DIFFUSION-THERMO EFFECT ON HYDROMAGNETIC FLOW IN THE PRESENCE OF RADIATION ABSORPTION IN A SLIP FLOW REGIME

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Abstract:

The present work aims at MHD buoyancy ratio flow in the presence of radiation absorption and diffusion-thermo effects in a slip flow regime. The governing partial differential equations using perturbation method. The analytical solutions are computed for velocity, temperature and concentration for different values of fluid flow parameters such as Schmidt number Sc , chemical reaction parameter Γ, Dufour number Du , Magnetic field parameter M, Radiation absorption parameterQ1, Porous permeability parameter ϕ1, Porocity parameter K, Solutal Grashof number Gr, buoyancy ratio parameter N are presented in figures.

I. INTRODUCTION

Magnetohydrodynamics (MHD) is the branch of continuum mechanics which deals the flow of electrically conducting fluids in electric and magnetic fields. Numerous characteristic wonders and designing problems merit being subjected to a MHD investigation. MHD conditions are normal electromagnetic and hydrodynamic conditions altered to check the link between the movement of the fluid and the electromagnetic field. In certain engineering problems, be that as it may, they can't be let well enough alone for thought. Realize that the heat transfer in blended convection can be fundamentally not quite the same as that both in unadulterated regular convection and in pure forced convection. The investigation of constrained and free convection stream and heat transfer for electrically leading liquids past a semi-interminable permeable plate affected by an attractive field has pulled in light of a legitimate concern for some specialists in perspective of its applications in numerous building issues, for example, geophysics, astronomy, limit layer control in the field of streamlined features. Engineers utilize MHD rule, in the configuration of heat transfer pumps and stream meters, in space vehicle impetus, warm security, braking, control and reentry, in making novel force creating frameworks and so on. In every one of these applications understanding the conduct of MHD free and constrained convective stream and the different issue parameters that impact is a vital resource for originators creating applications that plan to control this stream. For instance, the way toward melding of metals in an electrical heater by applying an attractive field and the way toward cooling of the principal divider inside an atomic reactor regulation vessel where the hot plasma is confined from the divider by applying an attractive field. Over the past years, this problem attracted the attention of several researchers. However, none of them included all relevant aspects that influence the flow behavior.

Watanabe [1] presented a laminar forced and free mixed convection flow on a flat plate with uniform suction or injection was theoretically investigated. Non-similar partial differential equations are transformed into non-similar ordinary ones by means of difference-differential method. Also, Ahmed and Liu [2] analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Hussain et al. [3] considered the problem of natural convection boundary layer flow, induced by the combined buoyancy forces from mass and thermal diffusion from a permeable vertical flat surface with non-uniform surface temperature and concentration but a uniform rate of suction of fluid through the permeable surface. Alom et al. [4] investigated the steady MHD heat and mass transfer by mixed convection flow from a moving vertical porous plate with induced magnetic, thermal diffusion, constant heat and mass fluxes and the non-linear coupled equations are solved by shooting iteration technique. Orhan and Kaya [5] investigated the mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects using the Keller box scheme, an efficient and accurate finite-difference scheme. Ghosh et al. [6] considered an exact solution for the hydromagnetic natural convection boundary layer flow past an infinite vertical flat plate under the influence of a transverse magnetic field with magnetic induction effects and the transformed ordinary differential equations are solved exactly. Dharmaiah et al.,[7] analyzed that MHD Free Convection flow through a porous medium along a aertical wall. Dharmaiah et al., [8] expalined that the effccts of radiation, chemical reaction and soret on unsteady mhd free convective flow over a vertical porous plate. Baby rani et al., [9] examined on synthetic response and radiation impacts. Balamurugan et al., [10] studied that MHD free convective flow past a semi-infinite vertical permeable moving plate with heat absorption. Takhar et al. [11], discussed about radiation effects on magneto hydrodynamic (MHD) free convection flow of a radiating gas past a semi-infinite vertical plate. Muthukumaraswamy et al. [12], studied effect of diffusion and first-order chemical reaction on impulsively started infinite vertical plate with variable temperature. Ibrahim et al. [13] considered the effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Patil et al. [14] discussed the effect of chemical reaction on free convection flow of a polar fluid through a porous medium in the presence of internal heat generation. Kandaswamy et al. [15], studied the chemical reaction effect on heat and mass transfer flow along a wedge in the presence of suction or injection. MHD free convection flows occurs in nature frequently. Fluid flows through porous medium have been attracting the attention of many researchers in the recent days based on the wide applications in many areas of science and technological fields, namely study of ground water resources in agricultural engineering, in petroleum technology to study the moment of ordinary gas, oil, and water through the oil reservoirs. Ibrahim et al. [16] investigated the effect of the chemical reaction and radiation absorption on unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and sink. Prasad et al. [17] studied the radiation effect on MHD unsteady free convection flow with mass transfer past a vertical plate with variable surface temperature and concentration. Cookey et al. [18] analyzed the effect of unsteady MHD free convection and mass transfer flow past an infinite heated porous vertical plate with time dependent suction. Gireesh kumar et al. [19] studied the effect of mass transfer on MHD unsteady free convective Walters memory flow with constant suction and heat sink.

Fluid flows through porous medium is seriously attracted by engineers and scientists. Now a days, due to their applications in the emerging trends in science and technology, namely in the field of agricultural engineering especially while studying water resources in the ground, to study the moment of natural gas, oil, and water through the reservoirs in the petroleum technology. Chen et al. [20], discussed the effect of free convection of non-Newtonian fluid along a vertical plate embedded in porous medium. Chamkha [21], studied the effect of heat and mass transfer of a non-Newtonian fluid flow along a surface embedded in a porous medium inform wall heat and mass fluxes and heat generation or absorption. Panda et al. [22], considered the effect of unsteady free convection flow and mass transfer past a vertical porous plate. Mahapatra et al. [23] , analyzed the effect of chemical reaction on free convection flow through a porous medium surrounded by a vertical surface. Mishra et al. [24], investigated the effect of mass and heat transfer on MHD flow of a visco-elastic fluid through porous medium with variable suction and heat source. Reddy et al. [25], considered unsteady free convection MHD non-Newtonian flow through a porous medium bounded by an infinite inclined porous plate. Raju et al. [26], investigated the effect of radiation and mass transfer effects on a free convection flow past a porous medium bounded by a vertical surface. Seddek et al. [27], studied the effects of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation. Ravikumar et al. [28], discussed the combined effect of heat absorption and MHD on convective Rivlin-Erichsen flow past a semi-infinite vertical porous plate with variable temperature and suction. Ibrahim et al. [29] analyzed the effect of the chemical reaction and radiation absorption on the unsteady MHD free convective flow past a semi-infinite vertical permeable moving plate with heat source and suction. Chamkha et al. [30] analyzed that unsteady MHD free convection flow past an exponentially accelerated vertical plate with mass transfer, chemical reaction and thermal radiation. Umamaheswar et al. [31] discussed the combined radiation and Ohmic heating effects on MHD free convective visco-elastic fluid past a porous plate with viscous dissipation. Rao et al. [32] put their efforts, on the study of unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with radiation, heat absorption, chemical reaction and Soret effects. Ravikumar et al. [33] studied the magnetic field effect on transient free convection flow through porous medium past an impulsively started vertical plate with fluctuating temperature and mass diffusion. Rao et al. [34] considered the unsteady MHD free convective double diffusive and dissipative visco-elastic fluid flow in porous medium with suction.

In recent times chemical reaction and radiation absorption influences the fluid flow, attracted the attention of engineers and scientists. This type of fluid flows plays importance role in food processing, flow in desert coolers, generating electrical power, groves of fruit trees etc., the present study is motivated towards this direction. The main objective of the present investigation will, therefore, be to study the effects of chemical reaction, radiation absorption and dufour effect over an infinite vertical porous plate in presence of transverse magnetic field, by means of analytical solutions. These analytical approximate solutions under perturbation technique give a wider applicability in understanding the basic physics and chemistry of the problem, which are particularly important in industrial and technological fields. In this article, it is considered the effects of chemical reaction as well as magnetic field on the heat and mass transfer of Newtonian fluids over an infinite vertical oscillating permeable plate with variable mass diffusion. The magnetic field is imposed transversely to the plate. The temperature and concentration of the plate is oscillating with time about a constant nonzero mean value. The dimensionless governing equations involved in the present analysis are solved using a closed analytical method and discussed.

II. FORMULATION OF THE PROBLEM

Consider an unsteady two dimensional flow of an incompressible viscous, electrically conducting, and heat absorbing fluid past a semi-infinite vertical permeable plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects.

- ❖ The applied magnetic field is also taken as being weak so that Hall and ion slip effects may be neglected.
- ❖ We assume that the Dufour effects may be described by a second order concentration derivative with respect to the transverse coordinate in the energy equation.
- ❖ Assumption is that there is no applied voltage which implies the absence of an electric field.
- ❖ The plate is maintained at constant temperature T_w and concentration C_w, which is higher than the ambient temperature T_∞ and concentration C_∞, respectively.
- ❖ The chemical reactions take place in the flow and all thermo physical properties are assumed to be constant.
- ❖ Due to the semi infinite plane surface assumption, the flow variables are the functions of y^* and time t^* only.

Under the usual boundary layer approximations and the above-stated assumptions, the governing equations and the initial and boundary conditions for the velocity distribution involving slip flow, temperature, and concentration distributions are in the following:

$$\frac{\partial v^*}{\partial y^*} = 0 \quad (1)$$

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \nu \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma B_0^2}{\rho} u^* + g\beta_T \left(T^* - T_\infty\right) + g\beta_C \left(C^* - C_\infty\right) - \frac{\nu}{K^*} u^*$$

(2)

$$\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}=\frac{K}{\rho Cp}\frac{\partial^2 T^*}{\partial y^{*2}}+\frac{A^*}{\rho Cp}\left(C^*-C_\infty\right)+\frac{D_m K_T}{C_S\rho Cp}\frac{\partial^2 C^*}{\partial y^{*2}} \tag{3}$$

$$\frac{\partial C^*}{\partial t^*}+v^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-C_R^*\left(C^*-C_\infty\right) \tag{4}$$

The boundary conditions are

$$u^*=u^*_{slip}=\frac{\sqrt{k}}{\alpha}\frac{\partial u^*}{\partial y^*},T^*=T_w+\varepsilon\left(T_w-T_\infty\right)e^{n^*t^*},C^*=C_w+\varepsilon\left(C_w-C_\infty\right)e^{n^*t^*}\quad at\quad y^*=0 \tag{5}$$

$$u^*=U^*_\infty=U_0\left(1+\varepsilon e^{n^*t^*}\right),T^*\to T_\infty,C^*\to C_\infty\quad as\quad y^*\to\infty \tag{6}$$

From Eq. (1) it is clear that the suction velocity at the plate surface is either constant or a function of time only. Hence, it is assumed that

$$v^*=-V_0\left(1+\varepsilon A e^{n^*t^*}\right) \tag{7}$$

Where V_0 is the mean suction velocity and $\varepsilon A \ll 1$. The negative sign indicated that the suction velocity is directed towards the plate.

In the free stream Eq.(2) gives

$$-\frac{1}{\rho}\frac{dp^*}{dx^*}=\frac{dU^*_\infty}{dt^*}+\frac{\sigma}{\rho}B_0^2U^*_\infty+\frac{v}{K^*}U^*_\infty \tag{8}$$

Non-dimensional quantities are given by

$$u=\frac{u^*}{U_0},y=\frac{V_0y^*}{v},U_\infty=\frac{U^0_\infty}{U_0},t=\frac{V_0^2t^*}{v},\beta_C=\frac{N\left(T_w-T_\infty\right)\beta_T}{\left(C_w-C_\infty\right)},\Pr=\frac{\mu Cp}{k},K=\frac{V_0^2K^*}{v^2},$$
$$\Gamma=\frac{C_R^*v}{V_0^2},Q_1=\frac{A^*v\left(C_w-C_\infty\right)}{V_0^2\left(T_w-T_\infty\right)},Sc=\frac{v}{D},Du=\frac{D_mK_T}{C_sK}\frac{\left(C_w-C_\infty\right)}{\left(T_w-T_\infty\right)},Gr=\frac{\rho g v\left(T_w-T_\infty\right)\beta_T}{U_0V_0^2}, \tag{9}$$
$$n=\frac{n^*v}{V_0^2},\theta=\frac{T^*-T_\infty}{T_w-T_\infty},C=\frac{C^*-C_\infty}{C_w-C_\infty}$$

Considering the above dimensionless variables, the basic field of Eqs. (2) through (4) can be expressed in a dimensionless form as:

$$\frac{\partial u}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+T\left(U_\infty-u\right)+Gr\theta+GrNC \tag{10}$$

$$\Pr\left[\frac{\partial\theta}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial\theta}{\partial y}\right]=\frac{\partial^2\theta}{\partial y^2}+\Pr Q_1C+Du\left[\frac{\partial^2 C}{\partial y^2}\right] \tag{11}$$

$$Sc\left[\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial C}{\partial y}\right]=\frac{\partial^2 C}{\partial t^2}-Sc\Gamma C \tag{12}$$

The corresponding initial and boundary conditions in Eqs. (5)&(6) in a non-dimensional form are given below:

$$u=u_{slip}=\phi_1\frac{\partial u}{\partial y},\theta=1+\varepsilon e^{nt},C=1+\varepsilon e^{nt}\quad at\quad y=0 \tag{13}$$

$$U\to U_\infty=1+\varepsilon e^{nt},\theta\to 0,C\to 0\quad as\quad y\to\infty \tag{14}$$

Where $\phi_1=\frac{\sqrt{k}}{\alpha}\frac{U_0V_0}{v}$ is the slip or porous permeability parameter.

III. METHOD OF SOLUTION

The Eqs. (10) - (12) are coupled non-linear partial differential equations whose solutions in closed-form are difficult to obtain. To solve these coupled non-linear partial differential equations, we assume that the unsteady flow is superimposed on the mean steady flow, so that in the neighborhood of the plate, we have

$$u=f_0(y)+\varepsilon e^{nt}f_1(y)+O\left(\varepsilon^2\right) \tag{15}$$

$$\theta=g_0(y)+\varepsilon e^{nt}g_1(y)+O\left(\varepsilon^2\right) \tag{16}$$

$$C=h_0(y)+\varepsilon e^{nt}h_1(y)+O\left(\varepsilon^2\right) \tag{17}$$

By substituting the set of Eqs. (15) - (17) into Eqs.(10) - (12) and equating the harmonic and non-harmonic terms, and neglecting the higher order terms in ε, we obtain

$$f_0''+f_0'-Tf_0=-T-Grg_0-GrNh_0 \tag{18}$$

$$f_1''+f_1'-\left(T+n\right)f_1=-\left(n+T\right)-Grg_1-GrNh_1-Af_0' \tag{19}$$

$$g_0''+prg_0'+\Pr Q_1h_0-Duh_0''=0 \tag{20}$$

$$g_1''+prg_1'-\Pr ng_1+\Pr Q_1h_1+Duh_1''+\Pr Ag_0'=0 \tag{21}$$

$$h_0''+Sch_0'-Sc\Gamma h_0=0 \tag{22}$$

$$h_1''+Sch_1'-Sc\left(\Gamma+n\right)h_1=-ASch_0'' \tag{23}$$

Where the prime denotes the differentiation with respect to y.

The corresponding boundary conditions are:

$$f_0=\phi_1f_0',f_1=\phi_1f_1',g_0=1,g_1=1,h_0=1,h_1=1\quad at\quad y=0 \tag{24}$$

$$f_0 = 1, f_1 = 1, g_0 \to 0, g_1 \to 0, h_0 \to 0, h_1 \to 0 \quad as \quad y \to \infty \tag{25}$$

By solving the set of Eqs. (18) - (23) using boundary conditions (24) - (25), the boundary layer flow solutions velocity, temperature, concentration, the coefficient of Skin-friction, rate of heat transfer in terms of Nusselt number and rate of mass transfer are:

$$\begin{aligned} u &= f_0 + \varepsilon e^{nt} f_1 \\ &= \left(E_{11} e^{-q_4 y} + 1 - E_9 e^{-\Pr y} - E_{10} e^{-q_1 y} \right) + \\ &\varepsilon e^{nt} \left(E_{17} e^{-q_5 y} + E_{12} e^{-q_4 y} + E_{13} e^{-\Pr y} - E_{14} e^{-q_1 y} + 1 - E_{15} e^{-q_3 y} + E_{16} e^{-q_2 y} \right) \end{aligned} \tag{26}$$

$$\begin{aligned} \theta &= g_0 + \varepsilon e^{nt} g_1 \\ &= \left(E_4 e^{-\Pr y} + E_3 e^{-q_1 y} \right) + \varepsilon e^{nt} \left(E_8 e^{-q_3 y} - E_5 e^{-\Pr y} + E_6 e^{-q_1 y} - E_7 e^{-q_2 y} \right) \end{aligned} \tag{27}$$

$$C = h_0 + \varepsilon e^{nt} h_1 = \left(e^{-q_1 y} \right) + \varepsilon e^{nt} \left(E_1 e^{-q_1 y} + E_2 e^{-q_2 y} \right) \tag{28}$$

$$\begin{aligned} Cf_x = \frac{\tau_w}{\rho U_0 V_0} = \left(\frac{\partial u}{\partial y} \right)_{at\ y=0} &= \left(-q_4 E_{11} + \Pr E_9 + q_1 E_{10} \right) + \varepsilon e^{nt} \\ &\left(-q_5 E_{17} - q_4 E_{12} - \Pr E_{13} + q_1 E_{14} + q_3 E_{15} - q_2 E_{16} \right) \end{aligned} \tag{29}$$

$$\begin{aligned} Nu_x &= x \frac{\left(\frac{\partial T}{\partial y} \right)_{at\ y=0}}{\left(T_w - T_\infty \right)} \Rightarrow \frac{Nu_x}{\mathrm{Re}_x} = \left(\frac{\partial \theta}{\partial y} \right)_{at\ y=0} \\ &= \left[-\Pr E_4 - q_1 E_3 \right] + \varepsilon e^{nt} \left[-q_3 E_8 + \Pr E_5 - q_1 E_6 + q_2 E_7 \right] \end{aligned} \tag{30}$$

$$\begin{aligned} Sh_x &= x \frac{\left(\frac{\partial C}{\partial y^*} \right)_{at\ y=0}}{\left(C_w - C_\infty \right)} \Rightarrow \frac{Sh_x}{\mathrm{Re}_x} = \left(\frac{\partial C}{\partial y} \right)_{at\ y=0} \\ &= \left[-q_1 \right] + \varepsilon e^{nt} \left[-q_2 E_2 - q_1 E_1 \right] \end{aligned} \tag{31}$$

IV. RESULTS AND DISCUSSION

The analytical solutions are performed for velocity, temperature and concentration for various values of fluid flow parameters such as Schmidt number Sc , chemical reaction parameter Γ, Dufour number Du , Magnetic field parameter M, Radiation absorption parameterQ1, Porous permeability parameter ϕ1, Porocity parameter K, Solutal Grashof number Gr, buoyancy ratio parameter N are presented in figures 1-18. Throughout the calculations the parametric values are choosen as Pr = 0.71, A = 0.5, ε = 0.02, n = 0.1, and t = 1. Various values of the thermal buoyancy ratio parameter N is plotted in Fig. 1. As seen from the figure, as buoyancy ratio values are increasing, the velocity is decreasing from zero to one and enhancing from 1 to 6. Figure2 displayed the effects of the radiation absorption parameter on velocity field. It is obvious from the figure that an increase in the absorption radiation parameter results in decrease in the velocity profiles from 0 to 1 and an increase in the velocity profiles from 1 to 6. Figure 3 illustrates the variation of velocity distribution across the boundary layer for various values of the porous permeability parameter ϕ_1. It is observed that velocity increases near the source and reaches the free stream condition. Permeability ϕ_1 is directly proportional to the square root of the actual permeability K. Hence, an increase in will decrease the resistance of the porous medium which will tend to accelerate the flow and increase the velocity. The velocity profiles for different values of magnetic parameter M are depicted in fig.4. From this figure it is clear that as the magnetic field parameter increases, the Lorentz force, which opposes the fluid flow also increases and leads to an enhance deceleration of the flow. This result qualitatively agrees with the expectations since the magnetic field exerts retarding force on the free convection flow. Figure 5 represents the influence of the porosity parameter K on velocity. It is clear that velocity increases significantly with the increasing values of K. Different values of the thermal buoyancy force parameter Gr is plotted in Fig. 6. As seen from the figure, the thermal buoyancy force enhances, fluid velocity increases and the boundary layer thickness increases. Fig.7 displays the velocity profiles for various values Dufour number. The velocity decreases from 0 to 1 and enhances from 1 to 6 with increasing of Dufour number. Fig.8 displays the velocity profiles for various values perturbation parameter ε .The velocity enhances, as increasing of perturbation parameter ε . Figure 9 illustrates the effect of chemical reaction parameter Γ. It is clear that, the velocity decreases uniformly with the increasing values of Γ. It is interesting to observe that the peak values of the velocity profiles are attained near the porous boundary surface. The influence of Schmidt number Sc on the velocity profiles is shown in Fig. 10. As Sc values are increasing, velocity is decreases. Further, it is observed that the momentum boundary layer decreases with an increase in the value of Sc. Figure 11 displayed the effects of the radiation absorption parameter on temperature field. It is obvious from the figures that an increase in the absorption radiation parameter results in an increase in the temperature profiles within the boundary layer as well as an increase in the momentum and thermal thickness, because the large values of correspond to the increased domination of conduction over absorption radiation, thereby increasing buoyancy force and thickness of the thermal and momentum boundary layers. Fig.12

displays the temperature profiles for various values perturbation parameter ε .The temperature enhances, as increasing of perturbation parameter ε . The temperature profiles for different values of Dufour number is shown in fig.13. It can be seen that the fluid temperature decreases with Dufour number. Physically, the Dufour term that appears in the temperature equation measures the contribution of concentration gradient to thermal energy flux in the flow domain. Figure 14 illustrates the effect of chemical reaction parameter Γ. It is clear that, the temperature profiles decreases uniformly with the increasing values of Γ. The effect of the Schmidt number Sc on the temperature is shown in Fig 15. As the Schmidt number increases, the temperature decreases. The concentration profiles for different values of perturbation parameter ε is presented through Fig. 16. From this figure it is seen that the concentration increases with an increases in perturbation parameter ε. The concentration profiles for different values of chemical reaction parameter is presented through Fig. 17. From this figure it is seen that the concentration decreases with an increases in chemical reaction parameter. The effect of Schmidt number Sc on the species concentration profiles is shown in Fig. 18. It is clear that the concentration decreases exponentially and reaches the free stream condition. Also, it is noticed that the concentration boundary layer thickness decreases with Sc.

Skin friction: The absolute value of Skin friction is depicted in Table 1, which illustrates the effect of the parameters Gr, ϕ_1, N, K, M, Du, Q_1, Γ and Sc on Skin friction at plate. It is noticed that absolute value of Skin friction at plate decreases with the increase of ϕ_1 and Q_1. Whereas increases with the increase of Gr, N, K, M, Du, Γ and Sc.

Nusselt Number: The absolute value of Nusselt number is depicted in Table 2.which illustrates the effect of the parameters Q1, Du, Γ, Sc and ε. It is noticed that absolute value of Skin friction at plate decreases with the increase of ε and Q_1. Whereas increases with the increase of Du, Γ and Sc.

Sherwood Number: Table 3 shows the effect of the parameters Sc, Γ and ε on absolute value of Sherwood number at plate, It is observed that absolute value of Sherwood number at the plate increases with the increase of Sc, Γ and ε.

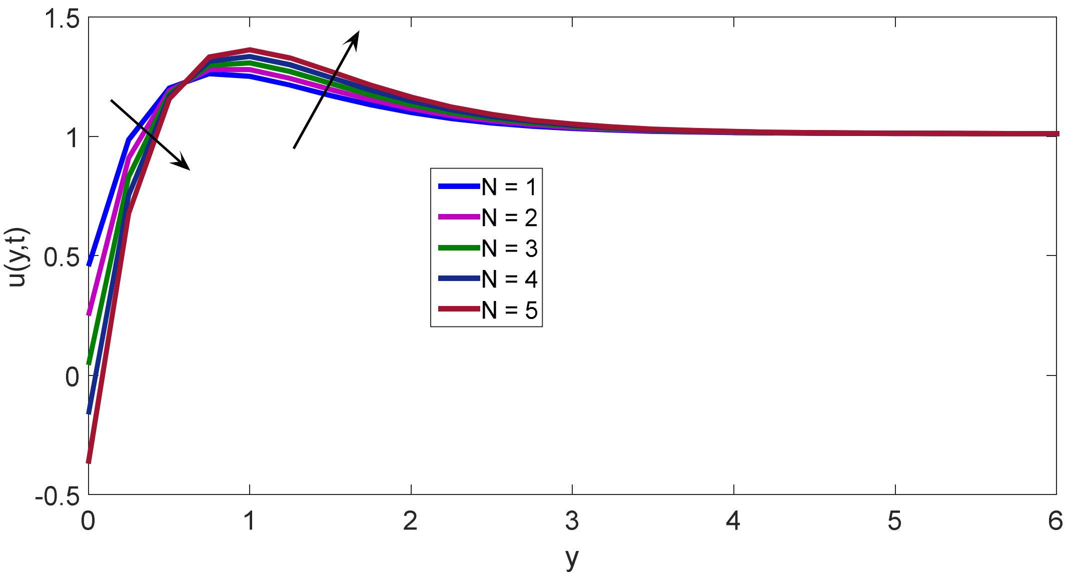

Figure 1: Velocity profiles for various values of buoyancy ratio N.

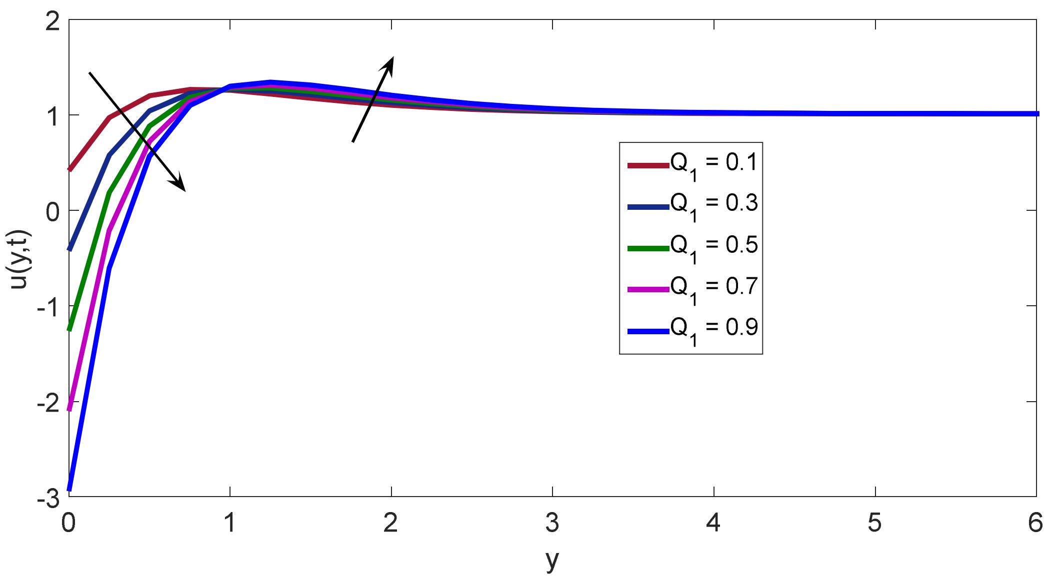

Figure 2: Velocity profiles for various values of radiation absorption parameter Q_1.

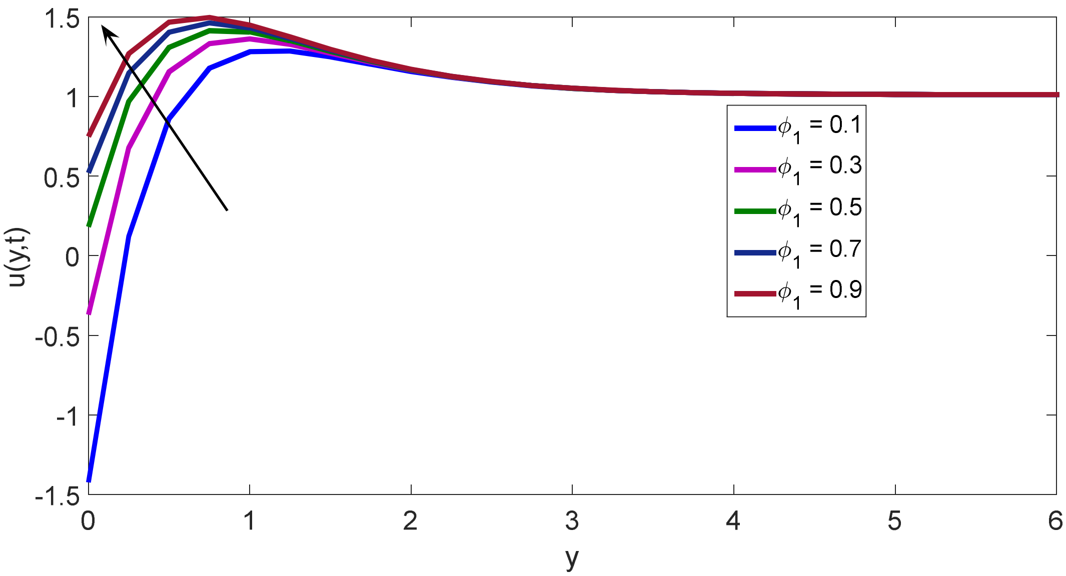

Figure 3: Velocity profiles for various values of porous permeability parameter ϕ_1.

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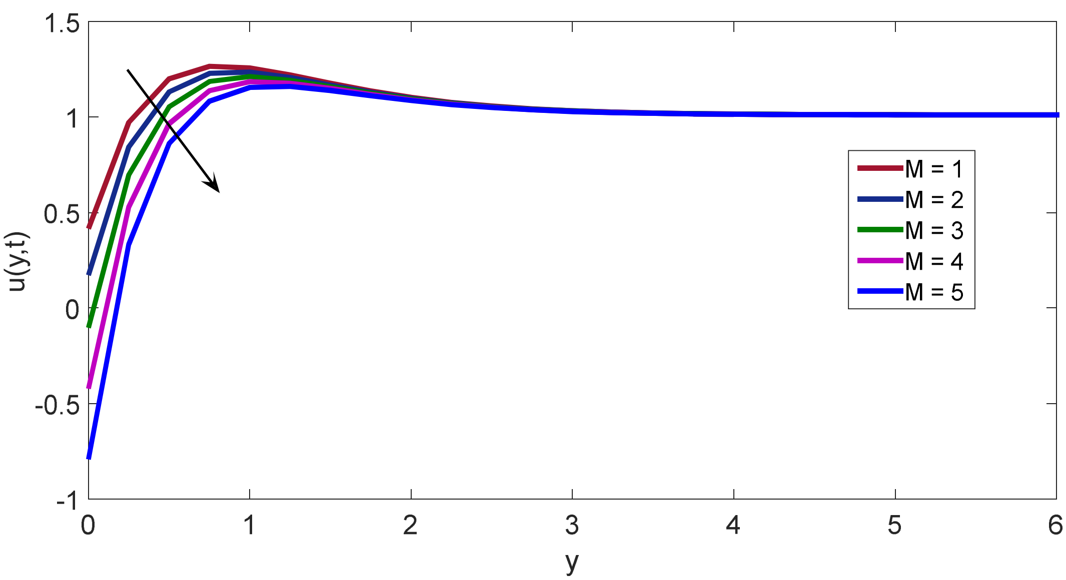

Figure 4: Velocity profiles for various values of magnetic parameter M.

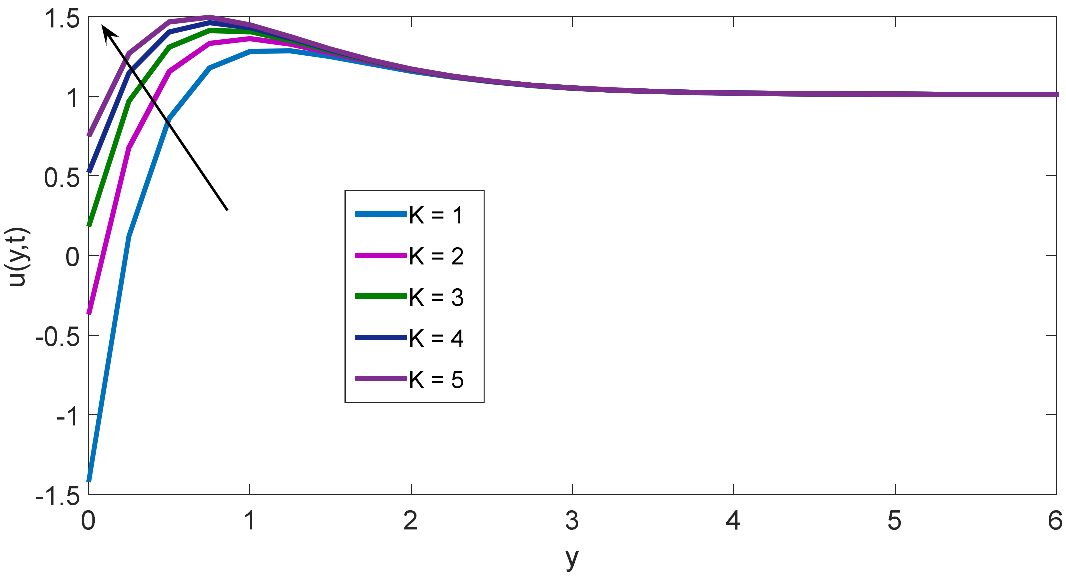

Figure 5: Velocity profiles for various values of porosity parameter K.

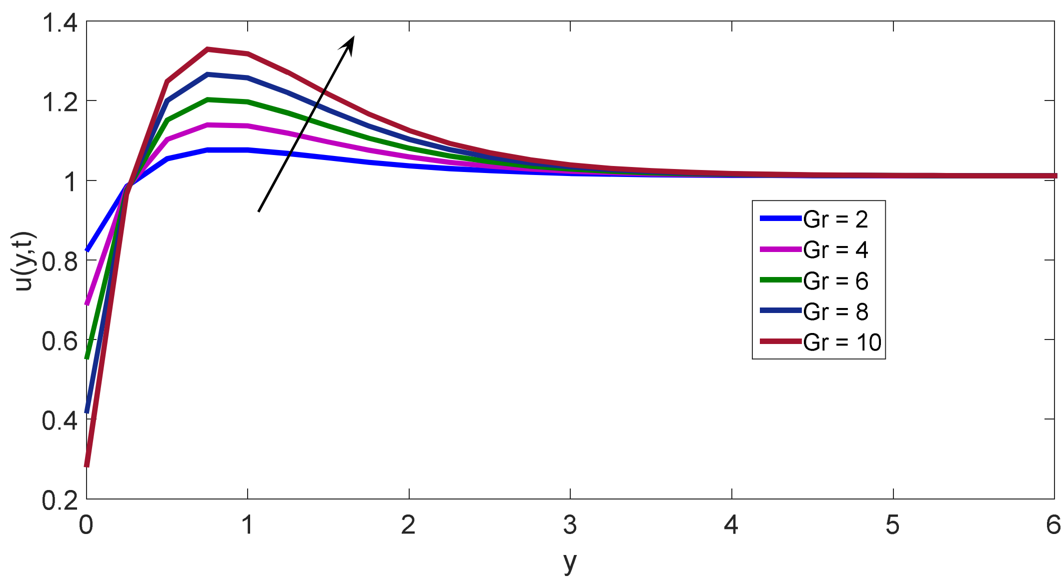

Figure 6: Velocity profiles for various values thermal buoyancy force parameter Gr.

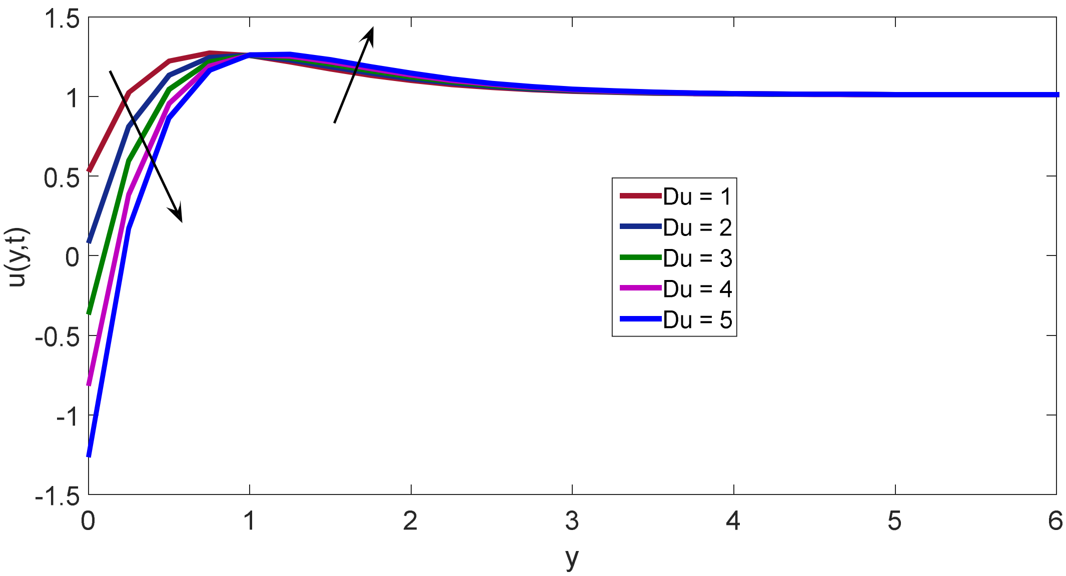

Figure 7: Velocity profiles for various values Diffusion thermo parameter Du.

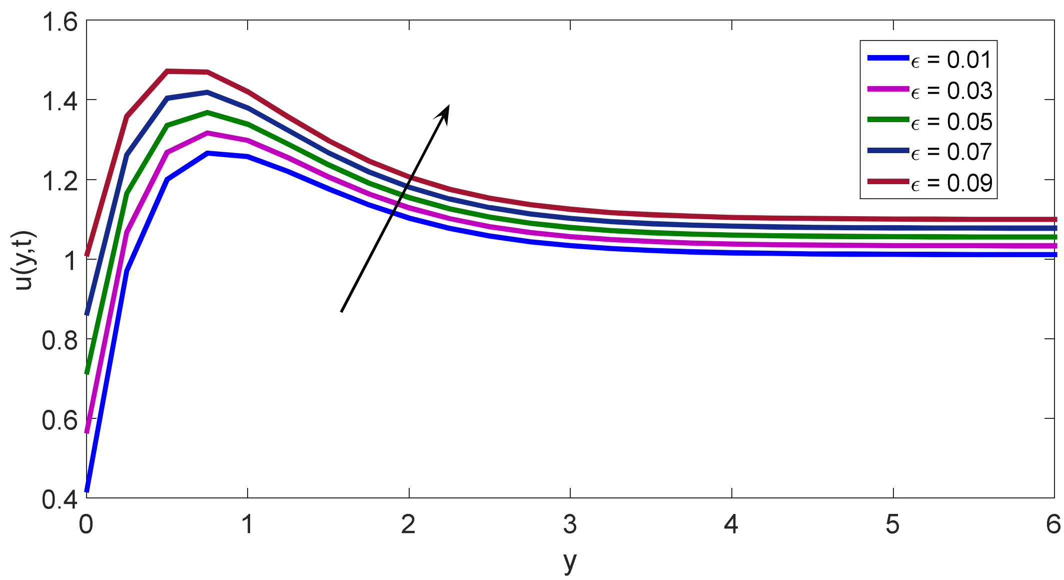

Figure 8: Velocity profiles for various values perturbation parameter ε .

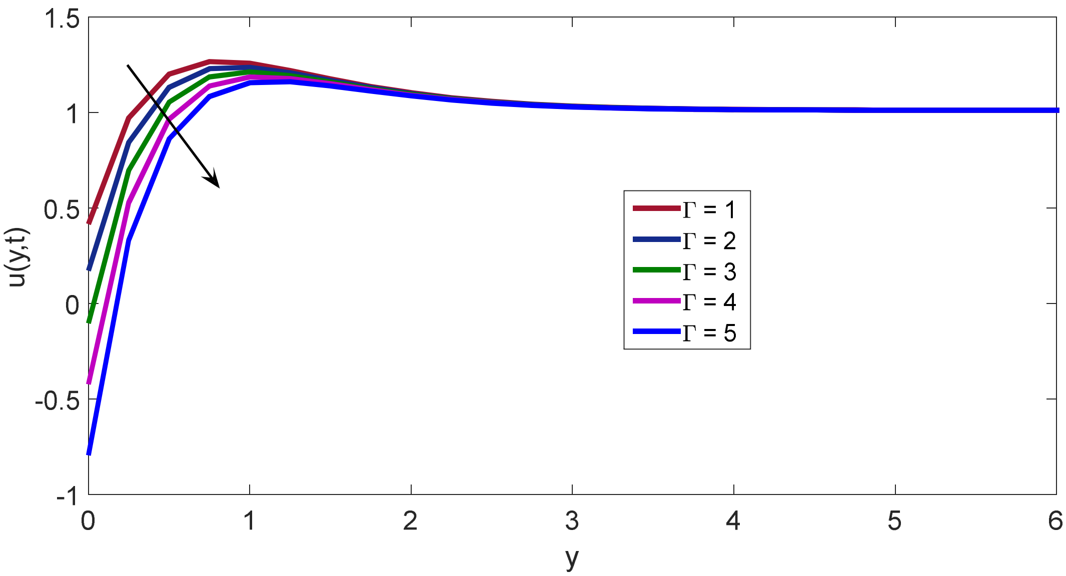

Figure 9: Velocity profiles for various values chemical reaction parameter Γ.

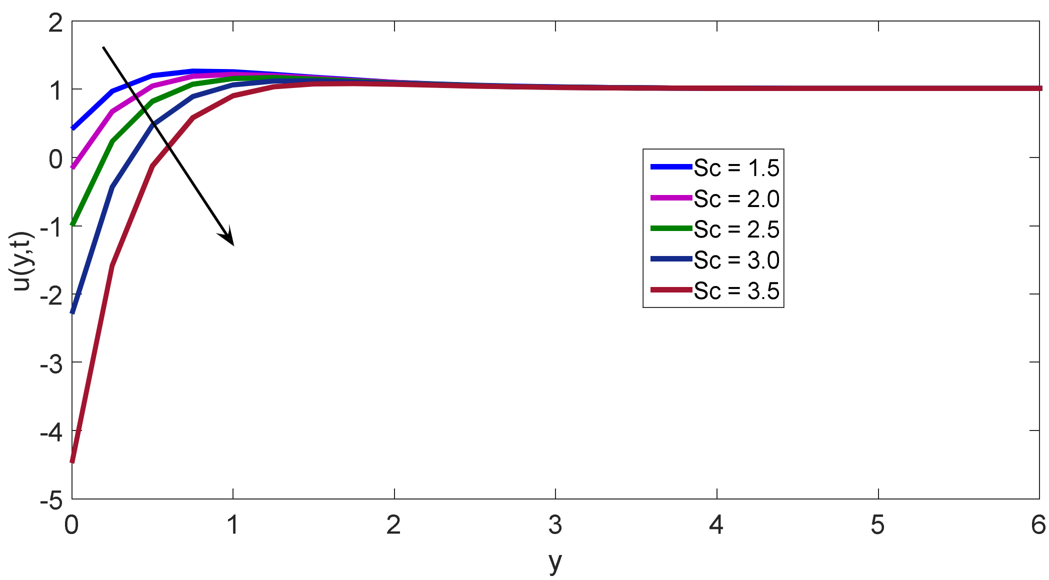

Figure 10: Velocity profiles for various values Schmidt number Sc.

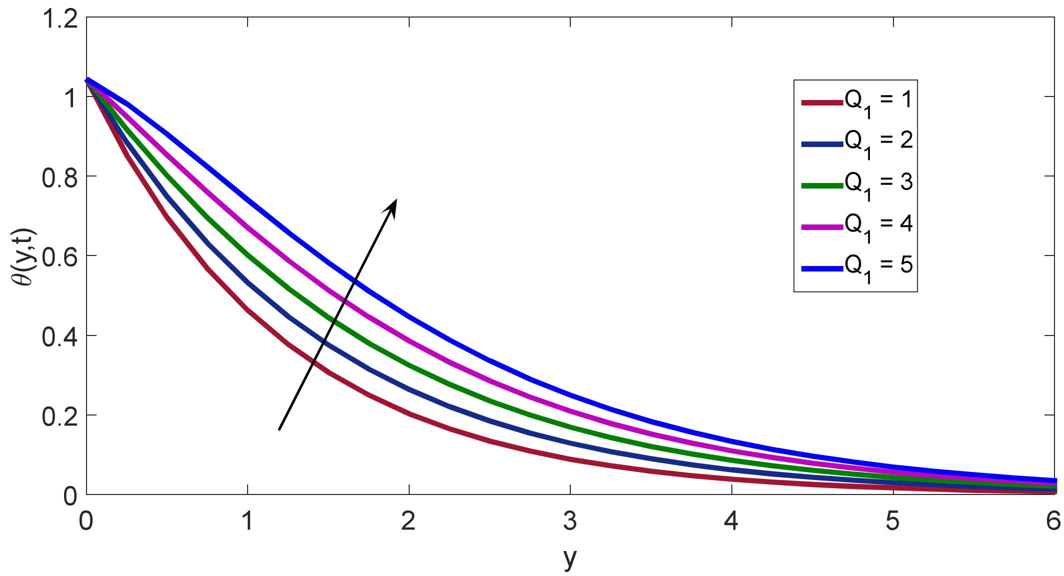

Figure 11: Temperature profiles for various values radiation absorption parameter Q_1.

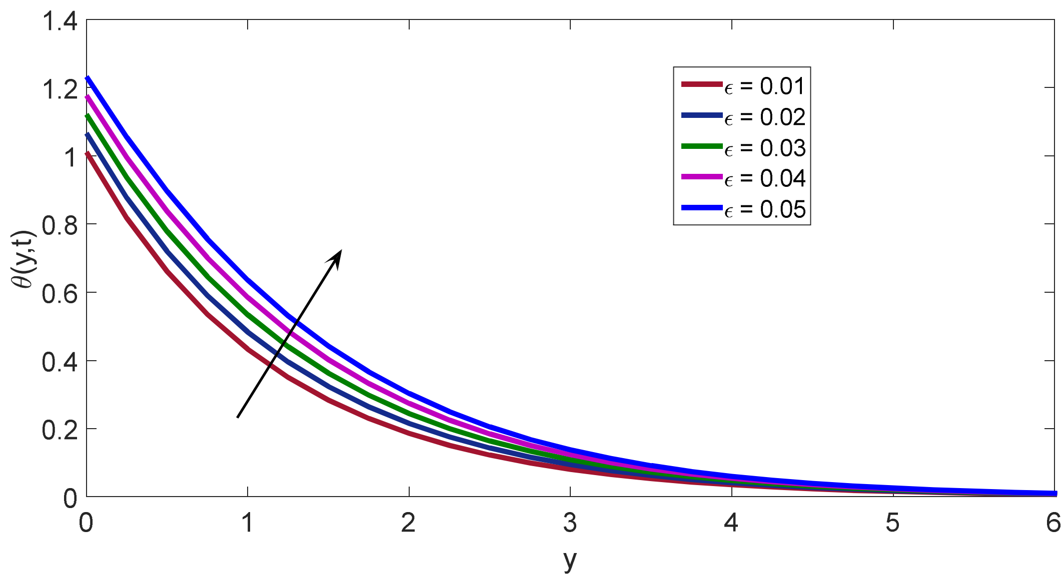

Figure 12: Temperature profiles for various values perturbation parameter ε .

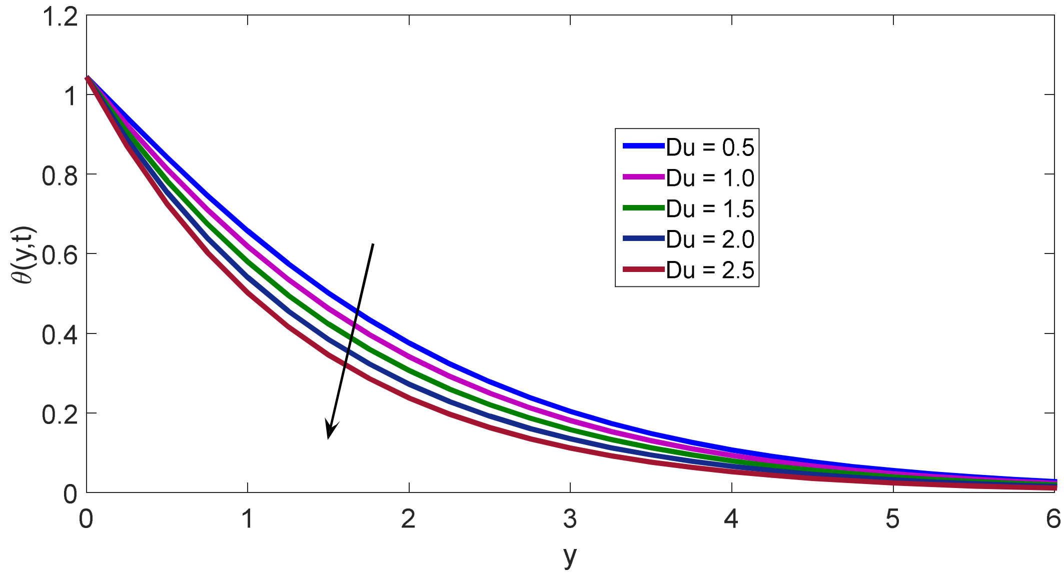

Figure 13: Temperature profiles for various values Diffusion thermo parameter Du.

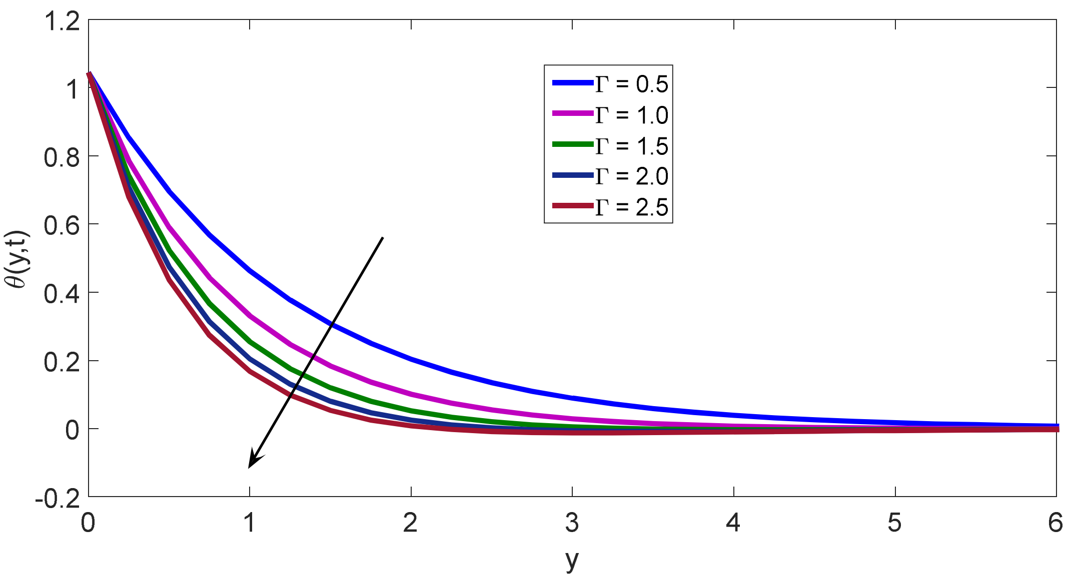

Figure 14: Temperature profiles for various values chemical reaction parameter Γ.

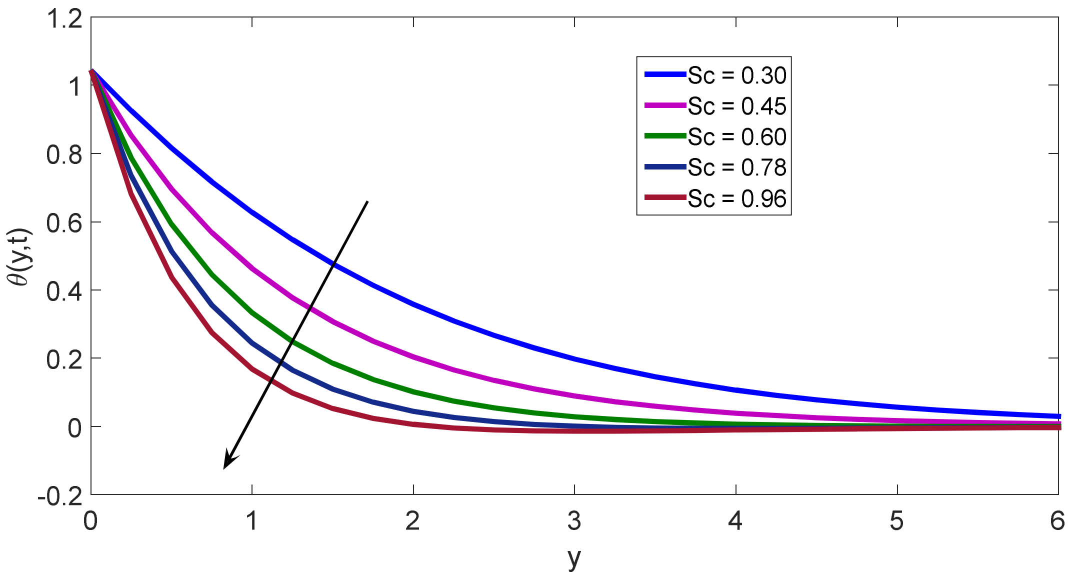

Figure 15: Temperature profiles for various values Schmidt number Sc.

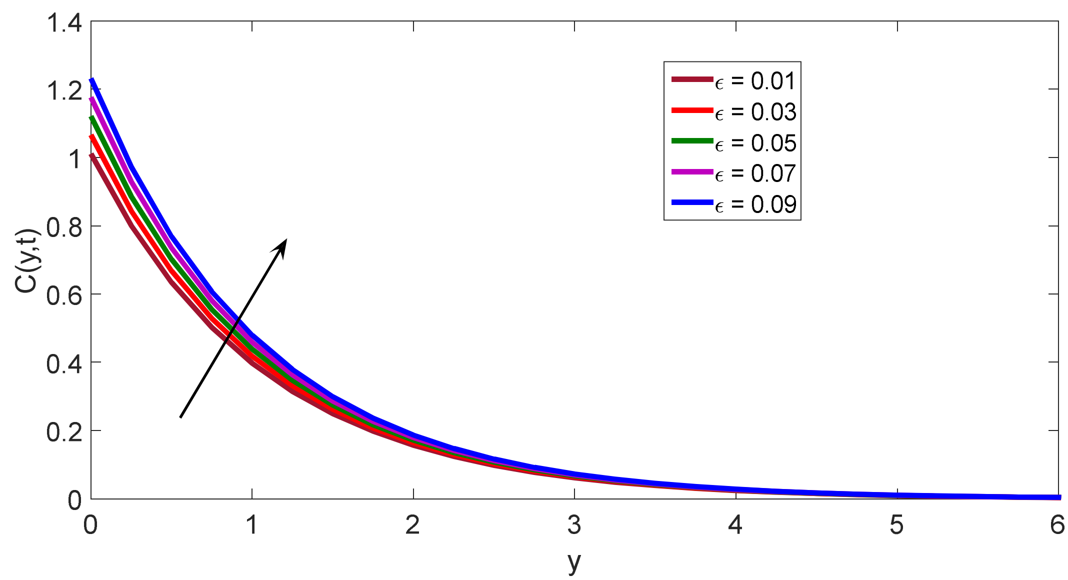

Figure 16: Concentration profiles for various values perturbation parameter ε .

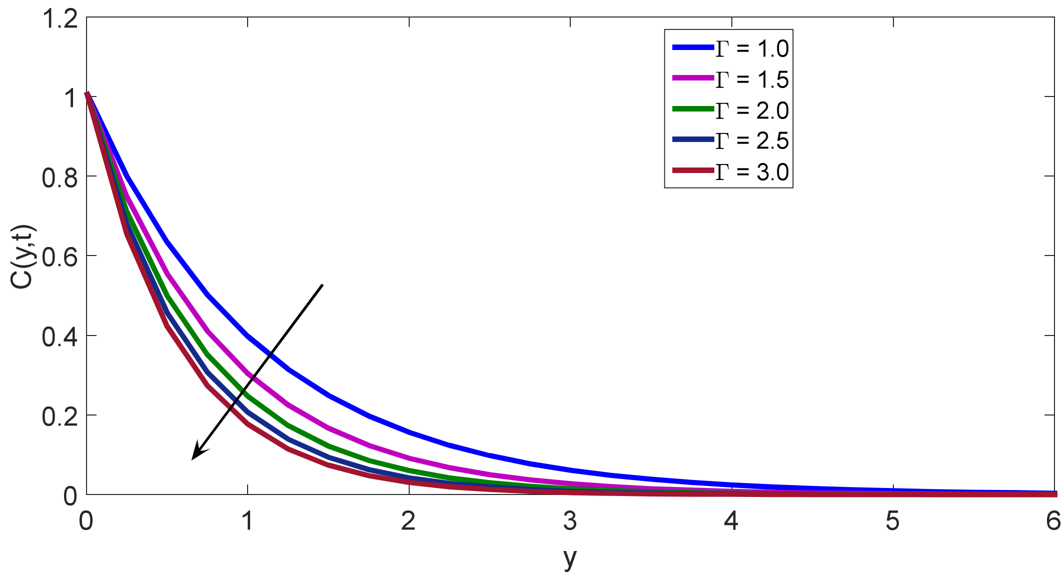

Figure 17: Concentration profiles for various values chemical reaction parameter Γ.

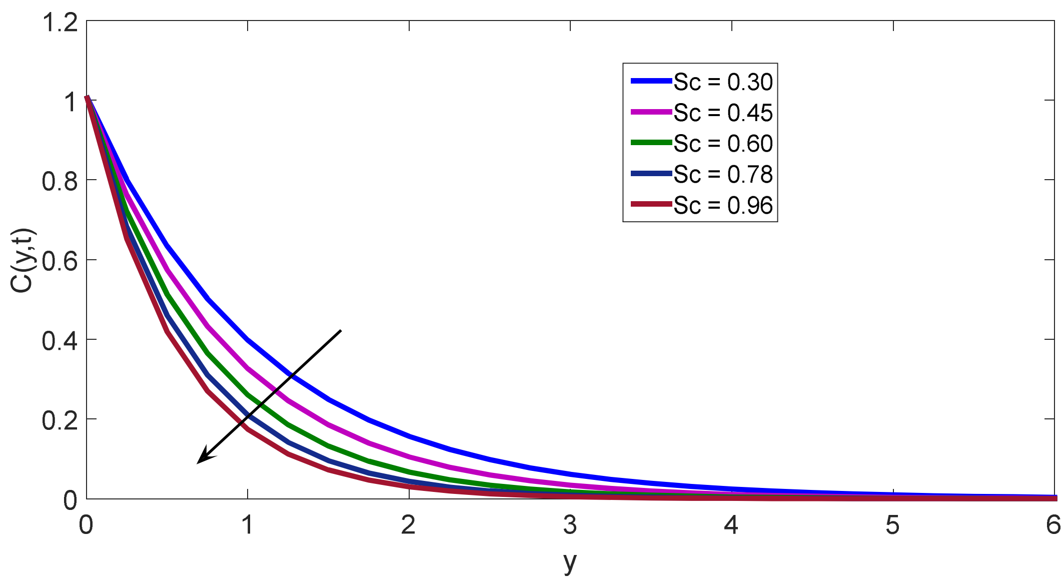

Figure 18: Concentration profiles for various values Schmidt number Sc.

V. CONCLUSIONS

In this chapter, we studied the Dufour effect on an unsteady MHD convective heat and mass transfer flow through a high porous medium over a vertical porous plate. From the present study, the following conclusions can be drawn:

1. The diffusion-thermo parameter decreases the thermal and increases momentum boundary layer thickness.
2. The fluid velocity increases with an increasing value of porous permeability parameter (slip parameter) ϕ_1.

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NOMENCLATURE:

A : Suction velocity parameter

ε : Perturbation parameter

B_0 : Magnetic field of uniform strength
C : Species concentration
C^* : Dimensional concentration
Cp : Specific heat at constant pressure
Cs : Concentration susceptibility
C_w : Species concentration at the plate
C_∞ : Species concentration far away from the plate
Cf : Skin friction coefficient
D : Molecular diffusivity
g : Acceleration due to gravity
N : Buoyancy ratio
Gr : Thermal Grashof number
K : Permeability parameter
Dm : Coefficient of mass diffusivity
K^* : Permeability of the porous medium
K_T : Thermal diffusion ratio
M : Magnetic field parameter
Nu : Nusselt number
n^* : Constant
P^* : Pressure
Pr : Prandtl number
Q_1 : Absorption of radiation parameter
A^* : Coefficient of proportionality for the absorption
Sc : Schmidt number
Sh : Sherwood number
T : Fluid Temperature
T^* : Temperature of the fluid near the plate
T_w : Temperature at the wall
T_∞ : Temperature far away from the plate
u^*, v^* : Components of dimensional velocities
u^* : Velocity of the fluid along x^*

v^* : Velocity of the fluid along

U_∞^* : Free stream dimensional velocity

U_0 : Scale of free stream velocity

V_0 : Suction velocity

x^*, y^* : Dimensional distances along and perpendicular to the plate

Re_x : Local Reynolds number

Greek symbols

α : Fluid thermal diffusivity

v : Coefficient of kinematic viscosity

β : Coefficient of volumetric expansion for the heat transfer

β^* : Coefficient of volumetric expansion for the fluid

β_0 : Magnetic field coefficient

β_T, β_C : Thermal and concentration expansion coefficients

ρ : Density of the fluid

σ : Electrically conductivity of the fluid

ϕ_1 : porous permeability (or) slip parameter

κ : Thermal conductivity

Γ : Chemical reaction parameter

Supersripts

$'$: Differentiation with respect to y

* : Dimensional properties

Subscripts

p : Plate

w : Wall condition

∞ : Free stream condition

APPENDIX:

$$q_1 = \frac{Sc + \sqrt{Sc\left(Sc + 4\Gamma\right)}}{2};\ q_2 = \frac{Sc + \sqrt{Sc\left(Sc + 4\left(\Gamma + n\right)\right)}}{2};\ q_3 = \frac{\Pr + \sqrt{\Pr\left(\Pr + 4n\Pr\right)}}{2};$$

$$T = M + \frac{1}{K};\ q_4 = \frac{1 + \sqrt{1 + 4T}}{2};\ q_4 = \frac{1 + \sqrt{1 + 4\left(T + n\right)}}{2};\ E_1 = \frac{AScq_1}{q_1^2 - Scq_1 - Sc\left(n + \Gamma\right)};$$

$$E_2 = 1 - E_1;\ E_3 = \frac{Duq_1^2 - \Pr Q_1}{q_1^2 - \Pr q_1};\ E_4 = \frac{A\Pr E_4}{n};\ E_6 = \frac{\Pr Aq_1E_3 - \Pr Q_1E_1 - Duq_1^2E_1}{q_1^2 - \Pr q_1 - n\Pr};$$

$$E_7 = \frac{\Pr Q_1E_2 + Duq_2^2E_2}{q_1^2 - \Pr q_1 - n\Pr};\ E_8 = 1 + E_5 - E_6 - E_7;\ E_9 = \frac{GrE_4}{\Pr^2 - \Pr - T};\ E_{10} = \frac{Gr\left(E_3 + N\right)}{\Pr^2 - \Pr - T};$$

$$E_{11} = \frac{\left(1 + \phi_1 q_1\right)E_{10} + \left(1 + \phi_1\Pr\right)E_9 - 1}{\left(1 + \phi_1 q_4\right)};\ E_{12} = \frac{Aq_4E_{11}}{q_4^2 - q_4 - \left(T + n\right)};\ E_{13} = \frac{GrE_5 - A\Pr E_9}{\Pr^2 - \Pr - \left(T + n\right)};$$

$$E_{14} = \frac{GrE_6 + Aq_1E_{10} + GrNE_1}{q_1^2 - q_1 - \left(T + n\right)};\ E_{15} = \frac{GrE_8}{q_3^2 - q_3 - \left(T + n\right)};\ E_{16} = \frac{Gr\left(E_7 - NE_2\right)}{q_1^2 - q_1 - \left(T + n\right)};$$

$$E_{17} = \frac{\left(1 + \phi_1 q_1\right)E_{14} + \left(1 + \phi_1 q_3\right)E_{15} - \left(1 + \phi_1 q_4\right)E_{12} - \left(1 + \phi_1 q\Pr\right)E_{13} - \left(1 + \phi_1 q_2\right)E_{16} - 1}{\left(1 + \phi_1 q_5\right)};$$