

An Unsteady MHD Flow Past a Vertical Porous Plate Under a Variable Suction Velocity with Soret-Dufour and Second-order Chemical Reaction

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Abstract: The objective of this work to study the combined effect of Soret-Dufour, radiation and second order chemical reaction on unsteady MHD(magnetohydrodynamics) flow past a vertical porous plate immersed in a porous medium under variable suction velocity. In this model, the nonlinear partial differential equation of flow problem has been solved numerically using the Crank-Nicolson implicit finite difference method. Characteristics of velocity, temperature and concentration are shown through graphically and characteristics of skin friction, Nusselt number and Sherwood number are discussed with the help of the table.

MSC: 76W05, 80A20, 80A21, 80A32, 80M20.

Keywords: Magnetohydrodynamics, Heat Transfer, Mass Transfer, Order of chemical reaction, Soret and Dufour effects, Crank-Nicolson finite difference method.

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1. Introduction

Due to a wide range of applications of natural convection MHD flow of second-order chemical reaction with Soret Dufour and radiation effects in chemical industries like drying, food processing, oil extraction, flow occurs in solid mechanics, etc. That is why many research workers attracted to this work. There is also much application of radiative-convective flow like heating and cooling thermal chambers and astrophysical flows. The theory of mass transfer in fluid dynamics is seen in the burning pool of oil, leaching by spray, and drying. Many scholars investigated the effects of Soret and Dufour in the flow problems due to their applications in sciences and engineering like isotope separation.

Sandeep and Babu [1] analyzed the numerical result of nonlinear radiation for heat transfer of nanofluid past a vertical plate. Rushi et al. [2] investigated unsteady nanofluid flow phenomena in the presence of chemical of a higher order. Mastroberardino et al. [3] worked on MHD boundary layer slip flow and heat transfer of a power-law fluid over a flat plate. Idowu and Falodun [4] look over change SoretDufour on MHD flow of viscoelastic fluid over a semi-infinite vertical plate. Saritha et al. [5] explored the combined effects of Soret and Dufour on MHD flow of a power-law fluid over a flat plate in a slip flow regime. Malik and Rahman [6] analyzed the effects of second-order chemical reaction on MHD free convection dissipative fluid flow past an inclined porous surface by way of Heat Generation.

Imtiaz et al. [7] observed effects of Soret and Dufour in the flow of viscous fluid by a curved stretching surface. Anuradha

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and Harianand [8] studied Soret and Dufour effects on MHD mixed convection flow towards a vertical plate in a porous medium. Ahmed [10] explored the exact solution of Heat and mass transfer in MHD Poiseuille flow with porous walls. Das and Dorjee [11] analyzed the MHD flow with Soret and Dufour effects in the presence of heat source and chemical reaction. The aim of the present work is to analyze the effects of Soret-Dufour, radiation, and second-order chemical reaction on unsteady MHD flow of viscous incompressible fluid through a vertical porous plate immersed in a porous medium under consideration of variable suction velocity. The result of variation in different parameters on velocity, heat transfer, and mass transfer as well as in physical quantities like skin friction, Nusselt number, and Sherwood number are received by solving the governing equations of the flow field with considering changes with appropriate parameters using Crank-Nicolson implicit finite difference method.

2. Formulation of Model

In this model, we consider a fluid capable of a second-order chemical reaction and an unsteady MHD boundary layer flow of a viscous incompressible electrically conducting fluid past a semi-infinite vertical porous plate immersed in a porous medium. Our assumption in starting the plate moves with velocity u_0 and concentration and temperature decrease exponentially with respect to time and the plate gets heated at temperature $\check{\Theta}_w$ and concentration $\check{\Phi}_w$. The $\check{x}$ -axis considered along with the semi-infinite plate in the vertically upward direction and $\check{y}$ -axis normal to it, the flow variables are functions of normal distance $\check{y}$ and $\check{t}$ only. A magnetic field B_0 is exerted normal to the plate, the induced magnetic field is neglected because of under low magnetic Reynolds number. Suction velocity is considered time-dependent and normal to the plate. We further consider that the plate is non-conducting. From the above model of the problem, the governing equations of flow field under the usual Boussinesq approximation are as follows:

Equation of Continuity:

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

Equation of momentum:

$$\frac{\partial \check{u}}{\partial \check{t}} + \check{v} \frac{\partial \check{u}}{\partial \check{y}} = \nu \frac{\partial^2 \check{u}}{\partial \check{y}^2} + g\beta_t(\check{\Theta} - \check{\Theta}_\infty) + g\beta_c(\check{\Phi} - \check{\Phi}_\infty) - \frac{\sigma B_0^2 \check{u}}{\rho} - \frac{\nu \check{u}}{K} \quad (2)$$

Energy Equation:

$$\rho c_p \left(\frac{\partial \check{\Theta}}{\partial \check{t}} + \check{v} \frac{\partial \check{\Theta}}{\partial \check{y}} \right) = k \frac{\partial^2 \check{\Theta}}{\partial \check{y}^2} - \frac{\partial q_r}{\partial \check{y}} + \frac{\rho D_m k_\Theta}{c_s} \frac{\partial^2 \check{\Phi}}{\partial \check{y}^2} \quad (3)$$

Equation of mass transfer:

$$\frac{\partial \check{\Phi}}{\partial \check{t}} + \check{v} \frac{\partial \check{\Phi}}{\partial \check{y}} = D_m \frac{\partial^2 \check{\Phi}}{\partial \check{y}^2} + \frac{D_m k_\Theta}{\Theta_m} \frac{\partial^2 \check{\Theta}}{\partial \check{y}^2} - k_r(\check{\Phi} - \check{\Phi}_\infty)^2 \quad (4)$$

The initial and boundary conditions for this model are

$$\begin{aligned} \check{t} \leq 0 \quad \check{u} &= 0 \quad \check{\Theta} = \check{\Theta}_\infty \quad \check{\Phi} = \check{\Phi}_\infty \quad \forall \check{y} \\ \check{t} > 0 \quad \check{u} &= u_0 \quad \check{\Theta} = \check{\Theta}_\infty + \epsilon(\check{\Theta}_w - \check{\Theta}_\infty)e^{-\check{n}\check{t}}, \\ \check{\Phi} &= \check{\Phi}_\infty + \epsilon(\check{\Phi}_w - \check{\Phi}_\infty)e^{-\check{n}\check{t}}, \quad \text{at } \check{y} = 0 \\ \check{u} &= 0 \quad \check{\Theta} \rightarrow \check{\Theta}_\infty \quad \check{\Phi} \rightarrow \check{\Phi}_\infty \quad \check{y} \rightarrow \infty \end{aligned} \quad (5)$$

where $\check{\Theta}$ and $\check{\Phi}$ are temperature and concentration, $\check{\Phi}_\infty$ and $\check{\Theta}_\infty$ are concentration and temperature of free stream boundary layer, k_r is chemical reaction parameter constant, β_t is coefficient of volumetric thermal expansion of the fluid, β_c is volumetric coefficient of expansion with concentration of fluid, q_r is radiative heat along $\check{y}$ -axis, ν is kinematic viscosity and Θ_m is mean fluid temperature, $\check{K}$ is permeability of porous medium, σ is electrical conductivity, D_m is molecular diffusivity, g is acceleration due to gravity, K_Θ is thermal diffusion ratio, μ is viscosity, ρ is fluid density, k is thermal conductivity of fluid, c_p is specific heat at constant pressure.

Integrating both sides of the continuity equation (1), we get $\check{v} = \text{constant}$. It is obvious that the suction velocity normal to the plate is a constant function or consider as a function of time. In this model, we assume as a case when it is both constant and time-dependent and expressed as

$$\check{v} = -u_0(1 + \epsilon A e^{\check{t}}) \quad (6)$$

where u_0 is mean suction velocity, which is a non-zero positive constant and the minus sign indicates that the suction is outwards the plate. A is the suction parameter, ϵ is a small reference parameter and $\epsilon A \ll 1$. The radiative flux term q_r by using the Rosseland approximation [12], is given by

$$q_r = -\frac{4\tilde{\sigma}}{3a_r} \frac{\partial \check{\Theta}^4}{\partial \check{y}} \quad (7)$$

where a_r is Rosseland radiation absorptivity constant and $\tilde{\sigma}$ is Stefan Boltzmann constant. In this problem, $\check{\Theta}^4$ can be expressed as linearly with temperature because the temperature difference within a flow is very small. It is seen by expanding in Taylor's series about $\check{\Theta}_\infty$ and considering the negligible higher-order term, so

$$\check{\Theta}^4 \cong 4\check{\Theta}_\infty^3 \check{\Theta} - 3\check{\Theta}_\infty^4 \quad (8)$$

so, with the help of equations (7) and (8), equation (3) is reduced to

$$\rho c_p \left(\frac{\partial \check{\Theta}}{\partial \check{t}} + \check{v} \frac{\partial \check{\Theta}}{\partial \check{y}} \right) = k \frac{\partial^2 \check{\Theta}}{\partial \check{y}^2} + \frac{16\sigma \check{\Theta}_\infty^3}{3k_m} \frac{\partial^2 \check{\Theta}}{\partial \check{y}^2} + \frac{\rho D_m k_\Theta}{c_s} \frac{\partial^2 \check{\Phi}}{\partial \check{y}^2} \quad (9)$$

In continuation of getting the non-dimensional form of governing partial differential equations, we introduce the following non-dimensional quantities

$$\begin{aligned} n &= \frac{\nu \check{t}}{u_0^2}, \quad u = \frac{\check{u}}{u_0}, \quad t = \frac{\check{t} u_0^2}{\nu}, \quad \theta = \frac{\check{\Theta} - \check{\Theta}_\infty}{\check{\Theta}_w - \check{\Theta}_\infty}, \quad C = \frac{\check{\Phi} - \check{\Phi}_\infty}{\check{\Phi}_w - \check{\Phi}_\infty}, \quad Gm = \frac{\nu g \beta_c (\check{\Phi}_w - \check{\Phi}_\infty)}{u_0^3}, \\ Gr &= \frac{\nu g \beta_t (\check{\Theta}_w - \check{\Theta}_\infty)}{u_0^3}, \quad y = \frac{\check{y} u_0}{\nu}, \quad Kr = \frac{k_r \nu}{u_0^2}, \quad Du = \frac{D_m k_\Theta (\check{\Phi}_w - \check{\Phi}_\infty)}{c_s c_p \nu (\check{\Theta}_w - \check{\Theta}_\infty)}, \quad M = \frac{\sigma B_0^2 \nu}{\rho u_0^2}, \\ So &= \frac{D_m k_\Theta (\check{\Theta}_w - \check{\Theta}_\infty)}{\Theta_m \nu (\check{\Phi}_w - \check{\Phi}_\infty)}, \quad R = \frac{4\tilde{\sigma} \check{\Theta}_\infty^3}{a_r k}, \quad Sc = \frac{\nu}{D_m}, \quad K = \frac{u_0^2 \check{K}}{\nu^2}, \quad Pr = \frac{\mu c_p}{k}. \end{aligned} \quad (10)$$

Here Gm , Gr , Kr , Du , M , So , R , Sc , K and Pr are respectively free convection parameter due to concentration, free convection parameter due to temperature, rate of chemical reaction parameter, Dufour number, magnetic parameter, Soret number, radiation parameter, Schmidt number, Darcy permeability parameter, and Prandtl number. Employing above dimensionless variables in equations (2), (9) and (4), we get non dimensional form of non linear partial differential equations:

$$\frac{\partial u}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr \theta + Gm C - M u + \frac{u}{K} \quad (11)$$

$$\frac{\partial \theta}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial \theta}{\partial y} = \frac{1}{Pr} \left(1 + \frac{4R}{3} \right) \frac{\partial^2 \theta}{\partial y^2} + Du \frac{\partial^2 C}{\partial y^2} \quad (12)$$

$$\frac{\partial C}{\partial t} - (1 + \epsilon A e^{nt}) \frac{\partial C}{\partial y} = \frac{1}{Sc} \frac{\partial^2 C}{\partial y^2} + Sr \frac{\partial^2 \theta}{\partial y^2} - Kr C^2 \quad (13)$$

with the initial and boundary conditions:

$$\begin{aligned} \text{for } t \leq 0 \quad u &= 0, \quad \theta = 0, \quad C = 0, \quad \forall y \\ \text{for } t > 0 \quad u &= 1, \quad \theta = 1 + \epsilon e^{-nt}, \quad C = 1 + \epsilon e^{-nt}, \quad \text{at } y = 0 \\ u &= 0, \quad \theta \rightarrow 0, \quad C \rightarrow 0, \quad y \rightarrow \infty. \end{aligned} \quad (14)$$

Mathematical expression for physical parameters skin-friction, Nusselt number and Sherwood number for primary interest of this type boundary layer flow problem are

$$\begin{aligned} \tau &= \left(\frac{\partial u}{\partial y} \right)_{y=0} \\ Nu &= - \left(\frac{\partial \theta}{\partial y} \right)_{y=0} \\ Sh &= - \left(\frac{\partial C}{\partial y} \right)_{y=0} \end{aligned} \quad (15)$$

3. Procedure of Solution

Equations (11), (12) and (13) represent non dimensional form of velocity, heat transfer and mass transfer equations, equation (14) represents non dimensional form of boundary conditions and these equations and boundary conditions are non linear partial differential equations. So the exact solution of this type of system of partial differential equations is not possible. Crank-Nicolson implicit finite difference method is used to get a numerical solution. Converted form of these systems of partial differential equations after employing Crank-Nicolson finite difference are:

$$\begin{aligned} \frac{u_{i,j+1} - u_{i,j}}{\Delta t} - (1 + \epsilon A e^{nj\Delta t}) \frac{u_{i+1,j} - u_{i,j}}{\Delta y} &= \left(\frac{u_{i-1,j} - 2u_{i,j} + u_{i+1,j} - 2u_{i,j+1} + u_{i+1,j+1}}{2(\Delta y)^2} \right) + Gr \left(\frac{\theta_{i,j+1} - \theta_{i,j}}{2} \right) \\ &+ Gm \left(\frac{C_{i,j+1} - C_{i,j}}{2} \right) - \left(M + \frac{1}{K} \right) \left(\frac{u_{i,j+1} + u_{i,j}}{2} \right) \end{aligned} \quad (16)$$

$$\begin{aligned} \frac{\theta_{i,j+1} - \theta_{i,j}}{\Delta t} - (1 + \epsilon A e^{nj\Delta t}) \frac{\theta_{i+1,j} - \theta_{i,j}}{\Delta y} &= \frac{1}{Pr} \left(1 + \frac{4R}{3} \right) \left(\frac{\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j} - 2\theta_{i,j+1} + \theta_{i+1,j+1}}{2(\Delta y)^2} \right) \\ &+ Du \left(\frac{C_{i-1,j} - 2C_{i,j} + C_{i+1,j} - 2C_{i,j+1} + C_{i+1,j+1}}{2(\Delta y)^2} \right) \end{aligned} \quad (17)$$

$$\begin{aligned} \frac{C_{i,j+1} - C_{i,j}}{\Delta t} - (1 + \epsilon A e^{nj\Delta t}) \frac{C_{i+1,j} - C_{i,j}}{\Delta y} &= \frac{1}{Sc} \left(\frac{C_{i-1,j} - 2C_{i,j} + C_{i+1,j} - 2C_{i,j+1} + C_{i+1,j+1}}{2(\Delta y)^2} \right) \\ &+ So \left(\frac{\theta_{i-1,j} - 2\theta_{i,j} + \theta_{i+1,j} - 2\theta_{i,j+1} + \theta_{i+1,j+1}}{2(\Delta y)^2} \right) \\ &- Kr \left(\frac{C_{i,j+1} + C_{i,j}}{2} \right)^2 \end{aligned} \quad (18)$$

initial and boundary conditions are also written as:

$$\begin{aligned} u_{i,0} &= 0 \quad \theta_{i,0} = 0 \quad C_{i,0} = 0 \quad \forall i \\ u_{0,j} &= 1 \quad \theta_{0,j} = 1 + \epsilon e^{-nj\Delta t} \quad C_{0,j} = 1 + \epsilon e^{-nj\Delta t} \\ u_{N,j} &= 0 \quad \theta_{N,j} \rightarrow 0 \quad C_{N,j} \rightarrow 0 \end{aligned} \quad (19)$$

where node i represents partition of y , $\Delta y = y_{i+1} - y_i$ and node j represents to partition of time t , $\Delta t = t_{j+1} - t_j$. Calculating values of u , θ and C at time t .

We compute the values at time $t + \Delta t$ as following method: we substitute $i = 1, 2, \dots, N - 1$, where N indicate to ∞ , equations (16) to (18) give tridiagonal system of equations with initial and boundary conditions in equation (19), are solved by using Thomos algorithm as given in Carnahan et al. [9], we find the values of θ and C for all y at $t + \Delta t$. Equation (16) is solved by same method to replace these values of θ and C , we find solution of u till required time t .

4. Results and Discussion

In continuation of discussion physical behavior of the problem, the numerical analysis of velocity, temperature, concentration, Skin-friction coefficient, Nusselt number and Sherwood number over the boundary layer for different values of flow parameters like magnetic parameter M , rate of chemical reaction parameter K_r , radiation parameter R , Soret number So , Prandtl number Pr , Schmidt number Sc , Dufour number Du and time t . In our investigation the values of thermal Grashof number Gr , solutal Grashof number Gm , Darcy permeability parameter K , small reference parameter ϵ , suction parameter A and constant n were fixed as 4, 6, 1.5, 0.02, 0.2 and 4 respectively.

With an increase in Du in figure 13, it is seen that velocity profiles increase slowly between the plate and boundary layer and it is also analyzed that at some distance from plate, velocity maintains constant after then goes to zero at the boundary layer. Temperature profiles increase in figure 14 as Du increases. Figure 15 depicts that concentration profiles decrease slowly near to plate on increasing Du . Figure 1 shows velocity profiles decreases in figure 1 and temperature profiles in figure 3 slightly increases near to plate while concentration profiles in figure 2 decreases rapidly near to plate as K_r increases.

Figure 10 drawn for various values of Pr on velocity profiles. It is seen that velocity profiles decrease rapidly near to boundary layer as Pr increases. Temperature profiles in figure 11 decreases as Pr increases. It is a good symptom with physical behavior that an increase in Pr leads to a decrease in thickness of the temperature boundary layer. Concentration profiles in figure 12 near to wall increases after then decreases when Pr increases. Higher Soret number So increases fluid velocity profiles in figure 17, decreases fluid temperature near to plate in figure 18 and increases concentration profiles in figure 19. Figure 16 shows that an increase in M leads to increases in velocity profiles of fluid. Velocity profiles increases in figure 7 as R increases, because of the increase in radiation parameter releases thermal energy to flow. It is obvious that on increase R , temperature profiles in figure 8 increases while concentration profiles in figure 9 decreases. Figure 4 shows the effect of Sc on velocity profiles. It is seen that on increase Sc , velocity profiles decrease rapidly after then decreases slowly. Temperature profiles increase slowly near to plate in figure 5 when Sc increases. Concentration profiles in figure 6 decrease fast for the first variation after then it decreases slowly on increases of Sc . On increase in time t , boundary layer thickness of velocity increases in figure 20, thickness of thermal boundary layer in figure 21 and concentration boundary layer in figure 22 are approximately same.

Table 1 represents the values of the skin friction coefficient, Nusslet number, and Sherwood number for different values of physical parameters. Table reveals that Skin friction is higher for increase Du , M , So , R , t and lower for Sc , K_r , Pr . Nusselt number is lower for increment of Du , Sc , K_r , M , R , t and higher for increment of Pr , So . Sherwood number increases for increase Du , Sc , K_r , M , M , R and Sherwood number decreases for increase Pr , So , t .

5. Conclusion

Based on the study of unsteady MHD flow past a vertical porous plate under a variable suction velocity with Soret-Dufour, second-order chemical reaction, variable temperature, and variable concentration, the following conclusions have arrived for this model:

- (1). With an increase in radiation parameter, velocity increment is slow near to plate after then increment is fast.
- (2). Concentration shows an attractive effect on the change of the Schmidt number.
- (3). With an increase in Soret number, velocity increases and shows a good change near to plate.
- (4). With an increase in Dufour number increment of velocity is seen from some distance to the plate, decrement of concentration is found out near to plate.
- (5). With an increase in the rate of reaction parameter, velocity decreases, temperature variates slowly, concentration goes lower near to the plate.

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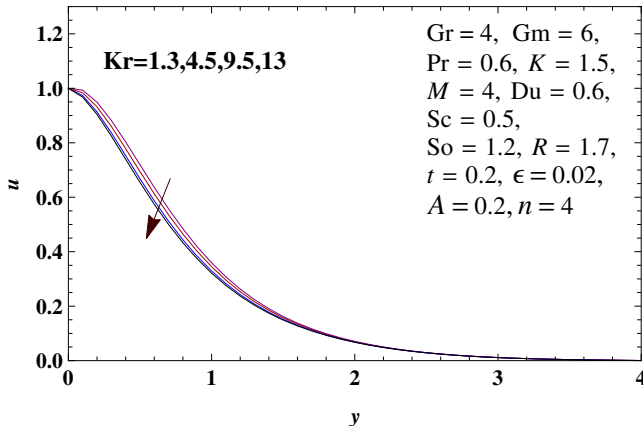


Figure 1. Velocity Profiles for Different Values of Kr

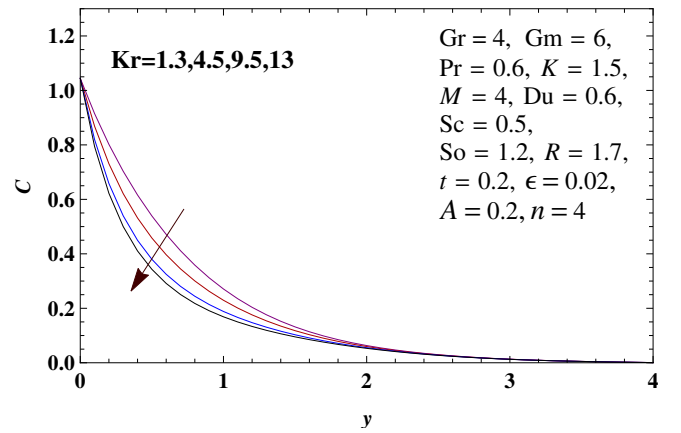


Figure 2. Concentration Profiles for Different Values of Kr

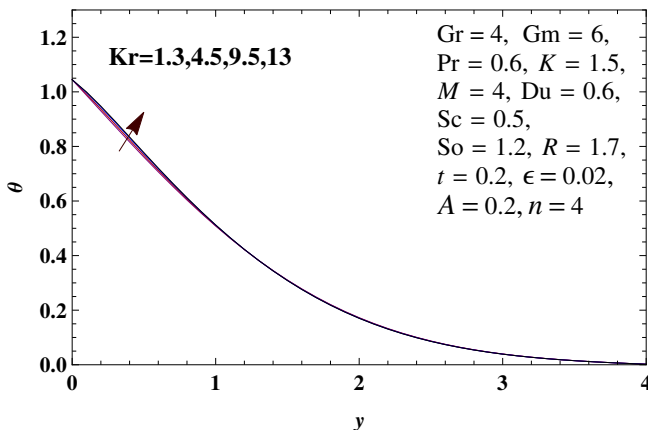


Figure 3. Temperature Profiles for Different Values of Kr

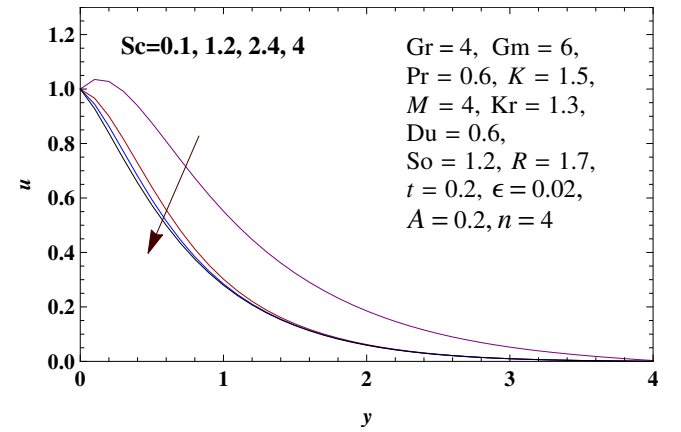


Figure 4. Velocity Profiles for Different Values of Sc

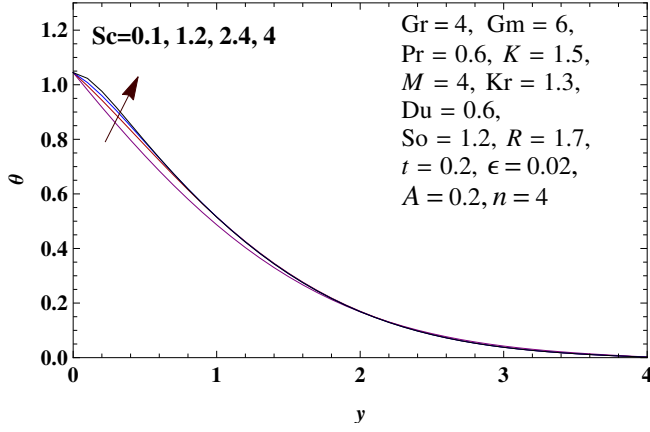


Figure 5. Temperature Profiles for Different Values of Sc

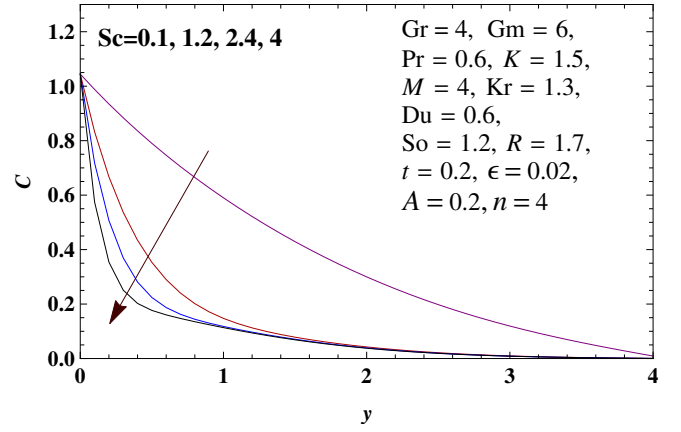


Figure 6. Concentration Profiles for Different Values of Sc

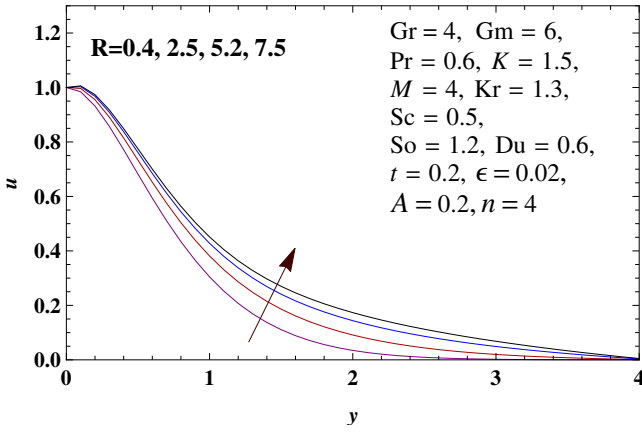


Figure 7. Velocity Profiles for Different Values of R

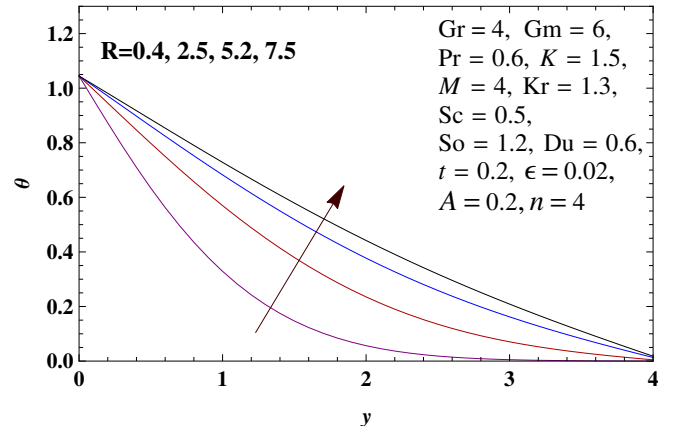


Figure 8. Temperature Profiles for Different Values of R

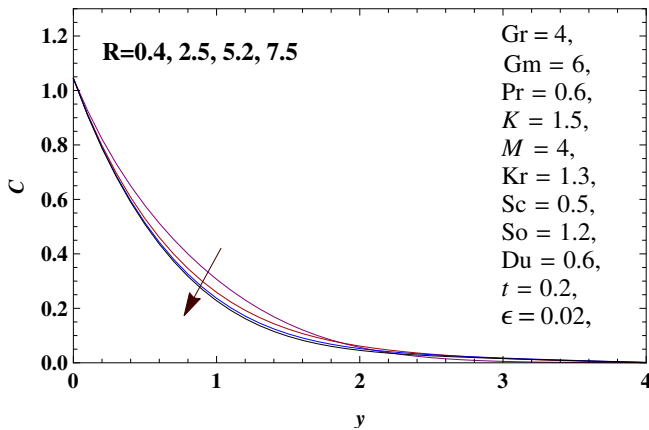


Figure 9. Concentration Profiles for Different Values of R

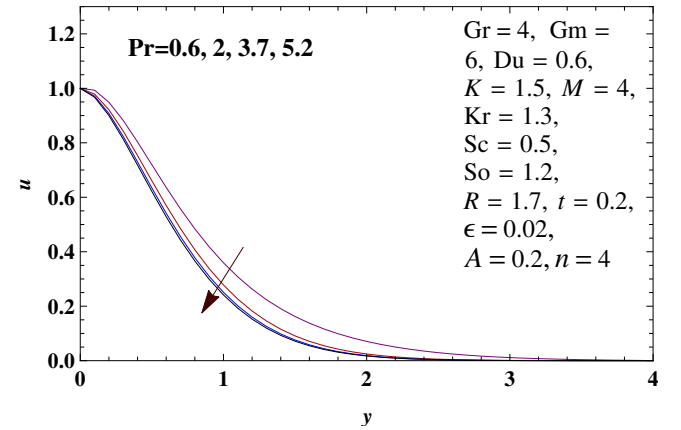


Figure 10. Velocity Profiles for Different Values of Pr

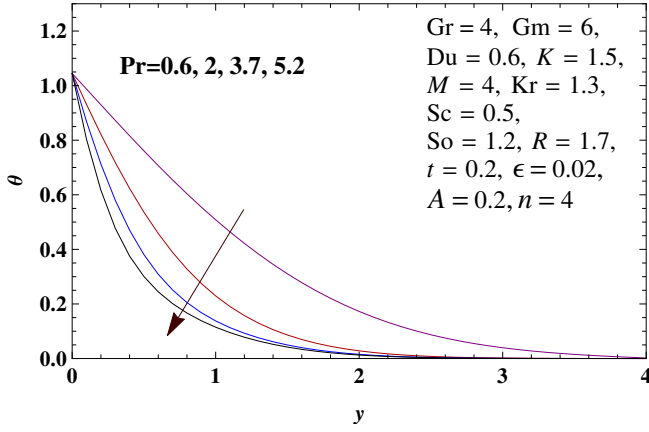


Figure 11. Temperature Profiles for Different Values of Pr

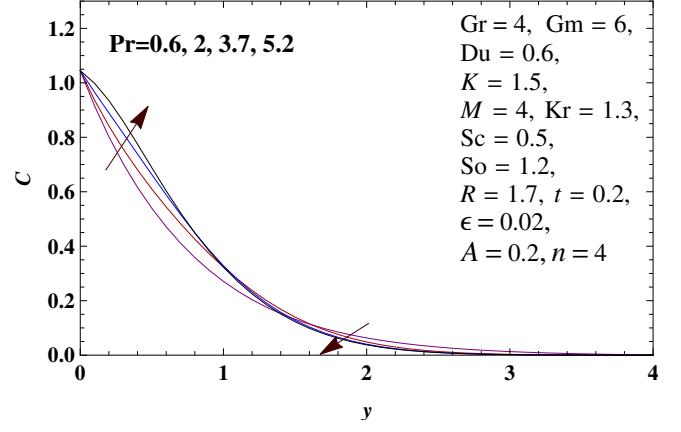


Figure 12. Velocity Profiles for Different Values of Pr

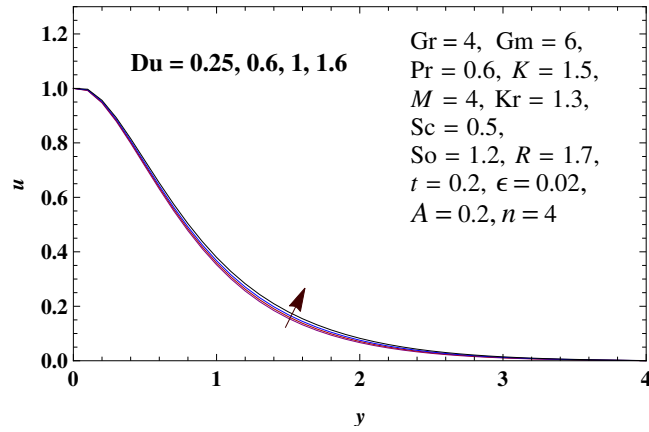


Figure 13. Velocity Profiles for Different Values of Du

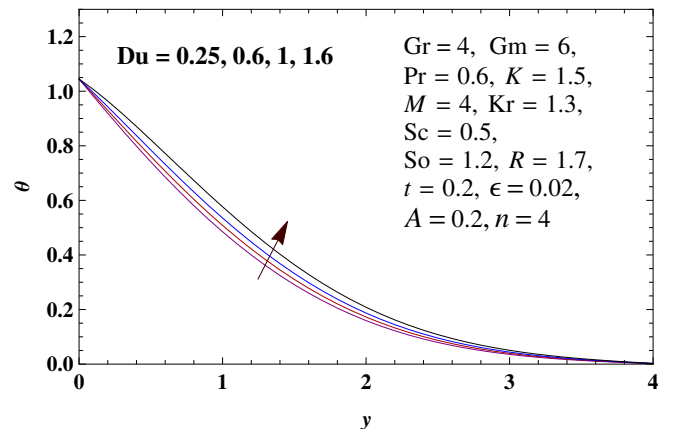


Figure 14. Temperature Profiles for Different Values of Du

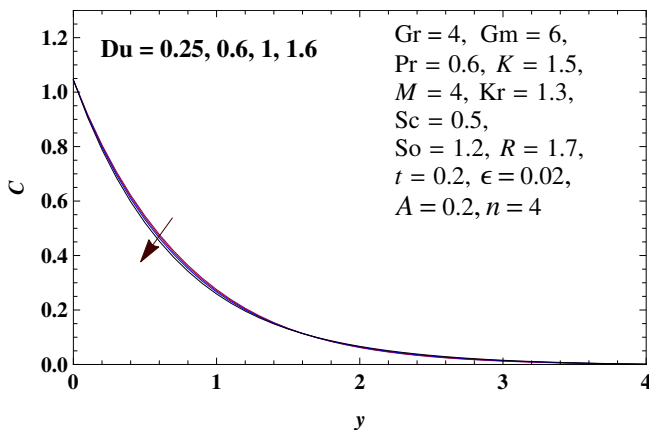


Figure 15. Concentration Profiles for Different Values of Du

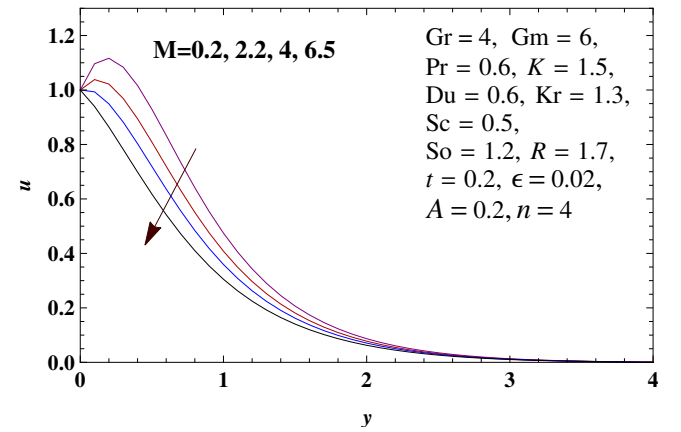


Figure 16. Velocity Profiles for Different Values of M

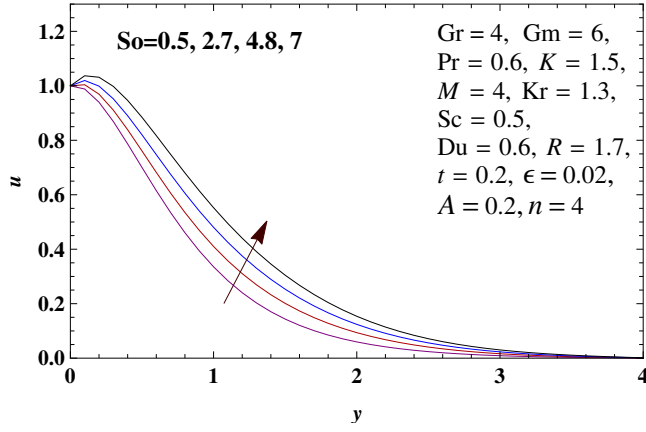


Figure 17. Velocity Profiles for Different Values of Sr

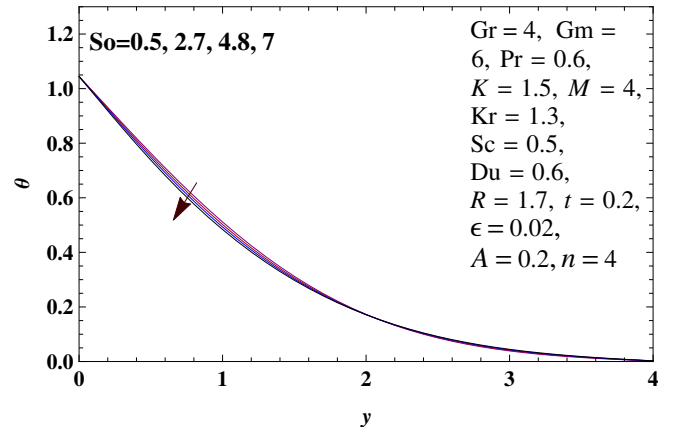


Figure 18. Temperature Profiles for Different Values of Sr

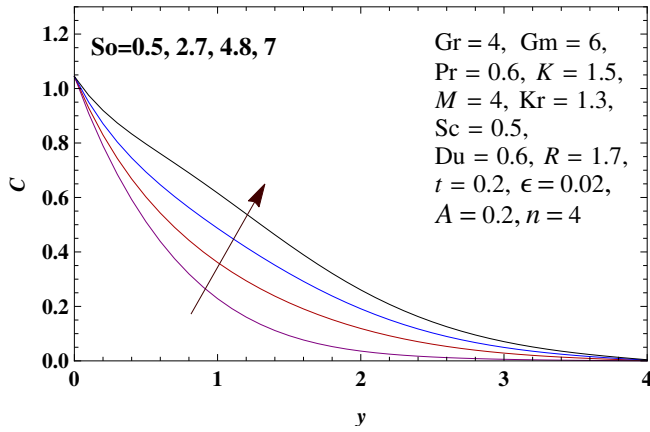


Figure 19. Concentration Profiles for Different Values of Sr

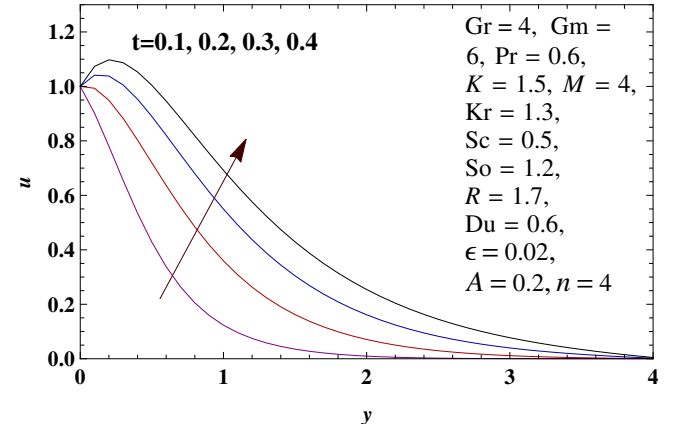


Figure 20. Velocity Profiles for Different Values of t

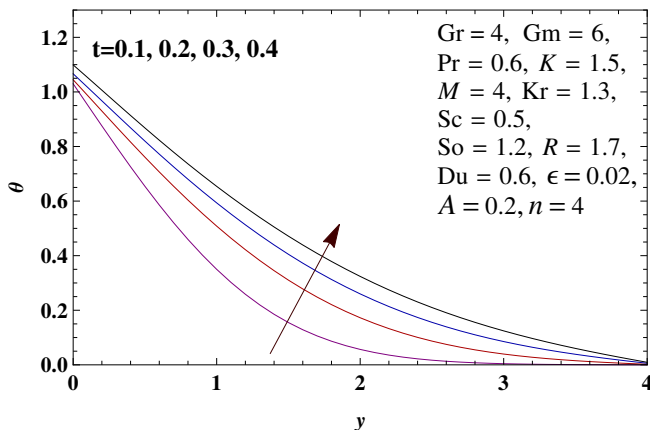


Figure 21. Temperature Profiles for Different Values of t

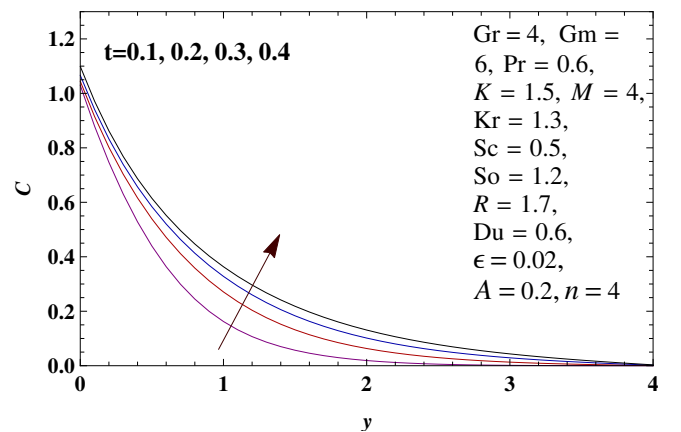


Figure 22. Concentration Profiles for Different Values of t

Du	Kr	M	Pr	So	Sc	R	t	τ	Nu	Sh
0.25	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0806652	0.631965	1.2725
0.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0680455	0.57171	1.29659
1	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0532918	0.498964	1.32602
1.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0304486	0.381013	1.37455
0.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0680455	0.57171	1.29659
0.6	4.5	4	0.6	1.2	0.5	1.7	0.2	-0.165811	0.525655	1.75917
0.6	9.5	4	0.6	1.2	0.5	1.7	0.2	-0.270591	0.47564	2.2504
0.6	13	4	0.6	1.2	0.5	1.7	0.2	-0.324344	0.449315	2.50522
0.6	1.3	0.2	0.6	1.2	0.5	1.7	0.2	-0.0806652	0.631965	1.2725
0.6	1.3	2.2	0.6	1.2	0.5	1.7	0.2	0.383285	0.57171	1.29659
0.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0680455	0.57171	1.29659
0.6	1.3	6.5	0.6	1.2	0.5	1.7	0.2	-0.605199	0.57171	1.29659
0.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0680455	0.57171	1.29659
0.6	1.3	4	2	1.2	0.5	1.7	0.2	-0.212385	1.13422	1.08335
0.6	1.3	4	3.7	1.2	0.5	1.7	0.2	-0.286346	1.76295	0.791948
0.6	1.3	4	5.2	1.2	0.5	1.7	0.2	-0.326854	2.21339	0.462493
0.6	1.3	4	0.6	0.5	0.5	1.7	0.2	-0.116983	0.56595	1.35887
0.6	1.3	4	0.6	2.7	0.5	1.7	0.2	-0.0390785	0.58478	1.15756
0.6	1.3	4	0.6	4.8	0.5	1.7	0.2	0.195199	0.605142	0.946436
0.6	1.3	4	0.6	7	0.5	1.7	0.2	0.36856	0.630033	0.69558
0.6	1.3	4	0.6	1.2	0.1	1.7	0.2	0.351464	0.641045	0.563936
0.6	1.3	4	0.6	1.2	1.2	1.7	0.2	-0.335173	0.487006	2.11836
0.6	1.3	4	0.6	1.2	2.4	1.7	0.2	-0.554599	0.365919	3.26151
0.6	1.3	4	0.6	1.2	4	1.7	0.2	-0.718693	0.212302	4.69537
0.6	1.3	4	0.6	1.2	0.5	0.4	0.2	-0.158118	0.464883	1.19349
0.6	1.3	4	0.6	1.2	0.5	2.5	0.2	-0.0357433	0.493682	1.32001
0.6	1.3	4	0.6	1.2	0.5	5.2	0.2	0.0291802	0.364647	1.35436
0.6	1.3	4	0.6	1.2	0.5	7.5	0.2	0.0607162	0.315013	1.36687
0.6	1.3	4	0.6	1.2	0.5	1.7	0.1	-0.987251	0.773219	1.50378
0.6	1.3	4	0.6	1.2	0.5	1.7	0.2	-0.0680455	0.57171	1.29659
0.6	1.3	4	0.6	1.2	0.5	1.7	0.3	0.412517	0.493131	1.25483
0.6	1.3	4	0.6	1.2	0.5	1.7	0.4	0.737488	0.461259	1.27625

Table 1. Skin friction coefficient τ , Nusselt number Nu and Sherwood number Sh for different values of parameters taking fix values of $\epsilon = 0.02$, $A = 0.2$, $n = 4$, $K = 1.5$, $Gr = 4$, $Gm = 6$

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