INFLUENCE OF HALL CURRENT AND BUOYANCY DISTRIBUTION ON MHD TIME DEPENDENT HEAT MASS TRANSFER

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Abstract

We have conducted analytical investigations to study the influence Hall current and Buoyancy distribution on (MHD) unsteady heat and mass transfer free convective in vertical channels. Appropriate dimensional quantities were used in changing the dimensional governing partial differential equations to non-dimensional form. An analytical method of variables separable was employed in finding the analytical solution of dimensionless governing partial differential equations. The expressions of velocity, temperature, concentration, skin friction, Nusselt number as well as Sherwood number were gotten analytically and discussed using line graph. From the result obtained, it was observed that velocity profile enhances with the increase of Grasshop number (Gr), Mass Grasshop number (Gc), Hall current (m) and Buoyancy parameter (r_t). While it reduces with the increase of Magnetic parameter (M) and Pradlt number (Pr). Similarly, temperature profile enlarges with the increase of Radiation parameter (R) and Buoyancy parameter (r_t). While the opposite behaviour was observed with the increase of Pradlt number (Pr). Concentration profile diminishes with the increase of both Chemical reaction parameter (K_r) and Schmidt number (Sc). Skin friction gets enhanced with the increase of and Buoyancy parameter (r_t) at both y=0 and y=1 and gets reduced with the increase of Hall current parameter (m) at both y=0 and y=1. Nusselt number enlarges with the increase of Radiation parameter (R) at both y=0 and y=1. While it gets lowered with the increase of Buoyancy parameter (r_t) at both y=0 and y=1. Sherwood number slightly increase with the increase of chemical reaction parameter (K_r) at both y=0 and y=1 and significantly decrease with the increase of Schmidt number (Sc) at both y=0 and y=1.

Introduction

An induced current applied in the direction normal to the magnetic field is called a Hall current. The impact of Hall current on Magneto-hydrodynamic (MHD) heat and mass transfer flow has received wide spread attentions due to its important applications. Hall current has many applications in many areas of field of study, which includes Hall current accelerators, refrigerator coils, electric transformer as well as power generators and pumps. Because of its significant impact on the study of heat and mass transfer flow many researches have been carried out to study the behavior of fluid velocity, and temperature. For example Panneerselvi (2019) analyzed the effects of MHD unsteady peristaltic flow in porous medium in the presence of Hall current. Also the investigations of unsteady MHD axisymmetric second grade fluid with suction under the influence of Hall current was carried out by [2]. Similarly, Seth et al. (2016) investigated the impact of thermal radiation and Hall current in unsteady MHD moving vertical plate due to ramped temperature. Chaudhary et al. (2013); Lavanya (2020); Seth et al. (2015) studied thermal Radiation and Hall current Effects on unsteady free convective flow in porous medium with constant heat and mass transfer. The influence of Hall current, rotation and Soret on MHD heat and mass transfer free convective in porous medium was analyzed by [7]. Furthermore the effects of MHD on heat and mass transfer flow in the presence of Hall current and joule heating was analyzed by (Srinivasacharya and Jagadeeshwar, 2017; Lavanya, 2020).

Khan et al. (2019) studied unsteady MHD under the influence of Hall current and Thermophoresis mixed convection and reported that velocity profile gets enlarged with the increase of Hall current parameter. Quader and Alam (2021) investigated the impact of soret and Dufour on MHD unsteady heat mass transfer in the presence of Hall current and heat flux and reported that the primary velocity profile gets enlarged with the increase of Hall current and secondary velocity gets reduced respectively. According to Krishna et al. (2020) Hall current accelerates the motion of fluid from their research analyzed on the effects of unsteady MHD heat and mass transfer flow over an exponentially inclined plate in the presence of Hall current and ion slip effects. The effects of magnetic field natural convective semi-vertically inclined plate in the presence of Hall current was studied by [12] and discovered that Hall current parameter rises both primary and secondary velocity. The investigations of heat and mass transfer MHD viscoelastic micro-polar flow through porous medium in the presence thermal radiation and Hall current was carried out by [13]. Buoyancy parameter is a parameter which is normally found in the boundary conditions and it is the consequences of the difference between the temperature of the fluid and the temperature of the wall of the plate (Isah and Abdullah, 2020). Buoyancy effect is very important in studying fluid flow analysis due to its boosting effects on fluid temperature which tantamount to the acceleration of fluid motion. As a result of this vital role that, buoyancy effect plays that is why many research works have been conducted just to study its impacts on fluid flow analysis. For examples the investigations of the influence of MHD heat and mass transfer free convective in the presence thermal radiation and chemical reaction was conducted by (Reddy, 2016). The analysis of the effects magnetic field, Joule heating, thermal radiation absorption, viscous dissipation, Buoyancy forces, Soret and Dufour on MHD heat and mass transfer flow over a permeable vertically stretching sheet was investigated by [16]. Similarly, Haq et al. (2021) studied MHD unsteady heat and mass transfer free convective of a viscous incompressible fluid in the existence chemical molecular diffusivity effects upon a perpendicular plate with arbitrary time dependent shear stresses and exponential heating phenomenon.

According to the Isah and Abdullah, (2020) buoyancy parameter has enhancing effects on velocity and temperature profile reported from their study on the influence of Soret and buoyancy Reaction on Unsteady MHD Couette Flow in Free Convective Vertical Channels. Ramzan et al. (2017) studied the influence of Rossel and thermal radiation on heat transfer in the flow of micro- polar Nano-fluid with chemical reaction and activation energy and reported that the velocity gets reduced by increasing buoyancy ratio parameter. Additionally Sreedevi et al. (2017) studied combined effects of the magnetic field, Joule heating, thermal radiation absorption, viscous dissipation, Buoyancy forces, Soret and Dufour on MHD free convective heat and mass transfer and stated that the temperature profile gets enhanced with increase of buoyancy forces. Furthermore Kishan and Shekar (2015) studied study the effects of viscous dissipation and heat source/sink on MHD unsteady heat and mass transfer in a vertical rectangular Duct and reported that buoyancy parameter magnifies both velocity and temperature. From the research of Venkatadri et al. (2017) heat and mass transfer inside the square cavity intensely linked with magnetic field, buoyancy ratio, heat generation/absorption and Lewis number effects this was discovered from their numerical investigation on Double-diffusive convective flow in a square cavity with the effect of magnetic and heat generation or absorption The present study originated from the work of Haq et al. (2021), where by their study analyzed the influence of MHD unsteady free convective flow of a viscous incompressible fluid in the presence of chemical molecular diffusive effects on perpendicular plate with arbitrary time dependent shear stresses and exponential heating phenomena. The study adopted and extended this model by incorporating hall current and buoyancy parameters on magneto-hydrodynamics

(MHD) unsteady heat and mass transfer free convective vertical channels. Additionally the study had also adopted the method of variables separable to find the analytical solution of governing partial differential equations. The analytical solution of velocity, temperature, concentration skin friction, Nusselt number and Sherwood number were obtained analytically and discussed using line graphs.

Formulation of the Problem

Consider an unsteady free convection flow of an incompressible electrically conducting fluid past an infinite vertical porous plate. Let the x* - axis be taken along the plate in the vertically upward direction and the y* - axis is taken normal to the plate. A uniform magnetic field of intensity H_0 is applied transversely to the plate. The induced magnetic field is ignored as the magnetic Reynolds number of the flow is taken to be very small. Initially, the temperature of the plate T^* and the fluid T_w^* are assumed to be the same. The concentration of species at the plate C_w^* and C_0^* are assumed to be the same. At time t*>0, the plate temperature is changed to T_w^*, which is then maintained constant, causing convection currents to flow near the plate and mass is supplied at a constant rate to the plate. Under these conditions the flow variables are functions of time y* and t* alone. The problem is governed by the following equations:

$$\frac{\partial u^*}{\partial t^*} = \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T^*) + g\beta(C^* - C_0^*) - \frac{\sigma\mu_{eH_0^2 u^*}}{\rho} - \frac{M}{(1+m^2)}\frac{\nu u^*}{K^*} \quad (1)$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = k\frac{\partial^2 T^*}{\partial y^{*2}} - RT^* \quad (2)$$

$$\frac{\partial C^*}{\partial t^*} = \frac{\partial^2 C^*}{\partial y^{*2}} - K_r \quad (3)$$

We have the following initial and boundary conditions in dimensional form:

$$t^* \leq 0:\ u^* = 0, T^* = T_0, \text{for all } 0 \leq y^* \leq L$$

$$t^* > 0 \begin{cases} u^* = u, T^* = T_0 + \frac{(T_W^* - T_0)t^*}{T_R}, C^* = C_w^*\ at\ y^* = 0 \\ u^* = 0, T^* = \gamma_t T_0, C^* = C_w^*\ at\ y^* = \infty \end{cases} \quad (4)$$

In order to change the dimensional governing partial differential equations and their boundary conditions into non-dimensional form, we the following non dimensional quantities:

$$\left.\begin{aligned} & U_0=(vg\beta\Delta T)^{\frac{1}{3}},\ L=\left(\frac{(g\beta\Delta T)}{v^2}\right)^{\frac{-1}{3}},\ T_R=\left(\frac{(g\beta\Delta T)}{v^{\frac{-1}{3}}}\right)^{\frac{-2}{3}} \\ & \Delta T=T_w^*-T_\infty^*,\ t=\frac{t^*}{T_R},\ y=\frac{y^*}{L} \\ & u=\frac{u^*}{U_0},\ K=\frac{K^*}{vT_R},\ \theta=\frac{T^*-T_0}{T_w^*-T_0},\ \phi=\frac{C^*-C_0}{C_w^*-C_0} \\ & \Pr=\frac{\mu C_p}{k},\ Sc=\frac{v}{D_m},\ Ec=\frac{U_0^2}{C_p\Delta T} \\ & N=\frac{\beta^*(C_w^*-C_\infty^*}{\beta(T_w^*-T_\infty^*)},\ M=\frac{\sigma\mu_0^2H_0^2T_R}{\rho} \end{aligned}\right\} \tag{5}$$

When the equations (5) is applied into (1)- (4) then the following governing partial differential equations and their boundary conditions in non-dimensional form are obtained.

$$\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}+Nu=Gr\theta+Gm\emptyset-\frac{M}{(1+m^2)}u \tag{6}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{Pr}\frac{\partial^2\theta}{\partial y^2}-R\theta \tag{7}$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-K_r\emptyset \tag{8}$$

Where $N=\frac{M}{(1+m^2)}$

$$\left\{\begin{matrix} t\geq 0: u=0, \theta=0.\emptyset=0,\ \text{for all } y \\ \text{For } t>0: u=t, \theta=\gamma_t,\ \emptyset=t\ \text{at } y=0 \\ u=0, \theta\to 0, \emptyset\to 0 \text{ at } y\to\infty \end{matrix}\right\} \tag{9}$$

Method of the Solution

The method of variables separable was found suitable in finding the analytical solution of equations (6) – (8) under the boundary initial and boundary conditions (9)

Now we take $N=\frac{M}{(1+m^2)}$ and assume the solution of (6) – (8) to be:

$$u(y,t)=u(y)\,u(t) \tag{10}$$

$$\theta(y,t)=\theta(y)\,\theta(t) \tag{11}$$

$$C(y,t)=C(y)\,C(t) \tag{12}$$

Having solved the equations (6) – (8) with given initial and boundary using the above assumed solutions then the solution of velocity, temperature as well as concentration are as follows:

$$u(y,t)=e^{-\lambda^2 t}(C_1\text{Cosh}(M_3y)+C_2\text{Shinh}(M_3y)+\frac{Gr\theta+GmC}{N} \tag{13}$$

$$\theta(y,t)=e^{-\lambda^2 t}(A_1\text{Cosh}(M_1y)+A_2\text{Shinh}(M_1y) \tag{14}$$

$$C(y,t) = e^{-\lambda^2 t}(B_1 \mathrm{Cosh}(M_2 y) + B_2 \mathrm{Shinh}(M_2 y) \quad (15)$$

Where

$M_1 = \sqrt{Pr(R+\lambda^2)}$ $\quad M_2 = \sqrt{Sc(R+\lambda^2)}$ $\quad M_3 = \sqrt{N+\lambda^2}$

$C_1 = e^{\lambda^2 t}\left(\frac{Gr\gamma_t + Ct - Nt}{N}\right)$ $\quad C_2 = \frac{-C_1 \mathrm{Cosh} M_3}{\mathrm{Shinh} M_3}$

$A_1 = \frac{\gamma_t}{e^{-\lambda^2 t}}$ $\quad A_2 = \frac{-A_1 \mathrm{Cosh} M_1}{\mathrm{Shinh} M_1}$

$B_1 = te^{\lambda^2 t}$ $\quad B_2 = \frac{-B \mathrm{Cosh} M_2}{\mathrm{Shinh} M_2}$

The skin friction is given by

$$\tau = \left[\frac{du}{dy}\right]_{y=0} = e^{-\lambda^2 t} C_2 M_3 \quad (16)$$

$$\tau = \left[\frac{du}{dy}\right]_{y=1} = e^{-\lambda^2 t}(-M_3 C_1 \mathrm{Sinh} M_3 + M_3 C_2 \mathrm{CoSh} M_3) \quad (17)$$

$$N_u = \left[\frac{d\theta}{dy}\right]_{y=0} = e^{-\lambda^2 t} A_2 M_1 \quad (18)$$

$$N_u = \left[\frac{d\theta}{dy}\right]_{y=1} = e^{-\lambda^2 t}(-M_1 A_1 \mathrm{Sinh} M_1 + M_1 A_2 \mathrm{CoSh} M_1) \quad (19)$$

$$s_h = \left[\frac{dC}{dy}\right]_{y=0} = e^{-\lambda^2 t} B_2 M_2 \quad (20)$$

$$S_h = \left[\frac{dC}{dy}\right]_{y=1} = e^{-\lambda^2 t}(-M_2 B_1 \mathrm{Sinh} M_2 + M_2 B_2 \mathrm{CoSh} M_2) \quad (21)$$

Results and Discussion

The solution of non- dimensional governing partial differential equations which were numbered as (3) uses the initial and boundary conditions (4) were obtained analytically using the method of undetermined coefficients. In this section of this paper the graphical presentation and interpretation of velocity, temperature, concentration, skin friction, Nusselt number as well as Sherwood number were demonstrated in order to have clear image of the model equations and the influence of various physical parameters such as Prandlt number (Pr) Schmidt number (Sc), Buoyancy parameter (r_t), Hall current (m), magnetic parameter (M), Grashop number (Gr), Mass grshop number (Gc), Radiation parameter (R), and chemical reaction parameter (K_r). t=1 was chosen constant while parameters: $M = 2,\ m = 2,\ Pr = 0.71,\ Sc = 2, R = 2,\ r_t = 2,\ K_r = 2,\ Gr = 10,$ and $Gc = 10$ were varied over the range.

Velocity Profile

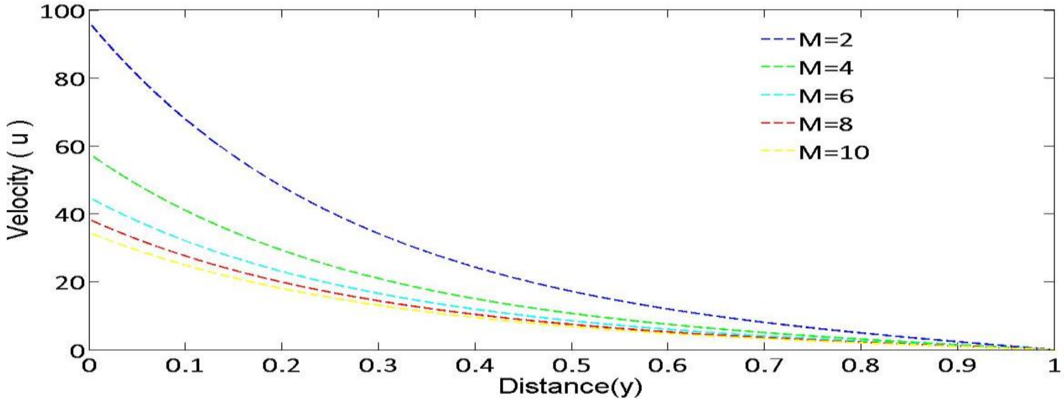

Figure 1: Influence of (M) on velocity Profile

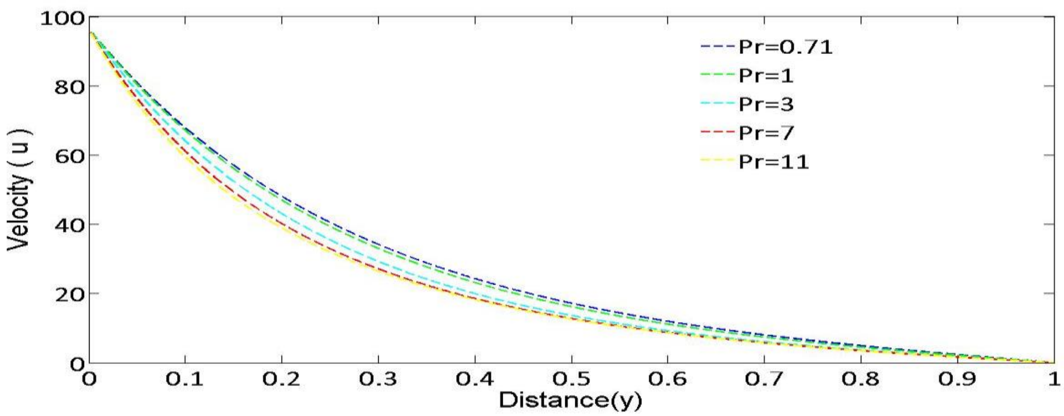

Figure 2: Influence of Pr on velocity Profile

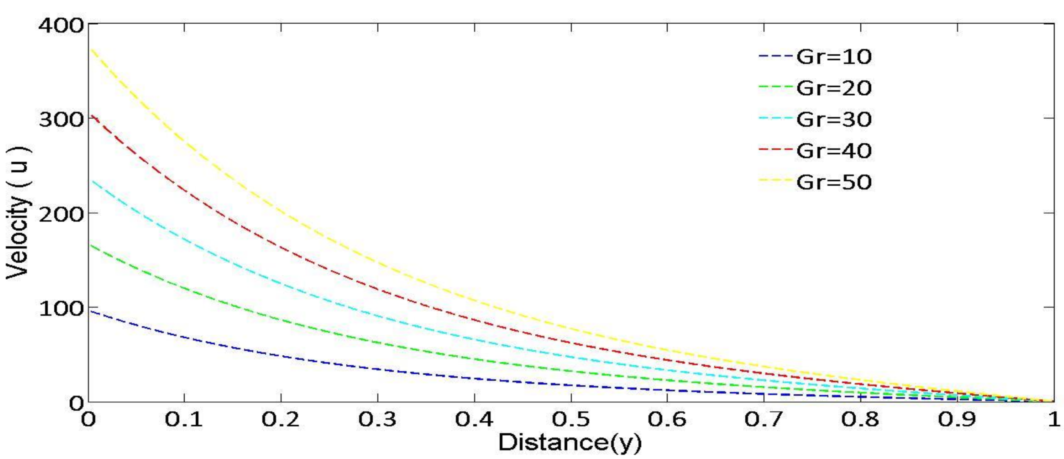

Figure 3: Influence of Gr on velocity Profile

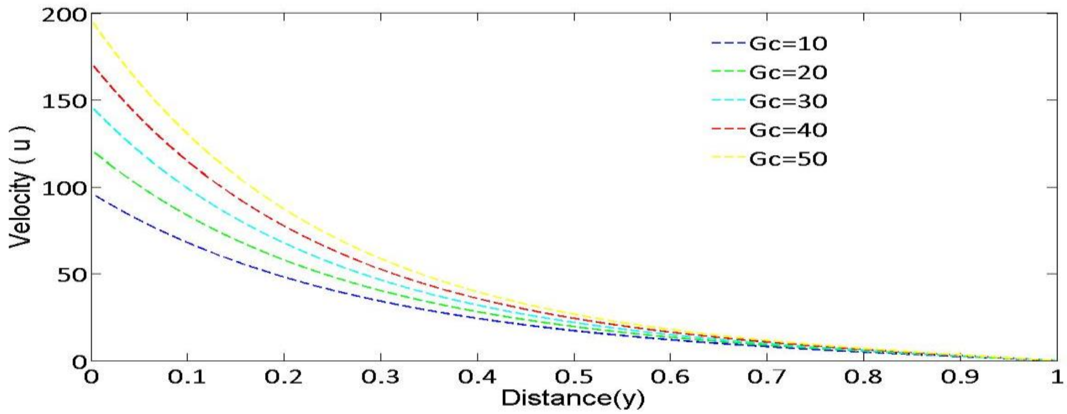

Figure 4: Influence of Gr on velocity Profile

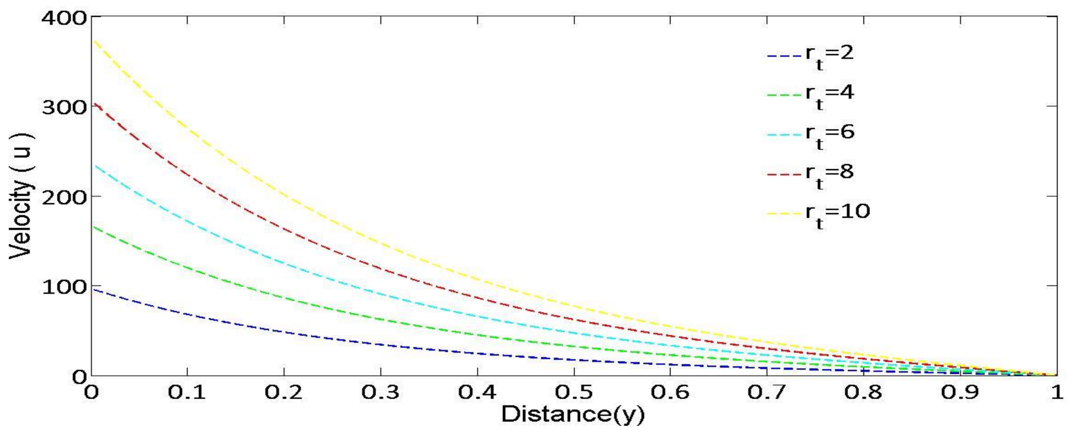

Figure 5: Influence of r_t on velocity Profile

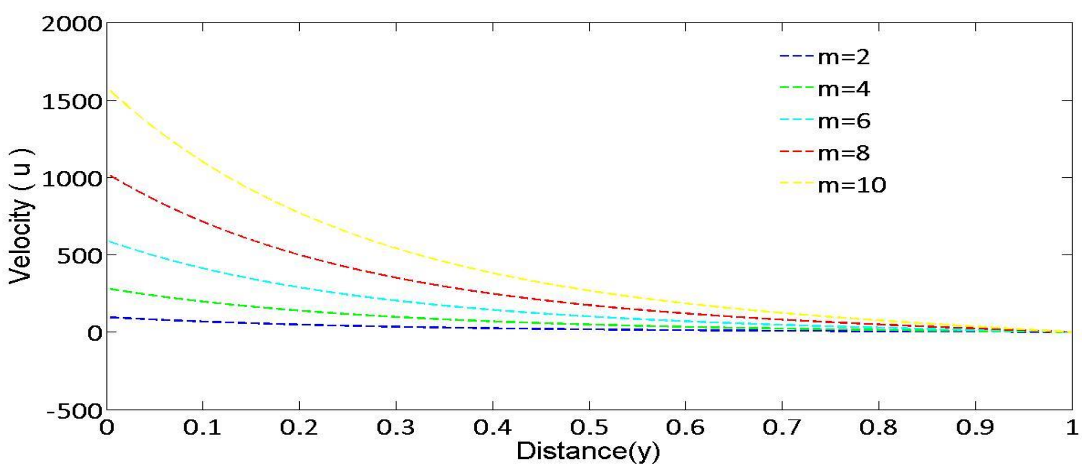

Figure 6: Influence of m on velocity Profile

Figure 1and 2 display the impact of Magnetic parameter (M) and Pradlt number (Pr) on velocity profile respectively. From the two figures it is clearly seen tthat the velocity profile gets diminished with the increase of both Magnetic parameter and Pradlt number respectively. While opposite behaviour was observed in **Figure 3and 4** with the increase in Grasshop number (Gr) and Mass Grasshop number (Gc). **Figure 5and 6** dipict the influence of Buoyancy parameter (r_t) and Hall current parameter (m) on velocity profile, from the figures the velocity profile gets intesified with the increase of Buoyancy parameter (r_t) and Hall current parameter (m) respectively.

Temperature Profile

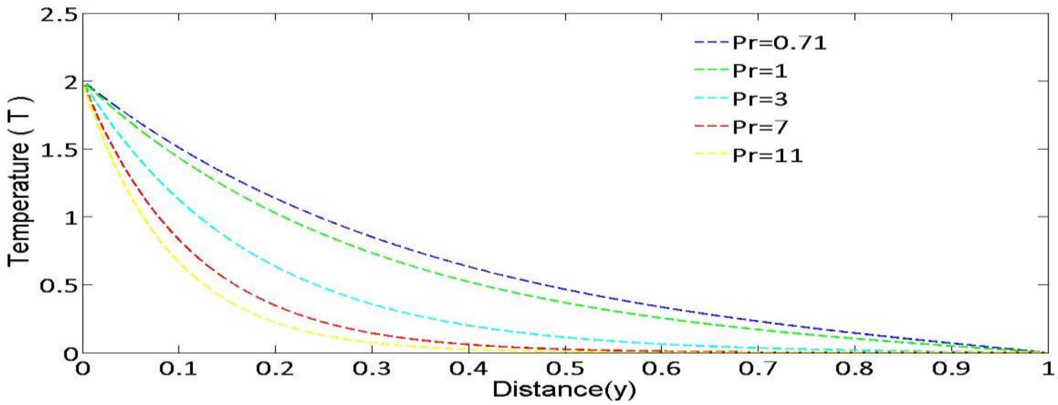

Figure 7: Influence of Pr on Temperature Profile

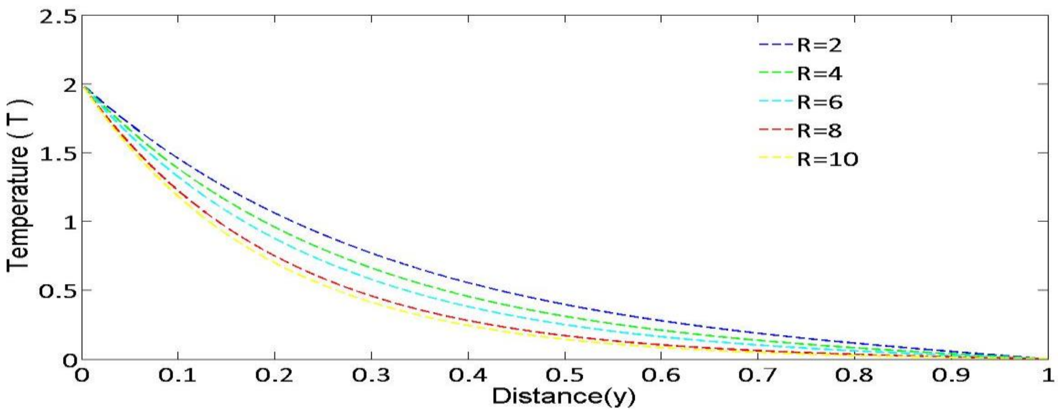

Figure 8: Influence of R Temperature Profile

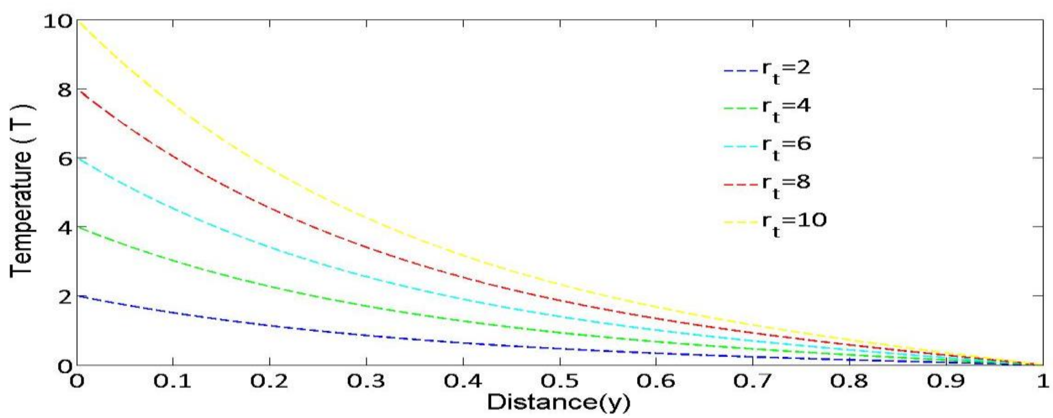

Figure 9: Influence of r_t on Temperature Profile

Figure 7 demonstrates the effects of Pradlt number (Pr) on Temperature profile. From the figureit is clearly shown that the temperature profile gets lowered with the increase of Pradlt number. While in **Figure 8 and 9** the Temperature profile gets enlarged with the increase of Radiation parameter (R) and Buoyancy parameter (r_t) respectively.

Concentration Profile

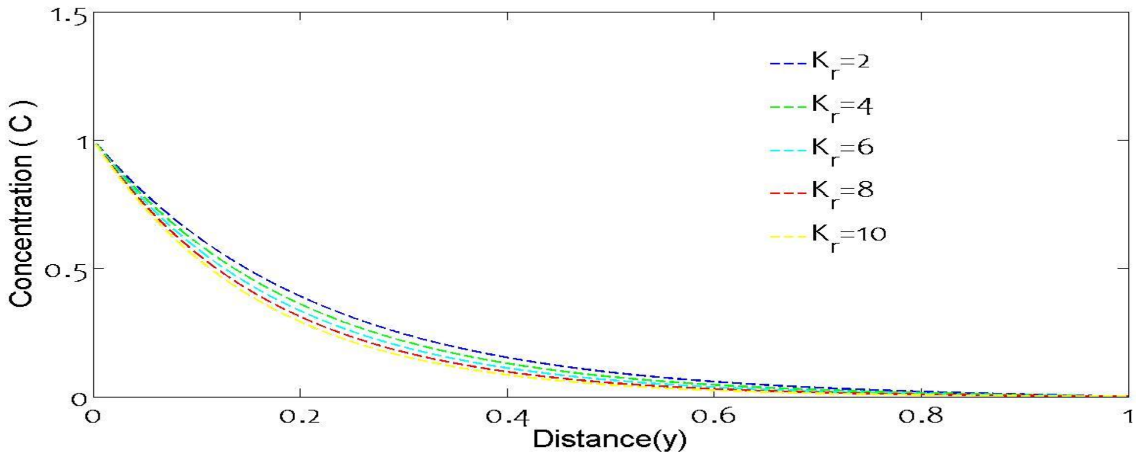

Figure 10: Influence of K_r on Concentration Profile

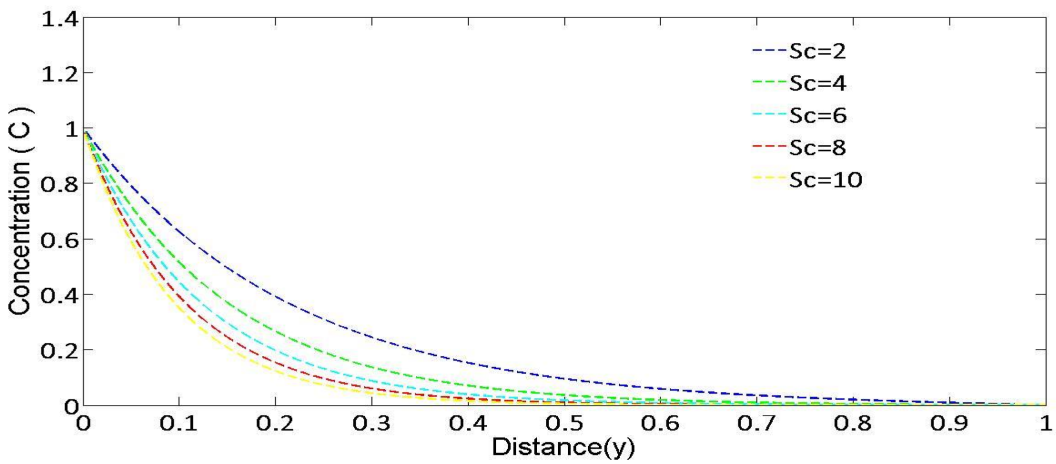

Figure 11: Influence of Sc on Concentration Profile

Figure 10 and 11 shows the control of Chemical reaction parameter (K_r) and Schmidt number (Sc) on concentration profile respectively. From the two figures it is clearly observed that the concentration profile gets reduced with the increase of both Chemical reaction parameter (K_r) and Schmidt number (Sc) respectively..

Skin Friction

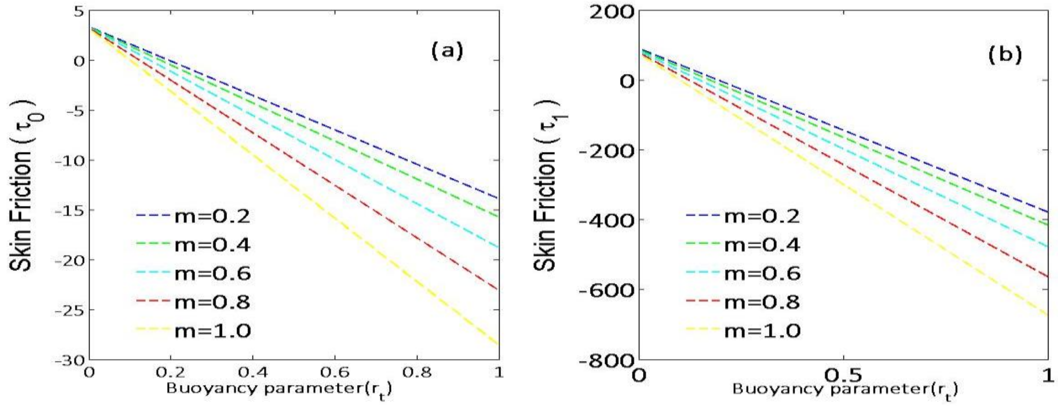

Figure 12 (a)&(b): Influence of m and r_t on Skin Friction

Nusselt Number

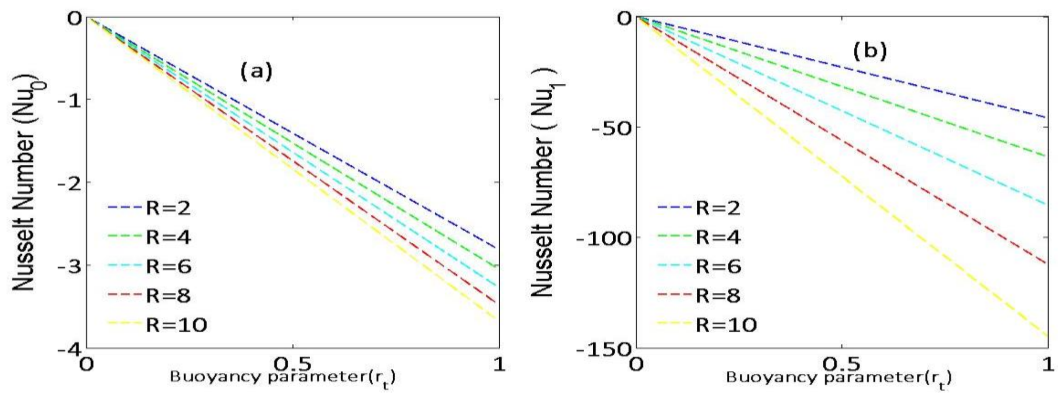

Figure 13 (a)&(b): Influence of m and r_t on Nusselt Number

Sherwood Number

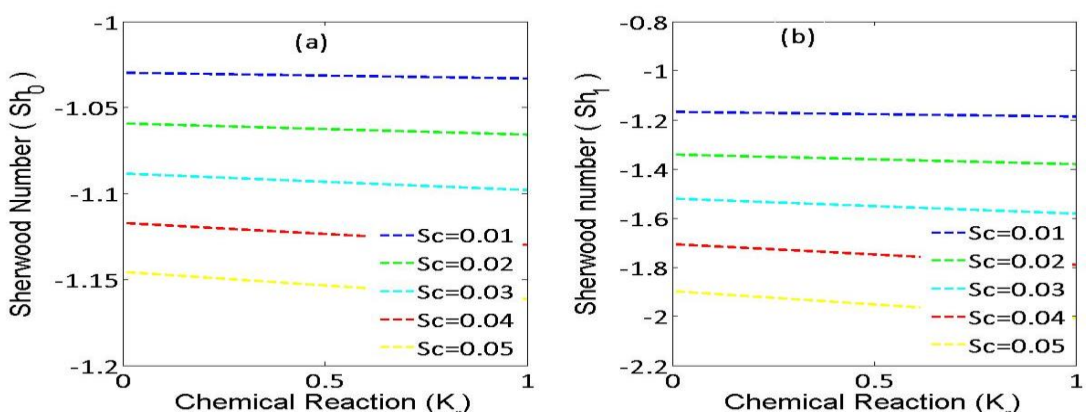

Figure 14 (a)&(b): Influence of Sc and K_t Sherwood Number

Figure 12(a) and 12(b) depicts the effects of Hall current parameter (m) and Buoyancy parameter (r_t) on fluid skin friction respectively. From the two figures the fluid skin friction gets enhanced with the increase of and Buoyancy parameter (r_t) and gets reduced with the increase of Hall current parameter. Similarly, **Figure 13(a) and 13(b**) display the influence of Buoyancy parameter (r_t) and Radiation parameter (R) on fluid Nusselt number. From the two figures it is clearly seen that the Radiation parameter (R) has enhancing effects on fluid Nusselt number, while Buoyancy parameter (r_t) has reduction effects on fluid Nusselt number. Furthermore 14**(a) and 14(b**) exhibits the impact of Schmidt number and chemical reaction parameter on Sherwood number. From the both figures there is slight increase on Sherwood number with the increase of chemical reaction parameter (K_r) and significant decrease with the increase of Schmidt number (Sc).

Conclusion

We have analyzed the impact of Hall current (m) and Buoyancy parameter (r_t) on magneto-hydrodynamics (MHD) unsteady heat and mass transfer free convective vertical channels. Additionally the study employed the method of undetermined confidents to find the analytical solution of governing partial differential equations. From the investigations the following conclusions were drawn:

i. Velocity profile enhances with the increase of Grasshop number (Gr), Mass Grasshop number (Gc), Hall current (m) and Buoyancy parameter (r_t) respectively. While it reduces with the increase of Magnetic parameter (M) and Pradlt number (Pr)

ii. Temperature profile enlarges with the increase of Radiation parameter (R) and Buoyancy parameter (r_t). While the opposite behaviour is observed with the increase of Pradlt number (Pr).

iii. Concentration profile diminishes with the increase of both Chemical reaction parameter (K_r) and Schmidt number (Sc)

iv. Skin friction gets enhanced with the increase of and Buoyancy parameter (r_t) at both y=0 and y=1 and gets reduced with the increase of Hall current parameter of Hall current parameter (m) and Buoyancy parameter (r_t) at both y=0 and y=1 (r_t) has reduction effects on fluid Nusselt number.

v. Nusselt number intensifies with the increase of Radiation parameter (R) at both y=0 and y=1. While it gets lowered with the increase of Buoyancy parameter (r_t) at both y=0 and

vi. Sherwood number slightly increase with the increase of chemical reaction parameter (K_r) and significant decrease with the increase of Schmidt number (Sc).

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