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RADIATION EFFECT ON MHD FREE CONVECTIVE FLOW PAST A SEMI-INFINITE POROUS VERTICAL PLATE THROUGH POROUS MEDIUM

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The study of MHD heat and mass transfer dissipative free convective flow past a semi-infinite porous vertical plate through porous medium in presence of thermal radiation is considered. The novelty of the present work is to examine radiation effect (Rosseland Approximation) on the flow transport characteristics. The equations governing the flow of heat and mass transfer are solved by asymptotic series expansion method to evaluate the expressions for velocity, temperature, concentration fields, skin-friction, rate of heat and mass transfer. The influence of various physical parameters on the flow is discussed through graphs and in tabular form. It is found that an increase in radiation parameter to decrease the velocity and temperature. Further, it is seen that the skin -friction at the plate decreased with increasing values of radiation parameter.
Keywords: *Radiation; MHD; Porous medium; Free convection*
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1. INTRODUCTION

The motion of fluid due to buoyancy forces is known as free or natural convection that occurs in the region of hot and cold through the method of heat transfer. Heat transfer is a exchange of energy through conduction, convection or radiation from high to low where conduction is through solid materials, convection is through liquids and gases and radiation is through electromagnetic waves. Mass transfer is the net movement of mass from one point to another. MHD refers to electrically conducting motion of fluids and nowadays it plays an important role in the application field of engineering and biomedical sciences.

Many authors contributed some works related to the MHD heat and mass transfer problems. Some of them are Jaluria [1], Javaherdeh et.al [2], Raju et al. [3], etc. The unsteady MHD free convection flow past a vertical plate with thermal diffusion and chemical reactions have been discussed by Hossain et.al [4]. Lavanya [5] analyzed the radiation and chemical reaction effects on a steady laminar forced convection flow of a viscous incompressible electrical conducting fluid over a plate embedded in a porous medium in the presence of heat generation. An exact solution of unsteady MHD free convective mass transfer flow past an infinite inclined plate embedded in a saturated porous medium has been presented by Agarwalla et.al [6]. Chamkha et.al [7] considered the problem of coupled heat and mass transfer by natural convection from a vertical, semi-infinite flat plate embedded in a porous medium. Sharma et.al [8] also considered the Soret and Dufour effects on unsteady MHD mixed convection flow past an infinite radiative vertical porous plate embedded in a porous medium in presence of chemical reaction. The investigation of Dufour effect and radiation effects on unsteady MHD free convection flow past an impulsively started infinite vertical plate with variable temperature and uniform mass diffusion in the presence of transverse applied magnetic field through porous medium is carried out by Prakash et.al [9]. Thermal radiative effects on moving infinite vertical plate in the presence of variable temperature and mass diffusion is considered by Muthucumaraswamy [10]. Ahmed e.al [11] also investigated the effect of thermal diffusion on unsteady free convective flow of an electrically conducting fluid over an infinite vertical oscillating plate immersed in porous medium. Seth et.al [12] investigated the unsteady hydromagnetic natural convection flow with heat and mass transfer of a viscous, incompressible, electrically conducting, chemically reactive and optically thin radiating fluid past an exponentially accelerated moving vertical plate with arbitrary ramped temperature is carried out with Laplace transform technique. The problem of a hydromagnetic convective flow of an electrically incompressible viscous conducting fluid past a uniformly moving vertical porous plate is investigated by Chamuah et.al [13]. An attempt has been made by Ahmed et.al [14] to perform a finite difference analysis to study the effects of the magnetic field, thermal radiation, Reynold's number, chemical reaction and of dissipating heat on the MHD transient dissipative flow past a suddenly started infinite vertical porous plate with ramped wall temperature. Ahmed et .al [15] also studied theoretically a three-dimensional mixed convective mass transfer flow past a semi-infinite vertical plate embedded in a porous medium. To analyze the effects of various parameters such as Soret and Dufour effects, chemical reaction, magnetic field, porosity on the fluid flow and heat and mass transfer of an unsteady Casson fluid flow past a flat plate is considered by Das et.al [16]. Kataria et.al [17] is considered with the study of flow, heat and mass transfer characteristics in the unsteady natural convective magnetohydrodynamics Casson fluid flow past over an oscillating vertical plate. Babu et.al [18] carried out to study the effects radiation and heat sink. Ragunath et.al [19] considered the heat and mass transfer on MHD flow

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through porous medium between two vertical plates. The study of the heat and mass transfer on MHD boundary layer flow of a viscous incompressible and radiating fluid over an exponentially stretching sheet is carried out by Devi et.al [20]. Ravikumar et.al [21] investigated the heat and mass transfer effects on MHD flow of viscous incompressible and electrically conducting fluid through a non-homogeneous porous medium in presence of heat source, oscillatory suction velocity is considered. Very recently Mopuri et.al [22] investigated in the presence of a diffusion thermal and coupled magnetic field effect, this manuscript seeks continuous free convective motion by a viscous, incompressible fluid that conducts electrically past a sloping platform via a porous medium. By using perturbation technique, Choudhury et.al [23] investigated the heat and mass transfer in MHD convective flow past an infinite plate, through a porous media in presence of radiation, diffusion-thermo effect, and heat sink.

The main objective of the present work is to investigate the effects of diffusion-thermo and heat sink in MHD free convective flow through a porous media in presence of thermal radiation (Rosseland Approximation). The equations governing the flow, heat and mass transfer are transformed into non-dimensional forms by using some similarity parameters. The perturbation technique is used to solve the non-dimensional governing equations and the results obtained have been discussed through graphs and tables.

2. MATHEMATICAL FORMULATION

The equations which describe the motion of steady, incompressible, viscous, electrically conducting fluid in the existence of a uniform magnetic field in vector form are as:

Equation of continuity:

$$\vec{\nabla}.\vec{q} = 0. \tag{1}$$

Gauss's law of magnetism:

$$\vec{\nabla} \cdot \vec{B} = 0. \tag{2}$$

Ohm's law:

$$\vec{J} = \sigma(\vec{E} + \vec{q} \times \vec{B}). \tag{3}$$

Momentum equation:

$$\rho(\vec{q} \cdot \vec{\nabla})\vec{q} = \rho\vec{g} - \vec{\nabla}p + \vec{J} \times \vec{B} + \mu\nabla^2\vec{q} - \frac{\mu\vec{q}}{K'}. \tag{4}$$

Energy equation

$$\rho C_p(\vec{q} \cdot \vec{\nabla})T = \kappa\nabla^2 T + \varphi + \frac{\vec{J}^2}{\sigma} + \frac{\rho D_M K_T}{C_S}\nabla^2 C + Q'^{(T'-T'_\infty)} - \vec{\nabla} \cdot \vec{q}_r. \tag{5}$$

Species continuity equation:

$$(\vec{q} \cdot \vec{\nabla})C\alpha = D_M\nabla^2 C + \bar{K}c(C_\infty - C). \tag{6}$$

Equation of state:

$$\rho_\infty = \rho[1 + \beta(T - T_\infty) + \bar{\beta}(C - C_\infty)]. \tag{7}$$

All the physical quantities are defined in the list of symbols.

We consider the two-dimensional natural convective flow of viscous, steady, incompressible, and radiating fluid through a porous vertical plate with uniform suction. The investigation is based on the following basic premises:

1. The entire fluid properties excluding the density are constant.
2. The plate is electrically insulated.
3. No external electric field is applied to the system.
4. Fluid motion is parallel to the plate.

We now introduce a Cartesian coordinate system (x', y', z') with x'-axis along the plate in the upward vertical direction, y'-axis normal to the plate directed into the fluid region, and z'-axis along the width of the plate and the induced magnetic field is negligible. A uniform magnetic field $\vec{B}_\circ = (0, B_\circ, 0)$ is applied transversely to the plate, along the y-axis. The fluid is subjected to a constant heat flux at the plate. With usual boundary layer conditions and above assumptions, we have the boundary layer equations as

Continuity Equation

$$\frac{\partial v'}{\partial y'} = 0. \tag{8}$$

MHD Equation

$$v'\frac{\partial u'}{\partial y'} = g\beta(T' - T'_\infty) + g\beta(C' - C'_\infty) + v\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_\circ^2 u'}{\rho} - \frac{vu'}{K'}. \tag{9}$$

Energy Equation

$$\rho C_P v' \frac{\partial T'}{\partial y'} = \kappa \frac{\partial^2 T'}{\partial y'^2} + \mu \left(\frac{\partial u'}{\partial y'}\right)^2 + \sigma B_\circ{}^2 u'^2 - \frac{\partial q'_r}{\partial y'} - Q'^{(T'-T'\infty)} + \frac{\rho D_M K_T}{C_S} \frac{\partial^2 C'}{\partial y'^2}. \quad (10)$$

Species continuity equation

$$v' \frac{\partial C'}{\partial y'} = D_M \frac{\partial^2 C'}{\partial y'^2} + \bar{K}_C (C'_\infty - C'). \quad (11)$$

The relevant boundary conditions are:

$$y'=0: \; u'=U, \; \frac{\partial T'}{\partial y'} = -\frac{q^*}{\kappa}, \; C'=C'_w \quad (12)$$

$$y' \to \infty: \; u' \to 0, \; T' \to T'_\infty, \; C' \to C'_\infty \quad (13)$$

Equation (8) yields

$$v' = \text{a constant} = -V_0 (V_0 > 0)\,. \quad (14)$$

To make the mathematical model normalized, the following non-dimensional parameters are introduced

$$y = \frac{V_0 y'}{\vartheta}, u = \frac{u'}{U}, \theta = \frac{T'-T'\infty}{\frac{q^* v}{\kappa v_0}}, \emptyset = \frac{C'-C'_\infty}{C'_W - C'_\infty}, Gr = \frac{v^2 g \beta q^*}{\kappa U V_0^3}, E = \frac{\rho U^2 V_0}{q^*}, Pr = \frac{\mu C_P}{\kappa}, K_C = \frac{\bar{K} c v}{V_0^2}, Gm = \frac{g \bar{\beta}(C'_W - C'_\infty)}{U V_0^2},$$

$$Sc = \frac{v}{D_M}, K = \frac{v K'}{U V_0^2}, M = \frac{\sigma B_0^2 v}{\rho V_0^2}, R = \frac{4 v I^*}{\rho C_P q^* V_0^2}, Q = \frac{Q' v}{\rho C_P V_0^2}, Du = \frac{D_M K_T V_0 \kappa (C'_W - C'_\infty)}{C_S C_P v^2 q^*}$$

Radiative heat flux under Rosseland Approximation

$$\vec{q}_r = -\frac{4\sigma^*}{3K^*} \vec{\nabla} T^4$$

$$T^4 = (T - T_\infty + T_\infty)^4 = [T_\infty + (T - T_\infty)]^4 = T_\infty^4 + 4T_\infty^3 (T - T_\infty) = T_\infty^4 + 4T_\infty^3 T - 4T_\infty^4 = 4T_\infty^3 T - 3T_\infty^4$$

Therefore,

$$\vec{\nabla} \cdot \vec{q}_r = -\frac{4\sigma^*}{3K^*} \nabla^2 T^4 = -\frac{4\sigma^*}{3K^*} 4T_\infty^3 \nabla^2 T$$

$$\frac{\partial q_r^*}{\partial y^*} = -\frac{16\sigma^* T_\infty^3}{3K^*} \nabla^2 T$$

Where σ^* and K^* are respectively the Seltan-Boltzmann constant and the mean absorption coefficient.

In dimensionless form, the governing equations are as follows:

$$\frac{d^2 u}{dy^2} + \frac{du}{dy} - \lambda_1 u = -Gr\theta - Gm\emptyset. \quad (15)$$

$$\frac{d^2\theta}{dy^2} + \lambda_3 \frac{d\theta}{dy} - \lambda_4 \theta = -\frac{M E_C}{\lambda_2} u^2 - \frac{E_C}{\lambda_2} u'^2 - \frac{DuPr}{\lambda_2} \frac{d^2\phi}{dy^2}. \quad (16)$$

$$\frac{d^2\emptyset}{dy^2} + Sc \frac{d\emptyset}{dy} - K_C Sc \emptyset = 0. \quad (17)$$

Where

$$\lambda_1 = M + \frac{1}{K}, \lambda_2 = 1 + \frac{4}{3R}, \lambda_3 = \frac{Pr}{\lambda_2} \text{ and } \lambda_4 = \frac{QPr}{\lambda_2};$$

with boundary conditions

$$y = 0: u = 1, \frac{d\theta}{dy} = -1, \emptyset = 1, \quad (18)$$

$$y \to \infty: u \to 0, \theta \to 0, \emptyset \to 0. \quad (19)$$

3. METHOD OF SOLUTION

The solution of (17) under its boundary conditions (18) and (19) is

$$\emptyset(y) = e^{-a_1 y}, \text{ where } a_1 = \frac{Sc + \sqrt{Sc^2 + 4ScKc}}{2}. \quad (20)$$

But the system of equations (15) and (16) are non-linear. Assuming the asymptotic form of the solutions to equations (15) and (16) are as follows:

$$u = u_0(y) + E_C u_1(y) + O(E_C^2), \quad (21)$$

$$\theta = \theta_0(y) + E_C \theta_1(y) + O(E_C^2). \quad (22)$$

Here, E denotes the Eckert number (E<< 1). By substituting equations (21)-(22) into equations (15)-(16) and equating the coefficient values of similar terms while neglecting the terms of O(E^2), the following equations are derived.

$$\frac{d^2u_0}{dy^2}+\frac{du_0}{dy}-\lambda_1 u_0=-Gr\theta_0-Gm\emptyset_0, \tag{23}$$

$$\frac{d^2\theta_0}{dy^2}+\lambda_3\frac{d\theta_0}{dy}-\lambda_4\theta_0=-A\frac{d^2\emptyset_0}{dy^2}, \tag{24}$$

$$\frac{d^2u_1}{dy^2}+\frac{du_1}{dy}-\lambda_1 u_1=-Gr\theta_1, \tag{25}$$

$$\frac{d^2\theta_1}{dy^2}+\lambda_3\frac{d\theta_1}{dy}-\lambda_4\theta_1=-Bu_0^2-Cu_0'^2. \tag{26}$$

Subject to the boundary conditions

$$y=0:\ u_0=1;\ \theta_0'=-1;\ u_1=0;\ \theta_1'=0; \tag{27}$$

$$y\to\infty:\ u_0\to 0;\ \theta_0\to 0;\ u_1\to 0;\ \theta_1\to 0. \tag{28}$$

The solutions to the equations (23)-(26) under the conditions (27) and (28) are

$$\theta_0=K_1e^{-a_2y}-S_1e^{-a_1y} \tag{29}$$

$$u_0=K_2e^{-a_3y}-S_2e^{-a_2y}+S_3e^{-a_1y} \tag{30}$$

$$\theta_1=K_3e^{-a_7y}-S_4e^{-2a_3y}-S_5e^{-2a_2y}-S_6e^{-2a_1y}+S_7e^{-a_4y}+S_8e^{-a_5y}-S_9e^{-a_6y}, \tag{31}$$

$$u_1=K_4e^{-a_8y}-S_{17}e^{-a_7y}+S_{18}e^{-2a_3y}+S_{19}e^{-2a_2y}+S_{20}e^{-2a_1y}-S_{21}e^{-a_4y}-S_{22}e^{-a_5y}+S_{23}e^{-a_6y}, \tag{32}$$

where

$$a_2=\frac{\lambda_3+\sqrt{\lambda_3^2+4\lambda_4}}{2},\ a_3=\frac{1+\sqrt{1+4\lambda_1}}{2},\ a_4=a_3+a_4,$$

$$a_5=a_2+a_1,\ a_6=a_1+a_3,$$

$$K_1=\frac{1}{-m_2}(1+S_1a_1),\ S_1=\frac{Aa_1^2}{a_1^2-\lambda_3a_1-\lambda_4},\ K_2=1+S_2-S_3,$$

$$S_2=\frac{D}{a_2^2-a_2-\lambda_1},\ S_3=\frac{E}{a_1^2-a_1-\lambda_1},\ S_4=\frac{F}{4a_3^2-2a_3\lambda_3-\lambda_4},$$

$$S_5=\frac{G}{4a_2^2-2a_2\lambda_3-\lambda_4},\ S_6=\frac{H}{4a_1^2-2a_1\lambda_3-\lambda_4},\ S_7=\frac{I}{a_4^2-a_4\lambda_3-\lambda_4},$$

$$S_8=\frac{J}{a_5^2-a_5\lambda_3-\lambda_4},\ S_9=\frac{K}{a_6^2-a_6\lambda_3-\lambda_4},\ S_{10}=GrK_3,\ S_{11}=GrS_4,$$

$$S_{12}=GrS_5,\ S_{13}=GrS_6,\ S_{14}=GrS_7,\ S_{15}=GrS_8,\ S_{16}=GrS_9,$$

$$S_{17}=\frac{S_{10}}{a_7^2-a_7-\lambda_1},\ S_{18}=\frac{S_{11}}{4a_3^2-2a_3-\lambda_1},\ S_{19}=\frac{S_{12}}{4a_2^2-2a_2-\lambda_1},$$

$$S_{20}=\frac{S_{13}}{4a_1^2-2a_1-\lambda_1},\ S_{21}=\frac{S_{14}}{a_4^2-a_4-\lambda_1},\ S_{22}=\frac{S_{15}}{a_5^2-a_5-\lambda_1},$$

$$S_{23}=\frac{S_{16}}{a_6^2-a_6-\lambda_1},\ K_3=\frac{1}{m_2}(2a_3S_4+2a_2S_5+2a_1S_6-a_4S_7-a_5S_8+a_6S_9),$$

$$K_4=S_{17}-S_{18}-S_{19}-S_{20}+S_{21}+S_{22}-S_{23},\ D=GrK_1,\ E=GrS_1-Gm,$$

$$F=BK_2^2+Ca_3^2K_2^2,\ G=BS_2^2+Ca_2^2S_2^2,\ H=BS_3^2+Ca_1^2S_3^2,$$

$$I=2BK_2S_2+2CK_2S_2a_3a_2,\ J=2BS_2S_3+2CS_2S_3a_2a_1,\ K=2BS_3K_2+2CS_3K_2a_1a_3.$$

3.1. Skin friction

The coefficient of skin friction is a dimensionless quantity obtained from the shear stress at the wall given by Newton's law of viscosity

$$\vec{\tau}_0=-\mu\vec{\nabla}u',$$

where τ_0 is the shear stress.

The coefficient of skin friction is given by

$$\tau = -\frac{du}{dy}|y_{=0} = -[K_2 a_3 + S_2 a_2 - S_3 a_1 + E_C(-K_4 a_8 + S_{17} a_7 - 2S_{18} a_3 - 2S_{19} a_2 - 2S_{20} a_1 + S_{21} a_4 + S_{22} a_5 - S_{23} a_6)]\,. \quad (33)$$

3.2. Plate temperature

The dimensionless temperature field is given by,

$$\theta(y) = \theta_0(y) + E_C \theta_1(y).$$

The non-dimensional plate temperature is given by,

$$\theta_w = \theta_0(0) + E_C \theta_1(0). \quad (34)$$

3.3. Sherwood number

Sherwood number represents the ratio of the convective mass transfer to the rate of diffusive mass transport. It is a dimensionless quantity obtained from Fick's law of diffusion:

$$\vec{J} = -D_M \vec{\nabla} C'\,,$$

where J is the diffusion flux.

The rate of mass transfer in terms of Sherwood number is given by

$$Sh = \frac{d\emptyset}{dy}|y_{=0} \quad = -a_1. \quad (35)$$

3.4. Nusselt number

The rate of heat transfer in terms of the Nusselt number quantified by Fourier's law of conduction is as follows:

$$\vec{q} = -\kappa \vec{\nabla} T'\,,$$

where $\vec{q}$ is the heat transfer rate.

Nusselt number is defined as

$$\frac{d\theta}{dy}|y_{=0} \; = [-K_1 a_2 + S_1 a_1 + E_C(-K_3 a_7 + 2S_4 a_3 + 2S_5 a_2 + 2S_6 a_1 - S_7 a_4 - S_8 a_5 + S_9 a_6)]. \quad (36)$$

4. RESULTS AND DISCUSSIONS

The diffusion-thermo effect in MHD convective flow past a vertical plate through a porous media in presence of heat sink and thermal radiation have been presented in this work. Computational estimations of velocity, temperature and concentration for a variety of relevant non-dimensional flow parameters have been obtained to establish the physical relevance of the problem and graphically presented in Figures 1-10. In the Table 1, the numerical calculations that depict the effects of the flow parameters on skin friction and rate of heat transfer (at plate temperature) have been tabulated. In this section, the effects of the magnetic field, thermal Grashof number, mass Grashof number, permeability parameter, Schmidt number, Prandtl number, Dufour number, heat sink and radiation parameter are discussed. The default values for the flow parameters as Pr = 0.71, Sc =0.6, R =5, $K_C = 5$, Du =0.10, Gr =10, Gm =5, M =1.5, K =1, E =0.01, Q =5.

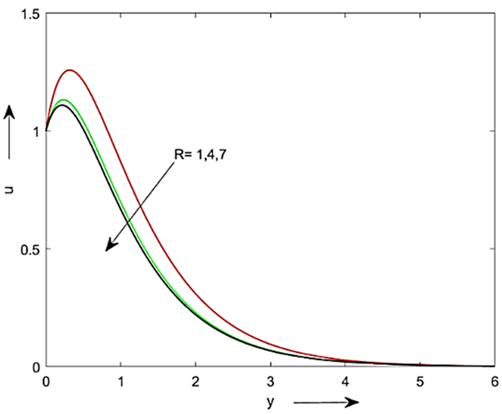

Figure 1. Velocity profile for variations in R when Pr = 0.71; Q = 5; Du = 0.1; Sc = 0.6; Kc=1; M = 1.5; Gr = 10; Gm = 5; E = 0.01; k = 1

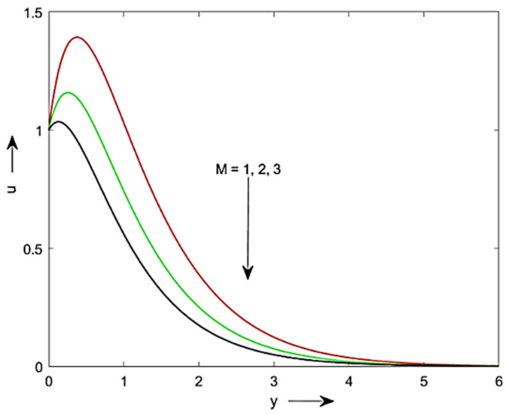

Figure 2. Velocity profile for variations in M When Pr = 0.71; R = 1; Q = 5; Du = 0.1; Sc = 0.6; Kc = 1; Gr = 10; Gm = 5; E = 0.01; k = 1

The effects of radiation parameter R on the fluid velocity indicates by Figure 1. It may be noted to determine the relative importance of thermal energy on the fluid flow, the radiation parameter is used. Thermal energy results in a fall in thermal energy, which then depicts a loss in the fluid of kinetic energy, as a result of which the fluid velocity decreases.

The significance of the application of the magnetic field in a fluid flow display in Figure 2 and from the figure it is observed that as the value magnetic field parameter *M* increases the fluid velocity declines. This results that when a magnetic field is applied to an electrically conducting fluid, a resistive type of force is generated known as Lorentz force which has the tendency to retard the fluid motion.

Table 1. Skin friction τ at the plate for the values of M = 1.5; Pr = 0.71; Q = 5; Du = 0.1; Sc = 0.6; Kc = 1; Gr = 10; Gm = 5; E = 0.01; k = 1

M	*k*	*R*	*Du*	τ
2	1	1	0.1	1.4338
4	1	1	0.1	1.2055
6	1	1	0.1	0.0980
1.5	**1**	1	0.1	1.9428
1.5	**2**	1	0.1	2.5402
1.5	**3**	1	0.1	2.7655
1.5	1	**5**	0.1	1.2370
1.5	1	**10**	0.1	1.1033
1.5	1	**15**	0.1	1.0573
1.5	1	1	**0.1**	1.9428
1.5	1	1	**0.2**	1.0514
1.5	1	1	**0.3**	0.1601

Figure 3 depicts the effects of permeability. Fluid velocity is increased with the increasing values of the permeability parameter. Figure 4 and Figure 5 respectively shows the effects of the thermal Grashof number *Gr* and mass Grashof number *Gm*. The ratio of thermal buoyancy force and viscous hydrodynamic force in the boundary layer is the Thermal Grashof number. The thermal buoyancy force dominates over the viscosity of the fluid as *Gr* increases. Likewise. The mass Grashof number is the relative effect of mass buoyancy force and viscous hydrodynamic force and thus the fluid motion enhances with the increase of *Gm*.

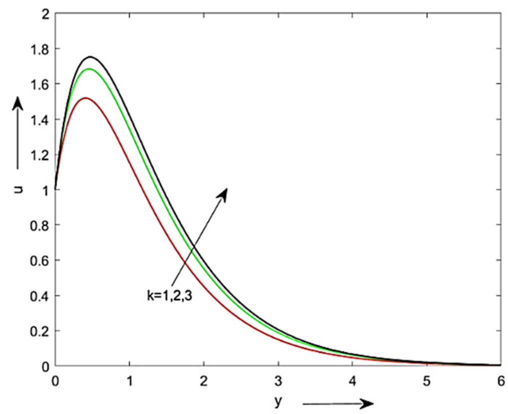

Figure 3. Velocity profile for variations in *k* when Pr = 0.71; R = 1; Q = 5; Du = 0.1; Sc = 0.6; Kc = 1; M = 1.5; Gr = 10; Gm = 5; E = 0.01

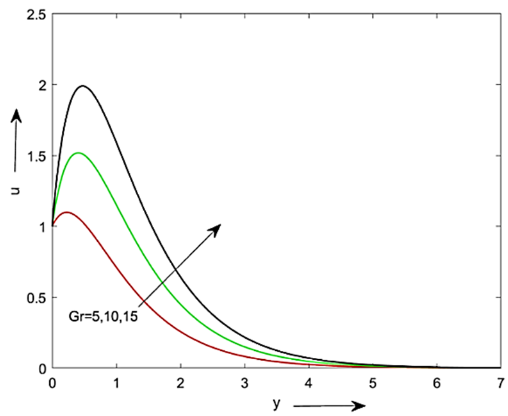

Figure 4. Velocity profile for variations in *Gr* when Pr = 0.71; R = 1; Q = 5; Du = 0.1; Sc = 0.6; Kc = 1; M = 1.5; E = 0.01; k =1

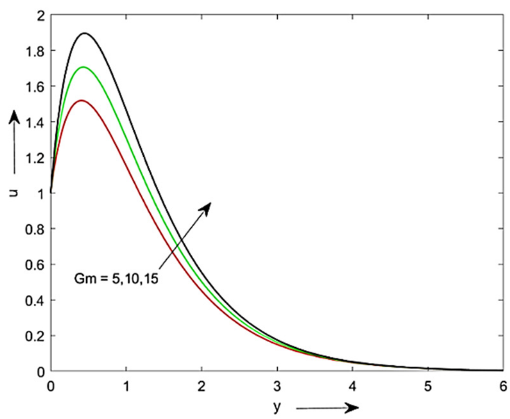

Figure 5. Velocity profile for variations in *Gm* when Pr = 0.71; R =1; Q =5; Du = 0.1; Sc= 0.6; Kc =1; M = 1.5; Gr = 10; E = 0.01; k = 1

The Figures 6-8 displays the effects of various parameters on temperature. Figure 6 indicates that due to thermal radiation the temperature of the fluid diminishes. This result qualitatively meets the expectations as the effect of radiation is to decrease the rate of energy transport to the fluid, thereby decreasing the temperature of the fluid. A fall in temperature profile occurs with heat absorption which is demonstrated in Figure 7. Figure 8, depicts the Dufour's effect on the temperature profile. It is obvious that the temperature of the fluid falls with the diffusion-thermo effect. All these figures clearly indicates that at the plate, the fluid temperature is maximum.

In Figure 9 and Figure 10 respectively, the variations of concentration in the flow domain due to Schmidt number and permeability parameter are illustrated. Figure 10 displays with the increasing values of Schimdt number diminish the fluid concentration. Schimdt number is the ratio of the momentum diffusivity to the mass diffusivity. So, as Sc increases, the fluid concentration reduces. Figure 11 depicts that it lowers the concentration of the fluid as the porosity of the medium increases.

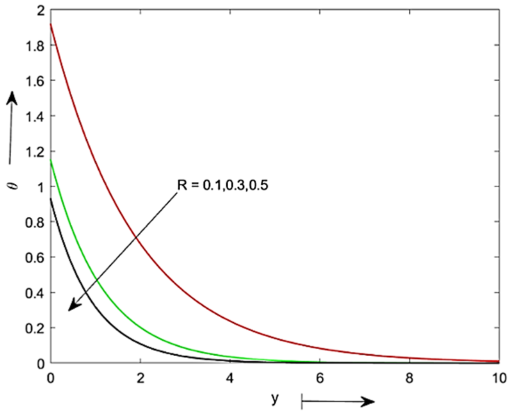

Figure 6. Temperature profile for variations in *R* when Pr = 0.71; Q = 5; Du = 0.1; Sc = 0.6; Kc = 1; M = 1.5; Gr = 10; Gm = 5; E = 0.01; K =1

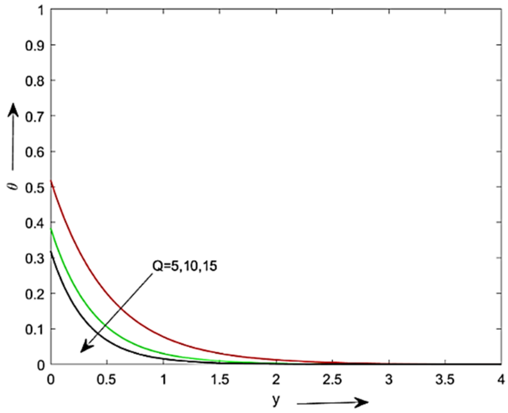

Figure 7. Temperature profile for variations in *Q* when Pr = 0.71; R = 5; Du = 0.1; Sc = 0.6; Kc = 1; M = 1.5; Gr = 10; Gm = 5; E = 0.01; k = 1

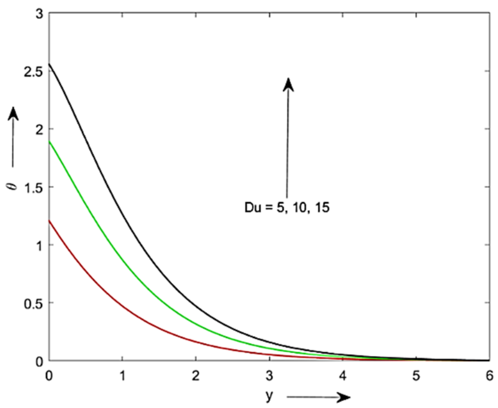

Figure 8. Temperature profile in variations *Du* when Pr = 0.71; Q = 5; R = 5; Sc = 0.6; Kc= 1; M = 1.5; Gr = 10; Gm = 5; E = 0.01; k =1

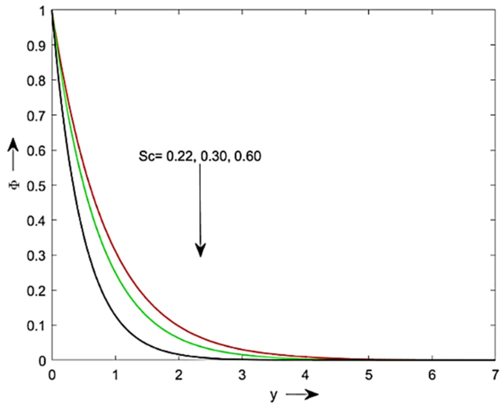

Figure 9. Concentration profile for variations in Sc when Kc =5

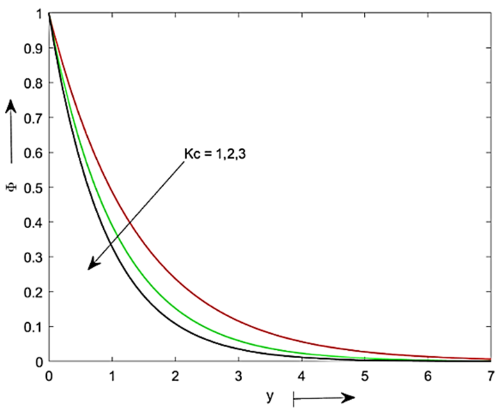

Figure 10. Concentration profile for variations in Kc when Sc = 0.30

Table 1 shows that the change of skin friction coefficient for different values of the parameters. It is seen from the table that skin friction gets decreased in the increasing values of magnetic parameter, radiation and Dufour number. But viscous drag is increased due to the increasing values of permeability parameter.

5. CONCLUSION

The present investigation leads to the following conclusions:

- ❖ The fluid velocity increases as the Dufour number increases whereas it decreases with thermal radiation and heat sink.
- ❖ The fluid motion decelerates as the strength of the magnetic field increases whereas it enhances with thermal Grashof number and mass Grashof number.
- ❖ The temperature of the fluid falls under the influence of Prandtl number, Dufour number, thermal radiation and heat absorption.
- ❖ The concentration level of the fluid drops with the Schmidt number and permeability of the porous medium.
- ❖ Skin friction at the plate increases as the Dufour number and heat sink parameter values increases. Viscous drag at the plate was reduced for increasing values of the magnetic parameter.
- ❖ Plate temperature of the body's surface decreased due to the effect of the Dufour number and Prandtl number.

Nomenclature

$\vec{q}$	fluid velocity (m/s)	$\bar{\beta}$	solutal expansion coefficient ($kmol^{-1}$)
$\vec{J}$	current density (A/m^2)	T_∞	free stream concentration (k)
$\vec{g}$	acceleration vector due to gravity (m/s^2)	C_∞	free stream concentration (kmol)
$\vec{B}$	magnetic flux density vector (Wb/m^2)	B_0	applied magnetic field strength (T)
$\vec{J}^2/\sigma$	energy of ohmic dissipation per unit volume ($A^2\Omega/m^3$)	μ	viscosity coefficient (kg/m s)
p	fluid pressure (N/m^2)	K	porosity parameter
U	velocity of free stream (m/s)	q^*	heat flux (W/m^2)
C_w	plate species concentration (kmol/m^3)	T	fluid temperature (K)
C_∞	free stream concentration (kmol/m^3)	C	concentration (kmol/m^3)
D_M	mass diffusivity (m^2/s)	θ	nondimensional temperature
K_T	thermal diffusion ratio, m(kmol).	$\emptyset$	nondimensional concentration
ρ_∞	fluid density far away from the plate (kg/m^3)	g	acceleration due to gravity
φ	energy viscous dissipation per unit volume (J/m^2S)	E	Eckert number
C_S	concentration susceptibility ($kmol^2s^2/m^2$)	Pr	Prandtl number
$\vec{q}_r$	radiation heat flux vector (W/m^2)	Q	heat sink parameter
$\bar{K}_C$	first order chemical reaction rate (s^{-1})	Sc	Schmidt number
ρ	fluid density (kg/m^3)	Gr	thermal Grashof number
v	kinematic viscosity (m^2/s)	M	magnetic parameter
κ	thermal conductivity (W/m K)	Gm	solutal Grashof number
κ^*	mean absorption coefficient (m^{-1})	R	radiation parameter
σ	electrical conductivity ($\Omega^{-1}m^{-1}$)	Du	Dufour number
$\vec{E}$	electrical field intensity vector (N/C)	K_C	chemical reaction parameter
β	thermal expression coefficient (k^{-1})		

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ВПЛИВ ВИПРОМІНЮВАННЯ НА МГД ВІЛЬНИЙ КОНВЕКТИВНИЙ ПОТІК ПОВЗ НАПІВНЕСКІНЧЕННУ ПОРИСТУ ВЕРТИКАЛЬНУ ПЛАСТИНУ ЧЕРЕЗ ПОРИСТЕ СЕРЕДОВИЩЕ

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Розглянуто дослідження МГД-тепломасообміну дисипативного вільного конвективного обтікання напівнескінченної пористої вертикальної пластини через пористе середовище за наявності теплового випромінювання. Новизна даної роботи полягає в дослідженні впливу випромінювання (наближення Росселанда) на транспортні характеристики потоку. Рівняння, що керують потоком тепло- та масообміну, розв'язуються за допомогою методу розкладання в асимптотичний ряд для оцінки виразів для швидкості, температури, полів концентрації, поверхневого тертя, швидкості тепло- та масообміну. Вплив різних фізичних параметрів на потік обговорюється за допомогою графіків і в табличній формі. Встановлено, що збільшення параметра випромінювання зменшує швидкість і температуру. Далі видно, що шкірне тертя на пластині зменшувалося зі збільшенням значень параметра випромінювання.

Ключові слова: *радіація; МГД; пористе середовище; вільна конвекція*