RADIATION EFFECT ON NATURAL
CONVECTIVE MHD FLOW THROUGH A
POROUS MEDIUM WITH DOUBLE DIFFUSION
IN THE PRESENCE OF CHEMICAL REACTION

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ABSTRACT:

The influence of radiation on natural convective MHD flow through a porous medium in the presence of chemical reaction and transverse magnetic field bounded by a vertical infinite surface is studied. The basic equations governing the flow, heat and mass transfer are reduced to a set of ordinary differential equations by suitable transformations. The resulting set of coupled non-linear ordinary differential equations are solved by using the MATLAB in-built numerical solver bvp4c for velocity, temperature and concentration, and that has been presented graphically for different values of needed parameters. It is observed that results of magnetic parameter and radiation parameter in the flow field change the flow significantly.

Keywords: Natural Convective MHD, Chemical Reaction, Double Diffusion

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1. INTRODUCTION

The natural convection flow past a vertical surface was examined widely for its application in designing and ecological process. In many transport forms in nature and modern application in which heat and mass exchange is an outcome of buoyancy force because of diffusivity of heat, chemical substances and concentration. In decades ago, the investigation of heat and mass transfer in MHD natural convective flow with chemical reaction and radiation has received a growing interest because of its significance in a many engineering, geophysical, and astrophysical applications, for example, polymer production, cooling of atomic reactors, underground energy transport, plasma flow, etc. Heat and mass transfer with radiation
assumes a main part in the manufacturing industries, in atomic power plants, gas turbines and different drive gadgets for air craft’s, rockets, satellites, and space vehicles.


In view of the above discussion the objective of the present paper is radiation effect on natural convective MHD flow through a porous medium with double diffusion in the presence of chemical reaction and the resulting set of coupled non-linear ordinary differential equations are solved by using the MATLAB in-built numerical solver bvp4c.

2. MATHEMATICAL ANALYSIS

Consider a steady incompressible viscous free convective MHD fluid flow with thermal radiation embedded in a permeable medium in a semi-infinite region bounded by a vertical endless surface, which experiences a homogeneous chemical reaction. The \( x \)-axis is taken the surface an upward way and the \( y \)-axis is perpendicular to it. A uniform Magnetic field is also connected toward the path opposite to the plate. The induced magnetic field and Hall effect are ignored. Here, there is no applied voltage, which implies there is no electric current. The equations describing the above flow are given by

\[
\begin{align*}
\nabla \cdot \mathbf{u} &= 0 \\
\mathbf{u} \cdot \nabla \mathbf{u} &= u \left( \nabla u + \nabla \mathbf{T} \right) + g b \left( \rho C \mathbf{T} - \theta \mathbf{C} \right) - \frac{u B^2}{K} - \frac{K}{r} u \end{align*}
\]

Equation of continuity:

\[
\frac{\partial v}{\partial h} = 0
\]

Momentum equation:
Energy equation:

\[
\frac{u^2 T}{h^2} = \frac{a}{r c_p} \frac{T^2}{h^2} - \frac{1}{r c_p} \frac{q}{h} + u \frac{u^2}{c_p} \frac{u^2}{h^2}
\]  

(3)

Diffusion equation:

\[
\frac{u^2 C}{h} = D \frac{C^2}{h^2} - K r C
\]

(4)

Equation (1) gives \( u = \text{const} = -u_o \)

(5)

Where \( u_o \) is scale of suction velocity which is a nonzero positive constant. The negative sign indicates that suction is towards the plate.

With the appropriate initial and boundary conditions are given by

\[
u = 0, T = T_0, C = C_0 \quad \text{at} \quad h = 0\]

(6)

The radiative heat flux term by using the Rosseland approximation is given \[1\] by

\[
q_r = \frac{-4 s \frac{\partial T}{h}}{3k_s} \frac{\partial^2 T}{h^2}
\]

(7)

Where \( s \) is the Stefan – Boltzmann constant and \( k_s \) is the mean absorption coefficient.

For sufficiently small temperature difference within the flow we can expressed \( T^2 \) as a linear function of the temperature and expanding

\[
T^2 = 4T_0^2 T - 3T_0 \frac{\partial T}{h}
\]

(8)

By using equation (5) and (6)

\[
\frac{\partial q_r}{h} = \frac{16s \frac{\partial^2 T}{h}}{3k_s} \frac{\partial^2 T}{h^2}
\]

(9)

Introducing the following non – dimensional quantities,

\[
u = \frac{u^2}{u_o}, h = \frac{u_o h}{u}, q = \frac{T}{T_0} - \frac{\partial T}{T_0} \frac{T}{T_0}, C = \frac{C}{C_0}, Pr = \frac{c_p}{a}, Sc = \frac{u_o}{D}
\]

\[
Gr = \frac{u g b (T^2 - T_0^2)}{u_o^2}, Gc = \frac{u g b^* (C^2 - C_0^2)}{u_o^2}, Ec = \frac{u_o^2}{C_p (T^2 - T_0^2)}
\]

\[
K = \frac{K \frac{u_o^2}{u^2}}, M = \frac{s B^2 u}{ru_o^2}, R = \frac{16s \frac{\partial^2 T}{h^2}}{3K a}, Ko = \frac{u K r \frac{\partial T}{h}}{u_o^2}
\]

(10)

In the view of above equation, the basic flow field equations can be expressed in the following form:

\[
\frac{\partial^2 u}{\partial \eta^2} + \frac{\partial u}{\partial \eta} + Gr \theta + Gc C = \left( \frac{1}{K} + M \right) u = 0
\]

(11)

\[
\frac{\partial^2 \theta}{\partial \eta^2} + \frac{Pr}{1 + R} \left( \frac{\partial \theta}{\partial \eta} + Ec \left( \frac{\partial u}{\partial \eta} \right)^2 \right) = 0
\]

(10)
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\[
\frac{1}{Sc} \frac{\partial^2 C}{\partial \eta^2} + \frac{\partial C}{\partial \eta} + KoC = 0
\]  

(12)

Where \(Gr\), \(Gc\), \(Pr\), \(Sc\), \(Ko\), \(R\), and \(\kappa\) are the thermal Grashof number, Solutal Grashof number, Prandtl number, Schmidt number, chemical reaction parameter, radiation parameter, heat generation parameter, and permeability of the porous medium respectively.

\[
u = 0, \quad q = 1, \quad C = 1 \text{ at } h = 0
\]

\[
u \to 0, \quad q \to 0, \quad C \to 0 \text{ as } h \to \infty
\]  

(13)

Knowing the velocity field, the skin-friction coefficient at the plate is given by

\[
\tau = \left( \frac{\partial u}{\partial \eta} \right)_{\eta=0}
\]

Other important physical quantity of interest is the rate of heat transfer in terms of Nusselt number at the plate which is non-dimensional form is given by \(Nu = \left( \frac{\partial \theta}{\partial \eta} \right)_{\eta=0}\)

An important phenomenon in this study is to study the Sherwood number at the plate is given by \(Sh = \left( \frac{\partial C}{\partial \eta} \right)_{\eta=0}\)

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<th>(Gr)</th>
<th>(Gc)</th>
<th>(K)</th>
<th>(ko)</th>
<th>(M)</th>
<th>(Pr)</th>
<th>(Sc)</th>
<th>(R)</th>
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<th>(B. R. Rout [2])</th>
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The comparison of variety of skin friction, Nusselt number, and Sherwood number is given in the table. Increasing the mass Grashof number, \(Gr\), and the thermal Grashof number, \(Gc\), skin friction increases, but the reverse effect is considered for Nusselt number, though there is no impact on Sherwood number. When \(Gr\) and \(Gc\) are negative, the skin friction becomes negative. Porosity parameter increases the skin friction, but decreases the Nusselt number without influencing the Sherwood number. At the point when chemical reacting substances increases, then there is a small decreases in skin contact, however opposite behaviour is appeared for Nusselt number and Sherwood number. For getting higher estimation of magnetic parameter \(M\) and Prandtl number \(Pr\), skin friction diminishes, so far Nusselt number increases. Skin friction and Nusselt number increase, yet Sherwood number decreases with increment in Schmidt number. At the point when radiation factor and Eckert number increment, skin friction increments, yet Nusselt number reduces, while Sherwood number stays unaltered.

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3. RESULTS AND DISCUSSIONS

In Fig. 1 the curves demonstrates that the velocity starts from a minimum value on the surface and increments till achieves a peak values close to the plate, at that point starts decreasing toward the boundary layer. The ebb and flow in Fig. 2 mirrors that with increment in $Gr$ there is increment in fluid speed because of enhancement of buoyancy force. The positive estimation of $Gr$ shows the cooling of the plate and it is observed that velocity increments quickly close to the wall of the plate and after that decays to the free stream velocity. At the point when $Gr$ is negative, the plate becomes hotter and there is retardation in the fluid velocity. A comparable impact of mass Grashof number $Gc$ on fluid velocity is also considered in Fig. 2. Eckert number, on the velocity profile is examined in Fig. 3 also, it demonstrates that the fluid velocity increments because of increment in the Eckert number. It is found out that the fluid velocity increments gradually and at a short distance from the wall it accomplishes the maximum value also, decreases to zero for positive estimation of the Eckert number, i.e., for $T_w > T_\infty$. This demonstrates there is a hot layer close to the plate with a cooler fluid far from the plate. At the point when $T_w < T_\infty$, i.e., for negative Eckert number, when the temperature of the fluid close to the wall is not as much as the surrounding temperature, the fluid velocity increments and attaining a peak values decreases step by step to zero. The curve and flow of $Pr$ and $Sc$ versus velocity in Fig. 4 specifies that the velocity profile diminishes with increment in $Pr$ and $Sc$. This occurs because of predominance of thermal diffusion and molecular diffusion over the viscous diffusion. The diagram of Fig. 5 demonstrates that with increment in porosity parameter there is increment in velocity profile, i.e., if the porosity parameter increases, at that point the resistive power for the fluid flow diminishes, which prompts the improvement of the fluid velocity. Closer to the wall the fluid flow achieves a peak value then slowly diminishes. The effects of the chemical reaction parameter on the velocity profile are studied in Fig. 6. It is observed that for $k_o < 0$, i.e., generative reaction constructs the fluid flow velocity yet $k_o > 0$, i.e., destructive reaction decreases the liquid stream speed. The velocity profiles accomplish most extreme close to the wall also, decrease step by step. In Fig. 7, it is fascinating to take note of that in a steady flow an increase in the radiation parameter prompts an increase in the extent of the fluid velocity inside the boundary layer.

The variety of temperature with $Gr$ and $Gc$ is considered in Fig. 8, for positive value of $Gr$, i.e., for externally cooled plate the temperature increments close to the wall yet for negative value of the $Gr$, i.e., for externally heated plate, the temperature decreases. In the two cases, with increment in $Gr$ there is an increase in the temperature profile. Comparable impacts are additionally examined for mass Grashof number $Gc$. Figure 9 describes that with increasing chemical reaction parameter there is an increment in the temperature profile. In Fig. 10, it is seen that the values of the Prandtl number $Pr$ is inversely proportional to the amount of temperature flow. If the value of $Pr$ is smaller, there is an increase in thermal conductivity of the fluid, which enables to flow in more normal temperature. Along these lines, amount of smaller Prandtl number the thermal boundary is thicker, for which the temperature profile increments. In any case, for the radiation parameter 'R' reverse behavior was appeared by the liquid, i.e., for larger thermal radiation parameter the thermal boundary layer is thicker, so the temperature profile expands, which is shown in Fig. 11.

The variety of focus as for the concentration with respect to the chemical reaction parameter and Schmidt number is examined in Figs. 12 and 13. Figure 12 shows that destructive, i.e., for $Ko > 0$, reduces the concentration because of the commitment of mass dissemination in concentration equation, meanwhile, in the generative reaction, i.e., for $Ko < 0$, the reverse effect is observed. The effect of Schmidt number on focus profile is defined in Fig. 13. It is observed that the concentration profile diminishes monotonically and
the boundary layer thicknesses decrease with the increase of Schmidt number. Figure 14 shows the effect of skin friction with various value of M. It is observed that increasing M decreases skin friction.

4. CONCLUSIONS:
The governing partial differential equations for the studying incompressible natural convective MHD flow with thermal radiation introduced in a permeable medium in an infinite region bounded by a vertical surface, which experiences homogeneous chemical reaction with magnetic field, are changed into a set of ordinary differential equations by utilizing the MATLAB in-built numerical solver bvp4c and under given boundary conditions. Some of the important conclusions of the present examination are as per the following:

- Radiation parameter improves the fluid velocity and the fluid temperature.
- Velocity diminishes with increment in the magnetic field parameter.
- The back flow is observed for the negative estimations of thermal and mass Grashof number.

![Figure 1](image1.png) Velocity profiles versus variation of M

![Figure 2](image2.png) Velocity profiles versus variation of Gr & Gc

![Figure 3](image3.png) Velocity profiles versus variation of Ec

![Figure 4](image4.png) Velocity profiles versus variation of Pr and Sc
Fig 5 Velocity profiles versus variation of $K$

Fig 6 Velocity profiles versus variation of $Ko$

Fig 7 Velocity profiles versus variation of $R$

Fig 8 Temperature profiles versus variation of $Gr$ and $Gc$

Fig 9 Temperature profiles versus variation of $Ko$

Fig 10 Temperature profiles versus variation of $Pr$
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**Figure 11** Temperature profiles versus variation of $R$

**Figure 12** Concentration profiles versus variation of $Ko$

**Figure 13** Concentration profiles versus variation of $Sc$

**Figure 14** Skin friction profiles versus variation of $M$

**REFERENCES:**


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