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Numerical Study of Heat & Mass Transfer on an Unsteady MHD Flow Past a Vertical Accelerated Plate Considering Soret and Dufour Effects: FEM

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Abstract: The aim of this paper is to investigate the numerical study of heat and mass transfer on an unsteady MHD flow past a vertical accelerated plate considering Soret and Dufour effects. The governing nonlinear partial differential equations are solved by finite element method and the numerical results are obtained for velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number. The effects of different flow parameters on the flow variables are discussed and presented through graphs and tables. Finally, the numerical results for some special cases were compared with previous results to ensure the correctness of this numerical scheme and were found to be in excellent agreement.

Keywords: Soret and Dufour effects, Chemical reaction, MHD, Heat and Mass Transfer.

I. INTRODUCTION

The phenomenon of hydromagnetic flow with heat and mass transfer in an electrically conducting fluid past a porous plate embedded in a porous medium has attracted the attention of a good number of investigators because of its varied applications in many engineering problems such as MHD generators, plasma studies, nuclear reactors, oil exploration, geothermal energy extractions and in the boundary layer control in the field of aerodynamics. Heat transfer in laminar flow is important in problems dealing with chemical reactions and in dissociating fluids.

In view of its wide applications, Acharya *et al.* [1] have reported the problem of heat and mass transfer over an accelerating surface with heat source in presence of suction and blowing. Chamkha and Takhar [2] are used the blotter difference method to study laminar free convection flow of air past a semi-infinite vertical plate in the presence of chemical species concentration and thermal radiation effects. Chaudhary *et al.* [3] studied the effect of free convection effects on magnetohydrodynamic flow past an infinite vertical accelerated plate embedded in porous media with constant heat flux by using Laplace transform technique for finding the analytical solutions. Das *et al.* [4] investigated numerically the unsteady free convective MHD flow past an accelerated vertical plate with suction and heat flux.

Ibrahim [5] studied the effects of chemical reaction and radiation absorption on transient hydromagnetic natural convection flow with wall transpiration and heat source The unsteady free convective MHD flow with heat transfer past a semi-infinite vertical porous moving plate with variable suction has been studied by Kim [6]. Makinde *et al.* [7] discussed the unsteady free convective flow with suction on an accelerating porous plate. Sharma and Pareek [8] explained the behavior of steady free convective MHD flow past a vertical porous moving surface. Singh et al. [9] have analyzed the effect of heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction velocity. Singh and Thakur [10] have given an exact solution of a plane unsteady MHD flow of a non – Newtonian fluid. Soundalgekar [11] showed the effect of free convection on steady MHD flow of an electrically conducting fluid past a vertical plate.

Motivate by above reference work, it is proposed here to Numerical Study of Heat and Mass transfer on an unsteady MHD flow past a vertical accelerated plate considering Soret and Dufour effects by finite element method (Reddy [12] and bathe [13]) which is more economical from computational view point.

II. MATHEMATICAL FORMATION

We consider a two – dimensional flow of an incompressible electrically conducting viscous fluid along an infinite non – conducting vertical flat plate through a porous medium. Initially, for time $t' \le 0,$ the plate and the fluid are at some temperature T'_∞ in a stationary condition with the same species concentration C'_∞ at all points. The x' – axis is taken along the plate in the vertically upward direction and the y' – axis is taken normal to the plate as shown in figure 1. At time $t' > 0$ a magnetic field of uniform strength is applied in the direction of y' – axis and the induced magnetic field is neglected. At time $t' > 0$, the plate starts moving impulsively in its own plane with a velocity U_o with heat supplied to the plate at constant rate.

The governing equations of motion and energy under usual Boussinesq approximation are given by:

$$\frac{\partial v'}{\partial y'} = 0 \Rightarrow v' = -v'_o \text{ (Constant)} \tag{1}$$

$$\frac{\partial u'}{\partial t'} = \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_o^2 u'}{\rho} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \frac{\nu u'}{K'} \tag{2}$$

$$\frac{\partial T'}{\partial t'} = \frac{\kappa}{\rho c_p} \frac{\partial^2 T'}{\partial y'^2} + \frac{D_m k_T}{c_S c_p} \frac{\partial^2 C'}{\partial y'^2} \tag{3}$$

$$\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} - K'_r C' + \frac{D_m k_T}{T_m} \frac{\partial^2 T'}{\partial y'^2} \tag{4}$$

With the following initial and boundary conditions:

$$\left.\begin{array}{l} t' \le 0 : \{u' = 0, T' = T'_\infty, C' = C'_\infty \ \ for\ all\ y' \\ t' > 0 : \left\{\begin{array}{l} u' = U_o, \ \dfrac{\partial T'}{\partial y'} = -\dfrac{q'}{\kappa'}, C' = C'_w \ at\ y' = 0, \\ u' = 0, T' = T'_\infty, \ C' = C'_\infty\ at\ y' \to \infty \end{array}\right. \end{array}\right\} \tag{5}$$

Introducing the following dimensionless quantities:

$$\left.\begin{array}{l} t = \dfrac{t' U_o^2}{\nu}, \ y = \dfrac{U_o y'}{\nu}, \ u = \dfrac{u'}{U_o}, \ \Pr = \dfrac{\mu C_p}{\kappa}, \\ Sc = \dfrac{\nu}{D}, \ M = \dfrac{\sigma B_o^2 \nu}{\rho U_o^2}, Gr = \dfrac{\nu g\beta(T'_w - T'_\infty)}{U_o^{\ 3}}, \\ Gc = \dfrac{g\beta^* \nu (C'_w - C'_\infty)}{U_o^3}, K = \dfrac{U_o^2 K'}{\nu^2}, \\ \theta = \dfrac{T' - T'_\infty}{T'_w - T'_\infty}, \ C = \dfrac{C' - C'_\infty}{C'_w - C'_\infty}, \\ Du = \dfrac{D_m k_T (C'_w - C'_\infty)}{c_S c_P (T'_w - T'_\infty)}, Sr = \dfrac{D_m k_T (T'_w - T'_\infty)}{\nu T_m (C'_w - C'_\infty)}, \\ k_r = \dfrac{K'_r \nu}{U_0^2} \end{array}\right\} \tag{6}$$

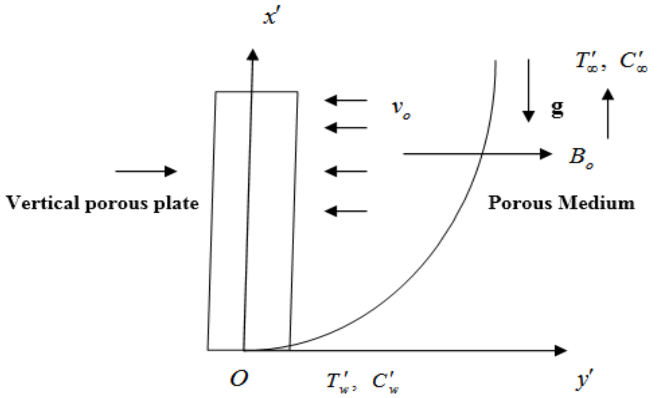

Figure 1. Physical sketch and geometry of the problem

Using dimensionless quantities from (6), the equations (2), (3) and (4) reduces to

$$\frac{\partial^2 u}{\partial y^2}+(Gr)\theta+(Gc)C=\frac{\partial u}{\partial t}+(M+\frac{1}{K})u \quad (7)$$

$$\frac{\partial^2 \theta}{\partial y^2}=(\Pr)\frac{\partial \theta}{\partial t}-(\Pr)(Du)\left(\frac{\partial^2 C}{\partial y^2}\right) \quad (8)$$

$$\frac{\partial^2 C}{\partial y^2}=(Sc)\frac{\partial C}{\partial t}-(Sc)(Sr)\left(\frac{\partial^2 \theta}{\partial y^2}\right)+(Sc)(k_r)C \quad (9)$$

With the following initial and boundary conditions,

$$\left.\begin{array}{l} t\le 0:\{u=0,\ \theta=0,\ C=0\ \ for\ all\ y \\ t>0:\left\{\begin{array}{l} u=1,\ \dfrac{d\theta}{dy}=-1,\ C=1\ at\ y=0 \\ u=0,\ \theta=0,\ C=0\ at\ y\to\infty \end{array}\right. \end{array}\right\} \quad (10)$$

The solutions of system of equations are obtained by using Thomas algorithm for velocity, temperature and concentration. In order to prove the convergence and stability of finite element method, the same C-Programme was run with smaller values of h and k no significant change was observed in the values of $u,\ \theta$ and C. Hence the finite element method is stable and convergent. The skin friction, Nusselt number and Sherwood number are important. Physical parameters for this type of boundary layer flow and are given by

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

III. RESULTS and DISCUSSIONS

The values of the Prandtl number are chosen for Mercury ($\Pr$ = 0.025), Air at $25^o C$ and one atmospheric pressure ($\Pr$ = 0.71), Water ($\Pr$ = 7.00) and Water at $4^o C$ ($\Pr$ = 11.62). Hydrogen (Sc = 0.22), Helium (Sc = 0.30), Water – vapour (Sc = 0.60), Oxygen (Sc = 0.66) and Ammonia (Sc = 0.78). The y values vary from 0 to 4, and the velocity, temperature, and concentration tend to zero as y tends to 4. This is true for any value of y .The effects of these parameters on the velocity field have been analyzed with the help of figures (2) to (7).

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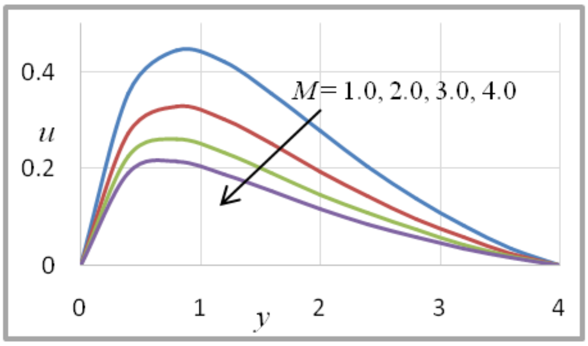

Fig.2. Effect of M on velocity profiles

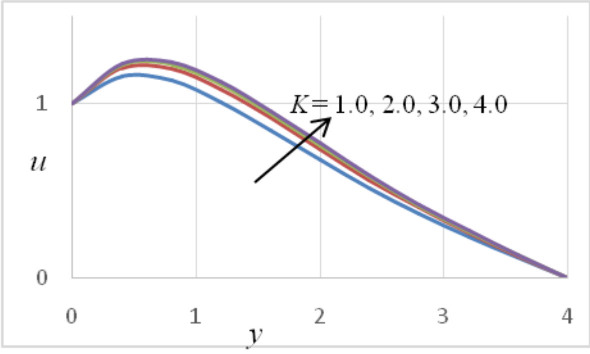

Fig.3. Effect of K on velocity profiles

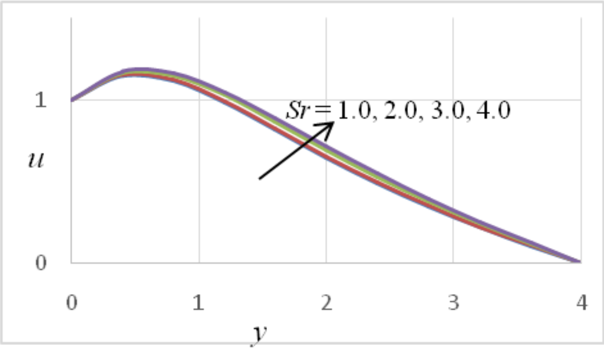

Fig.4. Effect of Sr on velocity profiles

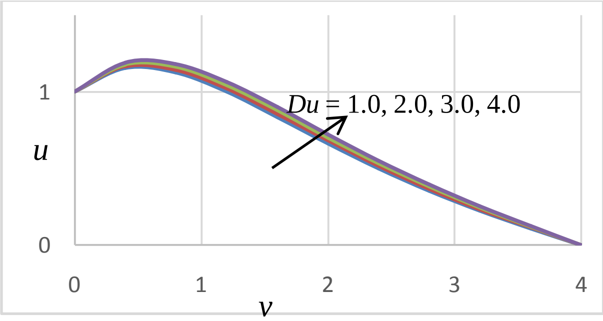

Fig.5. Effect of Du on velocity profiles

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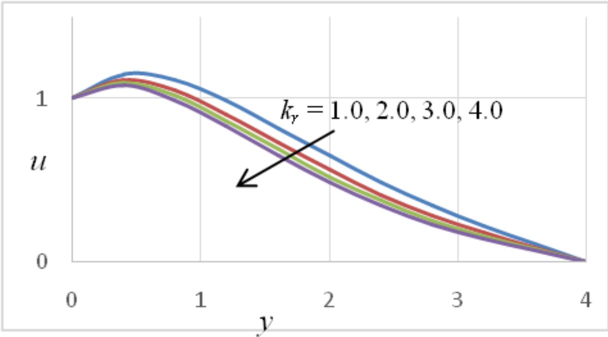

Fig.6. Effect of k_r on velocity profiles

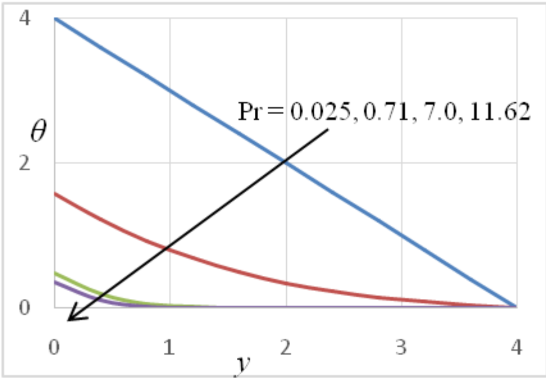

Fig.7. Effect of $\Pr$ on temperature Profiles

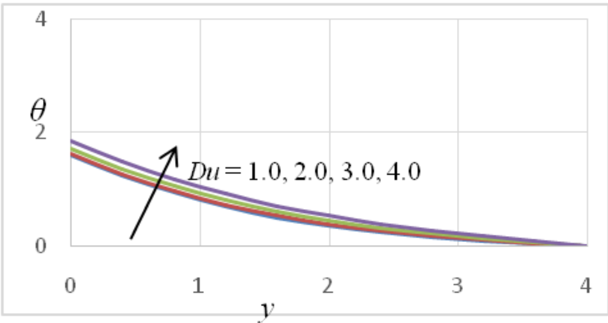

Fig.8. Effect of Du on temperature profiles

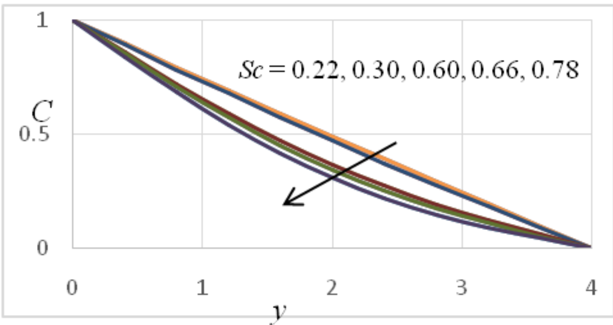

Fig.9. Effect of Sc on concentration profiles

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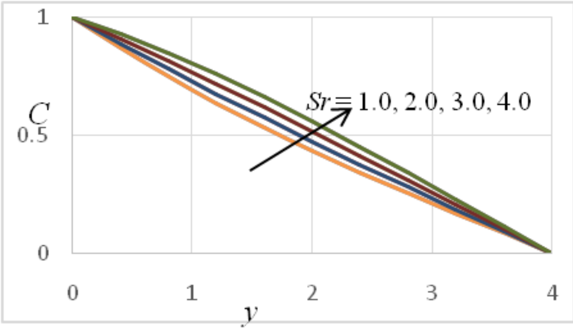

Fig.10. Effect of Sr on concentration profiles

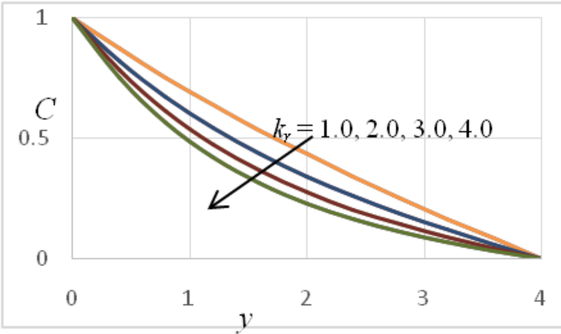

Fig.11. Effect of k_r on concentration profiles

The effect of Hartmann number M is shown in the figure (2). It is observed that the velocity of the fluid decreases with the increase of Hartmann number values. As expected, the velocity decreases with an increase in the Hartmann number. It is because that the application of transverse.

Figure (3) shows the effect of the permeability of the porous medium parameter (K) on the velocity distribution. As shown, the velocity is increasing with the increasing dimensionless porous medium parameter. The effect of the dimensionless porous medium K becomes smaller as K increase. Physically, this result can be achieved when the holes of the porous medium may be neglected. From figures (4) and (5), the effects of Soret and Dufour numbers on the velocity field are shown. We observe that the velocity increases with the increase of both Dufour and Soret number.

Figure (6) displays the effect of the chemical reaction parameter (k_r) on the velocity magnetic field will result in a resistive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity. Also, the boundary layer thickness decreases with an increase in the Hartmann number profiles. As chemical reaction (k_r) increases, the considerable reduction in the velocity profiles is predicted, and the presence of the peak indicates that the maximum value of the velocity occurs in the body of the fluid close to the surface but not at the surface. An increase in Prandtl number decreases the Temperature field (figure (7)). Also, it is noted that the effect of Dufour number on velocity and mass profiles is not apparent. Figure (8) shows the variation of temperature profiles for different values of Du. The parameter Du has marked effects on the temperature profiles. It is observed that the temperature profiles increase with the increasing values of Du. When the ratio between temperature and concentration gradient is very small the temperature profile shows its usual trend of gradual decay.

Figure (9) shows that an increase in Schmidt number decreases the concentration field. Also Concentration field falls slowly and steadily for Hydrogen and Helium but falls very rapidly for Oxygen and Ammonia in comparison to Water vapour. Figure (10) shows the variation of concentration profiles for different values of Sr. The parameter Sr has marked effects on the concentration profiles. It is observed that the concentration profiles increase with the increasing

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values of Sr. When the ratio between concentration and temperature gradient is very small the concentration profile shows its usual trend of gradual decay. As Soret number Sr becomes large the profiles overshoot the uniform concentration close to the boundary. Figure (11) displays the effect of the chemical reaction parameter (k_r) on concentration profiles. As chemical reaction (k_r) increases, the concentration decreases. It is evident that the increase in the chemical reaction (k_r) significantly alters the concentration boundary layer thickness but does not alter the momentum boundary layers.

TABLE I: Variation skin friction (τ) for different values of $Gr,\ Gc,\ Sc,\ \Pr,\ M,\ K,\ Sr,\ Du\, and\ k_r$

Gr	Gc	$\Pr$	Sc	M	K	Sr	Du	k_r	τ
1.0	1.0	0.71	0.22	2.0	1.0	1.0	1.0	1.0	1.5879
2.0	1.0	0.71	0.22	2.0	1.0	1.0	1.0	1.0	1.8742
1.0	2.0	0.71	0.22	2.0	1.0	1.0	1.0	1.0	1.9873
1.0	1.0	7.00	0.22	2.0	1.0	1.0	1.0	1.0	1.2590
1.0	1.0	0.71	0.60	2.0	1.0	1.0	1.0	1.0	1.3586
1.0	1.0	0.71	0.22	4.0	1.0	1.0	1.0	1.0	1.1167
1.0	1.0	0.71	0.22	2.0	2.0	1.0	1.0	1.0	1.6540
1.0	1.0	0.71	0.22	2.0	1.0	2.0	1.0	1.0	1.7412
1.0	1.0	0.71	0.22	2.0	1.0	1.0	2.0	1.0	1.6984
1.0	1.0	0.71	0.22	2.0	1.0	1.0	1.0	2.0	1.3695

TABLE II: Variation of Nusselt number (Nu) for different values of $\Pr,\ Du$ and λ

$\Pr$	Du	Nu
0.71	1.0	1.2875
7.00	1.0	1.0067
0.71	2.0	1.3481

TABLE III: Variation of Sherwood number (Sh) for different values of $Sc,\ Sr$ and k_r

Sc	Sr	k_r	Sh
0.22	1.0	1.0	1.0598
0.30	1.0	1.0	0.8436
0.22	2.0	1.0	1.2597
0.22	1.0	2.0	0.7694

TABLE IV: Comparison of present Skin friction results (τ_1) with the Skin friction results (τ_1^*) obtained by Chaudhary *et al.* [3] for different values of $Gr,\ \Pr$ and M

Gr	$\Pr$	M	τ_1	τ_1^*
1.0	0.71	2.0	1.2254	1.2197
2.0	0.71	2.0	1.3592	1.3465
1.0	0.71	2.0	0.9987	0.9954

TABLE – (1)-(3) shows the variation skin friction (τ), Nusselt number (Nu) and Sherwood number (Sh) different governing parameter values. In order to ascertain the accuracy of the numerical results, the present Skin friction (τ) results are compared with the previous Skin friction (τ^*) results of Chaudhary *et al.* [3] in TABLE – (4). They are found to be in an excellent agreement.

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IV. CONCLUSION

In this paper, the governing equations are solved numerically by employing the efficient finite element method. The results illustrate the flow characteristics for the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number. The conclusions from these results are, it is observed that the velocity (u) of the fluid increases with the increasing of parameters Gr, Gc, K, Sr, Du and decreases with the increasing of parameters $\Pr$, Sc, M and k_r. The fluid temperature increases with the increasing of Du.The concentration of the fluid increases with the increasing of Sr and decreases with the increasing of Sc.From tables, the skin friction (τ) increases with the increasing values of Gr, Gc, K, Sr, Du and this behavior is found just reverse with the increasing of $\Pr$, Sc, M *and* k_r., the Nusselt number (Nu) increases with the increasing values of Du and this behavior is found just reverse with the increasing of $\Pr$ and the Sherwood number (Sh) increases with the increasing values of Sr and this behavior is found just reverse with the increasing of Sc *and* k_r.

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