the concentration distribution for $S_c = 0.22$ as corresponds to hydrogen, $S_c = 0.60$ as corresponds to water-vapour and $S_c = 0.78$ as corresponds to ammonia. It is observed that an increase in the Schmidt number leads to decrease in the concentration field. The effects of the thermal diffusion parameter A on the concentration distribution are presented in figure 5. It can be seen that increasing value of the thermal diffusion parameter increases the concentration field. Figure 6 shows the effects of time parameter t on the concentration distribution. It is observed that an increase in the time parameter increases the concentration of the fluid.

The effects of the Prandtl number P_r on primary and secondary velocity profiles are presented in figure 7. It can be seen that an increase in the Prandtl number decrease the in both primary and secondary velocities. Figure 8 shows the effects of the Schmidt number S_c on primary and secondary velocity profiles. It is seen that the primary and secondary velocities decreases as the value of the Schmidt number increases. Figure 9 displays the effects of radiation parameter R on the primary and secondary velocity profiles. It is observed that an increase in the radiation parameter decreases in both primary and secondary velocities. Figure 10 depicts the effects of magnetic parameter M on the primary and secondary velocity profiles. It is seen that an increase in the magnetic parameter leads to decrease in the primary velocity and reverse effect is observed in the secondary velocity. That is retarded under the effect of transverse magnetic field. This phenomenon is clearly supported by the physical reality. The effect of Hall parameter m on the primary and secondary velocity profiles are presented in figure 11. It can be seen that an increase the Hall parameter increases the primary and secondary velocity fields. Also, the effect of Hall parameter m has a minor increasing effect on the primary velocity whereas there is quit larger increasing effect on the secondary velocity which indicates and also supports the fact that the Hall parameter induces a cross-flow in the boundary layer. Figure 12 shows the effects of thermal diffusion parameter A on the primary and secondary velocity profiles. It is observed that an increase in the thermal diffusion parameter leads to increase in both primary and secondary velocities. The effects of the thermal Grashof number G_r on the primary and secondary velocity profiles are presented in figure 13. It is clear that both primary and secondary velocities increase with an increase in the thermal Grashof number. Here, the positive values of thermal Grashof number correspond to externally cooling of the plate. Figure 14 shows the effects of the mass Grashof number G_m on the primary and secondary velocity profiles. It is observed that the increasing value of mass Grashof number increases in both primary and secondary velocities. Also, it is observed that the peak values of the velocity increases rapidly near the plate due to cooling of the plate and after attaining a maximum value, it decreases as y increases. Figure 15 shows the effects of angle of inclination α on the primary and secondary velocity profiles. It can be seen that an increase in the angle of inclination parameter leads to decrease in both primary and secondary velocities of the fluid. The fact is that as the angle of inclination increases the effect of buoyancy force due to thermal diffusion decreases by a factor of $\cos\alpha$.

The numerical data for variations in the $P_r, S_c, R, M, m, A, G_r, G_m$ and α on the shearing stresses τ_x and τ_z are presented in table 1. It can be seen that an increase in P_r, S_c, R and α leads to decrease in both shearing stresses τ_x and τ_z. An increase in M leads to decrease in the shearing stress τ_x and reverse effect is observed in τ_z. An increase in m, A, G_r and G_m increases both shearing stresses τ_x and τ_z. Table-2 shows the effects of P_r, R and time parameter t on heat transfer coefficient (Nusselt number Nu). It is observed that an increase in P_r, R and t increases the heat transfer coefficient. Table-3 shows the effects of S_c, A and time parameter t on mass transfer coefficient (Sherwood number Sh). It is observed that an increase in S_c, t increases in the mass transfer coefficient whereas an increase in A decreases in the mass transfer coefficient

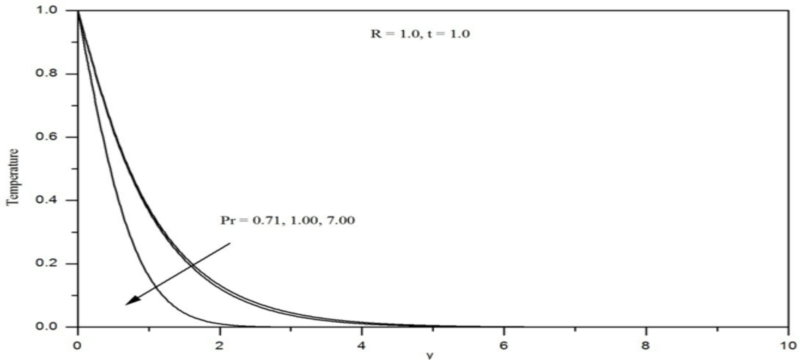

Fig.1: Temperature distribution for different values of P_r

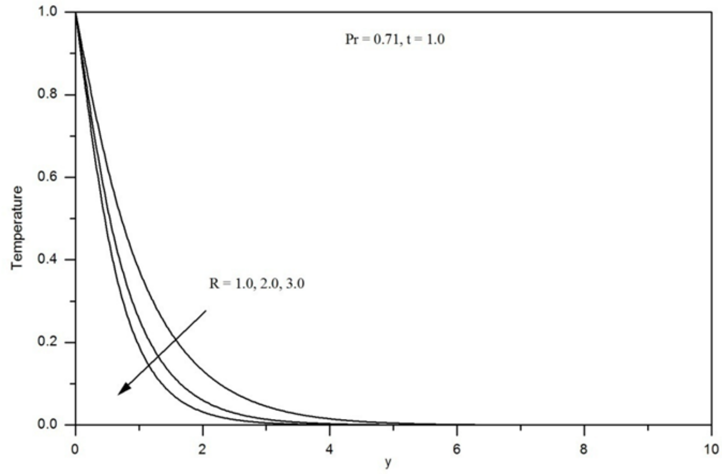

Fig.2: Temperature distribution for different values of R

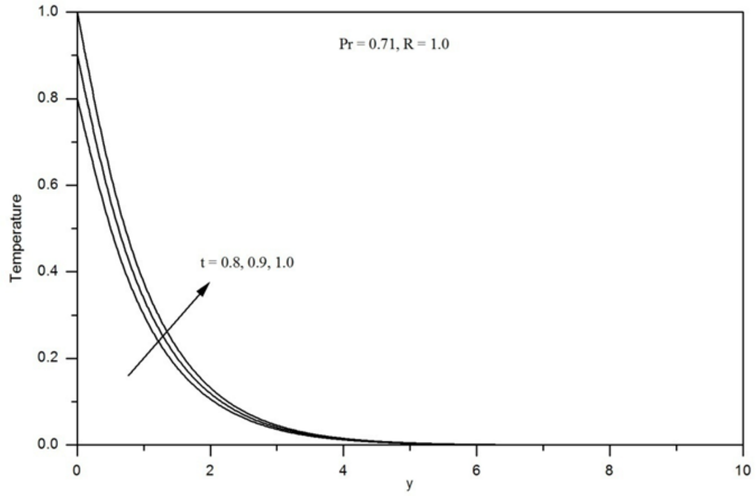

Fig.3: Temperature distribution for different values of t

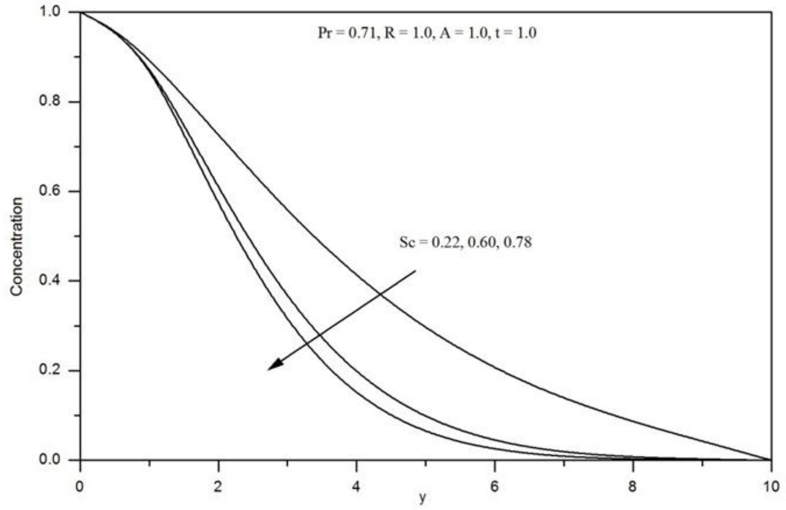

Fig.4: Concentration distribution for different values of S_c

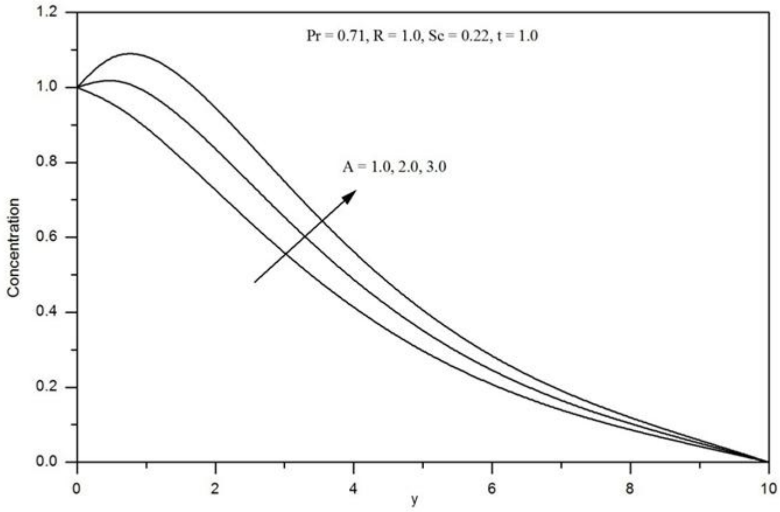

Fig.5: Concentration distribution for different values of A

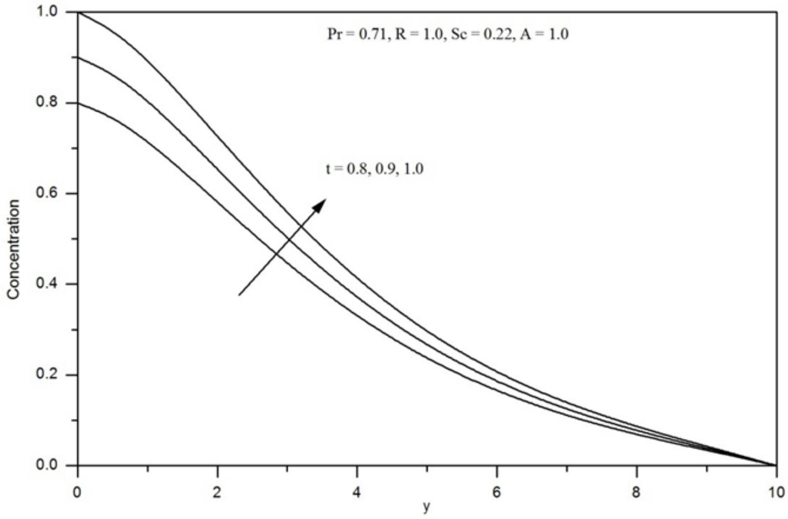

Fig.6: Concentration distribution for different values of t

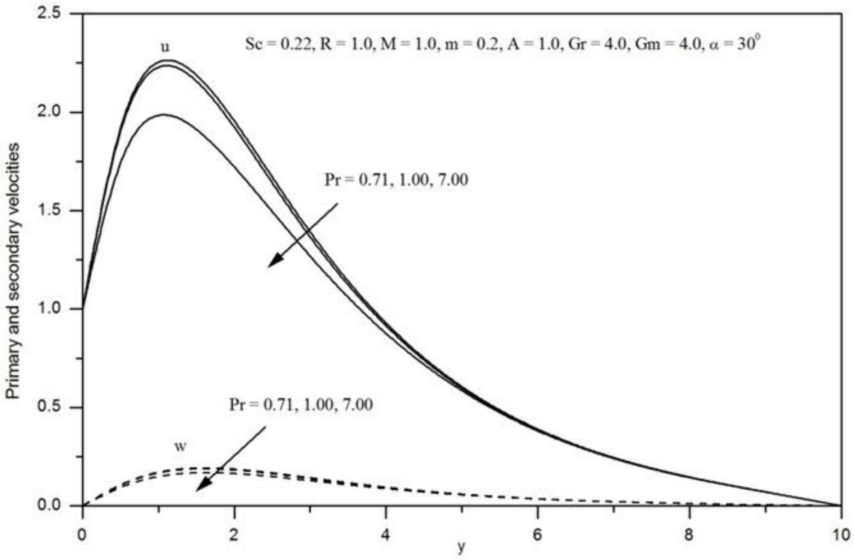

Fig.7: Primary and secondary velocity profiles for different values of P_r

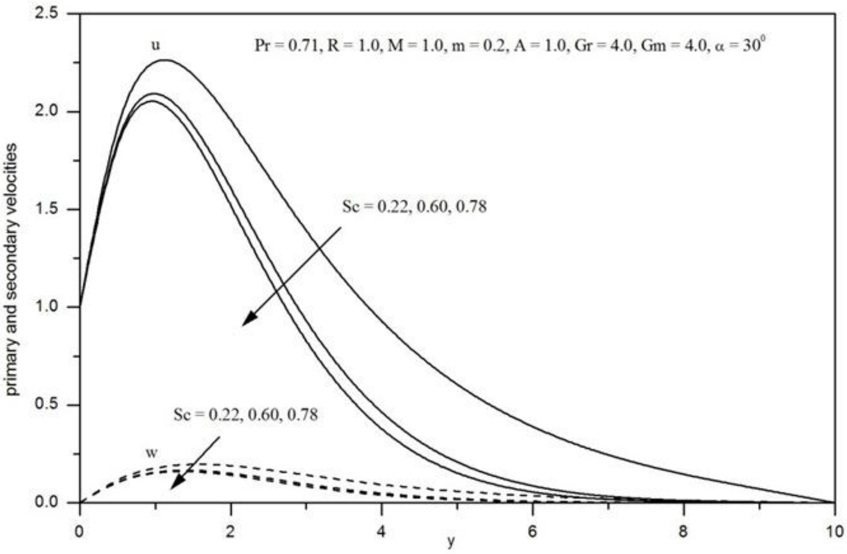

Fig.8: Primary and secondary velocity profiles for different values of S_c

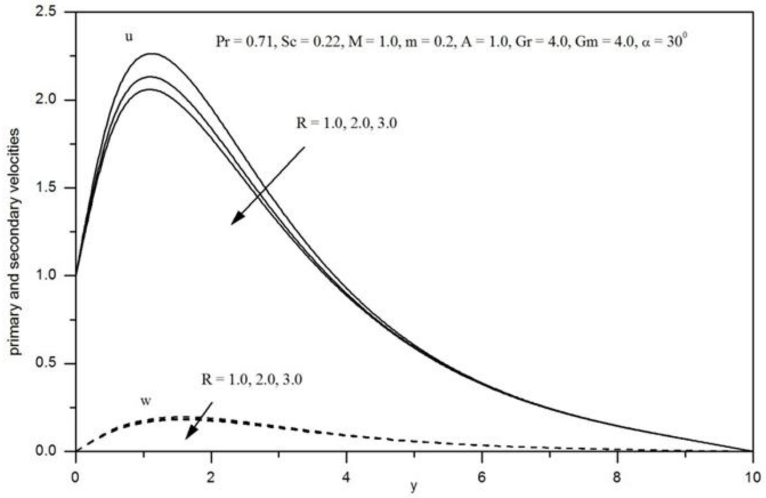

Fig.9: Primary and secondary velocity profiles for different values of *R*

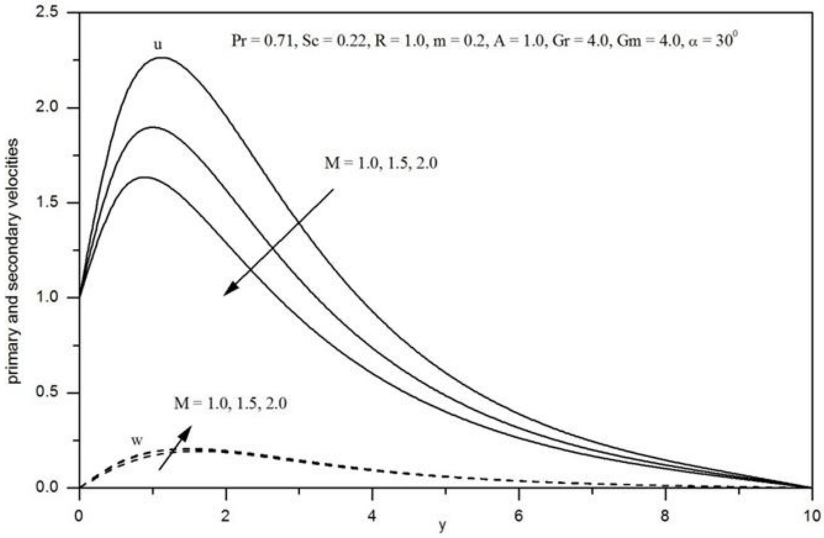

Fig.10: Primary and secondary velocity profiles for different values of *M*

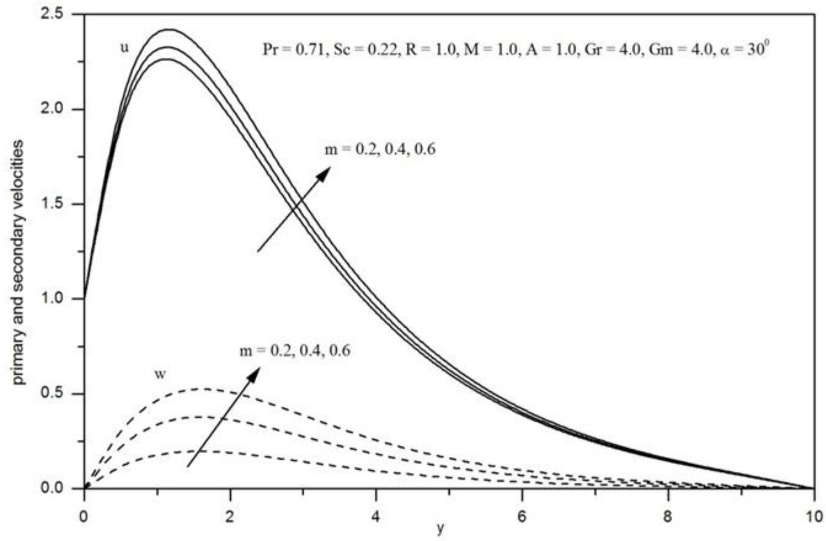

Fig.11: Primary and secondary velocity profiles for different values of *m*

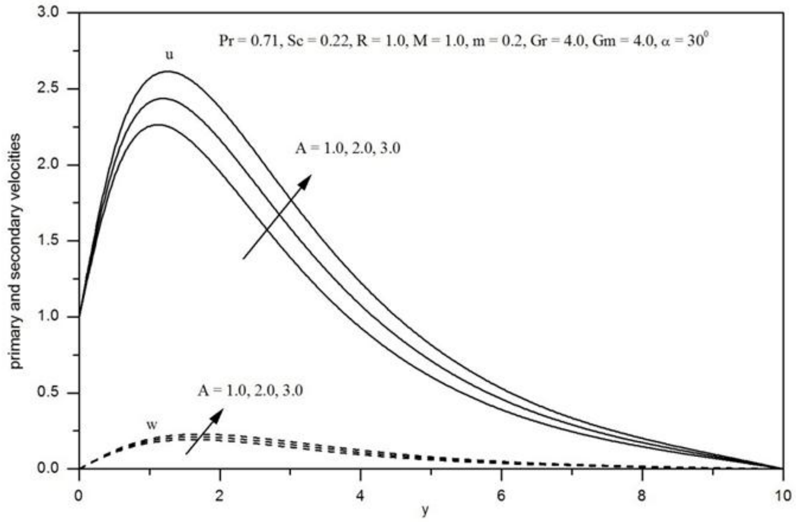

Fig.12: Primary and secondary velocity profiles for different values of *A*

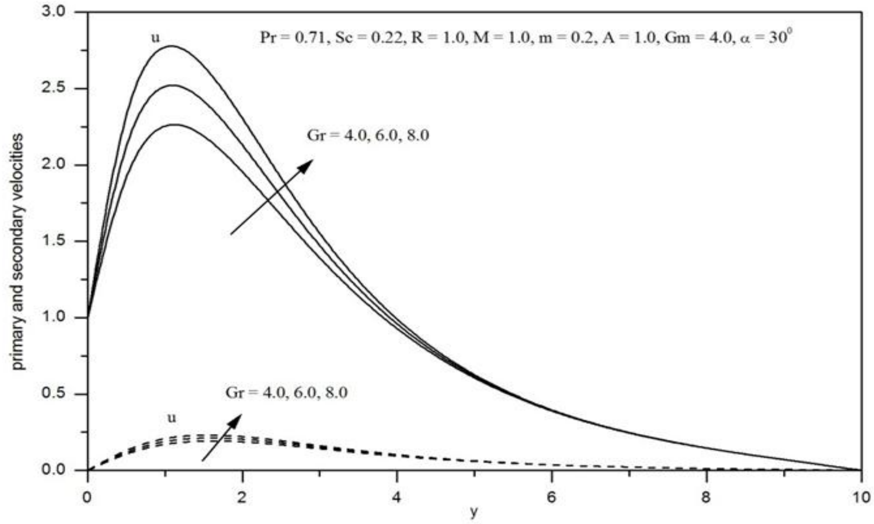

Fig.13: Primary and secondary velocity profiles for different values of G_r

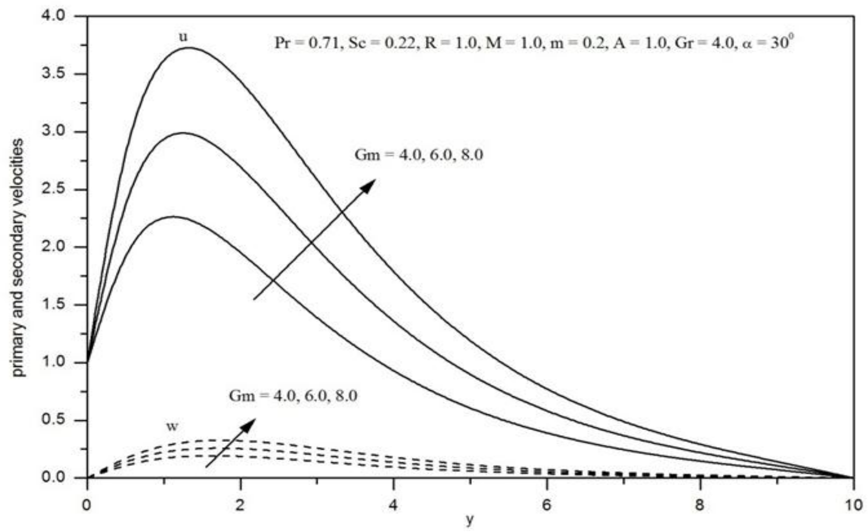

Fig.14: Primary and secondary velocity profiles for different values of G_m

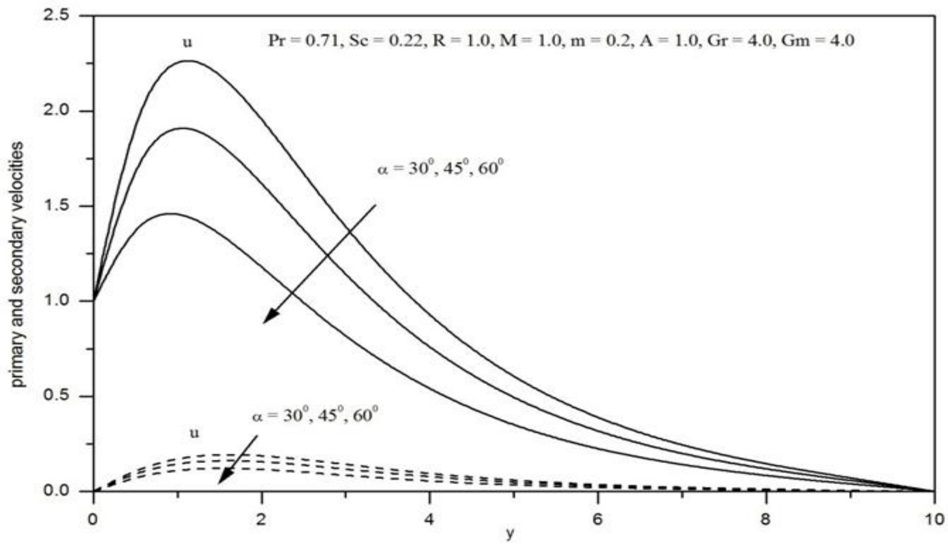

Fig.15: Primary and secondary velocity profiles for different values of α

Table-1: Numerical data for shearing stresses τ_x and τ_z for different values of $P_r, S_c, R, M, m, A,$ G_r, G_m and α.

P_r	S_c	R	M	m	A	G_r	G_m	α (in degree)	τ_x	τ_z
0.71	0.22	1.0	1.0	0.2	1.0	4.0	4.0	30	2.093974	0.232616
7.00	0.22	1.0	1.0	0.2	1.0	4.0	4.0	30	1.709738	0.205668
0.71	0.78	1.0	1.0	0.2	1.0	4.0	4.0	30	1.921828	0.207394
0.71	0.22	2.0	1.0	0.2	1.0	4.0	4.0	30	1.910686	0.221504
0.71	0.22	1.0	1.5	0.2	1.0	4.0	4.0	30	1.606452	0.267754
0.71	0.22	1.0	1.0	0.4	1.0	4.0	4.0	30	2.178526	0.438794
0.71	0.22	1.0	1.0	0.2	2.0	4.0	4.0	30	2.281174	0.246964
0.71	0.22	1.0	1.0	0.2	1.0	6.0	4.0	30	2.565564	0.258604
0.71	0.22	1.0	1.0	0.2	1.0	4.0	6.0	30	3.061082	0.297088
0.71	0.22	1.0	1.0	0.2	1.0	4.0	4.0	45	1.562218	0.199388

Table-2: Numerical data for heat transfer coefficient (Nu) for different values of P_r, R and t.

P_r	R	t	Nu
0.71	1.0	1.0	0.798794
7.00	1.0	1.0	1.179936
0.71	2.0	1.0	1.029424
0.71	1.0	0.9	0.718916

Table-3: Numerical data for mass transfer coefficient (Sh) for different values of S_c, A and t.

S_c	A	t	Sh
0.22	1.0	1.0	0.273144
0.78	1.0	1.0	0.544326
0.22	2.0	1.0	- 0.056976
0.22	1.0	0.9	0.067894

IV. CONCLUSIONS

The effects of thermal diffusion and Hall current on unsteady magneto-hydrodynamic (MHD) flow past an impulsively started inclined plate with variable temperature and mass diffusion in the presence of radiation has been carried out. The resulting systems of coupled partial differential equations were solved numerically by Ritz FEM. Numerical results were presented in figures and tables. These results obtained are show the effect of the material parameters on the quantities mentioned. It has been found that the radiation indeed affects the temperature, primary and secondary velocities and shearing stresses. As the radiation parameter increases the temperature as well as both primary and secondary velocities decrease. An increase in the Schmidt number leads to decrease in the concentration and both primary and secondary velocities. The effect of the Hall parameter has a minor increasing effect on the primary velocity, whereas there is a larger increasing effect on the secondary one, which indicates that the Hall current induces a cross flow in a free convective boundary layer. An increase in the thermal diffusion parameter increases in both primary and secondary velocities. These results are in very good agreement with those in the literature.

REFERENCES

[1] Hossian M. A and Takhar H. S. (1996). Radiation effects on mixed convection along a vertical plate with uniform surface temperature, Int. J. Heat and Mass Transfer, Vol.31, pp. 243 – 248.

[2] Chamkha A. J. (2000). Thermal radiation and buoyancy effects on hydro-magnetic flow over an accelerating permeable surface with heat source or sink, Int. J. Eng. Sci, Vol. 38, pp.1699 -1712.

[3] Abdus Sattar MD and Abdul Maleque MD (2000). Unsteady MHD natural convection flow along an accelerated porous plate with Hall current and mass transfer in a rotating porous medium, J. Energy, Heat and Mass Transfer, Vol.22, pp. 67-72.

[4] Takhar H. S, Chamkha A. J and Nath G (2002). MHD flow over a moving plate in a rotating fluid with magnetic field, Hall currents and free stream velocity, Int. J. Eng. Sci, Vol.40 (13), pp. 1511-1527.

[5] Prakash J and Ogulu A (2006). Unsteady two-dimensional flow of a radiating and chemically reacting MHD fluid with time-dependent suction, Indian J. Pure and Appl. Phys, Vol.44, pp. 805 – 810.

[6] Mbeledogu I. U and Ogulu A (2007). Heat and mass transfer of an unsteady MHD natural convection flow of a rotating fluid past a vertical porous flat plate in the presence of radiative heat transfer**,** Int. J. Heat and Mass Transfer, Vol.50, pp.1902 - 1908.

[7] Sharma B. K, Jha A. K and Chaudhary R.C (2007). Hall effects on MHD mixed convective flow of a viscous incompressible fluid past a vertical porous plate, immersed in a porous medium with heat source/sink. Rom. J. Phys, Vol.52, (5-7), pp. 487-503.

[8] Hitesh Kumar (2009). Radiative heat transfer with hydro-magnetic flow and viscous dissipation over a stretching surface in the presence of variable heat flux, Thermal Science, Vol.13, No. 2, pp. 441 - 450.

[9] Shanaker B, Prabhakar Reddy B and Ananad Rao J (2010). Radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation/absorption, Indian J. Pure and Appl. Phys, Vol.48, pp. 157-165.

[10] Swarup B Kumar P and Jha A (2010). Effects of thermal diffusion on MHD free convection flow past a vertical porous plate, Int. J. Stability and Fluid Mechanics, Vol.1, No. 1, pp. 43-54.

[11] Prabhakar Reddy B and Anand Rao J (2011). Radiation and thermal diffusion effects on an unsteady MHD free convection mass transfer flow past an infinite vertical porous plate with Hall current and heat source, J. Eng. Phys and Thermo-physics, Vol.84 (6), pp. 1369-1378.

[12] Ahmed N and Sarma H. K (2011). MHD transient flow past an impulsively started infinite horizontal porous plate in a rotating system with Hall current. Int. J. Appl. Math and Mech, Vol.7 (2), pp. 1-15.

[13] Prabhakar Reddy B and Anand Rao J (2011). Heat and mass transfer of an unsteady MHD free convection flow over a moving isothermal vertical plate with variable mass diffusion in the presence of radiation, Int. J. Appl. Mech and Engg, Vol.16 (3), pp. 821-833.

[14] Ramana Reddy G. V, Ramana Murthy Ch. V and Bhaskar Reddy N (2011). MHD flow over a vertical moving porous plate with heat generation by considering double diffusive convection, Int. J. Appl. Math and Mech, Vol.7(4), pp. 53 – 69.

[15] Prabhakar Reddy B and Anand Rao J (2011). Numerical solution of thermal diffusion effect on an unsteady MHD free convective mass transfer flow past a vertical porous plate with Ohmic dissipation, Int. J. Appl. Math and Mech, Vol.7(8), pp. 78 - 97.

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