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Magneto-Convective Fluid Flow past an Exponentially Accelerated Vertical Porous Plate in the Presence of Thermal Diffusion

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Abstract

A theoretical analysis is performed to analyze the characteristics of an unsteady free convective, radiative, chemically reactive, viscous, incompressible and electrically conducting fluid past an exponentially accelerated vertical porous plate in the presence of heat source and Soret effects. The set of non-dimensional governing equations along with boundary conditions are solved numerically by applying finite difference method. The effect of various physical parameters on flow quantities are studied with the help of graphs. For the physical interest, the variations in skin friction, Nusselt number and Sherwood number are also studied through tables. The novelty of this study is the consideration of exponentially varying temperature as well as concentration along with the exponentially accelerated vertical plate.

Keywords: Numerical study; MHD; Radiation; Chemical reaction; Thermal diffusion and heat generation.

1. INTRODUCTION

The MHD continues to attract the interest of outstanding engineering science and applied Mathematics researchers to explore the extensive applications of such flows in the context of aerodynamics, engineering, geophysics and aeronautics. Seth and Ansari [3] considered MHD natural convection flow past an impulsively moving vertical plate with ramped wall temperature in the presence of thermal diffusion with heat generation. Afify [4] analyzed MHD free convective flow and mass transfer over a stretching sheet with chemical reaction. Das and Mitra [5] deliberated unsteady mixed convective MHD flow and mass transfer past an accelerated infinite vertical plate with suction. Kim [6] studied unsteady MHD convective heat transfer past a semi – infinite vertical porous moving plate with variable suction. Makinde and Mhone [7] found heat transfer to MHD oscillatory flow in a channel filled with porous medium. Sharma and Singh [8] analyzed effects of variable thermal conductivity and heat source/source on MHD flow near a stagnation point on a linearly stretching sheet. Chamkha and Ahmed [9] studied similarity solution for unsteady MHD flow near a stagnation point of a three dimensional porous body with heat and mass transfer, heat generation/ generation and chemical reaction. Hayat and Mehmood [1] considered slip effects on MHD flow of third order fluid in a planar channel. Umamaheswar et al. [2] analyzed unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source, viscous dissipation and Ohmic heating. Harinath Reddy et al. [23] studied unsteady MHD free convection flow of a Kuvshinski fluid past a vertical porous plate in the presence of chemical reaction and heat source/source. Radiation effects on heat and mass transfer are of great importance in many processes and have, therefore, received a considerable amount of attention in recent time. It is applied in engineering fields and physiology such as transpiration, cooling gaseous diffusion and blood flow in arteries. Radiative heat and mass transfer play important roles in the design of spacecraft, filtrations processes, the drying of porous material in textiles industries solar energy collector and nuclear reactors. Seddeek [19] considered thermal radiation and buoyancy effects on MHD free convective heat generating flow over an accelerating permeable surface with temperature dependent viscosity. Muthucumaraswamy [25] studied radiative heat and mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction. Ravikumar et al. [26] analyzed magnetic field and radiation effects on a double diffusive free convective flow bounded by two infinite impermeable plates in the presence of chemical reaction. Reddy et al. [27] deliberated chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux. Raju et al. [28] studied radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Seth et al. [29] analyzed effects of thermal radiation and rotation on unsteady hydromagnetic free convection flow past an impulsively moving vertical Plate with ramped temperature in a porous medium. Seth [10] studied magneto hydrodynamic flow over a permeable non-linearly stretching surface with effects of viscous dissipation and thermal radiation. Seth et al. [11] analyzed effects of Hall current and rotation on unsteady MHD natural convection flow with heat and mass transfer past an impulsively moving vertical plate in the presence of radiation and chemical reaction. Seddeek et al. [12] considered effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation. Raptis et al. [13] analyzed effects of radiation in an optically thin gray gas flowing past a vertical infinite plate in the presence of a magnetic field. Ibrahim et al. [21] studied effect of the chemical reaction and radiation generation on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction.

Seth et al. [15] analyzed MHD natural convection flow with radiative heat transfer past an impulsively moving vertical plate with ramped temperature in the presence of Hall current and thermal diffusion. Chandra Reddy et al. [16] considered thermal and solutal buoyancy effect on MHD boundary layer flow of a visco-elastic fluid past a porous plate with varying suction and heat source in the presence of thermal diffusion. Srinivasacharya and Kaladhar [17] studied Soret and Dufour effects on mixed convection flow of couple stress fluid in a non-Darcy porous medium with heat and mass fluxes. Srinivasacharya and Upendar [18] analyzed Soret and Dufour effects on MHD free convection in a micro polar fluid. Seddeek [19] considered thermal-diffusion and diffusion-thermo effects on mixed free forced convective flow and mass transfer over accelerating surface with a heat source in the presence of suction and blowing in the case of variable viscosity. Narayana and Murthy [20] studied Soret and Dufour effects in a doubly stratified Darcy porous medium. Hayat and Nawaz [21] analyzed Soret and Dufour effects on the mixed convection flow of a second grade fluid subject to Hall and ion-slip currents. Patil et al. [22] considered double diffusive mixed convection flow over a moving vertical plate in the presence of internal heat generation and a chemical reaction. Raju et al. [30-35] focused on similar results in recent times.

Nomenclature

A	Constant
Cp	Specific heat at constant pressure
C	Concentration
Gr	Thermal Grashof number
Gc	modified Grashof number
G	Acceleration due to gravity
M	magnetic parameter
k_p^*	Permeability of the medium
k_T	Thermal diffusivity
Pr	Prandtl number
K	porosity parameter
Q	heat generation parameter
Ra	radiation parameter
Sc	Schmidt number
Kr	Chemical reaction parameter
Nu	Nusselt number
Sh	Sherwood number
S_0	Soret number
U	Velocity of the fluid
T	Time
Y	Coordinate axis normal to the plate
Greek symbols	
Β	Volumetric coefficient of thermal expansion
β^*	Volumetric coefficient of concentration expansion
θ	Temperature
Μ	Coefficient of viscosity
Ν	Kinematic viscosity
Ρ	Density of the fluid
Τ	skin friction
Σ	Electrical conductivity
Subscripts	
S	surface of the plate
∞	Conditions in the free stream

2. FORMULATION OF THE PROBLEM:

We consider a viscous incompressible, electrically conducting, heat absorbing and chemically reacting Newtonian fluid flow past an infinite vertical porous plate. A magnetic field of uniform strength is applied perpendicular to the plate. Let x^*-axis be taken along the plate in the vertically upward direction and the y^*-axis be taken perpendicular to the plate. At time $t \leq 0$, the plate is maintained at the temperature higher than ambient temperature T_∞ and the fluid is at rest. At time $t > 0$, the plate is linearly accelerated with increasing time in its own plane and also At time $t^*>0$ the temperature and

Concentration of the plate $y^*= 0$ is raised to $T_\infty^* + \left(T_W^* - T_\infty^*\right) e^{a^* t^*}$ and $C_\infty^* + \left(C_W^* - C_\infty^*\right) e^{a^* t^*}$ with time t and thereafter remains constant and that of $y^* \to \infty$ is lowered to T_∞^* and C_∞^*. The presence of thermal diffusion is taken into account. It is assumed that the effect of viscous dissipation is negligible. By usual Boussineq's and boundary layer approximation, the unsteady flow is governed by the following equations:

$$\frac{\partial u^*}{\partial t^*} = \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T_\infty^*\right) + g\beta^*\left(C^* - C_\infty^*\right) - \frac{\sigma B_0^2 u^*}{\rho} - \frac{\upsilon}{k_p^*} u^* \qquad (1)$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k_T \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\partial q^*}{\partial y^*} + S^*\left(T^* - T_\infty^*\right) \qquad (2)$$

$$\frac{\partial C^*}{\partial t^*} = D \frac{\partial C^*}{\partial y^{*2}} - K_r^*\left(C^* - C_\infty^*\right) + D_1 \frac{\partial^2 T^*}{\partial y^{*2}} \qquad (3)$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{ll} u^* = 0, T^* = T_\infty^*, C^* = C_\infty^* & \text{for all } y^*, t^* \le 0 \\ t^* > 0 : u^* = u_0 e^{a^* t^*}, T^* = T_\infty^* + \left(T_W^* - T_\infty^*\right) e^{a^* t^*}, & \\ \quad C^* = C_\infty^* + \left(C_W^* - C_\infty^*\right) e^{a^* t^*} & \text{at } y^* = 0 \\ \quad u^* \to 0, T^* \to T_\infty^*, C^* \to C_\infty^* & \text{as } y^* \to \infty \end{array}\right\} \qquad (4)$$

where $a = \frac{a^* \upsilon}{u_0^2}$

The non-dimensional quantities are as follows:

$$u = \frac{u^*}{u_0}, t = \frac{t^* u_0^2}{\upsilon}, y = \frac{y^* u_0}{\upsilon}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}, Gr = \frac{g\beta\upsilon\left(T_w^* - T_\infty^*\right)}{u_0^3},$$

$$Gc = \frac{g\beta^*\upsilon\left(C_W^* - C_\infty^*\right)}{u_0^3}, M = \frac{\sigma B_0^2 \upsilon}{\rho u_0^2}, K = \frac{k_p^* u_0^2}{\upsilon^2}, \Pr = \frac{\rho\upsilon C_p}{k_T}, S = \frac{S^* \upsilon}{\rho C_p u_0^2},$$

$$\frac{\partial q_r^*}{\partial y^*} = 4\left(T^* - T_\infty^*\right) I^*, R = \frac{4\upsilon I^*}{\rho C_p u_0^2}$$

$$Sc = \frac{\upsilon}{D}, K_r = \frac{K_r^* \upsilon}{u_0^2}, S_0 = \frac{D_1\left(T_W^* - T_\infty^*\right)}{\upsilon\left(C_W^* - C_\infty^*\right)}$$

After introducing the non-dimensional quantities into the equations (1)-(3), these equations reduces to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\,\theta + Gc\,C - M\,u - \frac{1}{K} u \qquad (5)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr} \frac{\partial^2 \theta}{\partial y^2} - R\theta + S\theta \qquad (6)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-K_r C+So\frac{\partial^2\theta}{\partial y^2} \tag{7}$$

The corresponding initial and boundary conditions are

$$\left.\begin{array}{ll} u=0,\theta=0,C=0 & \text{for all } y, t\le 0\\ t>0: u=e^{at},\theta=e^{at},C=e^{at} & \text{at } y=0\\ u\to 0,\theta\to 0,C\to 0 & \text{as } y\to\infty \end{array}\right\} \tag{8}$$

3. METHOD OF SOLUTION

Equations (5)-(7) are linear partial differential equations and are to be solved by using the initial and boundary conditions (8). However exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (5)-(7) are as follows:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t}=Gr\,\theta_{i,j}+Gc\,C_{i,j}+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}-M\,u_{i,j}-\frac{1}{K}u_{i,j} \tag{9}$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-R\theta_{i,j}+S\,\theta_{i,j} \tag{10}$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}=\frac{1}{Sc}\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}-K_r C_{i,j}+So\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2} \tag{11}$$

Here, the suffix i refers to y and j to time. The mesh system is divided by taking $\Delta y = 0.1$. From the initial condition in (8), we have the following equivalent:

$$u(i,0)=0,\ \theta(i,0)=0, C(i,0)=0 \ \text{ for all } i \tag{12}$$

The boundary conditions from (8) are expressed in finite-difference form as follows

$$\begin{array}{l} u(0,j)=e^{at},\theta(0,j)=e^{at},C(0,j)=e^{at} \ \text{ for all } j\\ u(i_{\max},j)=0,\theta(i_{\max},j)=0,C(i_{\max},j)=0 \ \text{ for all } j \end{array} \tag{13}$$

(Here i_{max} was taken as 200)

First the velocity at the end of time step viz, u (i, j+1)(i=1,200) is computed from (9) in terms of velocity, temperature and concentration at points on the earlier time-step. Then θ (i, j +1) is computed from (10) and C (i, j +1) is computed from (11). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.001.

Skin-friction:

The skin-friction in non-dimensional form is given by

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}, where\ \tau=\frac{\tau^1}{\rho u_0^2}$$

Rate of heat transfer:

The dimensionless rate of heat transfer is given by

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

Rate of mass transfer:

The dimensionless rate of mass transfer is given by

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

4. RESULT AND DISCUSSION:

In order to reveal the effects of various parameters on the dimensionless velocity field, temperature field, concentration field, skin friction, Nusselt number and Sherwood number and the effects of various physical parameters such as thermal Grashof number (Gr), the modified Grashof number (Gc), magnetic parameter (M), permeability parameter(k), Prandtl number (Pr), heat source (S), radiation parameter (R), Schmidt number (Sc), chemical reaction parameter (Kr) and Soret number (S_0) on velocity, temperature and concentration we present below the figures 1-10 and considered by indicating arbitrary values. The effect of these parameters on skin friction, Nusselt number and Sherwood number are also displayed in Tables 1–3.

Figures 1-4 demonstrate the variations of the fluid velocity under the effects of various parameters. Fig.1 represents the effect of Grashof number on velocity. We observe that the velocity of the fluid increases as Gr increases. This is due to the buoyancy which is acting on the fluid particles due to gravitational force that enhances the fluid velocity. The velocity of the fluid also increases when modified Grashof number increases and which is presented in the fig. 2. In figure 3, velocity profiles are exhibited with the variation in magnetic parameter. From this figure it is observed that velocity becomes reduced by the increase of magnetic parameter. When an electrically conducting fluid moves in the presence of an applied magnetic field, a magnetic force, called Lorentz force, is generated in the flow field whose tendency is to resist the fluid motion. Due to this reason fluid velocity gets retarded on increasing the magnetic parameter (*M*). Fig.4 depicts the variations in velocity profiles for different values of Permeability parameter. From this figure it is noticed that, velocity increases as K increases.

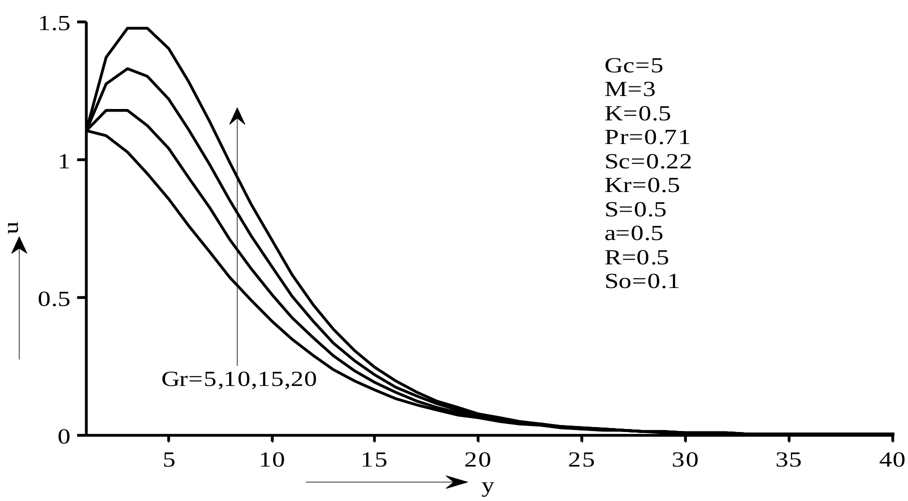

Fig. 1: Effect of Grashof number on velocity

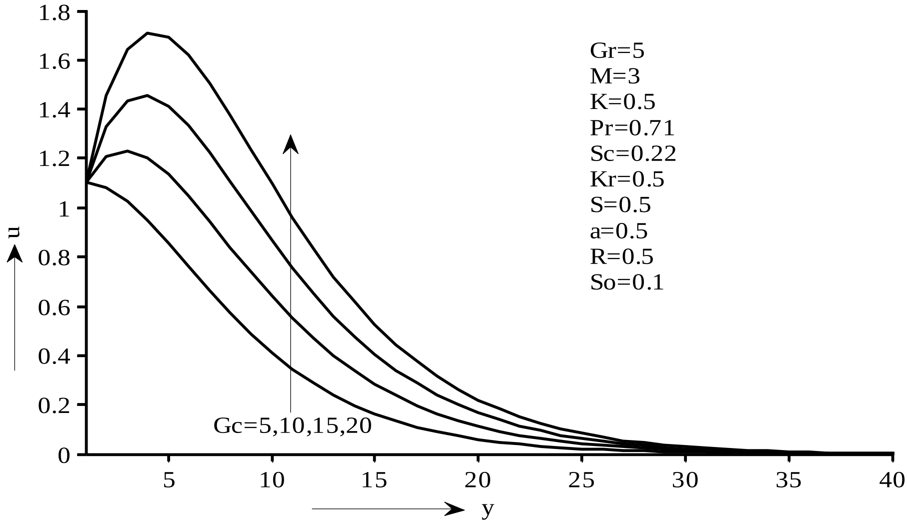

Fig. 2: Effect of modified Grashof number on velocity

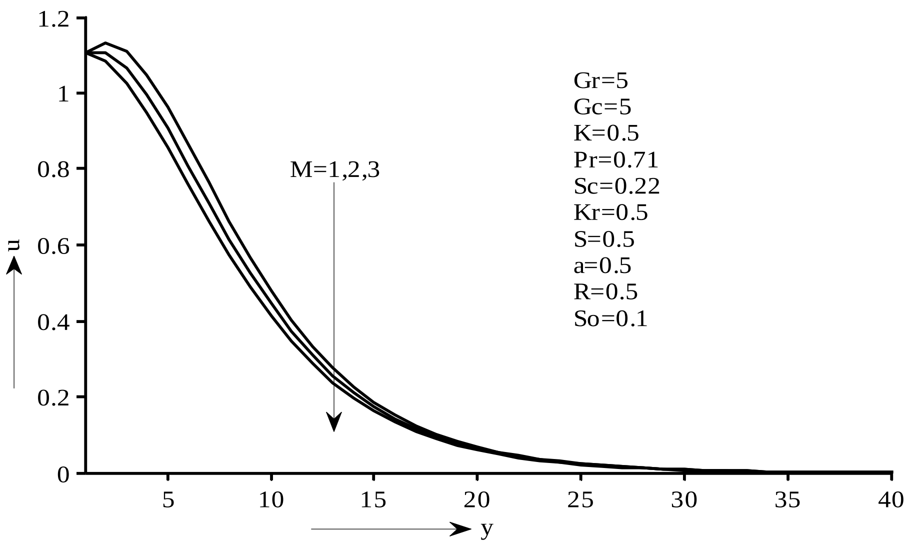

Fig. 3: Effect of magnetic parameter on velocity

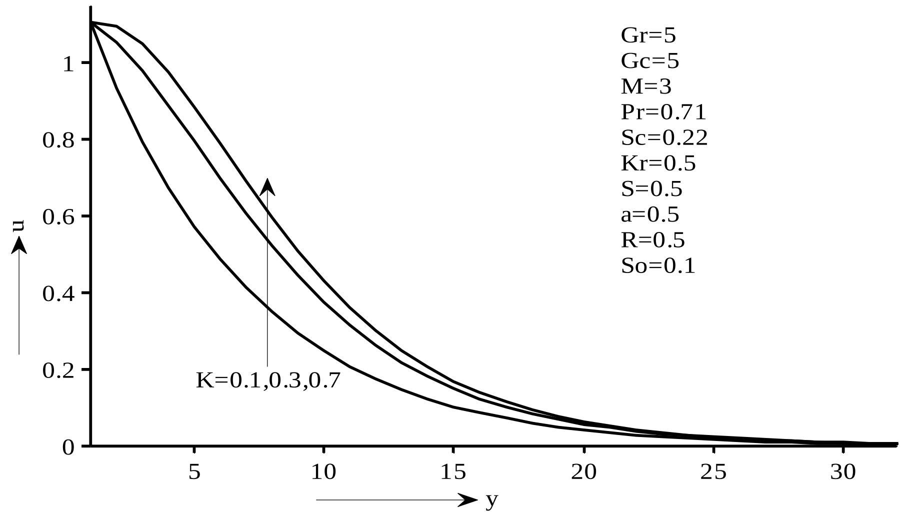

Fig. 4: Effect of permeability parameter on velocity

Figures 5-7 display the variations of the fluid temperature under the effects of different parameters.Fig.5 depicts that a rise in Pr significantly reduces the temperature in the viscous fluid. It can be found from Fig.5 that the thickness of thermal boundary layer decreases on increasing Pr. Fig.6 exhibits the effect of heat generation on temperature. It is noticed that the temperature increases with an increase in the heat generation parameter. The central reason behind this effect is that the heat generation causes an increase in the kinetic energy as well as the thermal energy of the fluid. The momentum and thermal boundary layers get thinner in case of heat generating fluids. It shows reverse effect in the case of heat generation parameter. Fig.7 shows the effect of radiation parameter on temperature distribution. It shows that the temperature reduces with increasing values of radiation parameter.

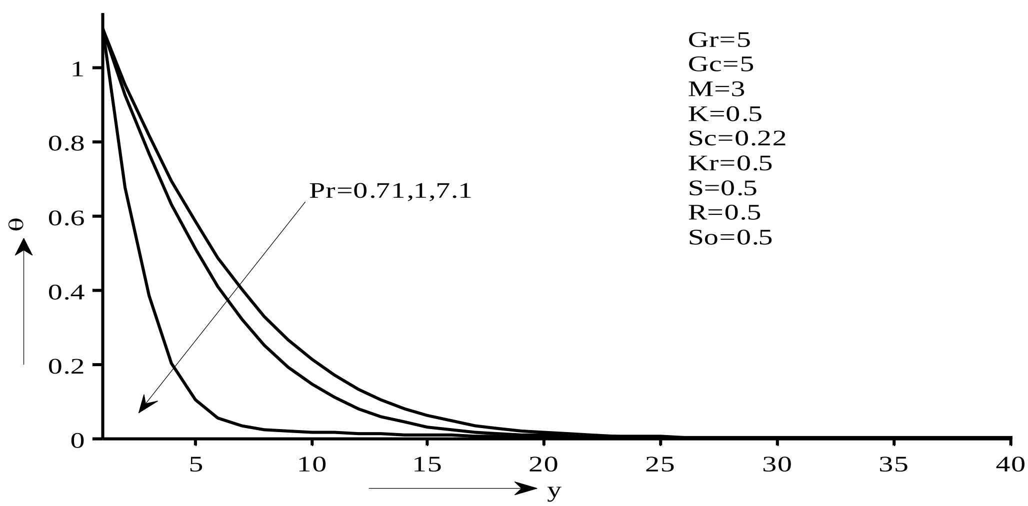

Fig. 5: Effect of Prandtl number on temperature

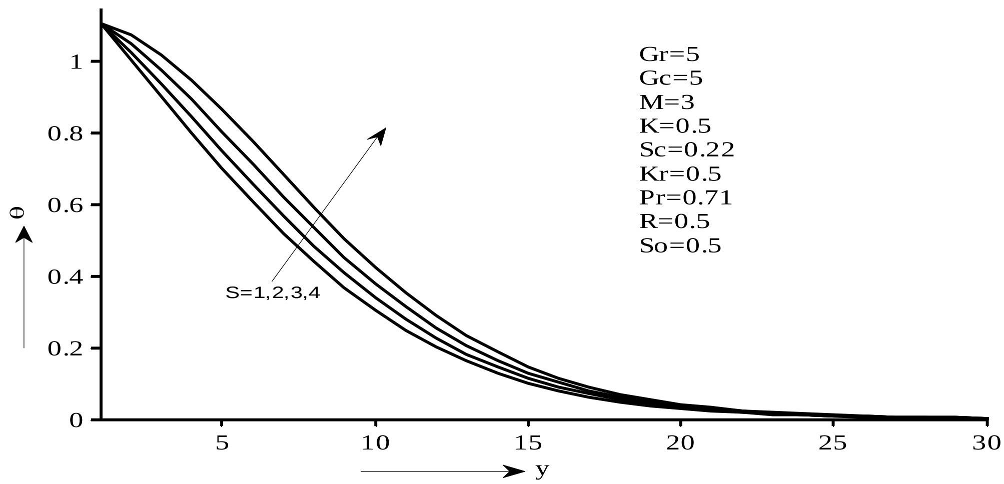

Fig. 6: Effect of heat source on temperature

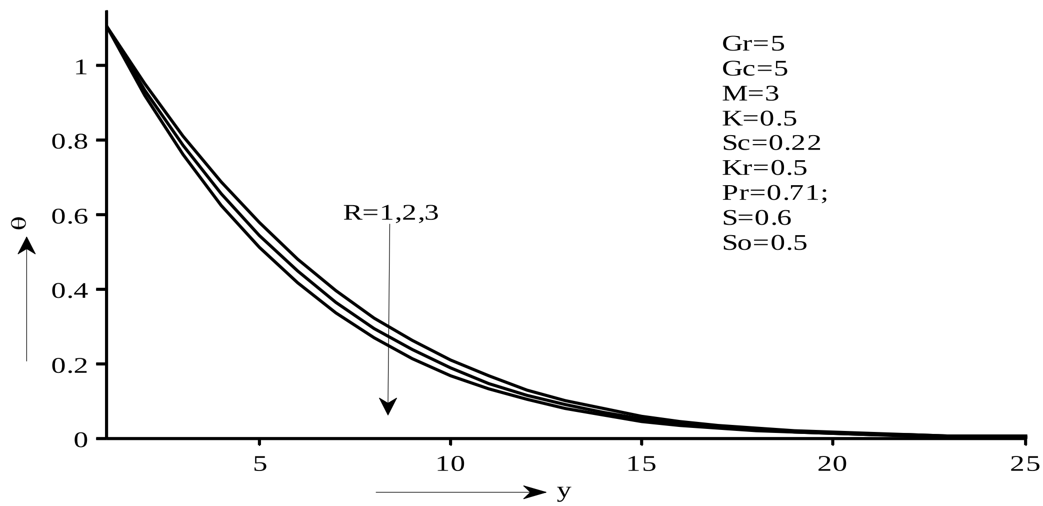

Fig. 7: Effect of radiation parameter on temperature

Figures 8-10 exhibit the variations of the fluid concentration under the effects of different parameters. Influence of Schmidt number on concentration is shown in fig.8, from this figure it is noticed that concentration decreases with an increase in Schmidt number. Because, Schmidt number is a dimensionless number defined as the ratio of momentum diffusivity and mass diffusivity, and is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes. Therefore concentration boundary layer decreases with an increase in Schmidt number. From Fig.9, we observe that the concentration(C) decreases as chemical reaction (Kr) increases. The effect of Soret number on concentration is displayed in fig.10. The concentration increases with increasing values of Soret number.

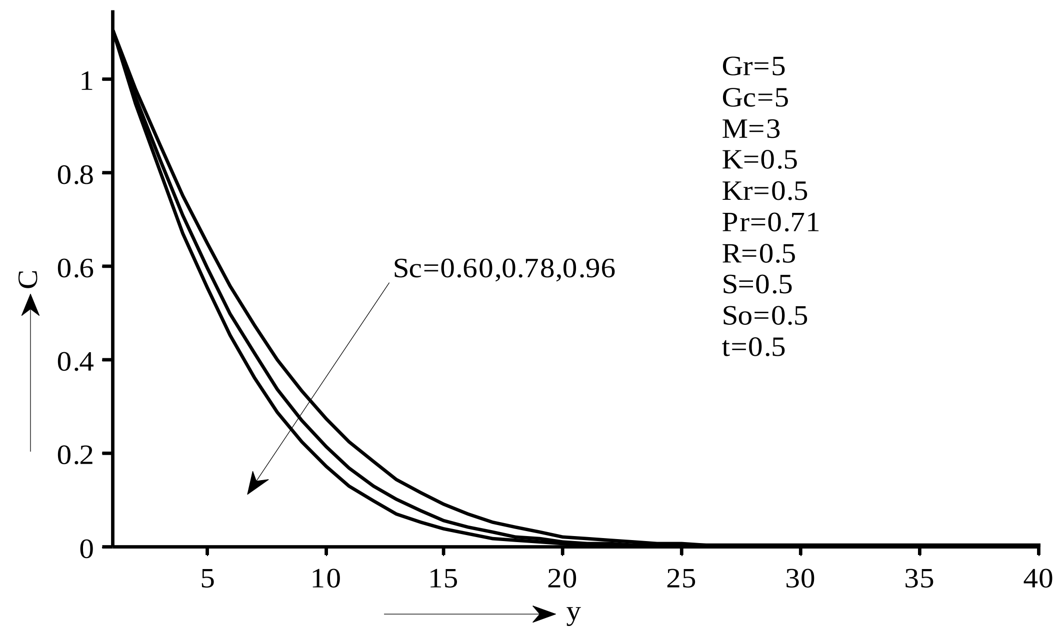

Fig .8: Effect of Schmidt number on concentration

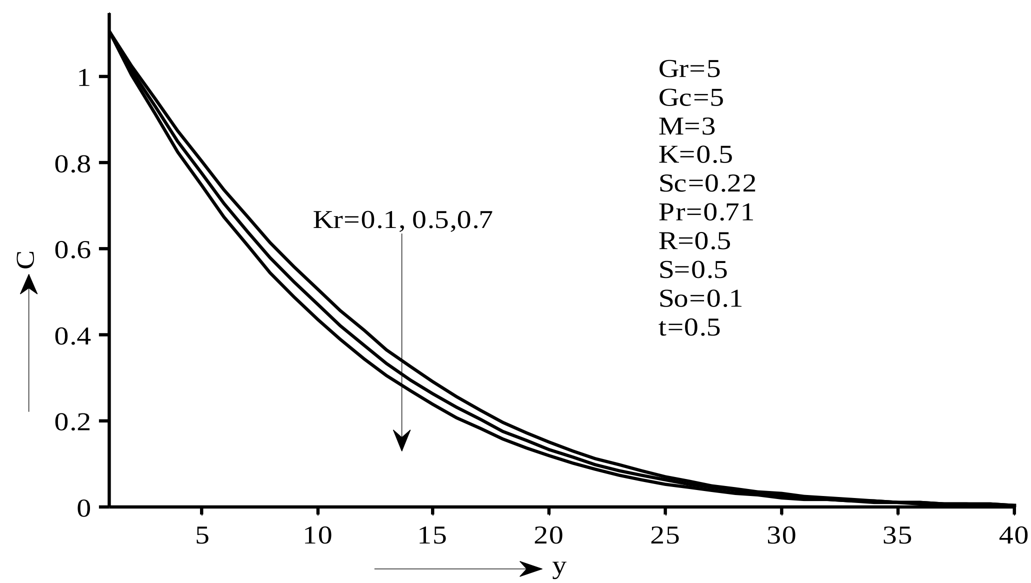

Fig. 9: Effect of chemical reaction on concentration

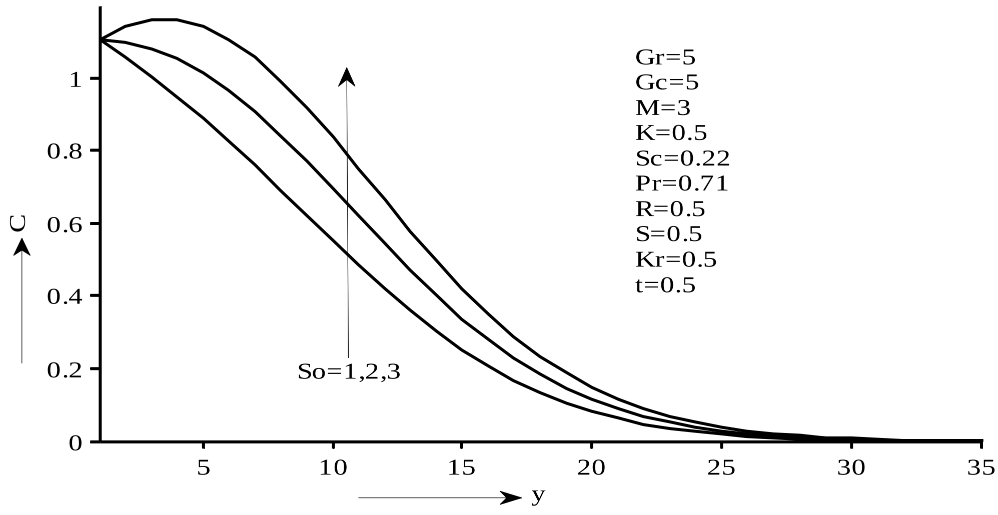

Fig.10: Effect of Soret number on concentration

Table.1 show numerical values of skin-friction for various of Grashof number (Gr), modified Grashof number (Gc), magnetic parameter (M), permeability parameter (K), Prandtl number (Pr), heat source (S), radiation parameter (R), Schmidt number (Sc), chemical reaction parameter (Kr) and Soret number (S_0). From table.1, we observe that the skin-friction increases with an increase in magnetic parameter, Prandtl number, radiation parameter, Schmidt number and chemical reaction parameter where as it decreases under the influence of Grashof number, modified Grashof number, permeability parameter, heat source and Soret number.

Table.2 demonstrates numerical values of Nusselt number (Nu) for different values of Prandtl number (Pr), heat source (S) and radiation parameter (R). From table.2, we notice that the Nusselt number increases with an increase in Prandtl number and radiation parameter and it shows reverse effect in case of heat source parameter. Table.3 shows numerical values of Sherwood (Sh) for distinct values of Schmidt number (Sc), chemical reaction parameter (Kr) and Soret number. It can be noticed from table 3, that the Sherwood number increases with rising values of Schmidt number and chemical reaction parameter. Increasing values of Soret number results in decreasing the Sherwood number.

Table 1: Variations in skin friction for different values of flow parameters

Gr	Gc	M	K	Pr	S	R	Sc	Kr	So	τ
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.4135
10	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.1652
15	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	5.8956
20	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	5.7034
5	10	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.0796
5	15	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	5.6957
5	20	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	5.3941
5	5	0.5	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.3072
5	5	1	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.3184
5	5	2	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.3586
5	5	3	0.1	0.71	0.5	0.5	0.22	0.5	0.1	6.6933
5	5	3	0.3	0.71	0.5	0.5	0.22	0.5	0.1	6.4520
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.4187
5	5	3	0.5	1	0.5	0.5	0.22	0.5	0.1	6.3314
5	5	3	0.5	3	0.5	0.5	0.22	0.5	0.1	6.5310

5	5	3	0.5	7.1	0.5	0.5	0.22	0.5	0.1	6.5671
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.4081
5	5	3	0.5	0.71	1	0.5	0.22	0.5	0.1	6.4089
5	5	3	0.5	0.71	2	0.5	0.22	0.5	0.1	6.4082
5	5	3	0.5	0.71	0.5	0.1	0.22	0.5	0.1	6.4075
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	0.1	6.4082
5	5	3	0.5	0.71	0.5	1	0.22	0.5	0.1	6.4089
5	5	3	0.5	0.71	0.5	0.5	0.60	0.5	0.1	6.4765
5	5	3	0.5	0.71	0.5	0.5	0.78	0.5	0.1	6.4969
5	5	3	0.5	0.71	0.5	0.5	0.96	0.5	0.1	6.5172
5	5	3	0.5	0.71	0.5	0.5	0.22	1	0.1	6.4082
5	5	3	0.5	0.71	0.5	0.5	0.22	2	0.1	6.4091
5	5	3	0.5	0.71	0.5	0.5	0.22	3	0.1	6.4093
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	1	6.3747
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	2	6.3468
5	5	3	0.5	0.71	0.5	0.5	0.22	0.5	3	6.3184

Table 2: Variations in Nusselt number

Pr	S	R	Nu
0.71	0.5	0.5	5.2507
1	0.5	0.5	6.5165
3	0.5	0.5	12.6173
7.1	0.5	0.5	16.5988
0.71	0.1	0.5	5.2234
0.71	0.3	0.5	5.2312
0.71	0.5	0.5	5.2390
0.71	1	0.5	5.2483
0.71	0.5	0.5	5.3391
0.71	0.5	1	5.3584
0.71	0.5	2	5.3970

Table 3: Variations in Sherwood number

Sc	Kr	S_0	Sh
0.22	0.8	0.1	2.9641
0.60	0.8	0.1	4.7048
0.78	0.8	0.1	5.5240
0.96	0.8	0.1	6.3379
0.22	0.1	0.1	2.9460
0.22	0.3	0.1	2.9512
0.22	0.5	0.1	2.9563
0.22	0.9	0.1	2.9693
0.22	0.8	1	2.3060
0.22	0.8	2	1.5674
0.22	0.8	3	0.8215
0.22	0.8	4	0.0688

5. CONCLUSION

In this paper we have considered a numerical study of magneto-convective fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration in the presence of Soret effect. Explicit finite difference method is employed to solve the equations governing the flow. From the present numerical investigation, following conclusions are drawn:

- Velocity increases with an increase in Grashof number and as well as modified Grashof number and permeability of the porous medium while it decreases in the presence of magnetic parameter.
- Temperature decreases in the presence of Prandtl number and radiation parameter but it shows the reverse effect in case of heat source.
- Concentration increases with an increase in Soret number but it shows the opposite effects in case of Schmidt number and chemical reaction parameter.
- A significance increase is seen in Skin friction for magnetic parameter, Prandtl number, heat source, radiation parameter, Schmidt number and chemical reaction parameter while a reversed tendency is observed for Grashof number, modified Grashof number, permeability parameter and Soret number.
- The rate of heat transfer increases with Prandtl number, heat source and radiation parameter.
- The rate of mass transfer increases with Schmidt number and chemical reaction but it shows opposite effects in the case of Soret number.

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