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Research Article

MHD rotating heat and mass transfer free convective flow past an exponentially accelerated isothermal plate with fluctuating mass diffusion

K. Jonah Philliph [*], M. C. Raju [†], A. J. Chamkha [‡§], S. V. K. Varma [¶]

Abstract

In this paper, we have considered the problem of rotating, magnetohydrodynamic heat and mass transfer by free convective flow past an exponentially accelerated isothermal vertical plate in the presence of variable mass diffusion. While the temperature of the plate is constant, the concentration at the plate is considered to be a linear function with respect to time t. The plate is assumed to be exponentially accelerated with a prescribed velocity against the gravitational field. The governing equations are solved by using Laplace transform technique and the effect of various physical parameters on the flow quantities are studied through graphs and the results are discussed. With the aid of the velocity, temperature and concentration fields the expressions for skin friction, rate of heat transfer in the form of Nusselt number and rate of mass transfer in the form of Sherwood number are derived and the results are discussed with the help of tables.

Keywords : MHD; rotation;heat and mass transfer; exponentially accelerated plate; **Nomenclature:** A, á, a constants; cp specific heat at constant pressure; g acceleration due to gravity; Gm Grashof number of mass transfer; Gr Grashof number of heat transfer; Pr Prandtl number; Sc Schmidt number; t dimensionless time; T temperature; t́ time; u dimensionless velocity; ú velocity of the fluid; u0 velocity of the plate; x dimensionless coordinate in the fluid direction; x́ coordinate in the fluid direction; y dimensionless perpendicular coordinate; ý coordinate perpendicular to the plate; **Greek Symbols:** α thermal conductivity; β volumetric coefficient of thermal expansion; μ dynamic viscosity; υ kinematic viscosity; κ thermal conductivity; θ dimensionless temperature; ϕ dimensionless concentration; ρ fluid density; η similarity variable; **Subscripts and Special Functions:** w wall; ∞ free stream; erf error function; erfc complimentary error function

1 Introduction

MAgnetohydrodynamic free convective flows along with the effects of heat and mass transfer have considerable applications in geophysics, metallurgy and engineering and science such as MHD pumps, MHD generators, magnetic suppression of molten semi conducting materials, MHD couples and bearings and magnetic control of molten iron flow in steel industry etc. An exact solution of flow past an exponentially

[*]Department of H&S, Mother Theresa Institute of Engineering & Technology, Palamaner - 517408, Andhra Pradesh, India.
[†]Department of H&S, Annamacharya Institute of Technology and Sciences, (Autonomous), Rajampet - 516126, Andhra Pradesh, India.
[‡]Corresponding author. achamkha@yahoo.com
[§]Manufacturing Engineering Department, The public authority for applied Education and training, Shuweikh - 70654 Kuwait.
[¶]Department of Mathematics, S. V. University, Tirupati - 517502, Andhra Pradesh, India.

accelerated infinite vertical plate and temperature with variable mass diffusion was found by Asogwa et al. [1]. Biswal et al [2] have considered hydrodynamic free convection flow of a rotating visco-elastic fluid past an isothermal vertical porous plate with mass transfer. In his study Chamkha [3, 4] has investigated hydromagnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium past a semi-infinite vertical permeable moving plate with heat absorption. Chamkha et al. [5] studied radiation effects on free convection flow past a semi infinite vertical plate with mass transfer. Flow past an accelerated horizontal plate in a rotating fluid was studied by Deka et al. [6]. The Combined effects of Joule heating and chemical reaction on unsteady magnetohydrodynamic mixed convection of a viscous dissipating fluid over a vertical plate in porous media with thermal radiation was studied by Dulal and Babulal [7]. Kim [8] investigated an unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Muthucumaraswamy et al. [9]. considered the heat transfer effects on flow past an exponentially accelerated vertical plate with variable temperature. Narasimha Charyulu and Sunder Ram [10] investigated MHD unsteady flow of a second order fluid through porous region bounded by rotating Infinite plate. Prasada Rao and Krishna [11] considered rotating convective fluid flows with Hall current effects. Rajput and Kumar [12] recently studied rotation and radiation effects on MHD flow past an impulsively started vertical plate with variable temperature. In their study Raju and Varma [13] have considered an unsteady MHD free convection oscillatory couette flow through a porous medium with periodic wall temperature. Raptis and Singh [14] have analyzed MHD free convection flow past an accelerated vertical plate. Ravikumar et al. [15] studied heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in the presence of temperature dependent heat source. Sathappan and Muthucumaraswamy [16] found Radiation effects on exponentially accelerated vertical plate with uniform mass diffusion. An exact solution was found by using the Laplace transform technique. Fee-Convection flow past an exponentially accelerated vertical plate was considered by Singh and Kumar [17]. Singh and Singh [18] found transient MHD free convection in a rotating system. Singh et al. [19] have considered convective flow past an accelerated porous plate in rotating system in the presence of magnetic field. Free convection effects on the flow past an accelerated vertical plate have been investigated by Soundalgekar and Gupta [20]. Yaqing et al. [21] investigated MHD flow and heat transfer of a generalized Burgers fluid due to an exponential accelerating plate with the effect of radiation. Ahmed and Chamkha [22] investigated on MHD flow along a vertical porous wall in the presence of induced magnetic field along with the effects of radiation and chemical reaction. Singh et al. [23] considered the effect of volumetric heat generation/ absorption on mixed convection stagnation point flow on an isothermal vertical plate in porous media. Vahidi et al. [24] used the Laplace transform decomposition algorithm for solving nonlinear differential equations. Effects of chemical reaction and pressure work on free convection over a stretching cone embedded in a porous medium was considered by Chamkha et al. [25]. Steady mixed convection flow of water at 4 ^{o}c along a non-isothermal vertical moving plate with transverse magnetic field, was investigated by Sharma et al. [26]. Recently Ravi et al. [27] investigated transient free convective flow of a micropolar fluid between two vertical walls. In this paper, we have considered Magnetohydrodynamic rotating heat and mass transfer free convective flow past an exponentially accelerated isothermal vertical plate with variable mass diffusion. An exact solution in the closed form is found by using Laplace transform Technique.

2 Problem Formulation

Consider unsteady flow of a viscous, incompressible and electrically-conducting fluid past an exponentially accelerated vertical plate when the fluid and the plate rotate as a rigid body with a uniform angular velocity about the y-axis in the presence of transversely applied uniform magnetic field of strength B0 Initially, the temperature of the plate and the concentration near the plate are assumed to be T∞ and C∞ respectively. At t>0, the plate is assumed to be exponentially accelerated in the vertical direction with a prescribed velocity against the gravitational field. At the same time the plate temperature is raised to Tw and the concentration near the plate raised linearly with time t. The x-axis is taken along the plate in the vertical direction and y-axis is perpendicular to it. Since length of the plate is infinite all the physical quantities are functions of yand tonly. It is assumed that as the magnetic Reynolds number is very small, the induced magnetic field is neglected and Hall Effect is also neglected. Under the above assumptions, the equations governing the unsteady flow of Magnetohydrodynamic rotating heat and mass transfer free convective flow past an exponentially accelerated isothermal vertical plate with variable mass diffusion, using the usual Boussinesqs approximation, are given below.

$$\frac{\partial u}{\partial t} - 2\Omega =$$

$$g\beta_T(T - T\infty) + g\beta_c(C - C_\infty) + \mu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2 u}{\rho} \tag{2.1}$$

$$\frac{\partial v}{\partial t} + 2\Omega u = \mu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2 v}{\rho} \tag{2.2}$$

$$\rho C_p\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial y^2} \tag{2.3}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} \tag{2.4}$$

with the following initial and boundary conditions:

$$u = 0, T' = T'_\infty, C' = C'_\infty \forall\, y \leq 0 \tag{2.5a}$$

$$for\ t > 0, u' = u_0 exp(\frac{u_0^2 t'}{v}), T' = T'_w \tag{2.5b}$$

$$, C' = C'_\infty + (C'_w - C'_\infty)At'\, at\ y = 0$$

$$for, t > 0, u \longrightarrow 0, \tag{2.5c}$$

$$T' \longrightarrow T'_\infty, C \longrightarrow C'_\infty as\ y \longrightarrow \infty$$

where

$$A = \frac{u_0^2}{v}$$

Upon introducing the following dimensionless quantities:

$$u = \frac{u'}{u_0}, t = \frac{T' u_0'^2}{v}, y = \frac{y' u_0'}{v},$$

$$\theta = \frac{T' - T'_\infty}{T'_w - T'_\infty{}'}, C = \frac{C' - C'_\infty}{C'_w - C\hat{'}_\infty}, v = \frac{v'}{u_0}$$

$$G_r = \frac{g\beta_T v(T_w - T_\infty)}{u_0^3}, G_m = \frac{g\beta_c v(C_w - C_\infty)}{u_0^3},$$

$$p_r = \frac{\mu c_p}{k}, S_c = \frac{v}{D}$$

$$\Omega = \frac{\Omega v}{u_0^2}, a = \frac{av}{u_0^2}, M^2 = \frac{\sigma B_0^2 v}{\rho u_0^2} \tag{2.6}$$

and using them in equations (2.1) - (2.4), the governing equations in the dimensionless form are as follows:

$$\frac{\partial u}{\partial t} - 2\Omega v = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m C - M^2 u \tag{2.7}$$

$$\frac{\partial v}{\partial t} + 2\Omega u = \frac{\partial^2 v}{\partial y^2} - M^2 v \tag{2.8}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{pr}\frac{\partial^2 \theta}{\partial y^2} \tag{2.9}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} \tag{2.10}$$

the corresponding dimensionless boundary conditions are

$$For\ t \leq 0, u = 0, \theta = 0, C = 0\ \forall\ y \tag{2.11a}$$

$$For\ t > 0, u = exp(at), \theta = 1, C = t\ at\ y = 0 \tag{2.11b}$$

$$For\ t > 0, u \longrightarrow 0, \theta \longrightarrow 0, C \longrightarrow 0\ as\ y \longrightarrow \infty \tag{2.11c}$$

It should be noted that all the physical variables are reported in the Nomenclature section.

3 Solution of the problem

To solve equations (2.7) and (2.8), a complex velocity potential function is introduced as and now combing these two equations, we obtain

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial y^2} - G_r\theta - G_m C - M_1 q \tag{3.12}$$

$$(where\ M_1 = M^2 + 2i\Omega)$$

Using Laplace transform on both sides of the equations (2.9) to (2.10) and (3.12), we get

$$\frac{d^2\overline{C}}{dy^2} - S_C s\overline{C} = 0 \tag{3.13}$$

$$\frac{d^2\bar{\theta}}{dy^2} - p_r s\bar{\theta} = 0 \tag{3.14}$$

$$\frac{d^2\overline{q}}{dy^2}-(M_1+s)\overline{q}=-G_r\overline{\theta}-Gm\overline{C} \qquad (3.15)$$

The relevant boundary conditions are

$$\overline{u}=\frac{1}{s-a},\overline{\theta}=\frac{1}{s},\overline{C}=\frac{1}{s^2}\ at\ y=0 \qquad (3.16a)$$

$$\overline{u}\longrightarrow 0,\overline{\theta}\longrightarrow 0,\overline{C}\longrightarrow 0\ as\ y\longrightarrow\infty \qquad (3.16b)$$

Solving the equations (3.13) to (3.15) along with the boundary conditions (16a) and (16b), the following solutions are obtained:

Case (i):for Sc≠1, Pr≠1:

$$q=\frac{e^{at}}{2}\left[e^{-y\sqrt{a+M_1}}erfc\left(\eta-\sqrt{a+M_1t}\right)+\right.$$
$$e^{y\sqrt{\alpha+M_1}}erfc\left(\eta+\sqrt{(a+M_1)\,t}\right)$$
$$+\frac{1}{2}\left[e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{M_1t}\right)+\right.$$
$$e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{M_1t}\right)$$
$$+\frac{e^{\alpha_1t}}{2}\left[e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{(\alpha_1+M_1)\,t}\right)+\right.$$
$$e^{y\sqrt{\alpha_1+M_1}}efrc\left(\eta+\sqrt{(\alpha_1+M_1)\,t}\right)$$
$$+\frac{e^{\alpha_3t}}{2}\left[e^{-y\sqrt{\alpha_3+M_1}}erfc\left(\eta-\sqrt{(\alpha_3+M_1)\,t}\right)+\right.$$
$$e^{y\sqrt{\alpha_3+M_1}}efrc\left(\eta+\sqrt{(\alpha_3+M_1)\,t}\right)$$
$$+\left(\frac{t}{2}-\frac{y}{4\sqrt{M_1}}\right)e^{-y\sqrt{M_1}}efrc\left(\eta-\sqrt{M_1t}\right)+$$
$$\left(\frac{t}{2}+\frac{y}{4\sqrt{M_1}}\right)e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{M_1t}\right)+t$$
$$(1+2\eta^2Pr)$$
$$\left[efrc\left(\eta\sqrt{Pr}-\frac{y\sqrt{Pr}}{\sqrt{\pi t}}exp\left(-\eta^2Pr\right)\right)\right]+$$
$$efrc\left(\eta\sqrt{Pr}\right)$$
$$+\frac{e^{\alpha_1t}}{2}\left[e^{-y\sqrt{Pr\alpha_1}}erfc\left(\eta\sqrt{Pr}-\sqrt{\alpha_1t}\right)+\right.$$
$$e^{y\sqrt{Pr\alpha_1}}efrc\left(\eta\sqrt{Pr}+\sqrt{\alpha_1t}\right)$$
$$+t\left[\left(1+2\eta^2Sc\right)erfc\left(\eta\sqrt{Sc}-\right.\right.$$
$$\frac{y\sqrt{Sc}}{\sqrt{\pi t}}exp\left(-\eta^2Sc\right)$$
$$+\frac{e^{\alpha_3t}}{2}\left[e^{-y\sqrt{Sc\alpha_3}}erfc\left(\eta\sqrt{Sc}-\sqrt{\alpha_3t}\right)+\right.$$
$$e^{y\sqrt{Sc\alpha_3}}erfc\left(\eta\sqrt{SC}+\sqrt{\alpha_3t}\right)$$
$$(3.17)$$

$$C=t\left(1+2\eta^2S_c\right)$$
$$\left[erfc\left(\eta\sqrt{S_c}-2\eta\sqrt{\frac{Sc}{\pi}}exp\left(-\eta^2S_c\right)\right)\right] \qquad (3.18)$$

$$\theta=erfc\left(\eta\sqrt{Pr}\right) \qquad (3.19)$$

Case (ii): For Sc=1 and Pr=1

$$q=\frac{e^{at}}{2}e^{-y\sqrt{a+M_1}}\left[erfc\left(\eta-\sqrt{(a+M_1)\,t}\right)\right]+$$
$$\frac{e^{at}}{2}e^{-y\sqrt{a+M_1}}\left[e^{y\sqrt{\alpha+M_1}}erfc\left(\eta+\sqrt{(a+M_1)\,t}\right)\right]$$
$$-\frac{Gr}{2M_1}\left[e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{M_1t}\right)\right]$$
$$-\frac{Gr}{2M_1}\left[e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{M_1t}\right)\right]-$$
$$\frac{G_m}{M_1}\left[\left(\frac{t}{2}-\frac{y}{4\sqrt{M_1}}\right)e^{-y\sqrt{M_1}}erfc\left(\eta-\sqrt{M_1t}\right)\right]-$$
$$\frac{G_m}{M_1}\left[\left(\frac{t}{2}+\frac{y}{4\sqrt{M_1}}\right)e^{y\sqrt{M_1}}erfc\left(\eta+\sqrt{M_1t}\right)\right]+$$
$$\frac{G_m}{M_1}erfc\left(\eta\right)+$$
$$\frac{G_m}{M_1}t\left[\left(1+2\eta^2\right)erfc\left(\eta\right)-2\eta\sqrt{\frac{1}{\pi}}exp\left(-\eta^2\right)\right]$$
$$(3.20)$$

$$\theta=erfc\left(\eta\right) \qquad (3.21)$$

$$C=t\left[\left(1+2\eta^2\right)erfc\left(\eta\right)-2\eta\sqrt{\frac{1}{\sqrt{\pi}}exp\left(-\eta^2\right)}\right] \qquad (3.22)$$

where

$$\alpha_2=\frac{G_m}{Sc-1},\alpha_3=\frac{M_1}{Sc-1},$$

$$\alpha_4=\frac{G_m}{(Sc-1)\,\alpha_3^2},\eta=\frac{y}{2\sqrt{t}}$$

$$\alpha_1=\frac{M_1}{Sc-1},erf\left(z\right)=\frac{2}{\sqrt{\pi}}\int_0^1 exp\left(-z^2\right)dz,$$

$$erfc\left(z\right)=\frac{2}{\sqrt{\pi}}\int_t^\infty exp\left(-z^2\right)dz$$

Skin Friction: The coefficient of skin friction at the plate surface is calculated as

$$
\begin{aligned}
\tau_x + i\tau_y &= -\left(\frac{\partial q}{\partial y}\right)_{y=0} \\
&= exp\,(at)\left[\sqrt{a+M_1}erf\left(\sqrt{(a+M_1)\,t}\right)\right] \\
&+ exp\,(at)\left[\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{(a+M_1)\,t}\right)\right] \\
&- (\alpha_1+\alpha_4)\left[\sqrt{M_1}erf\,(M_1 t)\right] \\
&- (\alpha_1+\alpha_4)\left[\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{M_1 t}\right)\right] - \frac{-2\alpha_4}{\sqrt{\pi}} \\
&- \alpha_3\alpha_4 t\left(\frac{2}{\sqrt{\pi}}+\sqrt{\frac{Sc}{\pi t}}\right) - \alpha_2 exp\,(\alpha_1 t) \\
&(\left[\sqrt{\alpha_1+M_1}erf\left(\sqrt{(\alpha_1+M_1)\,t}\right)\right] - \\
&\left[\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{(\alpha_1+M_1)\,t}\right)\right]) \\
&- \alpha_4 exp\,(\alpha_3 t) \\
&(\left[\sqrt{\alpha_3+M_1}erf\left(\sqrt{(\alpha_3+M_1)\,t}\right)\right] \\
&\left[+\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{(\alpha_3+M_1)\,t}\right)\right]) \\
&- \frac{\alpha_3\alpha_4 t}{2}\left[2 - t\sqrt{M_1 t}\right] + \\
&\frac{\alpha_3\alpha_4 t}{2}\left[\frac{1}{2\sqrt{M_1}}erf\left(\sqrt{M_1 t}\right)\right] + \\
&\frac{\alpha_3\alpha_4 t}{2}\left[\frac{2t}{\sqrt{\pi}}cosh\left(\sqrt{M_1 t}\right)\right] \\
&- \alpha_1 t\left[\frac{2}{\sqrt{\pi}}+\sqrt{\frac{Pr}{\pi t}}\right] \\
&- \alpha_2 exp\,(\alpha_1 t)\left[\sqrt{\alpha_1 p}ref\left(\sqrt{\alpha_1 Pr}\right)\right] - \\
&\alpha_2 exp\,(\alpha_1 t)\left[\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{\alpha_1 t}\right)\right] \\
&- \alpha_4 exp\,(\alpha_3 t)\left[\sqrt{\alpha_3 Sc}erf\left(\sqrt{\alpha_3 Sc}\right)\right] - \\
&\alpha_4 exp\,(\alpha_3 t)\left[\frac{2}{\sqrt{\pi}}cosh\left(\sqrt{\alpha_3 t}\right)\right]
\end{aligned}
\tag{3.23}
$$

Nusselt Number:
The rate of heat transfer in the form of Nusselt number is derived as

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=0} = \frac{-2}{\sqrt{\pi}} \tag{3.24}$$

Sherwood Number: The rate of mass transfer in the form of Sherwood number is derived as

$$Sh = -\left(\frac{\partial c}{\partial y}\right)_{y=0} = t\left[\frac{-2}{\sqrt{\pi}} - \sqrt{\frac{Sc}{\pi t}}\right] \tag{3.25}$$

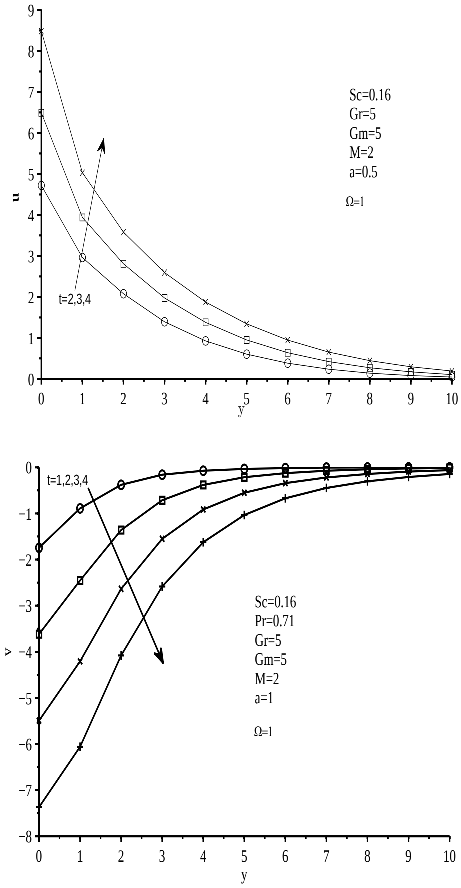

Figure 1: Effect of time t on primary velocity u and secondary velocity v

4 Results and Discussion

Numerical evaluation of the equations which are solved analytically in the previous section is performed and a representative set of results for velocity, temperature, concentration, skin friction, Nusselt number and the Sherwood number are considered and the effects of various physical parameters on flow quantities are studied though graphs. The value of Pr is chosen as 0.71 and 7.0, which corresponds to air and water respectively. The values of Schmidt number are chosen to represent the presence of species by hydrogen (0.22), water vapour (0.60), ammonia (0.78), Ethyl benzene (2.01) and carbon dioxide (0.96), [see Ref. [8]]. The other parameters such as time t, magnetic parameter M, rotation parameter and the acceleration parameter a, are chosen arbitrarily. In the present study the boundary condition for $y \longrightarrow \infty$ is replaced by where ymax is a suffi-

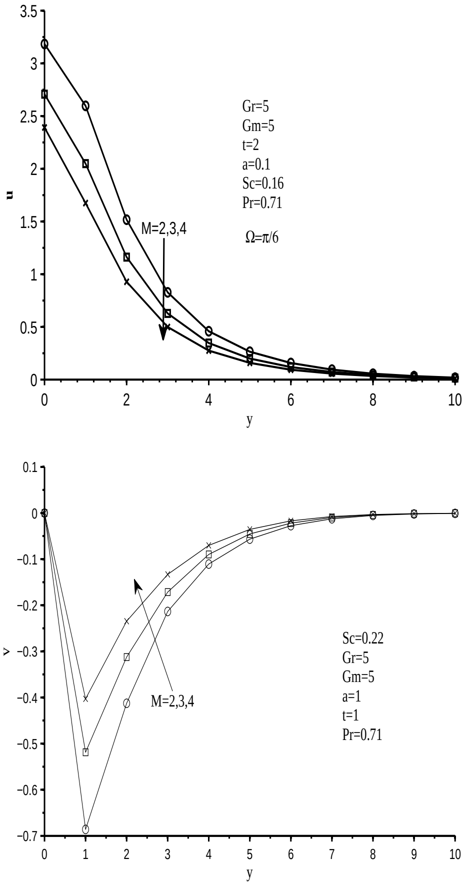

Figure 2: Effect of magnetic parameter M on primary velocity u and secondary velocity v

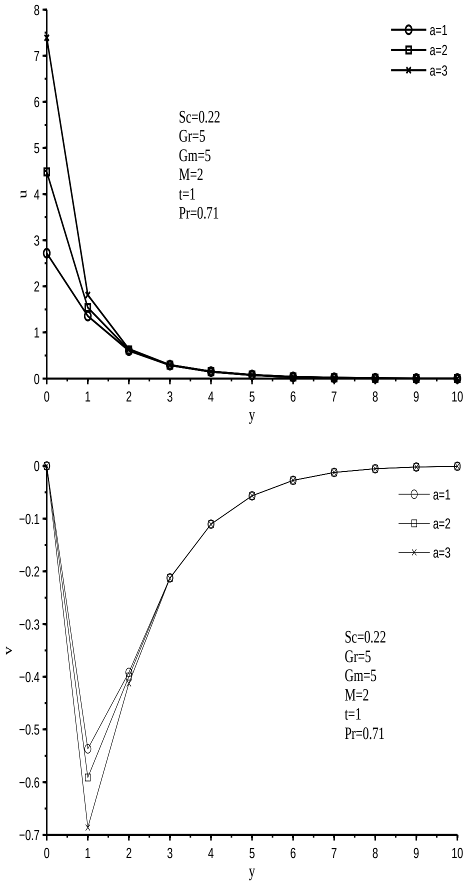

Figure 3: Effect of a on primary velocity u and secondary velocity v

ciently large value of y where the velocity profile approches the relevant free stream velocity asympotically. A span wise step distance $\triangle y$ of 0.01 is used with ymax = 7. In order to assess the accuracy of our method, we have compared our results with accepted data sets for the velocity and skin friction profiles for an exponentially accelerated vertical plate corresponding to the case computed by Muthucumarswamy et al. [9]. The results of this comparison are found to be in very good agreement in the absence of magnetic parameter M and rotation parameter Ω and Schmidt number Sc.

The primary and secondary velocity profiles are displayed in Figs. 1 - 5. Figure 1 depicts the effect of t on primary velocity and as well as the secondary velocity. It is observed that an increase in the values of t results the increase in the primary velocity. More over it is observed that velocity near the rotating and accelerating plate is observed to be maximum and gradually it reaches the free stream velocity along the momentum boundary layer. Whereas it shows reverse effect in the case of secondary velocity.

Velocity profiles are plotted in Fig. 2 for different values of magnetic parameter M, from this figure, it is noticed that the existence of the magnetic field is to decrease the primary velocity across the boundary layer, since the application of the transverse magnetic field results a resisting force termed as Lorentz force, which is very similar to drag force, that resists the fluid flow along the boundary layer that results in reducing the fluid velocity. But it has a different action on the other side in the case of the secondary velocity. Effects of acceleration parameter a is studied through Fig. 3 on both the velocities primary and as well as secondary. An increase in a results the increasing primary velocity, where as the secondary velocity decreases with an increase in a. In Fig. 5, velocity profiles are displayed with the variations in Sc From this figure it is observed that primary velocity decreases with the

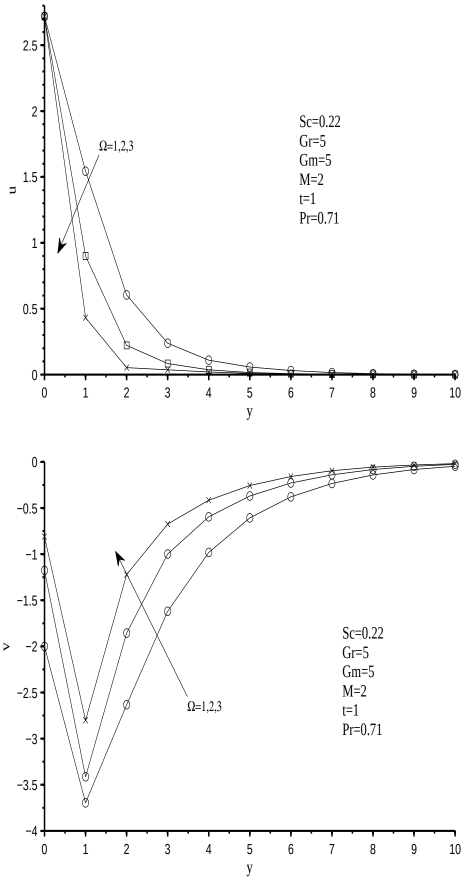

Figure 4: Effect of on Ω primary velocity and secondary velocity v

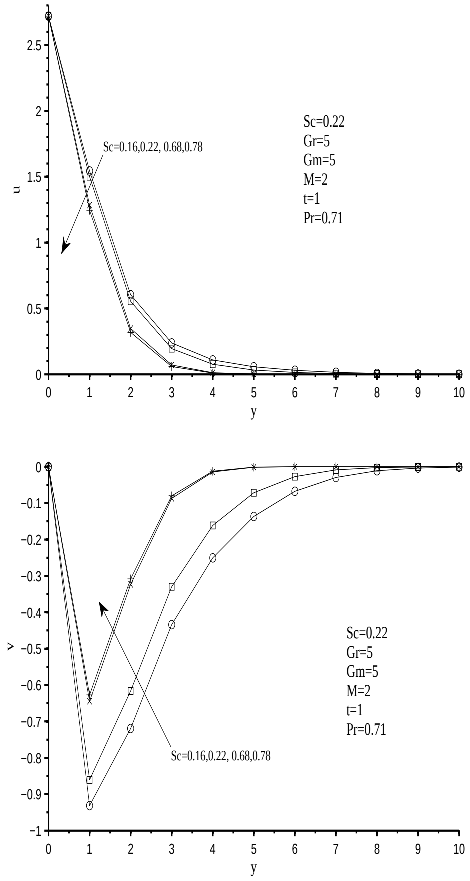

Figure 5: Effect of Sc on primary velocity u and secondary velocity v

increasing values of Sc where as it shows reverse effect in the case of secondary velocity. In Fig. 6, concentration profiles are displayed with the variations in Schmidt number Sc The concentration of the boundary layer decreases till it attains the minimum value of zero at the end of the boundary layer. As expected, the mass transfer decreases as the Schmidt number Scncreases, this is due to fact that the effect of Schmidt number decreases the concentration boundary layer slowly for higher values of Sc Figure 7 depicts the plot of temperature profiles for various values of Prandtl number Pr From this figure it is seen that an increase in the values of Prandtl number leads to a decrease in the temperature distribution, because this is due to fact that the thermal boundary layer decreases with the increasing values of the Prandtl number Pr

5 Conclusion

We have considered the problem of rotating, magnetohydrodynamic heat and mass transfer by free convective flow past an exponentially accelerated isothermal vertical plate in the presence of variable mass diffusion. While the temperature of the plate is constant, the concentration at the plate is considered to be a linear function with respect to time t. The plate is assumed to be exponentially accelerated with a prescribed velocity against the gravitational field. The governing equations are solved by using Laplace transform technique and the effect of various physical parameters on the flow quantities are studied through graphs. In this analysis the following conclusions are made.

1 Primary velocity increases with an increase in t and a, whereas it decreases with an increase in M, Sc but reverse effect is noticed in the case of secondary velocity.

2 Temperature is observed to decrease with an increase in Prandtl mumber.

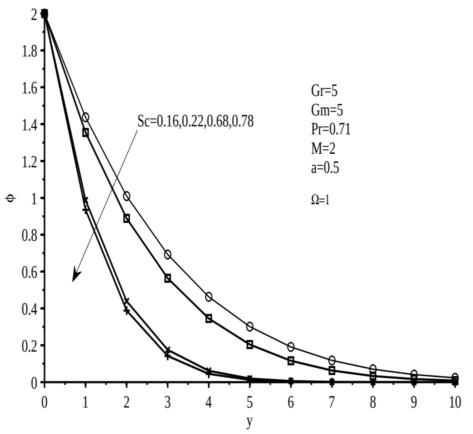

Figure 6: Effect of Scn concentration ϕ

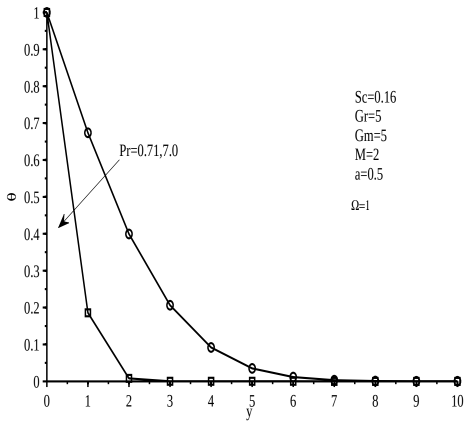

Figure 7: Effect of Prn Temperature θ

3 Concentration is also observed to decrease with an increase in Schmidt number.

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Dr. K. Jonah Philliph was born at Naidupeta in Nellore District in Andhra Pradesh. In 1998 he completed his MSc for which he received a Gold Medal from SV University, Tirupathi. He completed his PhD from the same University in the year 2014. He started his career in 1999 as lecturer in Mathematics at SVM College Naidupeta. Presently he is working as an Associate Professor of Mathematics in the Dept of Science and Humanities at Mother Theresa Institute

of Engineering and Technology, Palamaner. His area of research is in Fluid Mechanics, Magneto Hydrodynamics and Heat and Mass transfer. . He has published 4 papers in International Journals and one paper in National Conference. He is the life member of Indian Society for Technical Education and APSMS.

Dr. M.C. Raju, born in Utukuru Venkatampalli, a small village in Cuddapah district of Andhra Pradesh of south India. He studied B.Sc, M.Sc in Sri Venkateswara University, Tirupati. He also completed M.Phil and received PhD from the same university in 2005 and 2008 respectively. During the school days and at university level, he passed all the courses with first class. He started his career, as a lecturer in mathematics in 1999 at MITS, Madanapalli. Currently he is working as associate professor and Head of the department of Humanities and Science at Annamacharya Institute of Technology and Sciences, Rajampet. His area of research is Fluid Dynamics, Magneto Hydrodynamics, Heat and Mass transfer. He presented 18 papers in national and international conferences. He published 45 papers in National and International Journals. He is guiding 5 students for PhD in Mathematics. He is the reviewer for various National and International Journals. He is the life member in Indian Mathematical society and other bodies.

Ali J. Chamkha is a Professor in the Manufacturing Engineering Department, College of Technological Studies at the Public Authority for Applied Education and Training in Kuwait. He earned his Ph.D. in Mechanical Engineering from Tennessee Technological University, USA, in 1989. His research interests include multiphase fluid-particle dynamics, nanofluids flow in porous media, heat and mass transfer, magnetohydrodynamics and fluid-particle separation. He has served as an Associate Editor for many journals such as International Journal of Numerical Method for Heat and Fluid Flow, Journal of Applied Fluid Mechanics, International Journal for Microscale and Nanoscale Thermal and Fluid Transport Phenomena, International Research Journal of Engineering Science, Technology and Innovation and he is currently the Deputy Editor-in-Chief for the International Journal of Energy Technology and Editor for Hindawi ISRN Mechanical Engineering journal and Communications in Numerical Analysis journal. He is a referee for more than 55 international journals. He has authored and co-authored over 450 publications in archival journals and conferences.

Professor S.V.K.Varma, a senior professor in the department of Mathematics, Sri Venkateswara University Tirupati Andhra Pradesh, India. He has vast experience in teaching and administration and also in research. His area of research is Fluid Dynamics, Magneto hydrodynamics, Heat and Mass transfer. He presented several papers in various conferences at national and international levels. He guided 18 students for PhD and 15 M.Phil He is the life member of various bodies. He is the member of Board of Studies of various universities and Autonomous Institutions.