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Effects of Heat Absorption and Porosity of the Medium on MHD Flow past a Vertical Plate

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ABSTRACT

Effects of heat absorption and porosity of the medium on unsteady MHD flow past a moving vertical plate with variable wall temperature and mass diffusion in the presence of Hall current is studied here. Earlier we [5] have studied chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current. We obtained the results which were in agreement with the desired flow phenomenon. To study further, we are changing the model by considering heat absorbing fluid, and changing the geometry of the model. Here in this paper we are taking the plate positioned vertically upward. Further, medium of the flow is taken as porous. The governing equations involved in the flow model are solved by the Laplace-transform technique. The results obtained have been analyzed with the help of graphs drawn for different parameters. The numerical values obtained for the drag at boundary have been tabulated. Here too, the results are found to be in agreement with the actual flow.

Key words: MHD flow, heat absorbing fluid, mass diffusion, Hall current

INTRODUCTION

The unsteady flow under the action of strong magnetic field plays a decisive role in different areas of science and technology. MHD effect on heat transfer over stretching sheet embedded in porous medium with variable viscosity, viscous dissipation and heat source or sink was analyzed by Dessie and Naikoti [1]. They solved flow model by using Runge-Kutta fourth order numerical method, and observed that if heat sink parameter is increased then the thermal boundary layer increases, whereas the thermal boundary layer decreases with heat source. Hall effect on unsteady MHD natural convection flow of a heat absorbing fluid past an accelerated moving vertical plate with ramped wall temperature was investigated by Seth *et al* [7]. The model considered by Seth *et al* [7] was solved by Laplace transform technique. In their study they observed that velocity and temperature of fluid near the vertical plate decreases when heat absorption parameter increases. Reddy *et al* [6] have presented radiation and mass transfer effects on nonlinear MHD boundary layer flow of liquid metal over a porous stretching surface embedded in porous medium with heat generation. Hossain *et al* [10] have developed MHD free convection and mass transfer flow through a vertical oscillatory porous plate with Hall, ion-slip currents and heat source in a rotating system. Hossain *et al* [10] have used explicit finite difference method to solve the coupled non-linear partial differential equations. They examined that the shear stress and Sherwood numbers are decreased with the increase in heat source parameter, and Nusselt number is increased with increase in heat source. Mythreye *et al* [3] have proposed chemical reaction on unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. They solved the governing equations by using perturbation technique, and explained the presence of heat absorption effect caused reductions in the fluid temperature which resulted in decrease in the fluid velocity. Similar study was done by Seth *et al* [8], Shehzad *et al* [9] and Ibrahim and Suneetha [2]. Chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current was investigated by us [5]. Further we [4] have worked on effects of Hall current and chemical reaction on MHD flow through porous medium past an oscillating inclined plate with variable temperature and mass diffusion. The main purpose of the present investigation is to study the effects of heat absorption and porosity of the medium on unsteady MHD flow past a moving vertical plate with variable wall temperature and mass diffusion in the presence of Hall current. The models have been solved using the Laplace transforms technique. The results are shown with the help of graphs and table.

MATHEMATICAL ANALYSIS

The unsteady flow of an electrically conducting, incompressible, viscous fluid past through porous medium in a vertical plate has been considered. The x axis is taken in the direction of the motion and *z* normal to it. A transverse magnetic field B_0 of uniform strength is applied on the flow. The magnetic Reynolds number is considered to be small so that the induced magnetic field is neglected. 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 is taken as C_∞. At time t > 0, the plate starts moving with a velocity u_0 in its own plane, and temperature of the plate is raised to T_w. The concentration *C* near the plate is raised linearly with respect to time. The governing equations are as under:

$$\frac{\partial u}{\partial t} = \upsilon \frac{\partial^2 u}{\partial z^2} + g\beta (T - T_\infty) + g\beta^* (C - C_\infty) - \frac{\sigma B_0^2 (u + mv)}{\rho(1+m^2)} - \frac{\upsilon u}{K} \tag{1}$$

$$\frac{\partial v}{\partial t} = \upsilon \frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2 (mu - v)}{\rho(1+m^2)} - \frac{\upsilon v}{K} \tag{2}$$

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial z^2} \tag{3}$$

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2} - Q(T - T_\infty) \tag{4}$$

The initial and boundary conditions are

$$\left.\begin{array}{l} t \le 0 : u = 0,\ v = 0,\ T = T_\infty,\ C = C_\infty, \ \text{for every z.} \\ t > 0 : u = u_0,\ v = 0,\ T = T + (T_w - T_\infty)A,\ C = C_\infty + (C_w - C_\infty)A, \ \text{at } z=0. \\ u \to 0,\ v \to 0,\ T \to T_\infty,\ C \to C_\infty \ \text{as } z \to \infty, \ \text{where } A = \dfrac{u_0^2 t}{\upsilon}. \end{array}\right\} \tag{5}$$

The following non-dimensional quantities are introduced to transform equations (1), (2), (3) and (4) into dimensionless form:

$$\left.\begin{array}{l} \bar{z} = \dfrac{z u_0}{\upsilon},\ \bar{u} = \dfrac{u}{u_0},\ \bar{v} = \dfrac{v}{u_0},\ \theta = \dfrac{(T - T_\infty)}{(T_w - T_\infty)},\ S_c = \dfrac{\upsilon}{D},\ \mu = \rho\upsilon,\ P_r = \dfrac{\mu C_p}{k}, H = \dfrac{Q\upsilon}{u_0^2 \rho C_p} \\ G_r = \dfrac{g\beta\upsilon(T_w - T_\infty)}{u_0^{\ 3}},\ M = \dfrac{\sigma B_0^2 \upsilon}{\rho u_0^2},\ G_m = \dfrac{g\beta^* \upsilon(C_w - C_\infty)}{u_0^{\ 3}},\ \bar{C} = \dfrac{(C - C_\infty)}{(C_w - C_\infty)},\ \bar{t} = \dfrac{t u_0^2}{\upsilon}. \end{array}\right\} \tag{6}$$

The dimension less flow model becomes

$$\frac{\partial \bar{u}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + G_r\, \theta + G_m\, \bar{C} - \frac{M(\bar{u} + m\bar{v})}{(1+m^2)} - \frac{1}{\bar{K}} \bar{u} \tag{7}$$

$$\frac{\partial \bar{v}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + \frac{M(m\bar{u} - \bar{v})}{(1+m^2)} - \frac{1}{\bar{K}} \bar{v} \tag{8}$$

$$\frac{\partial \bar{C}}{\partial \bar{t}} = \frac{1}{S_c} \frac{\partial^2 \bar{C}}{\partial \bar{z}^2} \tag{9}$$

$$\frac{\partial \theta}{\partial \bar{t}} = \frac{1}{P_r} \frac{\partial^2 \theta}{\partial \bar{z}^2} - H\theta \tag{10}$$

The corresponding boundary conditions become

$$\left.\begin{array}{l} \bar{t} \le 0 : \bar{u} = 0,\ \bar{v} = 0,\ \theta = 0,\ \bar{C} = 0, \ \text{for every } \bar{z} \\ \bar{t} > 0 : \bar{u} = 1,\ \bar{v} = 0,\ \theta = \bar{t},\ \bar{C} = \bar{t}, \text{at } \ \bar{z} = 0. \\ \bar{u} \to 0,\ \bar{v} \to 0,\ \theta \to 0,\ \bar{C} \to 0, \text{as } \ \bar{z} \to \infty. \end{array}\right\} \tag{11}$$

Dropping bars in the above equations, we get

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + G_r\, \theta + G_m C - \frac{M(u + mv)}{(1+m^2)} - \frac{1}{K} u \tag{12}$$

$$\frac{\partial v}{\partial t}=\frac{\partial^2 v}{\partial z^2}+\frac{M(mu-v)}{(1+m^2)}-\frac{1}{K}v \tag{13}$$

$$\frac{\partial C}{\partial t}=\frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} \tag{14}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-H\theta \tag{15}$$

The boundary conditions are

$$\left.\begin{array}{ll} t\le 0: u=0, v=0, \theta=0, C=0, & \text{for every } z. \\ t>0: u=1, v=0,\ \theta=t,\ C=t, & \text{at } z=0. \\ u\to 0,\ v\to 0,\ \theta\to 0,\ C\to 0, & \text{as } z\to\infty. \end{array}\right\} \tag{16}$$

Combining equations (12) and (13), the model becomes

$$\frac{\partial q}{\partial t}=\frac{\partial^2 q}{\partial z^2}+G_r\theta+G_mC-qa \tag{17}$$

$$\frac{\partial C}{\partial t}=\frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} \tag{18}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-H\theta \tag{19}$$

Here $q=u+iv$ and $a=\frac{M(1-im)}{1+m^2}+\frac{1}{K}$.

Finally, the boundary conditions become:

$$\left.\begin{array}{ll} t\le 0: q=0, \theta=0, C=0, & \text{for all } z. \\ t>0: q=1, \theta=t, C=t, & \text{at } z=0. \\ q\to 0,\ \theta\to 0,\ C\to 0, & \text{as } z\to\infty. \end{array}\right\} \tag{20}$$

The dimensionless governing equations (17) to (20), subject to the boundary conditions (20), are solved by the usual Laplace - transform technique. The solution obtained is as under:

$$C=t\left\{(1+\frac{z^2S_c}{2t})erfc[\frac{\sqrt{S_c}}{2\sqrt{t}}]-\frac{z\sqrt{S_c}}{\sqrt{\pi}\sqrt{t}}e^{-\frac{z^2}{4t}S_c}\right\},$$

$$\theta=\frac{1}{4Hi}e^{-zi\sqrt{HP_r}}\left\{-2i\sqrt{H}t(A_1-e^{-zi\sqrt{HP_r}}A_2-2)+z\sqrt{P_r}(A_1+e^{-zi\sqrt{HP_r}}A_2-2)\right\},$$

$$q=\frac{1}{2}e^{-\sqrt{a}z}A_{33}+\frac{G_r}{4(a+HP_r)^2}[(at+P_r+HP_rt-1)(e^{-\sqrt{a}z}A_3-e^{-\sqrt{HP_r}zi}A_{11})+e^{-\sqrt{a}z}A_4(\sqrt{a}+\frac{HP_r}{\sqrt{a}})$$

$$+A_{14}(1-P_r)(A_5-A_{12})-\frac{1}{2i\sqrt{H}}ze^{-\sqrt{HP_r}zi}A_{10}\sqrt{P_r}(HP_r+a)]+\frac{G_mCos\alpha}{4a^2}[2A_6e^{-\sqrt{a}z}(1-at)+$$

$$e^{-\sqrt{a}z}(z\sqrt{a}A_8+2A_9S_c)+2A_{15}A_7(1-S_c)]--\frac{G_m}{2a^2\sqrt{\pi}}[2az\sqrt{tS_c}e^{-\frac{z^2S_c}{4t}}+A_{16}\sqrt{\pi}(az^2S_c+2at+$$

$$2S_c-2)+A_{13}A_{15}\sqrt{\pi}(1-S_c)]$$

The symbols involved in the above equations are mentioned in the appendix.

Skin Friction

The dimensionless skin friction at the plate z=0 is obtained by

$$\left(\frac{dq}{dz}\right)_{z=0}=\tau_x+i\tau_y\,.$$

The numerical values of τ_x and τ_y, for different parameters are given in table-1.

RESULT AND DISCUSSIONS

In this present paper we have studied the effects of heat absorption and permeability of porous medium on the flow. The behaviour of other parameters like magnetic field, Hall current and thermal buoyancy is almost similar the earlier model studied by us [5]. The analytical results are shown graphically in Figs1 to7. The numerical values of skin-friction τ_x and τ_y are presented in Table-1. From Figs1 and 2, it is observed that primary and secondary velocities increase with permeability parameter *(K)*. This result is due to the fact that increases in the value of *(K)* results in reducing the drag force, and hence increasing the fluid velocity.

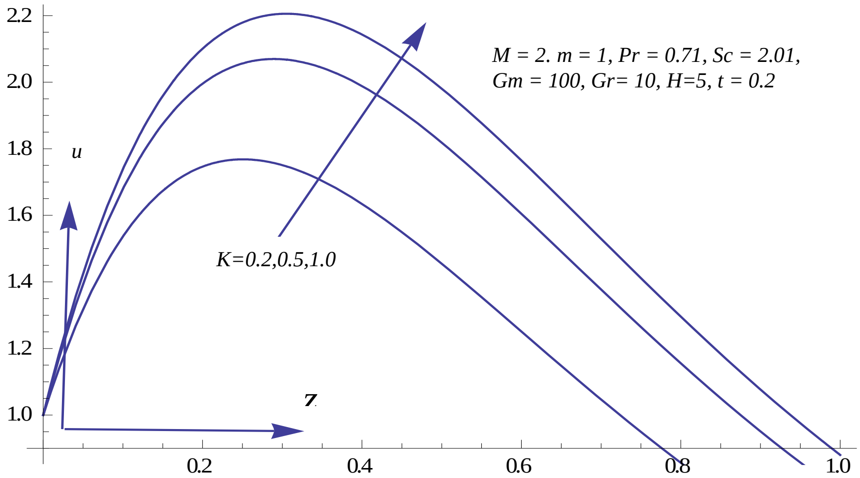

Fig. 1*u vs z*   for different values of *K*

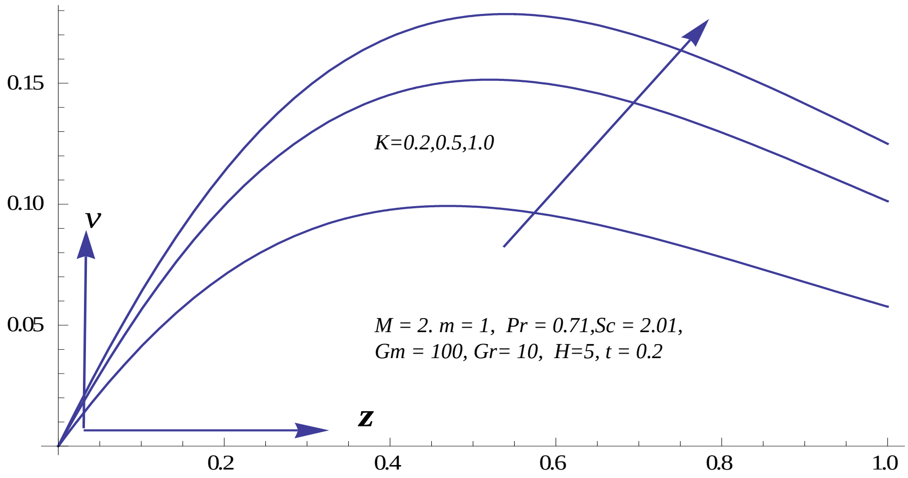

Fig. 2 *v vs z*   for different values of *K*

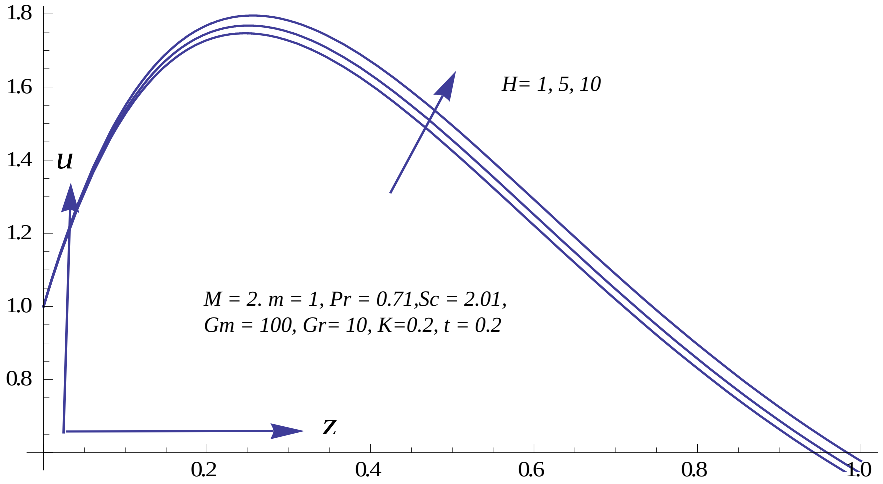

Fig. 3 *u vs z* for different values of *H*

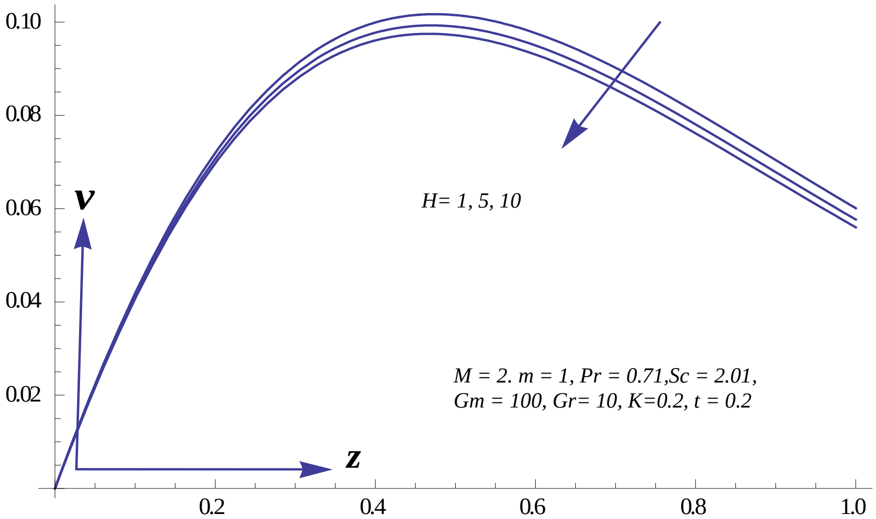

Fig. 4 ***v vs z*** **for different values of *H***

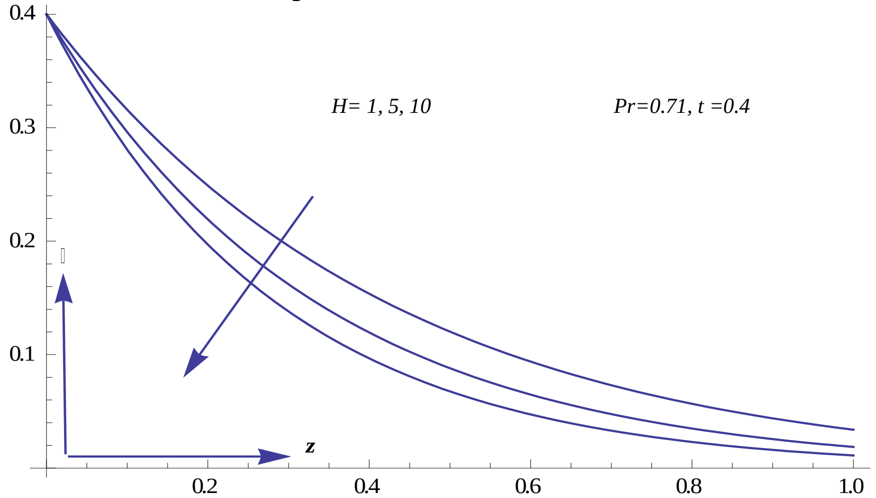

Fig. 5 *θ vs z* for different values of *H*

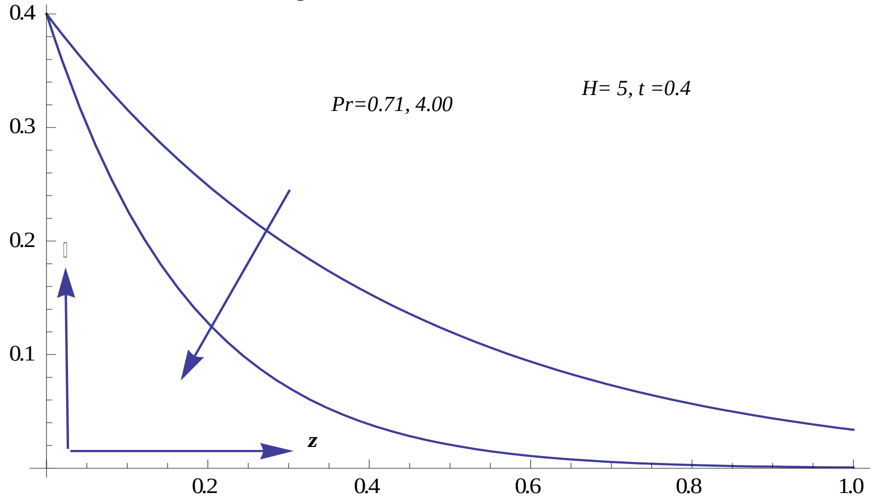

Fig. 6 *θvs z* for different values of Pr

Effect of heat absorption fluid flow behaviour is shown by Figs3 and 4. It is seen here that when heat absorption parameter (*H*) increases, primary velocity *u* increases throughout the boundary layer region; but secondary velocity v decreases near the surface of the plate. This implies that heat absorption tends to accelerate primary velocity, whereas it retards secondary velocity in the boundary layer region. Further, it is observed that the temperature decreases when Prandtl number and heat absorption parameter are increased (Figs5 and 6). However, from Fig. 7 it is observed that the temperature increases with time. This is due the reason heat is transported to the system continuously.

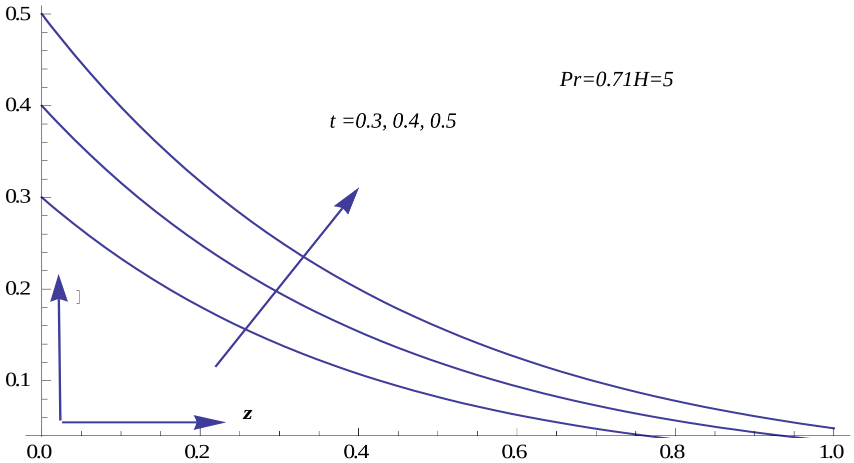

Fig. 7 *θvs z* for different values of t

Table -1 Skin Friction for Different Parameter

M	*M*	*Pr*	*Sc*	*Gm*	*Gr*	*H*	*K*	*t*	τ_x	τ_y
3	1.0	0.71	2.01	100	010	05	0.2	0.5	11.5145144	4.15812410
5	1.0	0.71	2.01	100	010	05	0.2	0.5	9.12045440	3.42149226
2	1.0	7.01	2.01	100	010	05	0.2	0.5	7.25045566	0.39490278
2	1.0	0.71	2.01	100	010	05	0.2	0.5	14.0808692	4.95645366
2	5.0	0.71	2.01	100	010	05	0.2	0.5	25.0956227	7.61259653
2	1.0	0.71	3.00	100	010	05	0.2	0.5	13.1748302	4.89180197
2	1.0	0.71	4.00	100	010	05	0.2	0.5	12.6029421	4.88279034
2	1.0	0.71	2.01	010	010	05	0.2	0.5	5.96165311	4.74283994
2	1.0	0.71	2.01	050	010	05	0.2	0.5	9.57019360	4.83777937
2	1.0	0.71	2.01	100	050	05	0.2	0.5	44.1654773	23.0300561
2	1.0	0.71	2.01	100	100	05	0.2	0.5	81.7712374	45.6220591
2	1.0	0.71	2.01	100	010	10	0.2	0.5	4.55750664	35.1068783
2	1.0	0.71	2.01	100	010	05	0.5	0.5	-8.0765170	-12.3614290
2	1.0	0.71	2.01	100	010	05	0.2	0.4	10.1257785	3.78312807
2	1.0	0.71	2.01	100	010	05	0.2	0.6	18.1080174	5.97775830

The values of skin friction are given in table1. The value ofτ_x increases with the increase in G_m, G_r and t. But τ_x decreases with M, P_r, S_c, m, H and K. Similar effects are observed with τ_y.

CONCLUSION

In this paper a theoretical analysis has been done to study effects of heat absorption and porosity of the medium on unsteady MHD flow past a moving vertical plate with variable wall temperature and mass diffusion in the presence of Hall current. It is observed that the primary velocity increases with increasing the values of heat absorption and permeability of the porous medium. The effect is similar on the secondary velocity except the case of heat absorption. That is the secondary velocity decreases when heat absorption parameter is increased.

Nomenclature

D	*Mass diffusion*	μ	*The coefficient of viscosity*	β	*Volumetric coefficient of thermal expansion*
ρ	*The fluid density*	G_m	*Mass Grashof number*		
σ	*Electrical conductivity*	G_r	*Thermal Grashof number*	β^*	*Volumetric coefficient of concentration expansion*
μ	*The magnetic permeability*	k	*The thermal conductivity*		
T	*Temperature of the fluid*	T_∞	*The temperature of the fluid*	u,v	*Velocity of the fluid in x & y- direction*
K	*the permeability parameter*	T_w	*Temperature of the plate*		
M	*The magnetic Field parame-*	C	*Species concentration in the fluid*	$\bar{u}$, $\bar{v}$	*Dimensionless velocity in x & y-direction*
m	*The Hall current parameter*	$\bar{C}$	*The dimensionless concentration*		
P_r	*Prandtl number*	C_P	*Specific heat at constant pressure*	θ	*The dimensionless temperature*
t	*Time*	C_w	*Species concentration at the plate*	g	*Gravity acceleration*
Sc	*Schmidt number*	C_∞	*The concentration in the fluid*	H	*heat absorption parameter*
υ	*The kinematic viscosity*				

Appendix

$$A_1 = erfc\left[\frac{2Hit - z\sqrt{P_r}}{2\sqrt{t}}\right], \quad A_2 = erfc\left[\frac{2Hit + z\sqrt{P_r}}{2\sqrt{t}}\right], \quad A_3 = (-1 - A_{17} + e^{2\sqrt{az}}(A_{18} - 1)),$$

$$A_4 = (1 + A_{17} + e^{2\sqrt{az}}(A_{18} - 1)), \quad A_5 = (-1 + A_{19} + \exp(2z\sqrt{\frac{(a+H)P_r}{\Pr - 1}})(A_{20} - 1)),$$

$$A_6 = (1 + A_{21} + \exp(2\sqrt{a}z)(1 - A_{22})), \quad A_7 = (-1 + A_{23} + \exp(2z\sqrt{\frac{aS_c}{S_c - 1}})(A_{24} - 1)),$$

$$A_8 = (1 + A_{21} + \exp(2\sqrt{a}z)(A_{22} - 1)), \quad A_9 = (-1 - A_{21} + \exp(2\sqrt{a}z)(A_{22} - 1)),$$

$$A_{10} = (1 + A_{25} + \exp(2Hiz\sqrt{P_r})(A_{26} - 1)), \quad A_{11} = (1 - A_{25} + \exp(2Hiz\sqrt{P_r})(A_{26} - 1)),$$

$$A_{12} = (-1 - A_{27} + \exp(2z\sqrt{\frac{(a+H)P_r}{P_r - 1}})(A_{28} - 1)), \quad A_{13} = (-1 - A_{29} + \exp(2z\sqrt{\frac{aS_c}{S_c - 1}})(A_{30} - 1)),$$

$$A_{14} = \exp(\frac{at}{P_r - 1} - z\sqrt{\frac{(a+H)P_r}{P_r - 1}} + \frac{HtP_r}{P_r - 1}), \quad A_{15} = \exp(\frac{at}{S_c - 1} - z\sqrt{\frac{aS_c}{S_c - 1}}),$$

$$A_{16} = (-1 + erf(\frac{z\sqrt{S_c}}{2\sqrt{t}})), \quad A_{17} = erf(\sqrt{at} - \frac{z}{2\sqrt{t}}), \quad A_{18} = erf(\sqrt{at} + \frac{z}{2\sqrt{t}}),$$

$$A_{19} = erf(\frac{z}{2\sqrt{t}} - \sqrt{\frac{(a+H)tP_r}{P_r - 1}}), \quad A_{20} = erf(\frac{z}{2\sqrt{t}} + \sqrt{\frac{(a+H)tP_r}{P_r - 1}}),$$

$$A_{21} = erf(\frac{\sqrt{at} - z}{2\sqrt{t}}), \quad A_{22} = erf(\frac{\sqrt{at} + z}{2\sqrt{t}}), \quad A_{23} = erf(\frac{z - 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2\sqrt{t}}),$$

$$A_{24} = erf(\frac{z + 2t\sqrt{\frac{aS_c}{S_c - 1}}}{2\sqrt{t}}), \quad A_{25} = erf(Hi\sqrt{t} - \frac{z\sqrt{P_r}}{2\sqrt{t}}), \quad A_{26} = erf(Hi\sqrt{t} + \frac{z\sqrt{P_r}}{2\sqrt{t}}),$$

$$A_{27} = erf(\sqrt{t}\sqrt{\frac{a+H}{P_r - 1}} - \frac{z\sqrt{P_r}}{2\sqrt{t}}), \quad A_{28} = erf(\sqrt{\frac{(a+H)t}{P_r - 1}} + \frac{z\sqrt{P_r}}{2\sqrt{t}}), \quad A_{29} = erf(\frac{1}{2\sqrt{t}}\left(\sqrt{\frac{at}{S_c - 1}} - z\sqrt{S_c}\right)),$$

$$A_{30} = erf(\frac{1}{2\sqrt{t}}\left(\sqrt{\frac{at}{S_c - 1}} + z\sqrt{S_c}\right)), \quad A_{31} = erf[\frac{2\sqrt{at} - z}{2\sqrt{t}}], \quad A_{32} = erf[\frac{2\sqrt{at} + z}{2\sqrt{t}}], \quad A_{33} = (A_{31} + A_{32}),$$

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