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Effect of Thermal Radiation on an Unsteady Magnetohydrodynamic Double Diffusive Boundary Layer Flow past a Permeable Infinite Vertical Plate with Heat Source

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Authors' contributions

This work was carried out in collaboration among all authors. Author OOK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FSA and ADA managed the analyses of the study. All authors read and approved the final manuscript.

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Abstract

In this paper, effect of radiation and heat source parameters on temperature, concentration and velocity profile of an electrically conducting fluid passing through an infinite permeable plate is investigated. The governing equation, which was based on the balanced mass, linear momentum, energy and species concentration, were non-dimensionalized to reduce the equations to system of ordinary differential equations. This was then solved by perturbation technique. Effects of radiation parameter, heat source parameter, and Schmidt parameter are analyzed. We observed that the velocity and concentration profiles increase with increase in radiation parameter and heat source parameter. The temperature profile increases with decrease in radiation parameter with increases boundary layer thickness.

Keywords: Magnetohydrodynamics (MHD); thermal radiation; heat source; permeable membrane; boundary layer.

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Nomenclatures

English symbols

B_0 : *Magnetic field component along y-axis*
C_p : *Specific heat at constant pressure*
G_r : *Thermal Grashof number*
G_m : *Solutal Grashof number*
g : *Acceleration of gravity*
K' : *The permeability of medium*
K : *The permeability parameter*
M : *Hartmann number*
P_r : *Prandtl number*
Sc : *Schmidt number*
Ec : *Eckert number*
S_O : *Soret number*
S : *Heat source parameter*
R : *Thermal radiation parameter*
U_p : *Plate velocity*
k_r : *Chemical reaction parameter*
D : *Chemical molecular diffusivity*
D_I : *Thermal diffusivity*
T' : *Temperature of fluid near the plate*
T_w' : *Temperature of the fluid far away of the fluid from the plate*
T_∞' : *Temperature of the fluid at infinity*
C : *Concentration of the fluid*
C' : *Concentration of the fluid near the plate*
C_w' : *Concentration of the fluid far away of the fluid from the plate*
C_∞' : *Concentration of the fluid at infinity*
t' : *Time in x' ,y' coordinate system*
t : *Time in dimensional coordinate*
u' : *Velocity component in x'-direction*
u : *Dimensionless velocity component in x'- direction*
Nu : *Nusselt number*
Sh : *Sherwood number*
C_f : *Skin fraction*
x', y' : *Co-ordinate system*
x, y : *Dimensionless coordinate*
U_O : *Reference velocity*
V_O : *Suction velocity*
Q_o : *Dimensional heat absorption*

Greek Symbols

β : *Coefficient of volume expansion for heat transfer*
β' : *Coefficient of volume expansion for mass transfer*
κ : *Thermal conductivity of the fluid*
σ : *Electrical conductivity of the fluid*
ν : *Kinematic viscosity*
θ : *Non-dimensional*
ρ : *Density of the fluid*
α : *Thermal diffusivity*

nt : *Phase angle*
ε : *A positive constant*

1 Introduction

A fluid is any substance that deforms continuously when acted on by a shearing stress of any magnitude. The study that deals with behavior of fluid in motion is known as fluid dynamics. Fluids dynamics therefore offers a systematic structure that embraces empirical and semi empirical laws derived from flow measurements and used to solve particular problems. The solution to a fluid dynamics problem typically involves properties of fluids such as velocity, pressure, density, concentration and temperature function of space and time. This research does not deal with the motion of an individual particle in a fluid but a continuum of particles in plasma; it is assumed that the distance between fluid molecules (mean free path) is very small.

Zueco and Ahmed [1] studied heat and mass transfer mixed convection MHD flow along a porous plate with chemical reaction in the presence of heat source. The equations were solved using perturbation technique and analyzed numerically. Sharma, Kumar and Sharma [2] investigated influence of chemical reaction and radiation on an unsteady MHD free convective flow, mass transfer through a viscous incompressible, electrically conducting fluid past an infinite vertical heated porous plate with suction, surrounded in porous medium in the presence of a transverse magnetic field, oscillating free stream and heat source considering viscous dissipation. Kesavaiah, Satyanarayana and Venkataramana [3] reported analytical solutions for mass and heat transfer by laminar flow of a viscous, Newtonian, electrically and heat generation/absorbing fluid on a continuously vertical permeable surface in the presence of a radiation, mass flux and first order homogeneous reaction. Ram et al. [4] studied unsteady magneto-hydrodynamics free convective flow past a vertical porous plate in motion in the presence of thermal radiation and first order chemical reaction with viscous dissipation. Second order perturbation technique was adopted to solve the nonlinear differential equations governing the fluid flow. Numerical analyses of different parameters on velocity and temperature profiles were made. In addition, the skin friction coefficients, rate of heat transfer as well as the rate of mass transfer of the plate were computed. Sagar et al. [5] studied on unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium. Kesavaiah, [6] studied MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects. Srinathuni [7] worked on Radiation effect on unsteady free convective MHD flow of a viscoelastic fluid past a tilted porous plate with heat source.

Singh [8] investigated steady flow of viscous incompressible fluid between two parallel infinite plates under the influence of inclined magnetic field. Results showed that velocity profiles decreased as the strength of magnetic field was increased. Ravicumar [9] worked on investigation of an unsteady MHD free convection mass and heat transfer flow of a non-Newtonian fluid flow past a permeable vertical plate in the presence of heat sink and thermal diffusion. Sharma et al. [10] Investigated Rotating Impact on Unsteady MHD Double Diffusive Boundary Layer Flow over an Impulsively Emerged Vertical Porous Plate. The expressions for the distributions of temperature, concentration and velocity were computed and skin friction, Nusselt number and Sherwood number were analyzed. Ramesh and Eytoo [11] examined the effect of diverse physical parameters on fluid flow. Three Ree-Eyring fluid between infinitely parallel plates with the effects on various parameters were considered. Anuradha and Priyadharshini [12] worked on Heat and mass transfer on unsteady MHD free convective flow pass a semi-infinite vertical plate with soret effect, using perturbation method in solving the governing equation subjected to the constant radiation term. Various parameters were analyzed and presented on the temperature concentration and velocity profile. Campos L M B C [13] carried out an investigation on vertical hydromagnetic waves in a compressible atmosphere under an oblique magnetic field. Results showed that the velocity perturbation transverse to the magnetic field and gravity dissatisfied a forth order wave and decoupled second order Alfven wave equations.

Soundalgekar, Takhar and Singh [14] studied the temperature and velocity field in MHD Falkner- Skan flow of an electrically conducting, incompressible viscous fluid. They reduced the problem to a system of two differential equations in terms of variables and solved numerically. Jha [15] also studied free convection flow through an annular porous medium where the study addresses the Brinkman-extended Darcy model (Brinkman flow) of a laminar free-convective flow in an annular porous region. Chamkha [16] worked on MHD chemically reactive and double diffusive flow through porous medium bounded by two vertical plates, considering a steady state and the effect of Reynolds number on the parameters, and numerical computation of the result were achieved and results were analyzed. Makinde [17] studied a hydro-magnetic mixed convection flow of an electrically conducting, incompressible viscous fluid and mass transfer over a vertical porous plate with embedded constant heat flux. Sharma et al. [18] worked on effects of chemical reaction on magneto-micropolar fluid flow from a radiative surface with variable permeability**.** They made analyses with altering permeability of the medium and the Rosseland approximation was used to describe the radiative heat flux in the energy equation.

2 Mathematical Formulations

We consider an unsteady two dimensional flow of an electrically conducting fluid passing through an infinite vertical permeable moving plate immersed in a uniform medium, subjected to a uniform transverse magnetic field in the presence of concentration and thermal and buoyancy effects. In Cartesian coordinate system, let x' be taken along the plate and y' be perpendicular to the plate. The wall is sustained at fixed temperature T'_ω and concentration C'_ω greater than the ambient temperature T'_∞ and concentration C'_∞ respectively. A uniform magnetic field of magnitude β_0 is applied parallel to the plate. The transverse applied magnetic field and magnetic Reynolds' number are taken to be very small, so that the induced magnetic field is trivial. Uniform magnetic field acts perpendicular to the permeable surface which absorbs the fluid with a suction velocity varying with time.

The plate is assumed to move with a constant velocity in the direction of the fluid flow. Except that the influence of density variation with temperature has been considered only in the body all other fluid properties assumed constant. Owing to the infinite plane surface assumption, the flow variables are voltage which denotes the absence of an electric field. The fluid has constant thermal conductivity and viscosity. The fluid is considered to be gray-absorbing emanating radiation but non-scattering medium and the Rosseland's approximation is used to describe the radiative heat flux. It is considered to be negligible in x' direction as compared in y'direction. The concentration of diffusing species is taken to be very small compared to other chemical species; the concentration of species away from the wall C'_∞ is extremely small, therefore Soret and Dufour effect are ignored. Based on these assumptions made, governing equations for conservation of momentum, energy, species and concentration are given as follows.

Continuity equation

$$\frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum equation

$$\frac{\partial u'}{\partial t'} + \nu' \frac{\partial u'}{\partial y'} = v\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta'(C' - C'_\infty) - \frac{\upsilon u'}{K} - \frac{\sigma B_0 u'}{\rho} \tag{2}$$

Energy equation

$$\frac{\partial T'}{\partial t'} + \nu'\frac{\partial T'}{\partial y'} = \frac{\kappa}{\rho C_P}\frac{\partial^2 T'}{\partial y'^2} + \frac{Q_0}{\rho C_P}(T' - T'_\infty) - \frac{1}{\rho C_P}\frac{\partial q_r}{\partial y'} \tag{3}$$

Species equation

$$\frac{\partial C'}{\partial t'} + \nu'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} + D_1\frac{\partial^2 T'}{\partial y'^2} - K_r(C' - C'_\infty) \tag{4}$$

Where y' and t' are dimensional distance along and perpendicular to the plate u' and v' are the component of dimensional velocity along y' direction. ν is the Kinematic viscosity, B_0 is the magnetic field component along y-axis, σ is the electrical conductivity, κ is the thermal conductivity, ρ is the density, g is the acceleration of gravity, K_r is the chemical reaction parameter, β is the coefficient of volume expansion for heat transfer $\beta'$is the coefficient of volume expansion for mass transfer B_o is the magnetic induction, K' is the permeability of medium K is the permeability parameter, c_p is the specific heat at fixed pressure, Q_o is the dimensional heat absorption coefficient, α is the thermal diffusivity D is the chemical molecular diffusivity, D_1 is the thermal diffusivity, c' is the concentration of the fluid near the plate, T' is the temperature of fluid near the plate.

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration are

$$u' = U_p', \qquad T = T_\omega + \varepsilon(T_\omega' - T_\infty'), \qquad c = c_\omega(c_\omega' - c_\infty')e^{nt} \quad \text{at} \quad y' = 0$$

$$u' = U_\infty' = U_o(1 + \varepsilon e^{nt}), \qquad T = T_\infty, c = c_\infty, \quad \text{as} \quad y' = \infty \tag{5}$$

Where U_p', c_ω, T_ω are the wall dimensional velocity, concentration and temperature respectively, and U_∞', c_∞, T_∞ are the free stream dimensional velocity, concentration and temperature. U_o and n are constant.

Using the following non dimensional quantity in non-dimensionalizing the modified model

$$\left.\begin{aligned}
&y = \frac{y'V_0}{v}, \quad t = \frac{t'V_0^2}{v}, \quad u = \frac{u'}{u_0}, \quad \theta = \frac{T' - T_\infty'}{T_\omega' - T_\infty'}, \quad \phi = \frac{C' - C_\infty'}{C_\omega' - C_\infty'}, \\
&U_P = \frac{U_P'}{V_0}, \quad G_r = \frac{g\beta v(T_\omega' - T_\infty')}{U_0 V_0^2}, \quad G_C = \frac{g\beta' v(C_\omega' - C_\infty')}{U_0 V_0^2}, \quad P_r = \frac{v\rho C_P}{\kappa}, \\
&S_C = \frac{v}{D}, \quad M = \frac{\sigma B_0^2 v}{\rho V_0^2}, \quad S = \frac{vQ_0}{\rho C_P V_0^2}, \quad K = \frac{K' V_0^2}{V^2}, \quad K_r = \frac{K_r' v}{V_0^2}, \\
&P_r = \frac{v\rho C_P}{\kappa}, \quad S_C = \frac{v}{D}, \quad R = \frac{\kappa K'}{4\sigma T_h'^3}, \quad E_C = \frac{V_0^2}{C_P(T_\omega' - T_\infty')}, \quad S_O = \frac{D_1(T_\omega' - T_\infty')}{(C_\omega' - C_\infty')}
\end{aligned}\right\} \tag{6}$$

Dimensionaling the governing equations for momentum, energy and species equations give rise to the set equations

$$\frac{\partial u}{\partial t} + \frac{v'}{v_0}\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m\phi - \left(M + \frac{1}{K}\right)u \tag{7}$$

$$\frac{\partial \theta}{\partial t} + \frac{v'}{v_0}\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\left(1 + \frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} - S\theta \tag{8}$$

$$\frac{\partial \phi}{\partial t} + \frac{v'}{v_0}\frac{\partial \phi}{\partial y} = \frac{1}{S_C}\frac{\partial^2 \phi}{\partial t^2} + S_0\frac{\partial \theta}{\partial y} - K_r\phi \tag{9}$$

Suction velocity in the plate.

$$v' = -v_0(1 + \varepsilon e^{nt}). \tag{10}$$

Where v_0 is scale of suction velocity.

ε is the value less than a unit.

Negative sign implies that the suction is in direction of the plate.

Substituting (10) into equation (7), (8), and (9), obtained

$$\frac{\partial u}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m\phi - \left(M + \frac{1}{K}\right)u \tag{11}$$

$$\frac{\partial \theta}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\left(1 + \frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} - S\theta \tag{12}$$

$$\frac{\partial \phi}{\partial t} - (1+\varepsilon e^{nt})\frac{\partial \phi}{\partial y} = \frac{1}{S_C}\frac{\partial^2 \phi}{\partial t^2} + S_0\frac{\partial \theta}{\partial y} - K_r\phi \tag{13}$$

Where, G_r is the thermal Grashof number, G_m is the solutal Grashof number, M is the hartmann number, P_r is the Prandtl number, Sc is the Schmidt number, S_O is the Soret number, S is the heat source parameter, R is the thermal radiation parameter.

The dimensional form of the boundary condition becomes

$$u = U_p,\ \theta = 1 + \varepsilon e^{nt}, \quad C = 1 + \varepsilon e^{nt}, \quad U = 1 + \varepsilon e^{nt} \quad \text{at} \quad y = 0$$

$$u = U_\infty,\ \theta \to 0, \quad C \to 0, \quad U \to 0, \quad \text{as } y \to \infty \tag{14}$$

3 Method of Solution

In order to solve the partial differential equations, subjected to the boundary condition; the partial differential equation is reduced to set of ordinary differential equations then solved analytically. We assumed that velocity, temperature and concentration in a series expansion in power of ε where $\varepsilon \ll 1$ as

$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{nt} + O(\varepsilon^2) + \ldots \tag{15}$$

$$\theta(y,t) = \theta_0(y) + \varepsilon\theta_1(y)e^{nt} + O(\varepsilon^2) + \cdots \tag{16}$$

$$\phi(y,t) = \phi_0(y) + \varepsilon\phi_1(y)e^{nt} + O(\varepsilon^2) + \cdots \tag{17}$$

Substitute equation 15 – 17 into 11 – 13, and neglecting higher- order terms of $O(\varepsilon^2)$, the follow pairs of equation for (θ_0, ϕ_0, U_0) and (θ_1, ϕ_1, U_1) are obtained.

$$\left(1 + \frac{4R}{3}\right)\theta_0'' - P_r\theta_0' + SP_r\theta_0 = 0 \tag{18}$$

$$\phi_0'' + S_C\phi_0' - K_rS_C\phi_0 = -S_CS_0\theta_0'' \tag{19}$$

$$U_0'' - U_0' + \left(M + \frac{1}{K}\right)U_0 = -G_r\theta_0 - G_m\phi_0 \tag{20}$$

$$\left(1 + \frac{4R}{3}\right)\theta_1'' - P_r\theta_1' + P_r(S+n)\theta_1 = -\theta_0'' \tag{21}$$

$$\phi_1'' + S_C\phi_1' - (K_r + n)S_C\phi_1 = S_C\phi_0' + S_CS_0\theta_1'' \tag{22}$$

$$U_1'' - U_1' + \left(M + n + \frac{1}{K}\right)U_1 = -G_r\theta_0 - G_m\phi_0 - \left(M + \frac{1}{K}\right)U_0 - U_0' \ . \tag{23}$$

Subjected to the below boundary conditions.

$$U_o = U_p, \quad U_1 = 0, \quad \phi_O = 1, \quad \phi_1 = 0, \quad \theta_0 = 0, \quad \theta_1 = 0 \quad \text{as } y = 0$$
$$U_o = 1, \quad U_1 = 1, \quad \phi_O \to 0, \quad \phi_1 \to 0, \quad \theta_O \to 0, \quad \theta_1 \to 0 \quad \text{as } y \to 0 \tag{24}$$

Solving equations 18 – 23, The corresponding values for θ_0, θ_1, ϕ_0, ϕ_1, U_0, U_1 are obtained.

$$\theta_0 = c_1 e^{m_2 y} \tag{25}$$

$$\theta_1 = c_3 e^{a_2 y} + c_4 e^{m_2 y} \tag{26}$$

$$\phi_0 = c_6 e^{b_2 y} + c_7 e^{m_2 y} \tag{27}$$

$$\phi_1 = c_9 e^{d_2 y} + c_{10} e^{b_2 y} + c_{11} e^{a_2 y} + c_{12} e^{m_2 y} \tag{28}$$

$$U_0 = c_{14} e^{r_2 y} + c_{15} e^{b_2 y} + c_{16} e^{m_2 y} \tag{29}$$

$$U_1 = c_{18} e^{z_2 y} + c_{19} e^{a_2 y} + c_{20} e^{m_2 y} + c_{21} e^{d_2 y} + c_{22} e^{b_2 y} + c_{23} e^{r_2 y} \tag{30}$$

In view of the above solution, the velocity, concentration and temperature distribution in boundary layer becomes

$$U(y,t) = c_{14} e^{r_2 y} + c_{15} e^{b_2 y} + c_{16} e^{m_2 y} + \varepsilon e^{nt}(c_{18} e^{r_2 y} + c_{19} e^{a_2 y} + c_{20} e^{m_2 y} + c_{21} e^{d_2 y} + c_{22} e^{b_2 y} + c_{23} e^{r_2 y}) \tag{31}$$

$$\emptyset(y,t) = c_6 e^{b_2 y} + c_7 e^{m_2 y} + \varepsilon e^{nt}\left(c_9 e^{d_2 y} + c_{10} e^{b_2 y} + c_{11} e^{a_2 y} + c_{12} e^{m_2 y}\right) \tag{32}$$

$$\theta(y,t) = c_1 e^{m_2 y} + \varepsilon e^{nt}(c_3 e^{a_2 y} + c_4 e^{m_2 y}) \tag{33}$$

The parameters of the physical quantities can be defined and determined as follows

The skin friction due to local wall shear is given by

$$c_f = \left(\frac{du}{dy}\right)_{y=0}$$

$$c_{14} + b_2 c_{15} + m_2 c_{16} + \varepsilon e^{nt}(z_2 c_{18} + a_2 c_{19} + m_2 c_{20} + d_2 c_{21} + b_2 c_{22} + r_2 c_{22}) \tag{34}$$

The Sherwood Number: Mass transfer coefficient (sh) in terms of amplitude and phase is given by

$$sh = -\left(\frac{d\phi}{dy}\right)_{y=0}$$

$$= b_2 c_6 + m_2 c_7 + \varepsilon e^{nt}(d_2 c_9 + b_2 c_{10} + a_2 c_{11} + m_2 c_{12}) \tag{35}$$

Nusselt Number

The rate heat transfer is given by

$$Nu = -(1 + {}^{4R}/_{3})\left(\frac{d\theta}{dy}\right)_{y=0}$$

$$Nu = -(1 + {}^{4R}/_{3})(m_2 c_1 + \varepsilon e^{nt}(a_2 c_3 + m_2 c_4\,) \tag{36}$$

Where

$c_1 = 1,\quad c_3 = 1 - c_4,\quad c_4 = \frac{M}{nP_r},\quad c_6 = 1 - c_7,\quad c_7 = \frac{-S_c S_0 M^2}{m_2^2 + S_c m_2 - K_r S_c},\quad c_9 = 1 - [c_{10} + c_{11} + c_{12}],\quad c_{10} = \frac{-S_c b_2 C_6}{b_2^2 + S_c b_2 - (k_r + n) S_c},\quad c_{11} = \frac{-S_0 S_c C_3 a_2^2}{a_2^2 + S_c a_2 - (k_r + n) S_c}$

$c_{12} = \frac{-[S_c m_2 C_7 + S_0 S_c C_4 m_2^2]}{m_2^2 + S_c m_2 - (k_r + n) S_c},\quad c_{14} = -[c_{15} + c_{16}],\quad c_{15} = \frac{-G_m C_6}{b_2^2 + b_2 - (M + {}^1/_k)}$

$c_{16} = \frac{-[G_r + C_7 G_m]}{m_2^2 + m_2 - (M + {}^1/_k)},\quad c_{18} = -[c_{19} + c_{20} + c_{21} + c_{22} + c_{23}],\quad c_{19} = \frac{-[G_r C_3 + G_m C_{11}}{a_2^2 + a_2 - (M + n + {}^1/_k)}$

$c_{20} = \frac{-(G_r C_4 + G_m C_{12} + (M + {}^1/_k + M_2))}{m_2^2 + m_2 - (M + n + {}^1/_k)},\quad c_{21} = \frac{-G_m C_9}{d_2^2 + d_2 - (M + n + {}^1/_k)},\quad c_{22} = \frac{-(G_m C_{10} + (M + {}^1/_k + b_2) C_{15}}{b_2^2 + b_2 - (M + n + {}^1/_k)}$

$$c_{23} = \frac{-(M + {}^1/_k + r_2) c_{14}}{r_2^2 + r_2 - (M + n + {}^1/_k)}$$

and

$m_2 = \frac{-P_r - \sqrt{Pr^2 + 4sPr(1 + {}^{4R}/_3)}}{2(1 + {}^{4R}/_3)}\qquad a_2 = \frac{-P_r - \sqrt{Pr^2 + 4(1 + {}^{4R}/_3) P_r (s + n)}}{2(1 + {}^{4R}/_3)}$

$b_2 = {}^1/_2 (-Sc - \sqrt{Sc^2 + 4k_r s_c}),\qquad d_2 = {}^1/_2 (-Sc - \sqrt{Sc + 4(k_r + n) s_c})$

$r_2 = {}^1/_2 (-1 - \sqrt{1 + 4(M + {}^1/_K)\, s_c}),\qquad z_2 = {}^1/_2\, (-1 - \sqrt{1 + 4(M + n + {}^1/_K)})$

4 Results and Discussion

In order to achieve good insight of the physical problem numerically, results of the governing equations are computed and graphs are presented. This enables us to carry out the numerical analysis for the distribution of the concentration, temperature and velocity across the boundary layer for various parameters. In the present study we have chosen values of the parameters as follows: A=0.5, t =1.0, n = 0.1, ε= 0.02, Gm= 5.0, Gr= 2.0, M = 1.0, P_r = 0.71, So = 0.4, kr = 0.2 k = 0.2 while R, S, S_c are varied over a range, which are listed in the figures. The representations of the parameters are given in the nomenclature below.

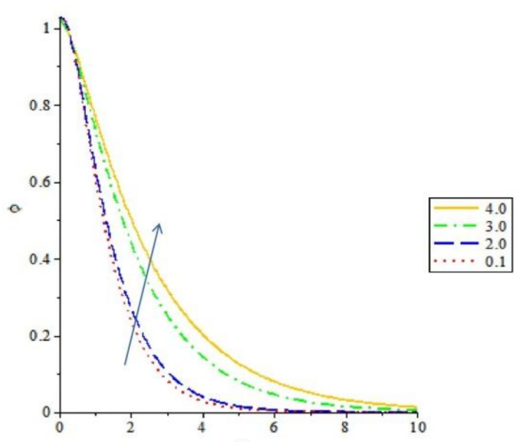

Fig. 1. Graph of concentration profile for difference value of R

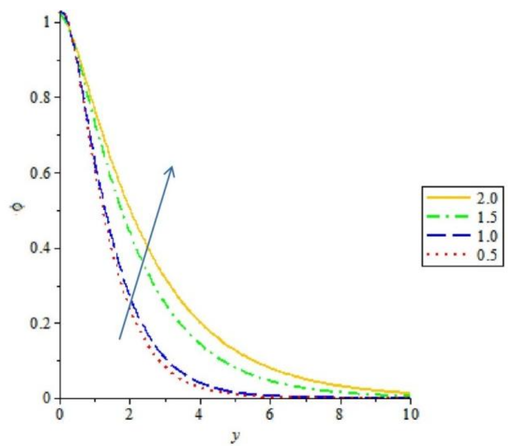

Fig. 2. Graph of concentration profile for difference value of S

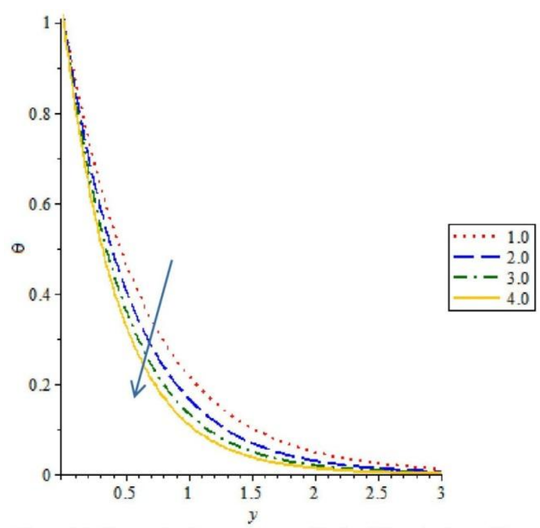

Fig. 3. Graph of temperature profile for difference value of R

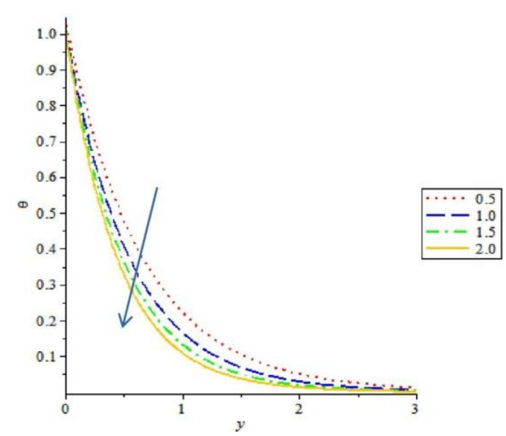

Fig. 4. Graph of temperature profile for difference value of S

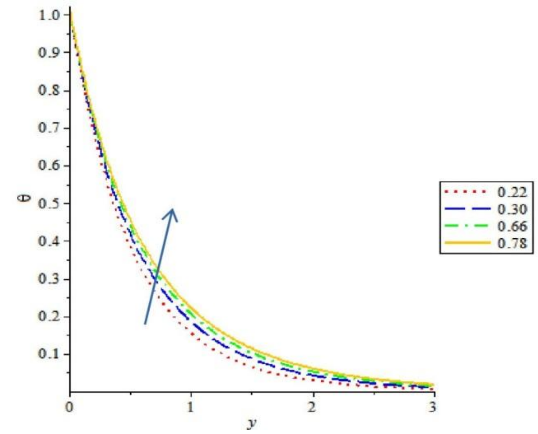

Fig. 5. Graph of temperature profile for difference value of Sc

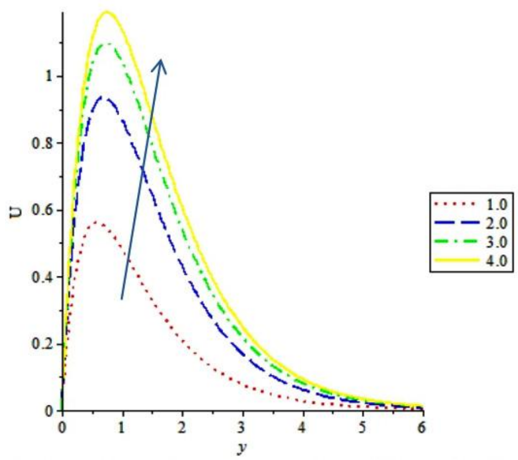

Fig. 6. Graph of velocity profile for difference value of R

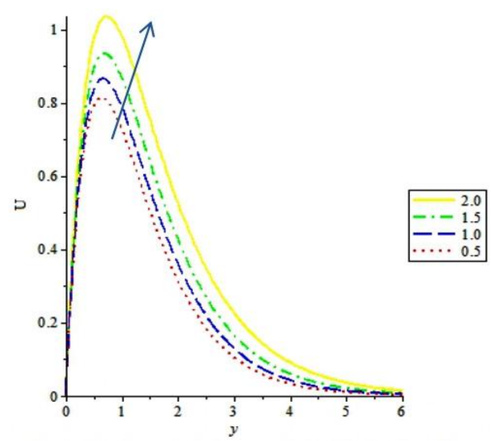

Fig. 7. Graph of velocity profile for difference value of S

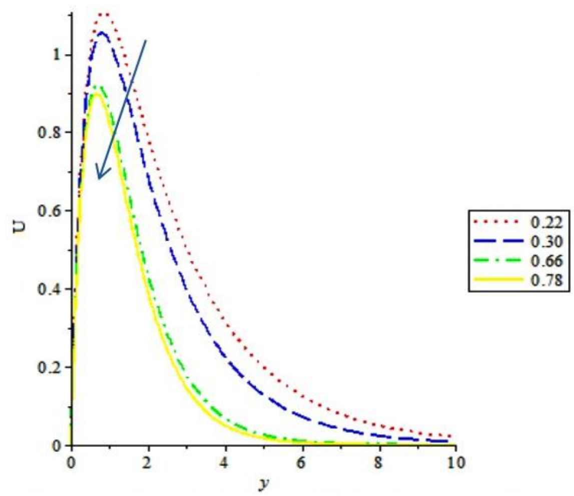

Fig. 8. Graph of velocity profile for difference value of Sc

Concentration profile for diverse values of radiation parameter is described in Fig. 1 we observe that increase in radiation parameter leads to increase in concentration profile. Hence thermal radiation improves convention flow. Fig. 2 shows the concentration profile for different values for heat source S, we observe that the heat is generated as the buoyancy force increases which induced the flow rate to increase and hence the concentration profile also increases. The effect of radiation parameter (R) on the temperature profiles are presented in Fig. 3. From this figure we observe that, as the value of (R) increases the temperature profile decreases, with an increasing in the boundary layer thickness. The effect of heat source on temperature profile is observed in Fig. 4. We also obtain from the figure that the temperature profile increases with decrease in heat source parameter. Fig. 5 shows the effect of Schmidt number (Sc) on temperature profile. We observe that increase in values of Schmidt number (Sc) leads to increase in the temperature of the system.

Fig. 6 shows the effect of thermal radiation (R) on the velocity profile. We observed that increase in R result to increase in velocity profile. Similarly it can be seen as shown in Fig. 7 that increase in heat source (S) results in the increase in the velocity profile. While Fig. 8 shows the effect of Schmidt number (Sc) on the velocity profile. We can see, in the figures that increase in values of Schmidt number (Sc) leads to decrease in the velocity profile.

5 Conclusions

This work effect of thermal radiation on an unsteady magnetohydrodynamic double diffusive boundary layer flow past a permeable infinite vertical plate with heat source is investigated. From this study we conclude that the velocity profile increases with an increase in the free convection current flow which increases the flow rate through the vertical permeable medium. An increasing in Thermal radiation and heat source parameter, increases the velocity profile and concentration profile of the flow field at all points. Furthermore, we notice an increase in Schmidt number decreases the velocity profile of the flow. Temperature profile deceases with increase in thermal radiation and Heat source parameters which are noticed to increase the viscosity of the fluid thereby inhibit the flow at all points.

Competing Interests

Authors have declared that no competing interests exist.

References

[1] Zueco J, Ahmed S. Combined heat and mass transfer by mixed convection MHD flow along a porous plate with chemical reaction in presence of heat source. Applied Mathematics and Mechanics. 2010;31(10):1217-1230.

[2] Sharma PR, Kumar N, Sharma P. Influence of chemical reaction and radiation on unsteady MHD free convection flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in the presence of heat source. Appl. Math. Sciences. 2011;5(46):2249-2260.

[3] Kesavaiah DC, Satyanarayana PV, Venkataramana S. Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction. Int. J. of Appl. Math and Mech. 2011;7(1):52-69.
Available:https://doi.org/10.1002/htj.21101

[4] Ram P, Singh H, Kumar R, Kumar V, Joshi VK. Free convective boundary layer flow of radiating and reacting MHD fluid past a cosinusoidally fluctuating heated plate. International Journal of Applied and Computational Mathematics. 2017;3(1):261-294.

[5] Sagar BV, Raju MC, Varma SVK, Venkataramana S. Unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium. Rev. Adv. Phys. Theor. Appl. 2014;1(3):48-62.

[6] Kesavaiah DC, Md IS, Jahagirdar RS. MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects. Suraj Punj Journal for Multidisciplinary Research. 2018;8(11):46-62.

[7] Srinathuni Lavanya, Devika B, Chenna Kesavaiah D. Radiation effect on unsteady free convective MHD flow of a viscoelastic fluid past a tilted porous plate with heat source. Journal of Xidian University. 2020;14(4):2298–2312.

[8] Singh CB. Steady flow of viscous incompressible fluid between two parallel infinite plates in presence of transverse magnetic field; 1989.

[9] Ravikumar V, Raju MC, Raju GSS. Theoretical investigation of an unsteady MHD free convection heat and mass transfer flow of a non-Newtonian fluid flow past a permeable moving vertical plate in the presence of thermal diffusion and heat sink. In International Journal of Engineering Research in Africa. Trans Tech Publications Ltd. 2015;16(2):90-109.

[10] Sharma RP, Ravikumar V, Raju MC, Raju GSS, Varma SVK. Rotational impact on unsteady MHD double diffusive boundary layer flow over an impulsively emerged vertical porous plate. Journal of International Academy of Physical Sciences. 2016;20(4):303-317.

[11] Ramesh K, Eytoo SA. Effects of thermal radiation and magnetohydrodynamics on Ree-Eyring fluid flows through porous medium with slip boundary conditions. Multidiscipline Modeling in Materials and Structures. 2019;15(2):492-507.
Available:https://doi.org/10.1108/MMMS-05-2018-0103

[12] Anuradha S, Priyadharshini P. Head and mass transfer on unsteady MHD Free convective flow pass a semi-infinite vertical plate with soret effect. The International Journal of Science and Technoledge. 2014;2(4):328.

[13] Campos LMBC. On vertical hydromagnetic waves in a compressible atmosphere under an oblique magnetic field. Geophysical & Astrophysical Fluid Dynamics. 1985;32(3-4):217-272.
Available:https://doi.org/10.1080/03091928508208786

[14] Soundalgekar VS, Takhar H, Singh M. Velocity and temperature field in MHD Falkner-Skan flow. Journal of the Physical Society of Japan. 1981;50(9):3139-3143.
Available:https://doi.org/10.1143/JPSJ.50.3139

[15] Jha BK. Free-convection flow through an annular porous medium. Heat and Mass Transfer. 2005;41(8):675-679.

[16] Chamkha A. MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates; 2013.

[17] Makinde OD. On MHD boundary-layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux. International Journal of Numerical Methods Heat & Fluid Flow. 2009;19(3):546-554.
Available:https://doi.org/10.1108/09615530910938434

[18] Sharma BK, Singh AP, Yadav K, Chaudhary RC. Effects of chemical reaction on magneto-micropolar fluid flow from a radiative surface with variable permeability. International Journal of Applied Mechanics and Engineering. 2013;18(3):833-851.
Available:https://doi.org/10.2478/ijame-2013-0050

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