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Combined effect of Hall current and chemical reaction on MHD flow through Porous medium with heat generation past an impulsively started vertical plate with constant wall temperature and mass diffusion

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Abstract

Unsteady flow with magneto-hydrodynamics and heat generation through porous medium past an impulsively started vertical plate with constant wall temperature and mass diffusion is considered here. The effect studied is a combination of Hall current and chemical reaction. The motivation behind this study is the applications of such kind of problems in industry. In many industrial applications electrically conducting fluid is subjected to magnetic field. The fluid is passed through porous medium. The flow may be on a plate. There may be substance on the plate which may cause chemical reaction. The solution of flow model studied here is obtained by using Laplace transform method. The respective profiles have been drawn for velocity. The numerical data have been obtained using latest software techniques available. The profiles have been analyzed and discussed. The values of Nusselt number, Sherwood number, and drag on plate have been tabulated for analysis. The findings have been summarized in conclusion section.

Nomenclature

B_0'	The magnetic field
C	Species conc. in the fluid
$\overline{C}$	The dimensionless conc.
C_P	Specific heat at constant pressure
C_w	Species conc. at the plate
C_∞	The conc. in the fluid away from the plate
D	Mass diffusion
E	The electric field
g	Gravity acceleration
θ	The dimensionless temp.
Gm	Mass G. no.
Gr	Th. Grashaf no.
J	The current density
k	The thermal conductivity
K	Permeability of the medium
K_c	Chemical reaction parameter
K_0	The dimensionless chemical reaction parameter
K_T	Thermal diffusion ratio
L	A characteristic length of the system
M	The magnetic parameter
m	Here ($m = \omega_e \tau_e$) The Hall current parameter
ω_e	Cyclotron freq. of electrons
τ_e	Electron collision time
P	Pressure

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Pr	Prandtl number
Sc	Schmidt number
T	Temp. of the fluid
T_∞	The temp. on the fluid away from the plate
T_m	The mean fluid temp.
T_w	Temp. of the plate
T	Time
V	The fluid velocity
β	Volum. Coeff. of thermal expansion
β^*	Volum. Coeff. of conc. Expansion
υ	The kinematic viscosity
ρ	The fluid density
μ	The coeff. of viscosity of the fluid
μ_e	The effec. viscosity in the porous medium
ω	Oscillating freq. of the plate
η_e	The number of density of electrons
P_e	The electron pressure
	Heat generation parameter

1. Introduction

The study of magneto-hydrodynamics with heat generation effect on moving fluid is quite relevant due to its applications in the problems related to endothermic and exothermic chemical reactions in the fluid. Some related studies are mentioned here. Reddy and Sandeep [1] have studied transfer of heat and mass on magneto bio-convective flow. Seth et al [2] have discussed Hall effect on magneto-hydrodynamic free convection flow of a heat absorbing fluid on an accelerated moving vertical plate. Further, effects of heat and mass transfer on magneto-hydrodynamics free convection flow was studied by Siva and others [3]. Seddeek [4] has studied the effects of chemical reaction, thermophoresis and variable viscosity on steady flow over a flat plate.

Attia et al. [5] studied the heat transfer effect in Couette flow under pressure gradient along with Hall current. Hossain, et al. [6] have analyzed flow of viscous incompressible fluid over a permeable wedge with uniform heat flux. Chemical reaction on unsteady magneto-hydrodynamics was studied by Mythreye et al. [7]. They used perturbation technique to solve the governing equations. Cowling [8] studied Magnetohydrodynamics. Rajput and Kanaujia [9] have studied magneto-hydrodynamics with chemical reaction over a vertical plate. Reddy et al. [10] have worked on chemical reaction and thermal radiation effects on magneto-hydrodynamics micro polar fluid. Further, Naramgari et al. [11] have analyzed magneto-hydrodynamics nano fluid with heat source/sink. Hayat et al. [12] have examined magneto-hydrodynamics with Dufour and Soret effects. Chemical reaction and thermal diffusion on magneto-hydrodynamics flow on a porous plate was presented by Ibrahim and Suneetha [13]. A numerical analysis of magneto-hydrodynamics radiative flow over a rotating cone was done by Sulochanna et al. [14]. Abdulaziz et al. [15] have studied magneto-hydrodynamics flow and heat diffusion in a liquid film. Further, Ishak et al. [16] focused their work on magneto-hydrodynamics flow and heat transfer.

Earlier we [9] studied magneto-hydrodynamics with chemical reaction over a vertical plate. In the present paper, we consider combined effect of chemical reaction and Hall current on magneto-hydrodynamics flow with heat generation past an impulsively started vertical plate. The effects have been observed with graphs and the drag has been tabulated.

2. Mathematical formulation

Let the flow be unsteady and electrically conducting. The medium considered is porous. The x' axis is along the motion with z' taken normal to it. The boundary layer is formed in the direction of y'. A uniform field B'_0 is applied transversely on the flow. At the start, it is assumed that the temperatures of the plate and the fluid are each T_∞. Further, C_∞ is the species concentration. After some time, the plate starts oscillating with frequency ω. Then the temp of the plate and the concentration of the fluid, respectively, are raised to T_w and C_w. Using the relation $\nabla \cdot B = 0$ for the magnetic field

$$\overline{B}' = \overline{B}'_{x'}, \overline{B}'_{y'}, \overline{B}'_{z'}$$

we get $B'_{y'}$ (say B'_0) = constant,
i.e. $B' = (0, B'_0, 0)$, where B'_0 is externally applied transverse magnetic field. The Geometry of the problem is given in Fig. 1.

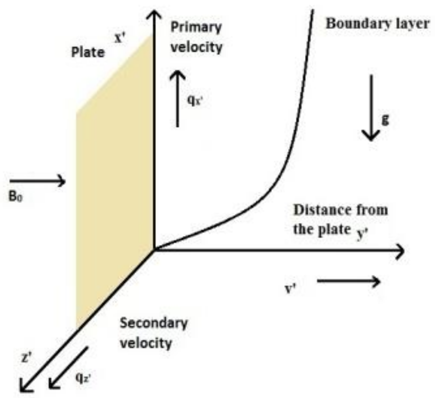

Fig. 1. Geometry of the problem.

Let q' be the velocity vector, and $q_{x'}$, $q_{y'}$, $q_{z'}$ are respectively the velocity components along x', y' and z' - directions. The governing equation of continuity is

$$\frac{\partial q_{x'}}{\partial x'}+\frac{\partial q_{y'}}{\partial y'}+\frac{\partial q_{z'}}{\partial z'}=0$$

Since there is no variation of flow in the y' - direction, therefore $v' = 0$

The generalized ohm's law including the effect of Hall current according to cowling [9] is given as:

$$\bar{J}+\frac{\omega_e\tau_e}{B_0'}(\bar{J}\times\bar{B}')=\sigma(E+\bar{q}\times\bar{B}')$$

The external electric field $E = 0$, since polarization of charges is negligible.

Let $J = (j_{x'}, j_{y'}, j_{z'})$. Here $j_{x'}$ $j_{y'}$ and $j_{z'}$ are the components of current density in the x', y', and z' directions, respectively. Using the above assumption, we get

$$J_{x'}=\frac{\sigma B_0'^2}{1+m^2}(q_{x'}+mq_{z'}),\quad J_{y'}=0$$

$$and\quad J_{z'}=\frac{\sigma B_0'^2}{1+m^2}(mq_{x'}-q_{z'})$$

The fluid model is as under:

$$\frac{\partial q_{x'}}{\partial t}=\frac{\partial^2 q_{x'}}{\partial y'^2}\upsilon+\beta\,g\,(T-T_\infty)+\beta^*\,g(C-C_\infty) \\ -\frac{\sigma B_0^2(q_{x'}+mq_{z'})}{\rho(1+m^2)}-\frac{\upsilon q_{x'}}{K}, \tag{1}$$

$$\frac{\partial q_{z'}}{\partial t}=\frac{\partial^2 q_{z'}}{\partial y'^2}\upsilon+\frac{\sigma B_0^2(mq_{x'}-q_{z'})}{\rho(1+m^2)}-\frac{\upsilon q_{z'}}{K}, \tag{2}$$

$$\frac{\partial C}{\partial t}=\frac{\partial^2 C}{\partial y'^2}D-K_c(C-C_\infty), \tag{3}$$

$$\rho C_P\frac{\partial T}{\partial t}=\frac{\partial^2 T}{\partial y'^2}k+(T-T_\infty)Q_0, \tag{4}$$

The initial and b. c. are

$$\left.\begin{array}{l} t\le 0: q_{x'}=0, q_{z'}=0, T=T_\infty, C=C_\infty \text{ for all values } y', \\ t>0: q_{x'}=q_{x'_0}\cos\omega t, q_{z'}=0, T=T_w \text{ at } y'=0, \\ q_{x'}\to 0, q_{z'}\to 0, T=T_\infty, C\to C_\infty, \text{as } y'\to\infty. \end{array}\right\} \tag{5}$$

Here $q_{x'}$ and $q_{z'}$ are the primary and the secondary velocities along x' and z' respectively.

The non-dimensional quantities introduced to transform equations (1), (2), (3) and (4) are as follows:

$$\bar{q}_{x'}=\frac{q_{x'}}{q_{x'_0}},\bar{q}_{z'}=\frac{q_{z'}}{q_{x'_0}},\bar{y}'=\frac{y'q_{x'_0}}{\upsilon},Sc=\frac{\upsilon}{D},Pr=\frac{C_P\mu}{k},$$
$$Q=\frac{Q_0\upsilon}{q_{x'_0}{}^2\rho C_p},\bar{K}=\frac{q_{x'_0}K}{\upsilon^2}M=\frac{\upsilon\sigma B_0'^2}{\rho\, q_{x'_0}{}^2},\bar{t}=\frac{q_{x'_0}{}^2 t}{\upsilon},$$
$$\bar{\omega}'=\frac{\upsilon\omega'}{q_{x'_0}{}^2},Gm=\frac{g\upsilon\beta^*(C_w-C_\infty)}{q_{x'_0}{}^3},Gr=\frac{g\upsilon\beta(T_w-T_\infty)}{q_{x'_0}{}^3},$$
$$\theta=\frac{(T-T_\infty)}{(T_w-T_\infty)},\bar{C}=\frac{C-C_\infty}{C_w-C_\infty},K_0=\frac{\upsilon K_C}{q_{x'_0}{}^2}. \tag{6}$$

The dimensionless flow model becomes

$$\frac{\partial\bar{q}_{x'}}{\partial\bar{t}}=\frac{\partial^2\bar{q}_{x'}}{\partial\bar{y}'^2}+Gr\,\theta+Gm\,\bar{C}-\frac{M(\bar{q}_{x'}+m\bar{q}_{z'})}{(1+m^2)}-\frac{1}{\bar{K}}\bar{q}_{x'}, \tag{7}$$

$$\frac{\partial\bar{q}_{z'}}{\partial\bar{t}}=\frac{\partial^2\bar{q}_{z'}}{\partial\bar{y}'^2}+\frac{M(m\bar{q}_{x'}-\bar{q}_{z'})}{(1+m^2)}-\frac{1}{\bar{K}}\bar{q}_{z'}, \tag{8}$$

$$\frac{\partial\bar{C}}{\partial\bar{t}}=\frac{\partial^2\bar{C}}{\partial\bar{y}'^2}\frac{1}{Sc}-K_0\bar{C}, \tag{9}$$

$$\frac{\partial\theta}{\partial\bar{t}}=\frac{\partial^2\theta}{\partial\bar{y}'^2}\frac{1}{Pr}+Q\theta. \tag{10}$$

The corresponding b. c. become

$$\left.\begin{array}{l}\bar{t} \le 0, \bar{q}_{x'} = 0, \bar{q}_{z'} = 0, \bar{C} = 0, \theta = 0,\ for\ all\ values\ of\ \bar{y}' \\ \bar{t} > 0, \bar{q}_{x'} = cos\,\bar{\omega}\bar{t}, \bar{q}_{z'} = 0, \theta = 1, \bar{C} = 1\ at\ \bar{y}' = 0 \\ \bar{q}_{x'} \to 0, \bar{q}_{z'} \to 0, \bar{C} \to 0, \theta \to 0,\ as\ \bar{y}' \to \infty.\end{array}\right\} \quad (11)$$

Removing the bars and combining eqs. (7 and 8), we get

$$\frac{\partial q'}{\partial t} = \frac{\partial^2 q'}{\partial y'^2} + GmC + G\theta - \left(\frac{M}{1+m^2}(1-mi) + \frac{1}{K}\right)q', \quad (12)$$

$$\frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y'^2}\frac{1}{Sc} - K_0 C, \quad (13)$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y'^2}\frac{1}{Pr} + Q\theta, \quad (14)$$

where $q' = q_{x'} + iq_{z'}$, with corresponding b. c.

$$\left.\begin{array}{l}t \le 0 : q' = 0, \theta = 0, C = 0,\ for\ all\ values\ of\ y', \\ t <: q' = cos\,\omega t, q' = 0, \theta = 1, C = 1, at\ y' = 0, \\ q' \to 0, C \to 0, \theta \to 0, as\ y' \to \infty.\end{array}\right\} \quad (15)$$

Solving analytically using Laplace transform method, equations (12, 13 and 14) are changed to

$$sq^*(y',s) - q'(y',0) = \frac{\partial^2 q'^*}{\partial y^2}(y',s) + Gr\theta^* \quad (16)$$
$$+ GmC^* - \left(\frac{M}{1+m^2}(1-mi) + \frac{1}{K}\right)q'^*$$

$$sC^*(y',s) - C(y',0) = \frac{1}{Sc}\frac{\partial^2}{\partial y'^2}C^*(y',s) - K_0 C^* \quad (17)$$

$$s\theta^*(y',s) - \theta(y',0) = \frac{1}{Pr}\frac{\partial^2}{\partial y'^2}\theta^*(y',s) + Q\theta^* \quad (18)$$

where *s* is a parameter of Laplace transformation. On further solving, the solution obtained is as under:

$$\begin{aligned} q' &= [\tfrac{1}{4}exp(-it\omega)(P_1 + P_2 - exp(-y'\sqrt{a-i\omega})P_3 \\ &- exp(P_4 y') - exp(-y'P_0)P_5 - exp(y'P_0)P_6) + \frac{1}{2(a+Q\,Pr)}Gr \\ &[\{-exp(-\sqrt{a}y')(A_1 + exp(2\sqrt{a}y')A_2) + exp(B_0 - B_1) \\ &(A_3 + exp(2B_1)A_4)\} - \{exp(B_0 - B_1)(1 + exp(2B_1) + A_7 - exp(2B_2)A_8) \\ &- exp(-y'\sqrt{-Q\,Pr})(1 + A_9 + exp(2y'\sqrt{-Q\,Pr})A_{10})\}] + \frac{1}{2(a-K_0 Sc)} \\ &Gm\{-exp(\sqrt{a}y')(1 + A_1 + exp(2\sqrt{a}y')A_2) + exp(B_2 - B_3)(A_5 + exp(2B)A_6) \\ &- exp(B_2 - B_3)(1 + exp(2B_3) + A_{11} - exp(2B_3)A_{12})\} + Gm\frac{1}{2(-a+K_0 Sc)} \\ &exp(-y'\sqrt{K_0 Sc})(1 + A_{13} + exp(2y'\sqrt{K_0 Sc})A_{14})], \end{aligned}$$

$$\theta = \frac{1}{2}exp(-\sqrt{-Q\,Pr}\,y')(1 + A_9 + exp(2\sqrt{-Q\,Pr}\,y')A_{10}),$$

$$C = \frac{1}{2}exp(-y'\sqrt{ScK_0})(B_4 + exp(2y'\sqrt{ScK_0})A_{14}).$$

3. Drag at the surface

The drag at the plate $y' = 0$ is given by

$$\left(\frac{\partial q'}{\partial y'}\right) = \tau_{(x')} + i\,\tau_{(z')}.$$

Here $\tau_{(x')}$ and $\tau_{(z')}$ are drags at the plate in x' and z' directions.

4. Sherwood number

$$Sh = \left(\frac{\partial C}{\partial y'}\right).$$

$$= \frac{1}{2}\exp(-y'\sqrt{ScK_0})\left(\begin{array}{l} -B_6 - \exp(2y'\sqrt{ScK_0})A_{14}\}\sqrt{ScK_0}\{\frac{\exp(-B_7)\sqrt{Sc}}{\sqrt{\pi t}} \\ (-1 - \exp(2y'\sqrt{ScK_0})) + 2\exp(2y'\sqrt{ScK_0})A_{14}\sqrt{ScK_0} \end{array}\right).$$

5. Nusselt number

$$Nu = \left(\frac{\partial \theta}{\partial y'}\right).$$

$$= \frac{1}{2}exp(-\sqrt{-Q\,Pr}\,y')\left(\begin{array}{l} -(\sqrt{-Q\,Pr}\,y'\{1 + A_9 + exp(2\sqrt{-Q\,Pr}\,y')A_{10}\} + \{\frac{exp(-B_5)\sqrt{Pr}}{\sqrt{\pi t}} \\ (1 - exp(2\sqrt{-Q\,Pr}\,y')) + 2\,exp(2\sqrt{-Q\,Pr}\,y')A_{10}\sqrt{-Q\,Pr}\,\}) \end{array}\right)$$

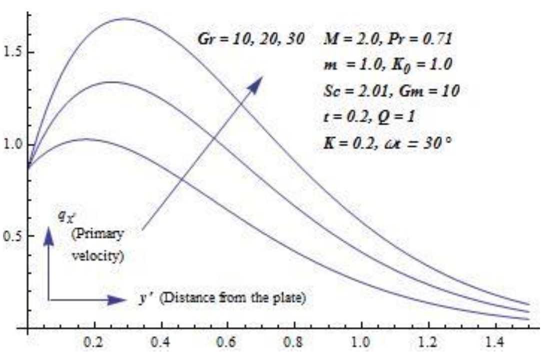

Fig. 2. *Gr* versus $q_{x'}$.

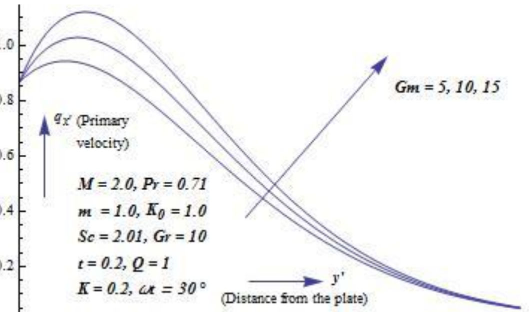

Fig. 3. *Gm* versus $q_{x'}$.

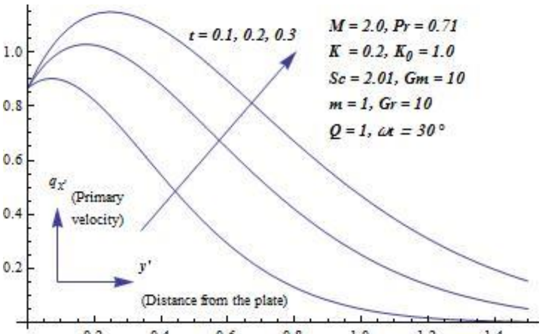

Fig. 7. *t* versus $q_{x'}$.

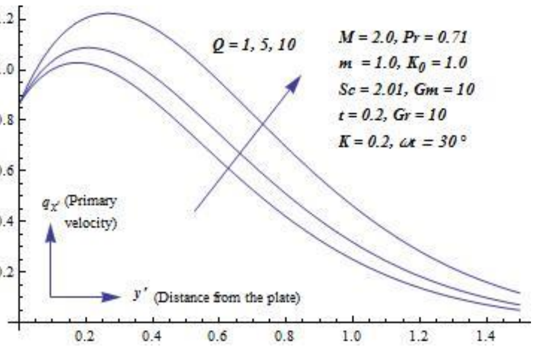

Fig. 4. *Q* versus $q_{x'}$.

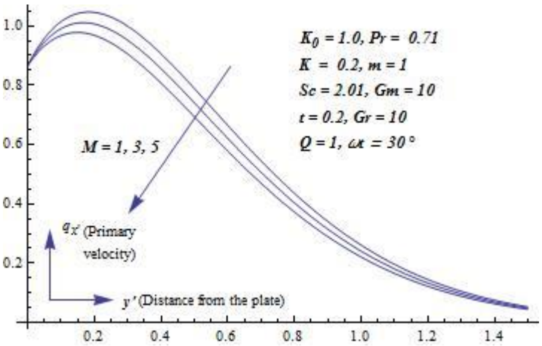

Fig. 8. *M* versus $q_{x'}$.

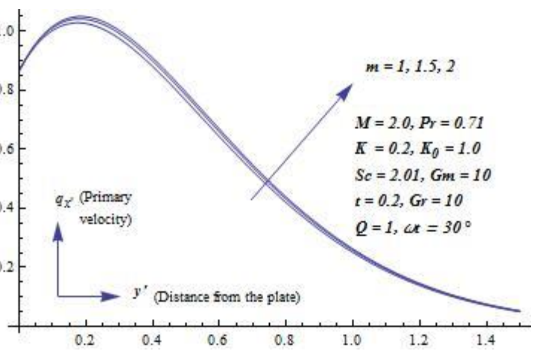

Fig. 5. *m* versus $q_{x'}$.

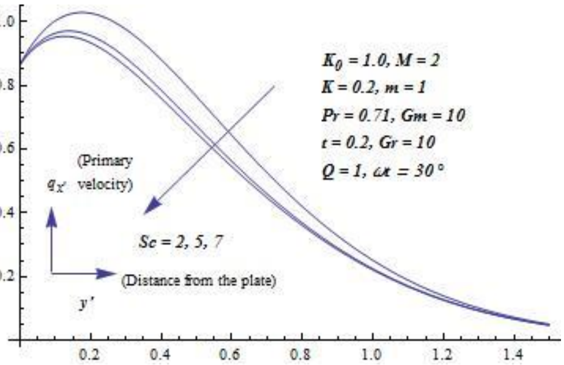

Fig. 9. *Sc* versus $q_{x'}$.

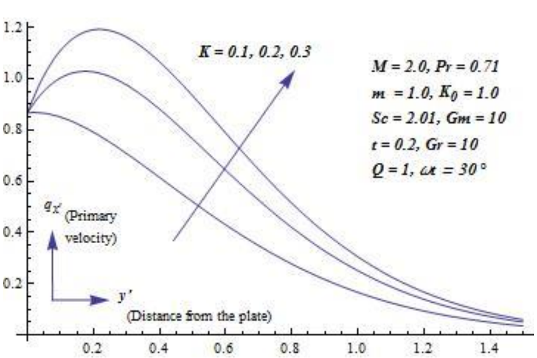

Fig. 6. *K* versus $q_{x'}$.

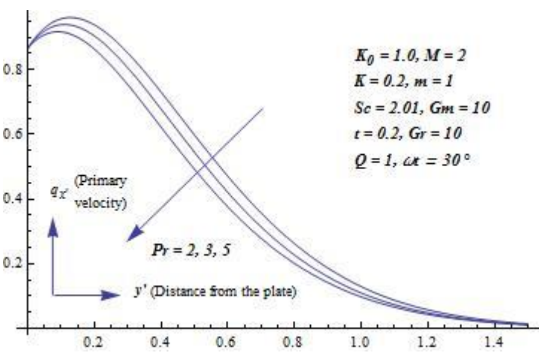

Fig. 10. *Pr* versus $q_{x'}$.

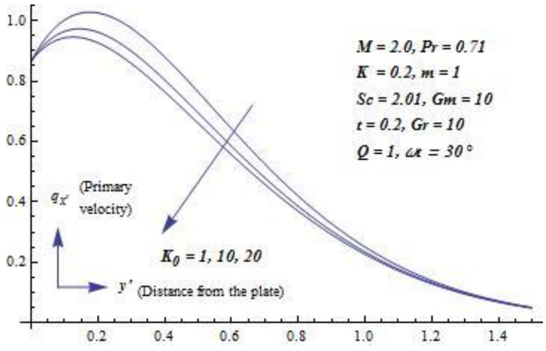

Fig. 11. *K₀* versus $q_{x'}$.

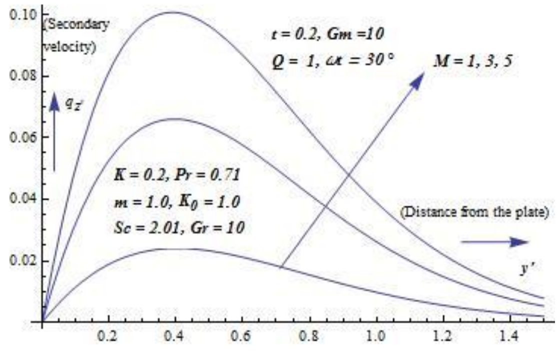

Fig. 15. *M* versus $q_{z'}$.

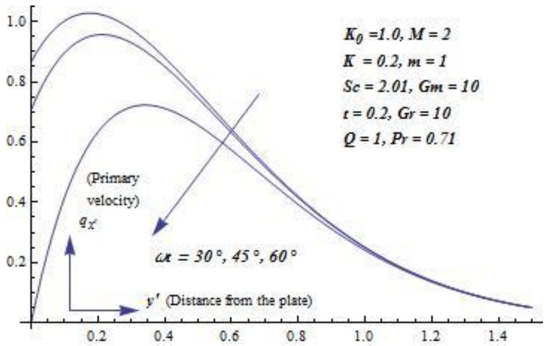

Fig. 12. *ωt* versus $q_{x'}$.

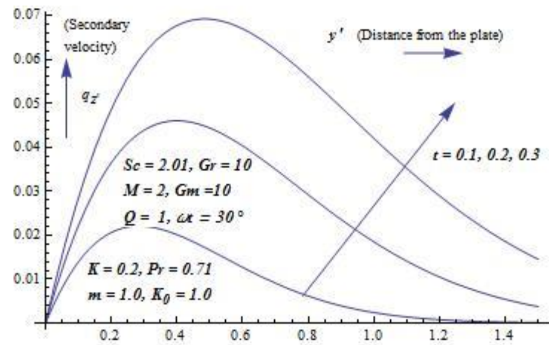

Fig. 16. *t* versus $q_{z'}$.

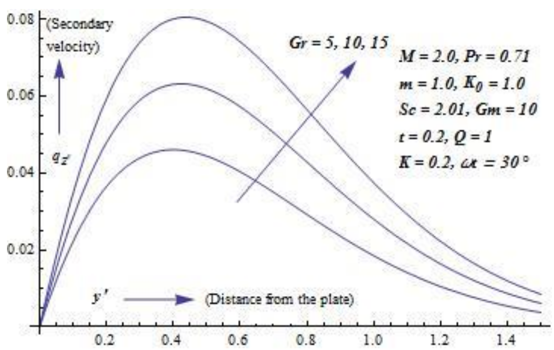

Fig. 13. *Gr* versus $q_{z'}$.

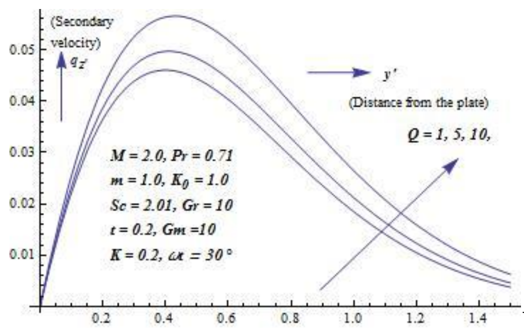

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Fig. 17. *Q* versus $q_{z'}$.

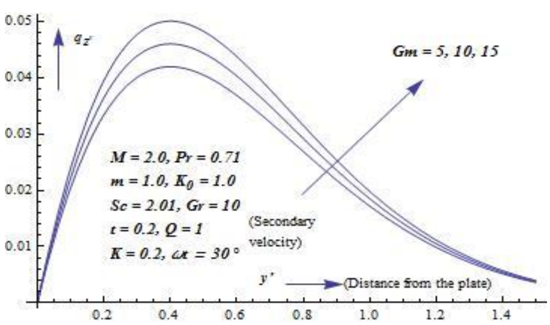

Fig. 14. *Gm* versus $q_{z'}$.

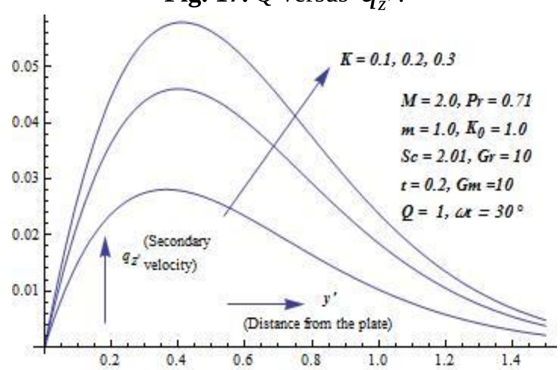

Fig. 18. *K* versus $q_{z'}$.

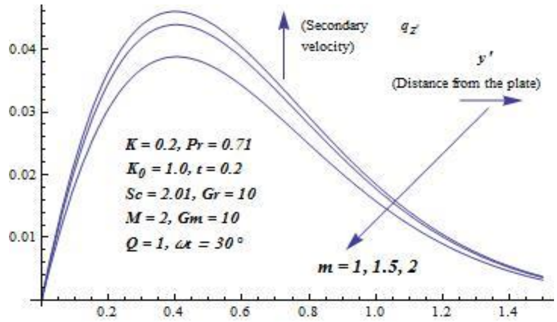

Fig. 19. *m* versus $q_{z'}$.

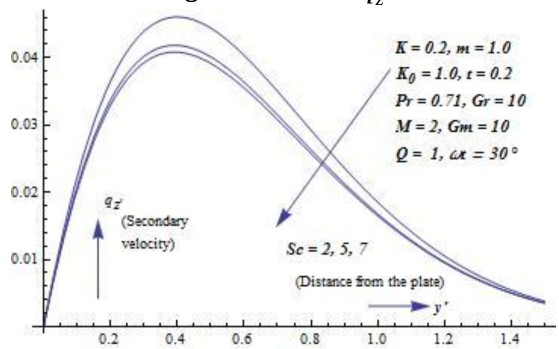

Fig. 20. *Sc* versus $q_{z'}$.

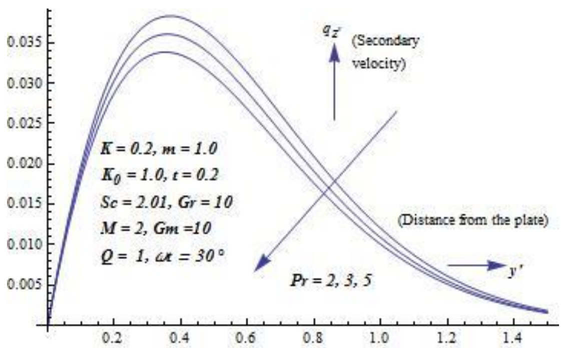

Fig. 21. *Pr* versus $q_{z'}$.

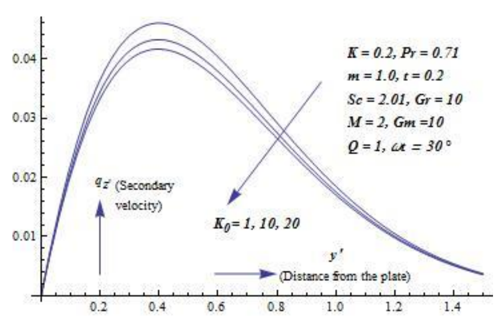

Fig. 22. K_0 versus $q_{z'}$.

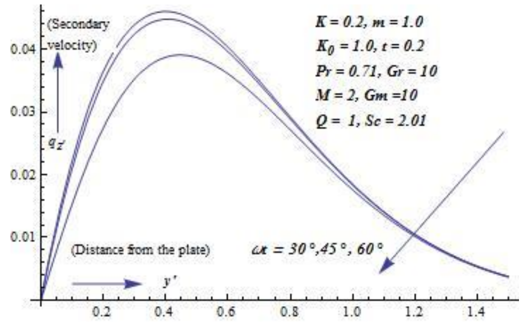

Fig. 23. ωt versus $q_{z'}$.

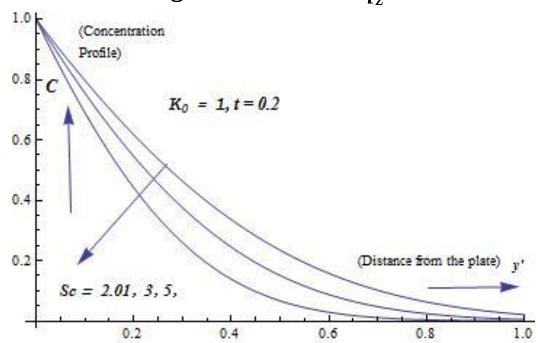

Fig. 24. *Sc* versus *C*.

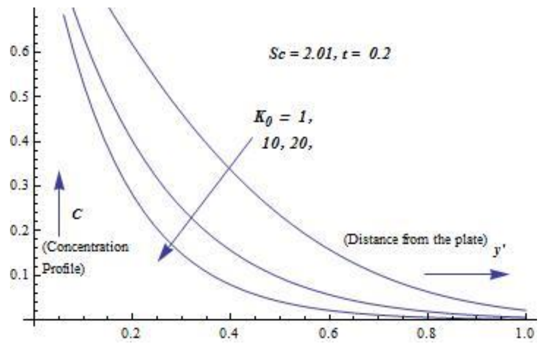

Fig. 25. K_0versus *C*.

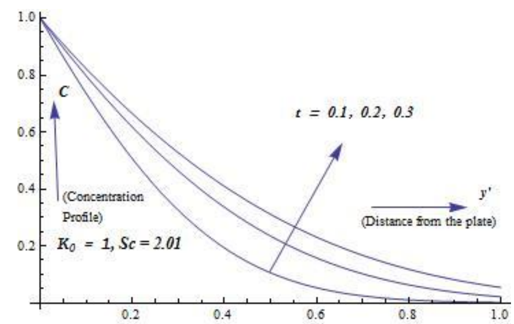

Fig. 26. *t* versus *C*.

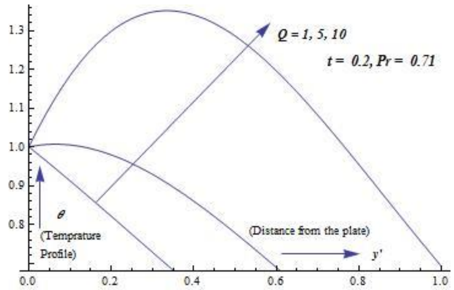

Fig. 27. Q versus θ.

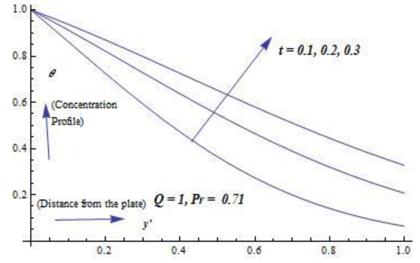

Fig. 28. t versus θ.

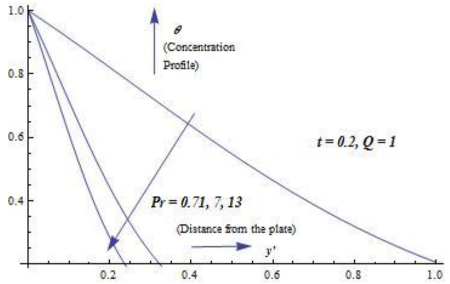

Fig. 29. Pr versus θ.

Table 1. Drag for different parameters.

M	m	Pr	Sc	Gm	Gr	Q	K_0	K	t	ωt (in degree)	$\tau_{(x')}$	$\tau_{(z')}$
3	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.2	30	1.9414	0.3862
5	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.2	30	1.6660	0.6075
2	1.5	0.71	2.01	10	10	1.0	1.0	0.2	0.2	30	2.1849	0.2502
2	2.0	0.71	2.01	10	10	1.0	1.0	0.2	0.2	30	2.2452	0.2196
2	10	3.00	2.01	10	10	1.0	1.0	0.2	0.2	30	1.4412	0.2327
2	1.0	5.00	2.01	10	10	1.0	1.0	0.2	0.2	30	1.2122	0.2242
2	1.0	0.71	5.00	10	10	1.0	1.0	0.2	0.2	30	1.6801	0.2497
2	1.0	0.71	7.00	10	10	1.0	1.0	0.2	0.2	30	1.5415	0.2454
2	1.0	0.71	2.01	5.0	10	1.0	1.0	0.2	0.2	30	1.2117	0.2468
2	1.0	0.71	2.01	15	10	1.0	1.0	0.2	0.2	30	2.9499	0.2834
2	1.0	0.71	2.01	10	20	1.0	1.0	0.2	0.2	30	4.4124	0.3299
2	1.0	0.71	2.01	10	30	1.0	1.0	0.2	0.2	30	6.7441	0.3947
2	1.0	0.71	2.01	10	10	5.0	1.0	0.2	0.2	30	2.4193	0.2770
2	1.0	0.71	2.01	10	10	10	1.0	0.2	0.2	30	3.0597	0.2985
2	1.0	0.71	2.01	10	10	1.0	10	0.2	0.2	30	1.6801	0.2538
2	1.0	0.71	2.01	10	10	1.0	20	0.2	0.2	30	1.4438	0.2470
2	1.0	0.71	2.01	10	10	1.0	1.0	0.1	0.2	30	0.9180	0.2054
2	1.0	0.71	2.01	10	10	1.0	1.0	0.3	0.2	30	2.5439	0.2925
2	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.1	30	1.0604	0.1806
2	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.3	30	2.6484	0.3283
2	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.2	45	2.7210	0.2465
2	1.0	0.71	2.01	10	10	1.0	1.0	0.2	0.2	60	5.4080	0.1602

Table 2. Sherwood number.

Sc	K_0	*t*	*Sh*
0.16	1.0	0.2	-0.21346
3.0	1.0	0.2	-0.26078
5.0	1.0	0.2	-3.3665
2.01	10	0.2	-2.1346
2.01	20	0.2	-4.5193
2.01	1.0	0.1	-2.7780
2.01	1.0	0.3	-1.8776

Table 3. Nusselt number.

Pr	*Q*	*t*	*Nu*
0.71	1.0	0.2	-0.8430
7.0	1.0	0.2	-2.6470
13.0	1.0	0.2	-3.6073
0.71	5.0	0.2	0.2206
0.71	10	0.2	2.1991
0.71	1.0	0.1	-1.3504
0.71	1.0	0.3	-0.5937

6. Results and discussion

The values computed for velocity, drag, Sherwood number and Nusselt number for different parameters have been ploted.

Table 4: Different value of parameters.

Symbols	Values		
m	1.0	1.5	2.0
M	1.0	3.0	5.0
Gm	5.0	10	15
Sc	2.0	5.0	7.0
Pr	2.0	3.0	5.0
ωt	30°	45°	60°
K	0.1	0.2	0.3
K_0	10	10	30
Q	1.0	5.0	10
t	0.1	0.2	0.3

It has been observed from Figs. 2-7 that $q_{x'}$ increases when *Gr, Gm, Q, m, K,* and *t* are increased respectively one at a time. In each case only one parameter changes with others keeping constant. We imply the same interpretation in our further discussion. Figs. 8, 9, 10, 11 and 12 show that $q_{x'}$ decreases, when *M, Sc, Pr,* K_0 and ωt are increased. Almost similar pattern is observed for $q_{z'}$. Figs. 13, 14, 15, 16, 17 and 18 show that the $q_{z'}$ increases when *Gr, Gm, M, t, Q* and *K* are increased. However, Figs. 19-23 show that $q_{z'}$ decreases when *m, Sc, Pr,* K_0 and ωt are increased. This implies that the Hall parameter slows down the transverse velocity.

Figs. 24, and 25 show that concentration decreases when *Sc* and K_0 are increased. However, Figs. 26 shows that concentration increases when *t* is increased. Figs. 27 and 28 show that the temperature increases when *Q* and *t* are increased. Fig. 29 shows that it decreases when *Pr* is increased.

Table 1 shows that drag along x' axis decreases with increase in *Sc, Pr,* K_0 and *M*; and it increases with *Gr, Gm, m, t, Q, K* and ωt. On the other hand, drag along z' axis increases with increase in *Gr, Gm, t, Q, K* and *M*; and it decreases with *Pr, m, Sc,* K_0 and ωt. Table 2 shows that Sherwood number decreases with increase in *Sc*, and *t*. However, Sherwood number increases with increase in K_0. Further, Table 3 shows that Nusselt number decreases with increase in *Pr*. However, it increases with increase in *t* and *Q*. The main parameters are in Table 4. The findings are concluded in the next section.

7. Conclusions

It has been observed that $q_{x'}$ increases with heat generation, permeability of the medium and Hall parameter. However it decreases with chemical reaction parameter. Further, $q_{z'}$ increases when heat generation parameter, and permeability of the medium are increased. But it decreases with Hall parameter and chemical reaction parameter.

As far as drag is concerned, $\tau_{(x')}$ increases with heat generation parameter, permeability of the medium and Hall parameter; and it decreases with chemical reaction parameter. The Sherwood number decreases with increase in Schmidt number, and time. Further, the Nusselt number increases with increase in time and heat generation parameter. The results obtained are as per expectation for real flow.

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Appendix

$$P_0 = (a + i\omega)^{1/2} + 2it\omega,$$

$$P_1 = exp(-y'(a - i\omega)^{1/2}) + exp(y'(a - i\omega)^{1/2}),$$

$$P_2 = exp(-y'P_0) + exp(y'P_0),$$

$$P_3 = erf\,[\frac{y' - 2t(a - i\omega)^{1/2}}{2t^{1/2}}],$$

$$P_4 = erf\,[\frac{y' + 2t(a - i\omega)^{1/2}}{2t^{1/2}}],$$

$$P_5 = erf\,[\frac{y' - 2t(a + i\omega)^{1/2}}{2t^{1/2}}],$$

$$A_1 = efr[\frac{2t(a)^{1/2} - y'}{2(t)^{1/2}}],$$

$$A_2 = efr[\frac{2t(a)^{1/2} + y'}{2(t)^{1/2}}],$$

$$A_3 = erfc[\frac{y' - 2t\left(\frac{(a+Q)Pr}{-1+Pr}\right)^{1/2}}{2(t)^{1/2}}],$$

$$A_4 = erfc[\frac{y' + 2t\left(\frac{(a+Q)Pr}{-1+Pr}\right)^{1/2}}{2(t)^{1/2}}],$$

$$A_5 = erfc[\frac{y' - 2t\left(\frac{(a+K_0)Pr}{-1+Sc}\right)^{1/2}}{2(t)^{1/2}}],$$

$$A_6 = erfc[\frac{y' - 2t\left(\frac{(a-K_0)Pr}{-1+Sc}\right)^{1/2}}{2(t)^{1/2}}],$$

$$A_7 = erf\,[\frac{2t\left(\frac{(a+Q)}{-1+Pr}\right)^{1/2} - y'(Pr)^{1/2}}{2(t)^{1/2}}],$$

$$A_8 = erf\,[\frac{2t\left(\frac{(a+Q)}{-1+Pr}\right)^{1/2} + y'(Pr)^{1/2}}{2(t)^{1/2}}],$$

$$A_9 = erf\,[\frac{2(-Q)^{1/2}t - y'(Pr)^{1/2}}{2(t)^{1/2}}],$$

$$A_{10} = erf\,[\frac{2(-Q)^{1/2}t + y'(Pr)^{1/2}}{2(t)^{1/2}}],$$

$$A_{11} = erf\,[\frac{2t\left(\frac{(a+K_0)}{-1+Sc}\right)^{1/2} - y'(Sc)^{1/2}}{2(t)^{1/2}}],$$

$$A_{12} = erf\,[\frac{2t\left(\frac{(a+K_0)}{-1+Sc}\right)^{1/2} + y'(Sc)^{1/2}}{2(t)^{1/2}}],$$

$$A_{13} = erf\,[\frac{2t(K_0)^{1/2} - y'(Sc)^{1/2}}{2(t)^{1/2}}],$$

$$A_{13} = erf\,[\frac{2t(K_0)^{1/2} + y'(Sc)^{1/2}}{2(t)^{1/2}}],$$

$$B_0 = \frac{at}{-1+Pr} + \frac{Pr\,tQ}{-1+Pr},\; B_1 = y'\left(\frac{(a+H)Pr}{-1+Pr}\right)^{1/2},$$

$$B_2 = \frac{at}{-1+Sc} - \frac{tK_0Sc}{-1+Sc},\; B_3 = y'\left(\frac{(a-K_0)Sc}{-1+Sc}\right)^{1/2},$$

$$B_4 = erfc[\frac{y'(Sc)^{1/2} - 2t(K_0)}{2(t)^{1/2}}],$$

$$B_5 = \frac{\left(2(-Q)^{1/2} t - (Pr\, y')\right)^2}{4t},$$

$$B_6 = erfc[\frac{y'(Sc) - 2t(K_0)}{2(t)^{1/2}}],$$

$$B_7 = [\frac{(Sc)^{1/2} y' - 2t(K_0)^2}{4(t)^{1/2}}],$$

$$a = \frac{M}{1+m^2}(1-im) + \frac{1}{K}.$$

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