Combined influence of chemical reaction and radiation absorption on mixed convective heat and mass transfer flow of a micropolar fluid through a porous medium in a vertical channel with varied temperature

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Abstract

In the this chapter, we investigate the combined influence of chemical reaction and radiation absorption on mixed convective heat and mass transfer flow of a micropolar fluid through a porous medium in a vertical channel with varied temperature in the presence of heat sources. The governing differential equations have been solved by applying finite element analysis with quadratic interpolation functions. The velocity, micro rotation and temperature functions are shown graphically. The effects of magnetic field; radiation and micropolar parameter are studied. Such type of study may be applicable in nuclear reactors, heat exchangers and various electronic devices.

Keywords: Chemical reaction, radiation absorption, micropolar fluid, micro rotation, vertical parallel plates

Introduction:

The analysis of mixed convection boundary layer flow along a vertical plate embedded in a fluid saturated porous media has received considerable theoretical and practical interest. The phenomenon of mixed convection occurs in many technical and industrial problems such as electronic devices cooled by fans, nuclear reactors cooled during an emergency shutdown, a heat exchanger placed in a low-velocity environment, solar
collectors and so on. Several authors have studied the problem of mixed convection in different surface geometries. The analysis of convective transport in a porous medium with the inclusion of non-Darcian effects has also been a matter of study in recent years. The inertia effect is expected to be important at a higher flow rate and it can be accounted for through the addition of a velocity squared term in the momentum equation, which is known as the Forchheimer’s extension of the Darcy’s law. A detailed review of convective heat transfer in Darcy and non-Darcy porous medium can be found in the book by Nield and Bejan [21].

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and the mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries, for example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. There are two types of reactions. A homogeneous reaction is one that occurs uniformly throughout a give phase. The species generation in a homogeneous reaction is analogous to internal source of heat generation. In contrast a heterogeneous reaction takes place in a restricted region or within the boundary of a phase. It can therefore be treated as a boundary condition similar to the constant heat flux condition in heat transfer. The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Muthucumaraswamy and Ganesan [18] studied the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate. Deka et.al. [8] Studied the effect of the first-order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer. Chamkah [6] studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction. Muthucumaraswamy and Ganesan [20] investigated the effects of a chemical reaction on the unsteady flow past an impulsively started semi-infinite vertical plate which subjected to uniform heat flux. Muthucumaraswamy and Ganesan [19] analyzed the effect of a chemical reaction on the unsteady flow past an
The study of heat generation or absorption effects in moving fluids is important in view of several physical problems such as fluids undergoing exothermic or endothermic chemical reactions. The volumetric heat generation has been assumed to be constant or a function of space variable. For example, a hypothetical core – disruptive accident in a liquid metal fast breeder reactor (LMFBR) could result in the setting of fragmented fuel debris on horizontal surfaces below the core. The porous debris could be saturated sodium coolant and heat generation will result from the radioactive decay of the fuel particulate.


The study of non-Newtonian fluid flows has gained much attention from researchers because of its applications in biology, physiology, technology and industry. In addition, the
effects of heat and mass transfer in non-Newtonian fluid also have great importance in engineering applications such as thermal design of industrial equipment dealing with molten plastics, polymeric liquids, foodstuffs, or slurries. Several investigators have extended many of the available convection heat and mass transfer problems to include the non-Newtonian effects. Many of the non-Newtonian fluid models describe the nonlinear relationship between stress and the rate of strain. But the micropolar fluid model introduced by Eringen[9] exhibits some microscopic effects arising from the local structure and micro motion of the fluid elements. Further, they can sustain couple stresses and include classical Newtonian fluids as a special case. The model of micropolar fluid represents fluids consisting of rigid, randomly oriented (or spherical) particles suspended in a viscous medium where the deformation of the particles is ignored. Micropolar fluids have been shown to accurately simulate the flow characteristics of polymeric additives, geomorphological sediments, colloidal suspensions, hematological suspensions, liquid crystals, lubricants etc. The mathematical theory of equations of micropolar fluids and applications of these fluids in the theory of lubrication and porous media is presented by Lukaszewicz.

Eringen[9] introduced the concept of micro fluids, which deals with a class of fluids, exhibiting certain microscopic effects arising from the local structure and micro-motions of the fluid elements. These fluids can support stress moments and body moments and body moments and are influenced by the spin inertia. Later Eringen [10] developed a subclass of these micro fluids, called micropolar fluids, where the micro-rotational effects and micro-rotational inertia exist but they do not support stretch. They can support couple stresses and body couples only. Physically some polymeric fluids, fluids containing small amounts of polymeric additives, blood, paints, lubricating oils, liquid crystals, colloidal fluids and suspension fluid may be represented by the mathematical model, underlying micropolar fluids. An excellent review of micropolar fluids and their applications were provided by Ariman et al [3].

Hoyt and Fabula [14] have shown experimentally that the fluids containing minute polymeric additives indicate considerable reduction of the skin friction (about 25 – 30 %); a concept, which is well explained by the theory of micropolar fluids. As an application, these fluids with microstructure are also capable of representing the body fluids.

The problems of micropolar fluid flow between two vertical plates (channel) are of great technical interest. A lot of attention has been given by many researchers. Sastry and
Rao [24] have studied the effect of suction in the laminar flow of a micropolar fluid in a channel, considering the Poiseuille flow at the entry of the channel. Bhargava and Rani [4] have examined the convective heat transfer in micropolar fluid flow between parallel plates. Its extension to free and forced convection is an interesting area of research including liquid crystals, dilute solutions of polymer fluids and many types of suspensions, since in many configurations in the technology and nature, one continually encounters masses of fluid rising freely in an extensive medium due to the buoyancy effects. Agarwal and Dhanapal [1] analyzed free convection micropolar fluid flow between two parallel porous vertical plates. The problem of fully developed free convection of a micropolar fluid in vertical channels has been discussed by Chamkha et al. [5]. Srinivasacharya et al. [26] have investigated the problem of unsteady Stokes flow of micropolar fluid between two parallel porous plates. In a forced convection situation, natural convection effects are also present in the presence of gravitational body forces. The situation where both the natural and forced convection effects are of comparable order is called mixed or combined convection.

Gorla et al [11] studied the fully developed laminar mixed convection flow of a micropolar fluid between two vertical parallel plates maintained at uniform but different temperatures. Excellent applications can be found in Nigam et al [22], where the authors discussed the problem of micropolar fluid film lubrication between two parallel plates with reference to human joints. One of the recent but excellent papers demonstrating the basic theories of micropolar fluids and its applications is that given by Lukaszewicz [17].

Tulasi et al [27] have investigated the convective heat and mass transfer flow of a micropolar fluid through a porous medium in a vertical channel by employing Galerkin finite element technique.

Kumar et al [16] have discussed the finite element solution of mixed convection micropolar fluid flow between two vertical plates with varying temperature.

The purpose of the present paper is to analyze the combined influence of chemical reaction and radiation absorption on mixed convective heat and mass transfer flow of a micropolar fluid between two vertical parallel plates with varying temperature in the presence of heat sources. Such type of study may be applicable in nuclear reactors, heat exchangers and various electronic devices.
2. FORMULATION OF THE PROBLEM

We consider a fully developed laminar convective heat and mass transfer flow of a viscous, electrically conducting fluid through a porous medium confined in a vertical channel bounded by flat walls. We choose a Cartesian co-ordinate system O(x, y, z) with x-axis in the vertical direction and y-axis normal to the walls. 'u' is the velocity component along the x-axis the component of micro rotation, T—the temperature and C—the concentration. Temperature is varying linearly along the x-axis with \( c_x \) and \( mc_x \) being the temperature of the left (y=-L) and the right hand plate (y=+L) respectively while the walls are maintained at constant concentration. The porous medium is assumed to be isotropic and homogeneous with constant porosity and effective thermal diffusivity. The thermo physical properties of porous matrix are also assumed to be constant and Boussinesq approximation is invoked by confining the density variation to the buoyancy term. In the absence of any extraneous force flow is unidirectional along the x-axis which is assumed to be infinite.

Thus the governing equations of this type of flow can be written as:

Momentum:

\[
(\mu + k) \frac{d^2u}{dy^2} + k \frac{dN}{dy} = \frac{dP}{dx} + \rho_c g (\beta T + \beta^e C) - \left( \frac{\mu}{k} \right) u - \left( \frac{\sigma \mu^2 H^2}{\rho_c} \right) u = 0
\]  

Angular Momentum:

\[
\gamma \frac{d^2N}{dy^2} - k \frac{du}{dy} - 2kN = 0
\]  

Energy equation:

\[
k_f \frac{d^2T}{dy^2} + \left( \mu + \frac{k}{2} \right) \frac{du}{dy} \left( \frac{du}{dy} \right)^2 + k \left( \frac{du}{dy} + 2N \right)^2 + \gamma \left( \frac{dN}{dy} \right)^2 - Q_h T + Q_i C = 0
\]  

Diffusion equation:

\[
D_m \frac{d^2C}{dy^2} - k_i C = 0
\]
\[ N(x, o) = -s \left( \frac{\partial u}{\partial y} \right)_{y=0} \]  

(5)

Where \( s \) is the surface condition parameter and varies from 0 to 1.

The appropriate physical boundary conditions are given by

\[ u = 0 \quad , \quad N = N_o \quad , \quad T = cx \quad , \quad C = C1 \quad \text{on} \quad y = -L \]
\[ u = 0 \quad , \quad N = N_o \quad , \quad T = cmx \quad , \quad C = C2 \quad \text{on} \quad y = +L \]  

(6)

Where \( m \) is the wall temperature ratio parameter and \( c \) is the varying temperature.

Introducing the dimensionless functions \( f, g, \theta, \phi \), defined by

\[ \eta = \frac{y}{L}, u = \frac{U_0}{S}, f, T = \frac{cL}{S} \theta, C = \frac{L}{S} \phi, N = \frac{U_o}{L S} g, U_0 = \frac{D \beta g_c L^2 c}{\mu}, S = \frac{k \mu U_o^2}{k_f c l} \]  

(7)

The set of differential equations (1)-(4) can be written in the following form:

\[ (1 + R) \frac{d^2 f}{d\eta^2} + R \frac{d g}{d\eta} + \left( \theta + N \phi \right) - (D^{-1} + M^2) f = \frac{\mu U_o^2}{k_f \rho g_c \beta (cL)^2} \frac{dP}{dx} \]  

(8)

\[ A \frac{d^2 g}{d\eta^2} - \frac{df}{d\eta} = 2g = 0 \]  

(9)

\[ \frac{d^2 \theta}{d\eta^2} + \frac{(1 + R)}{2} \left( \frac{df}{d\eta} \right)^2 + \frac{R}{2} \left( \frac{dg}{d\eta} + 2g \right)^2 + AR \frac{dg}{d\eta} - \alpha \theta + Q_o \phi = 0 \]  

(10)

\[ \frac{d^2 \phi}{d\eta^2} - \gamma \phi = 0 \]  

(11)

Where \( R = k / \mu \) is the dimensionless micropolar parameter, \( A = \frac{\gamma}{kL} \) is the dimensionless micro rotation parameter, \( \Delta P = \frac{\mu U_o^2}{k_f \rho g_c \beta (cL)^2} \frac{dP}{dx} \) is the pressure gradient parameter, \( D^{-1} = \frac{L}{k} \) is the Darcy parameter, \( S_c = \frac{V}{D_m} \) is the Schmidt number, \( N = \frac{\beta^* \Delta C}{\beta \Delta T} \) is the buoyancy ratio.
where \( \mathbf{v} = (u,0,0) \) is the velocity, \( T, C \) are the temperature and Concentration, \( p \) is the pressure, \( \rho \) is the density of the fluid, \( C_p \) is the specific heat at constant pressure, \( \mu \) is the coefficient of viscosity, \( k \) is the permeability of the porous medium, \( \delta \) is the porosity of the medium, \( \beta \) is the coefficient of thermal expansion, \( k_f \) is the coefficient of thermal conductivity, \( \beta^* \) is the volumetric coefficient of expansion with mass fraction concentration, \( K_r \) is the chemical reaction coefficient and \( D_m \) is the chemical molecular diffusivity, \( q_r \) is the radiative heat flux, \( k_1 \) is the cross diffusivity and \( k'_1 \) is the chemical reaction coefficient. Here, the thermo physical properties of the solid and fluid have been assumed to be constant except for the density variation in the body force term (Boussinesq approximation) and the solid particles and the fluids are considered to be in the thermal equilibrium.

The condition: \( \Delta P = 0 \rightarrow \frac{dp}{dx} = 0 \) corresponds to a free convection flow, while non-zero values of the pressure gradient corresponds to a mixed convection flow.

The corresponding boundary conditions are

\[
\begin{align*}
f & = 0 , \quad g = \frac{LS}{U_o} N_0 = g_o, \quad \theta = \frac{x}{L} S , \quad C = 1 \quad \text{on} \ \eta = -1 \\
f & = 0 , \quad g = \frac{LS}{U_o} N_0 = g_o, \quad \theta = m \frac{x}{L} S , \quad C = 0 \quad \text{on} \ \eta = +1 \\
\end{align*}
\]

(12)

The differential equations (8)-(11) with the boundary conditions as those given in (12) have been solved numerically using the finite element technique for the different parameters, namely the pressure gradient parameter \( \Delta P \), micropolar parameter \( R \), Surface condition parameter \( g_o \), Magnetic parameter \( M \), Darcy parameter \( D^{-1} \), Schmidt number \( Sc \), heat source parameter \( \alpha \), Radiation parameter \( Nr \), Radiation absorption parameter \( Q_1 \) and the variable \( x \).

3. Method of Solution

3.1 Finite element Method:

The set of differential equations given in eqs. (8)- (11) are highly nonlinear therefore it cannot be solved analytically. Hence finite element analysis has been used in obtaining their solution. The steps involved in the finite element method are as follows:

1. Division of the domain into linear elements, called the finite element mesh.
2. Generation of the element equations using variation formulations.

3. Assembly of the element equations as obtained in steps. (2)

4. Introduction of the boundary conditions to the equations obtained in (3)

5. Solution of the assembled algebraic equations.

The assembled equations can be solved by any of the numerical technique viz., Gaussian elimination, LU Decomposition method etc.

3.2 Variation formulation:

To solve these differential equations with the corresponding boundary conditions, we assume if \( f^i, g^i, \theta^i, \phi^i \) the approximations of \( f \) are, \( g \), \( \theta \) and \( \phi \) we define the errors (residual) \( E^i_u, E^i_g, E^i_\theta, E^i_\phi \) as

\[
E^i_u = (1 + R) \frac{d}{d\eta} \left( \frac{df^i}{d\eta} \right) + R \frac{dg^i}{d\eta} + (\theta^i + N\phi^i) - (D^{-1} + M^2) f^i - \Delta P \quad (13)
\]

\[
E^i_g = A \frac{d}{d\eta} \left( \frac{dg^i}{d\eta} \right) - \frac{df^i}{d\eta} - 2g^i \quad (14)
\]

\[
E^i_\theta = \frac{d}{d\eta} \left( \frac{d\theta^i}{d\eta} \right) + \left( 1 + \frac{R}{2} \right) \frac{df^i}{d\eta} \left( \frac{df^i}{d\eta} \right)^2 + R \frac{df^i}{d\eta} \frac{dg^i}{d\eta} + R \left( \frac{df^i}{d\eta} + 2g^i \right)^2 + AR \frac{dg^i}{d\eta} + \alpha \theta + Q_i \phi^i \quad (15)
\]

\[
E^i_\phi = \frac{d}{d\eta} \left( \frac{d\phi^i}{d\eta} \right) - \gamma \phi^i \quad (16)
\]

Where
\[ f^i = \sum_{k=1}^{3} f_k \psi_k \]
\[ g^i = \sum_{k=1}^{3} g_k \psi_k \]
\[ \theta^i = \sum_{k=1}^{3} \theta_k \psi_k \]
\[ \phi^i = \sum_{k=1}^{3} \phi_k \psi_k \]

These errors are orthogonal to the weight function over the domain of \( e_i \) under Galerkin finite element technique we choose the approximation functions as the weight function. Multiply both sides of the equations (13 – 16) by the weight function i.e. each of the approximation function \( \psi_i^j \) and integrate over the typical three nodded linear element \((\eta_e, \eta_{e+1})\) we obtain

\[ \int_{\eta_e}^{\eta_{e+1}} E_i^j \psi_j^i d\eta = 0 \quad (i = 1,2,3,4) \quad (18) \]
\[ \int_{\eta_e}^{\eta_{e+1}} E_\phi^i \psi_j^i d\eta = 0 \quad (i = 1,2,3,4) \quad (19) \]
\[ \int_{\eta_e}^{\eta_{e+1}} E_\theta^i \psi_j^i d\eta = 0 \quad (i = 1,2,3,4) \quad (20) \]
\[ \int_{\eta_e}^{\eta_{e+1}} E_{\psi}^i \psi_j^i d\eta = 0 \quad (i = 1,2,3,4) \quad (21) \]

Where

\[ \int_{\eta_e}^{\eta_{e+1}} \left( (1 + R) \frac{d}{d\eta} \left( \frac{df^i}{d\eta} + R \frac{dg^i}{d\eta} \right) + (\theta^i + N\phi^i) - (D^{-1} + M^2) f^i - \Delta P \right) \psi_j^i d\eta = 0 \quad (22) \]

\[ \int_{\eta_e}^{\eta_{e+1}} (A \frac{d}{d\eta} \left( \frac{dg^i}{d\eta} \right) - \frac{df^i}{d\eta} - 2g^i) \psi_j^i d\eta = 0 \quad (23) \]
\[ \int_{\eta} \left( \frac{d}{d\eta} \frac{d\theta^i}{d\eta} \right) + \left( 1 + \frac{R}{2} \right) \left( \frac{df^i}{d\eta} \right)^2 + \frac{R}{2} \left( \frac{df^i}{d\eta} + 2g^i \right)^2 + AR \left( \frac{dg^i}{d\eta} \right)^2 - \alpha \partial^i + Q_1 \phi^j \psi^j d\eta = 0 \]  

(24)

\[ \int_{\eta} \left( \frac{d}{d\eta} \frac{d\phi^i}{d\eta} \right) - \gamma \phi^j \psi^j d\eta = 0 \]  

(25)

Following the Galerkin weighted residual method and integration by parts method to the equations (3.10) – (3.13) we obtain

\[ \int_{\eta} \left( 1 + R \right) \frac{d\psi^i}{dy} \frac{d\psi^j}{dy} d\eta - M^2 \int_{\eta} \left( f^i + \Delta P \right) \psi^j d\eta + R \int_{\eta} \left( \frac{dg^i}{d\eta} \right) \psi^j d\eta + \int_{\eta} \left( \partial^i + NC^i \right) \psi^j d\eta = Q_{11,j} + Q_{12,j} \]  

(26)

Where \( Q_{11,j} = \psi^j(\eta_c) \frac{df^j}{d\eta}(\eta_c) \)

\[ Q_{12,j} = \psi^j(\eta_{e+1}) \frac{df^j}{d\eta}(\eta_{e+1}) \]

\[ A \int_{\eta} \frac{d\psi^j}{d\eta} \frac{dg^j}{d\eta} d\eta - \int_{\eta} \left( \frac{df^j}{d\eta} + 2g^j \right) \psi^j d\eta = Q_{21,j} + Q_{22} \]  

(27)

Where \( Q_{21,j} = \psi^j(\eta_c) \frac{dg^j}{d\eta}(\eta_c) \)

\[ Q_{22,j} = \psi^j(\eta_{e+1}) \frac{dg^j}{d\eta}(\eta_{e+1}) \]

\[ \int_{\eta} \frac{d\psi^j}{d\eta} \left( \frac{d\theta^i}{d\eta} \right) d\eta + \int_{\eta} \left( 1 + \frac{R}{2} \right) \left( \frac{df^i}{d\eta} \right)^2 + \frac{R}{2} \left( \frac{df^i}{d\eta} + 2g^i \right)^2 + AR \left( \frac{dg^i}{d\eta} \right)^2 + \int_{\eta} \frac{d\psi^j}{d\eta} \left( \frac{d\phi^i}{d\eta} \right) \psi^j d\eta + \alpha \int_{\eta} \partial^i \psi^j d\eta + Q_{31,j} \int_{\eta} \phi^i \psi^j d\eta = Q_{31,j} + Q_{32,j} \]  

(28)

Where \( Q_{31,j} = \psi^j(\eta_c) \frac{d\theta^j}{d\eta}(\eta_c) \)

\[ Q_{32,j} = \psi^j(\eta_{e+1}) \frac{d\theta^j}{d\eta}(\eta_{e+1}) \]

\[ \int_{\eta} \frac{d\psi^j}{d\eta} \left( \frac{d\phi^i}{d\eta} \right) d\eta - \gamma \int_{\eta} \phi^i \psi^j d\eta = Q_{41,j} + Q_{42,j} \]
Where \( Q_{41,j} = \Psi_j(\eta_e) \frac{d\phi_j^i}{d\eta}(\eta_e) \)

\[ Q_{42,j} = \Psi_j(\eta_{e+}) \left( \frac{d\phi_j^i}{d\eta}(\eta_{e+}) \right) \]

Making use of equations (17) we can write above equations as

\[
\sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} (1 + R) \frac{d\psi^i_j}{d\eta} \frac{d\psi^j_i}{d\eta} d\eta - M J \sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} (\psi^i_j + \Delta P) \psi^j_i d\eta + R \sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} \left( \frac{d\psi^j_i}{d\eta} \right) \psi^j_i d\eta +
\]

\[
+ R_{Q_{11,j}} + Q_{12,j}
\]

\[
A \sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} \frac{d\psi^i_j}{d\eta} \frac{d\psi^j_i}{d\eta} d\eta - \sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} (f^k_j \frac{d\psi^i_j}{d\eta} + 2g^k_j \psi^i_j) \psi^j_i d\eta = Q_{21,j} + Q_{22}
\]

\[
\sum_{i=1}^{3} \theta_k \int_{\eta_e}^{d\eta} \frac{d\psi^i_j}{d\eta} \frac{d\psi^j_i}{d\eta} d\eta + \sum_{i=1}^{3} \eta_{a_i} \int_{\eta_e}^{d\eta} (f^k_j \frac{d\psi^i_j}{d\eta} + 2g^k_j \psi^i_j) \psi^j_i d\eta = Q_{31,j} + Q_{32,j}
\]

Choosing different \( \Psi_j^i \)'s corresponding to each element \( \eta_e \) in the equation (30) yields a local stiffness matrix of order 3×3 in the form

\[
(f^k_j)(u^k_i) - \Delta G(g^k_i)(\theta^k_j + \Delta \theta^k_i) + \Delta D^{-1}(m^k_i)(u^k_i) + \Delta^2 A(n^k_i)(u^k_i) = (Q^k_{x,j}) + (Q^k_{z,j})
\]

Likewise the equation (32) & (33) gives rise to stiffness matrices

\[
(e^k_i)(C^k_i) - PNC(m^k_i)(u^k_i) = R^k_{1,j} + R^k_{2,j}
\]

\[
(l^k_i)(\theta^k_i) - P, N, (r^k_i)(\theta^k_i) = S^k_{1,j} + S^k_{2,j}
\]

Where \((f^k_i), (g^k_i), (m^k_i), (n^k_i), (e^k_i), (l^k_i)\) are 3×3 matrices and \((Q^k_{2,j}), (Q^k_{x,j}), (R^k_{1,j}), (R^k_{2,j}), (S^k_{1,j}), (S^k_{2,j})\) are 3×1 column matrices and such stiffness matrices (30) – (32) in terms of local nodes in
each element are assembled using inter element continuity and equilibrium conditions to obtain the coupled global matrices in terms of the global nodal values of k, \( \theta \) & C. In case we choose \( n \)-quadratic elements then the global matrices are of order \( 2n+1 \). The ultimate coupled global matrices are solved to determine the unknown global nodal values of the velocity, temperature and concentration in fluid region. In solving these global matrices an iteration procedure has been adopted to include the boundary and effects in the porous region.

The shape functions corresponding to

\[
\begin{align*}
\psi_1^i &= \frac{(y-4)(y-8)}{32} \\
\psi_2^i &= \frac{(y-2)(y-4)}{8} \\
\psi_3^i &= \frac{(3y-4)(3y-8)}{32} \\
\psi_4^i &= \frac{(y-1)(y-2)}{2} \\
\psi_5^i &= \frac{(5y-4)(5y-8)}{32}
\end{align*}
\]

\[
\begin{align*}
\psi_1^j &= \frac{(y-12)(y-16)}{32} \\
\psi_2^j &= \frac{(y-6)(y-8)}{8} \\
\psi_3^j &= \frac{(3y-12)(3y-16)}{32} \\
\psi_4^j &= \frac{(y-3)(y-4)}{2} \\
\psi_5^j &= \frac{(5y-12)(5y-16)}{32}
\end{align*}
\]

\[
\begin{align*}
\psi_1^k &= \frac{(y-20)(y-24)}{32} \\
\psi_2^k &= \frac{(y-10)(y-12)}{8} \\
\psi_3^k &= \frac{(3y-20)(3y-24)}{32} \\
\psi_4^k &= \frac{(y-5)(y-6)}{2} \\
\psi_5^k &= \frac{(5y-20)(5y-24)}{32}
\end{align*}
\]

4. STIFFNESS MATRICES

The global matrix for \( \theta \) is

\[ A_3 X_3 = B_3 \] (37)

The global matrix for N is

\[ A_4 X_4 = B_4 \] (38)

The global matrix g is

\[ A_5 X_5 = B_5 \] (39)

The global matrix \( f' \) is

\[ A_5 X_6 = B_6 \] (40)

The global matrix equations are coupled and are solved under the following iterative procedures. At the beginning of the first iteration the values of \( (f_i) \) are taken to be zero and the global equations (37) & (38) are solved for the nodal values of \( \theta_i \) and \( \phi_i \). These nodal values \( (\theta_i), (\phi_i) \) and \( (g_i) \) obtained are then used to solve the global equation (40) to obtain \( (f_i) \). In the second iteration these \( (f_i) \) values are obtained are used in (37) & (38) to
calculate (θi) and (ϕi) and vice versa. The four equations are thus solved under iteration process until two consecutive iterations differ by a pre-assigned percentage.

4. SHEAR STRESS, NUSSELT NUMBER AND SHERWOOD NUMBER

The shear stress on the boundaries \( y = \pm 1 \) in the non-dimensional form is

\[
\tau_{y=\pm1} = \left( \frac{df}{dy} \right)_{y=\pm1}
\]

The rate of micro rotation on the boundaries \( y = \pm 1 \) in the non-dimensional form is

\[
m_{y=\pm1} = \left( \frac{dg}{dy} \right)_{y=\pm1}
\]

The rate of heat transfer (Nusselt Number) is given by

\[
Nu_{y=\pm1} = \left( \frac{d\theta}{dy} \right)_{y=\pm1}
\]

The rate of mass transfer (Sherwood Number) is given by

\[
Sh_{y=\pm1} = \left( \frac{dC}{dy} \right)_{y=\pm1}
\]

5. DISCUSSION OF RESULTS:

The velocity, micro rotation, temperature and concentration have been evaluated by employing the finite element method and the results as shown graphically in fig 1a – 4a. The values of material constants \( S, L \) and \( A \) are taken to be fixed at 1.0 each while \( m \) is kept to be fixed at 2.0 and the effect of other important parameters, namely pressure gradient parameter \( \Delta p \), micropolar parameter \( R \), buoyancy ration, Schmidt number \( Sc \), surface condition go, heat source and parameter \( \gamma, \alpha \), chemical reaction parameter \( \gamma \), radiation absorption parameter \( Q_1 \) and axial distance \( x \).
Figs. 1a, 1b and 1c represent the variation of velocity, micro rotation and temperature function with pressure gradient $\Delta p$, while other parameters $x$, $R$, $g_0$, $Sc$, $N$, $\alpha$, $\theta$ are assumed to be fixed as 1, 1, 3, 1.3, 1, 2, 0.5 respectively.

The velocity decreases with increase in the pressure gradient parameter $\Delta p$. It is also clear from the figure that with an increase in $\Delta p$, the maxima are shifted towards the right hand plate ($\eta = 1$). An increase in $x$, micropolar parameter $R$, $|g_0|$ leads to an increase in the velocity $f$ (figs. 1b, 2b, 3b). Fig. 3a represents $f$ with Schmidt number $Sc$. It can be seen from the profiles that lesser the molecular diffusivity smaller the velocity $f$ in the flow region. Fig. 2a shows the variation of $f$ with buoyancy ratio $N$. When the molecular buoyancy force dominates over the thermal buoyancy force, the velocity enhance when the buoyancy forces are in the same direction and for the forces acting in opposite directions, it reduces in the flow region. The variation of $f$ with heat source parameter $\alpha$ shows that the velocity (fig. 4a). Fig. 5a represents $f$ with chemical reaction parameter. The velocity reduces both in the degenerating and generating chemical reaction cases. An increase in the radiation absorption parameter $Q_1$ results in an enhancement in the velocity $f$ (fig. 6a).

Figs. 5b, 6b, 7b, 8b & 9b depict the variation of micro ration. Fig. 8a shows that in the first half-region the micro rotation increases with an increase of the pressure gradient parameter while it reduces in the second half region which is opposite to $x$ and micropolar parameter $R$ as shown in figs. 7a & 9a.

From fig. 8b it is clear that micro rotation increases with the increase of the surface condition parameter $g_0$. It is also clear the fig. 8b that for the positive values $g_0$, micro rotation decreases continuously, until it reaches the minima and then increases continuously, while with the negative value of $g_0$, micro rotation increases continuously until it reaches the maxima and then decrease continuously. Thus the pattern is different for negative and positive values of $g_0$.

Fig. 2b depicts the micro rotation with buoyancy ratio $N$. It is found that micro rotation enhances in the first half region and reduces in the second half region with increase in $N>0$, and an increase in $|N|$ ($<0$), reduces micro ration in the first half region and enhances in the second half region. Fig. 3b depict micro ration with $Sc$. It is found that lesser the molecular diffusivity larger micro rotation in the first half region and reduces in the second half region.

Fig. 4b represents $g$ with heat source parameter $\alpha$. It can be seen from the profiles that micro rotation enhances in the first half region and reduces in the second half region with
increase in the strength of the heat generating source ($\alpha>0$) while in the case of heat absorption of heat source ($\alpha<0$), micro rotation reduces with $|\alpha|\leq 6$ and enhances with higher $|\alpha|\geq 10$. With reference to the chemical reaction parameter $\gamma$, we find that micro rotation enhances in the first half region and reduces in the second half region in both degenerating and generating chemical reaction cases (fig. 6b).

An increase in $Q_1$ reduces micro rotation in the first half region and enhances in the second half region (fig. 7b).

The non-dimensional temperature ($\theta$) is shown in figs. 2c, 3c, 4c, 5c, 6c, 7c, 8c&9c for different parametric values. Temperature decreases with the increase of the pressure gradient parameter, while it increases with increasing $x$, micropolar parameter $R\leq 2$ decreases with higher $R\geq 3$, and with the absolute value of surface condition parameter $|g_0|$ (fig. 8a, 8b, 8c). From fig. 2c we find that when the molecular buoyancy force dominates over the thermal buoyancy force the temperature enhances when the buoyancy forces are in the same direction and for the forces acting in opposite directions, it depreciates in the entire flow region. Lesser the molecular diffusivity smaller the temperature in the flow region (fig. 3c). From fig. 4c we notice depreciation in the temperature with increase in the strength of the heat generation/absorption source (fig. 4c). With reference to the chemical reaction parameter $\gamma$, we find that the temperature experiences depreciation in both degenerating and generating chemical reaction cases (fig. 6c). An increase in the radiation absorption parameter $Q_1$, results in an enhancement in the temperature in the entire flow region (fig. 7c).

Figs. 3d & 5d represent the concentration distribution with Schmidt number $Sc$ and chemical reaction parameter $\gamma$. It is found from fig. 3d that lesser the molecular diffusivity lesser the concentration in the entire flow region. With reference to $\gamma$, we notice depreciation in the concentration in both degenerating and generating chemical reaction cases (fig. 5d).

The skin friction ($\tau$) on the plates $\eta = \pm 1$ is shown in table. 1. It is found that the skin friction reduces with increase in $\Delta p$, and $Sc$, enhances with absolute value of surface condition $g_0$ and axial distance $x$. An increase in the micropolar parameter $R\leq 2$ leads to an increase in $|\tau|$ and reduces with higher $R\geq 3$. When the molecular buoyancy force dominates over the thermal buoyancy force $|\tau|$ enhances at $\eta = \pm 1$ and reduces at $\eta = \pm 1$ irrespective of the directions of the buoyancy forces. With reference to the chemical reaction parameter $\gamma$, we find that $|\tau|$ reduces at $\eta = \pm 1$ in the degenerating chemical reaction and enhances at $\eta = \pm 1$ in
the generating case. The variation of $\tau$ with radiation absorption parameter $Q_1$ shows that $|\tau|$ enhances with increase in $Q_1 \leq 1.5$ and reduces with higher $Q_1 \geq 2.5$ at both the plates.

The rate of micro rotation ($g'$) at $\eta = \pm 1$ is shown in table 2. It is found that $g'$ enhances with increase in $\Delta p$, $|g_0|$, $x$ at $\eta = \pm 1$. At $\eta = -1$, the rate of micro rotation enhances with $R \leq 2$ and reduces with $R \geq 3$. While at $\eta = -1$, it reduces at $\eta = +1$.

The variation of $g'$ with Schmidt number shows that the rate of micro rotation enhances at $\eta = +1$ and reduces $\eta = -1$ with increase in $Sc$. Thus lesser the molecular diffusivity larger $|g'|$ at $\eta = +1$ and smaller $\eta = -1$ with respect to chemical reduction parameter $\gamma$. We find that the rate of micro rotation enhances in the degenerating chemical reaction case and enhances in the chemical reaction case at $\eta = +1$ while $\eta = -1 |g'|$ exhibited reversed effect. An increase in the radiation absorption parameter $Q_1$ reduces $|g'|$ at $\eta = +1$ and enhances $\eta = -1$.

The rate of heat transfer (Nusselt number) at $\eta = \pm 1$ is exhibited in table (3) for different parameter values. It is found that the rate of heat transfer reduces with increase in $\Delta p$ & $Sc$ and enhances with increase in $x$ at both the walls with respect to micro rotation parameter $R$ we find that the rate of heat transfer enhances $R \leq 2$ and reduces with $R \geq 3$ at $\eta = -1$ & $\eta = +1$. $|Nu|$ enhances with $R$. with respect to surface condition parameter ‘$g_0$’ we notice and enhancement at $Nu$ at $\eta = \pm 1$ with increases in the absolute value of $g_0$ with molecular buoyancy force dominates the thermal buoyancy force. The rate of heat transfer enhances at $\eta = \pm 1$ when the buoyancy force are in the same direction and for the forces acting on the opposite direction $|Nu|$ enhances $\eta = +1$ and reduces at $\eta = -1$ with increase $|Nu|$. The rate of heat transfer reduces in the degenerating chemical reaction case & enhances in the generating chemical reaction case at both the walls.

The rate of mass transfer Sherwood number $\eta = \pm 1$ is shown in table l(4). It is found that the rate of mass transfer enhances at $\eta = \pm 1$ with increase in Schmidt number $Sc$ with respect to chemical reaction parameter $\gamma$ we find that the rate of mass transfer enhances at $\eta = \pm 1$ in both the degenerating & generating reaction cases.
Table 1: Table for the skin friction \((f')_\eta = +1, 1\) with different values of the pressure gradient parameter \(\Delta P\), micropolar parameter \(R\), surface condition parameter \(g_o\) and with \(x\).

<table>
<thead>
<tr>
<th>(S = L = A = 1, m = 2)</th>
<th>(\Delta P = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, N = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta)</td>
<td>(0)</td>
</tr>
<tr>
<td>(-1)</td>
<td>2.57045</td>
</tr>
<tr>
<td>(+1)</td>
<td>-3.7594</td>
</tr>
</tbody>
</table>

| \(\Delta P = R = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, N = 1\) | \(x\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 0.908524 | 1.73685 | 2.75284 | 4.2478 |
| \(+1\) | -2.07145 | -2.99482 | -4.0896 | -5.6182 |

| \(\Delta P = x = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, N = 1\) | \(R\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 1.4425 | 1.73655 | 1.88691 | 1.15303 |
| \(+1\) | -2.15038 | -2.99482 | -3.30526 | -2.97341 |

| \(\Delta P = x = R = 1, Sc = 1.3, N = 1, Q_1 = 0.5\) | \(g_o\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 2.61615 | 1.6229 | 0.97359 | 1.73655 |
| \(+1\) | -2.02436 | -2.28101 | -1.98091 | -2.99482 |

| \(\Delta P = x = R = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, N = 1, Q_1 = 0.5\) | \(Sc\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 1.81092 | 1.73655 | 1.64469 | 1.56453 |
| \(+1\) | -3.06431 | -2.99482 | -2.90846 | -2.83251 |

| \(\Delta P = R = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, Q_1 = 0.5\) | \(N\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 3.06431 | 1.73655 | 2.49876 | 1.015048 |
| \(+1\) | -2.99482 | -2.83538 | -2.83538 | -2.83538 |

| \(\Delta P = R = 1, g_o = 1, Sc = 1.3, Q_1 = 0.5\) | \(\gamma\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 1.73655 | 1.56755 | 2.02845 | 2.66559 |
| \(+1\) | -2.99482 | -2.83538 | -3.26607 | -3.84989 |

| \(\Delta P = R = 1, g_o = 1, Sc = 1.3, \gamma = 0.5, N = 1\) | \(Q_1\) | \(\eta\) | \(0\) | \(1\) | \(2\) | \(3\) |
|----------------------------------------------------------|----------------------------|----------------------------------------------------------|
| \(-1\) | 1.73655 | 2.14043 | 2.33655 | 2.49876 |
| \(+1\) | -2.99482 | -3.20618 | -3.32482 | -3.48765 |
Table 2: Table for the rate of micro rotation \((g')_\eta = +1,1\) with different values of the pressure gradient parameter \(\Delta P\), micropolar parameter \(R\), surface condition parameter \(g_o\) and with \(x\).

<table>
<thead>
<tr>
<th>(S = L = A = 1, m = 2)</th>
<th>((g')_\eta = +1,1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\Delta P)</td>
</tr>
<tr>
<td>(R = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5, N = 1)</td>
<td>(\eta)</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(x)</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(R)</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(g_o)</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(Sc)</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>+1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(\gamma)</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
<tr>
<td>(\Delta P = x = 1, g_o = 3, Sc = 1.3, \gamma = 0.5)</td>
<td>(Q_1)</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>-1</td>
</tr>
</tbody>
</table>
Table 3: Table for the Nusselt Number ($-\theta'$) with different values of the pressure gradient parameter $\Delta P$, micropolar parameter $R$, surface condition parameter $g_o$ and with $x$.

<table>
<thead>
<tr>
<th>$S = L = A = 1$, $m = 2$</th>
<th>$\Delta P$</th>
<th>$\theta'$</th>
<th>$N = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R = x = 1$, $g_o = 3$, $Sc = 1.3$, $\gamma = 0.5$, $N = 1$</td>
<td>$\eta$</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-22.0204</td>
<td>-17.6414</td>
<td>-14.6549</td>
</tr>
<tr>
<td>$\eta$</td>
<td>1.3978</td>
<td>9.47187</td>
<td>8.49759</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta P = R = 1$, $g_o = 3$, $Sc = 1.3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>-14.1674</td>
<td>-17.6414</td>
<td>-23.28</td>
<td>-34.4228</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>9.51225</td>
<td>9.47187</td>
<td>11.0653</td>
<td>16.6514</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta P = x = 1$, $g_o = 3$, $Sc = 1.3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
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<tbody>
<tr>
<td>$\eta$</td>
<td>-0.763858</td>
<td>-17.6414</td>
<td>-36.213</td>
<td>-33.371</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>-0.08809</td>
<td>9.47187</td>
<td>18.4956</td>
<td>20.9823</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>$\Delta P = x = R = 1$, $Sc = 1.3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>$\eta$</td>
<td>16.7175</td>
<td>6.27292</td>
<td>3.41488</td>
<td>9.47187</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>-10.1669</td>
<td>-4.31323</td>
<td>-7.2255</td>
<td>-17.6414</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta P = x = R = 1$, $g_o = 3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>0.24</td>
<td>0.6</td>
<td>1.3</td>
<td>2.01</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>-18.0388</td>
<td>-17.6414</td>
<td>-17.163</td>
<td>-16.7568</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>9.62896</td>
<td>9.47187</td>
<td>9.28905</td>
<td>9.13962</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta P = x = R = 1$, $g_o = 3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>1</td>
<td>2</td>
<td>-0.5</td>
<td>-0.8</td>
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</tr>
<tr>
<td>$\eta$</td>
<td>-17.6414</td>
<td>-23.8217</td>
<td>-12.6282</td>
<td>-11.59885</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>9.47187</td>
<td>12.5427</td>
<td>8.07171</td>
<td>8.10666</td>
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<table>
<thead>
<tr>
<th>$\Delta P = x = R = 1$, $g_o = 3$, $Sc = 1.3$, $Q_1 = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>0.5</td>
<td>1.5</td>
<td>-0.5</td>
<td>-1.5</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>-17.6414</td>
<td>-16.7919</td>
<td>-17.163</td>
<td>-16.7568</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
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<td>9.14508</td>
<td>9.28905</td>
<td>9.13962</td>
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</table>

<table>
<thead>
<tr>
<th>$\Delta P = x = R = 1$, $g_o = 3$, $Sc = 1.3$, $\gamma = 0.5$</th>
<th>$\eta$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta$</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>-17.6414</td>
<td>-18.4967</td>
<td>-19.2524</td>
<td>-23.2413</td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>9.47187</td>
<td>10.3481</td>
<td>10.5612</td>
<td>10.78965</td>
<td></td>
</tr>
</tbody>
</table>
Table 4: Table for the Sherwood number \((\phi)_{\eta=+1,1}\) with different values of the Schmidt number \((Sc)\), Chemical reaction parameter \((\gamma)\)

<table>
<thead>
<tr>
<th>(\Delta P=x=R=1, g_0=3, \gamma=0.5)</th>
<th>(Sc)</th>
<th>0.24</th>
<th>0.6</th>
<th>1.3</th>
<th>2.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td>-0.346716</td>
<td>-0.106936</td>
<td>2.03325</td>
<td>0.489564</td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>-0.692971</td>
<td>-1.00072</td>
<td>-1.4115</td>
<td>-1.80407</td>
<td></td>
</tr>
<tr>
<td>(\gamma)</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\eta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td>-0.106936</td>
<td>0.478467</td>
<td>-1.0015</td>
<td>-2.62194</td>
<td></td>
</tr>
<tr>
<td>+1</td>
<td>-1.00072</td>
<td>-1.78856</td>
<td>0.113995</td>
<td>1.796</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1a: Variation of \(f^'\) with \(\Delta P\)

Fig. 1b: Variation of \(g\) with \(\Delta P\)
Fig. 1c: Variation of temperature ($\theta$) with $\Delta P$

$$\Delta P=1, 2, 3, 4$$

$M=0.5, N=1, Sc=0.66, \alpha=0.5,$
$$\gamma=0.5, Q_{t}=0.5, R_{1}=1, \theta_{0}=-3, x=0.1$$

Fig. 2a: $f'$ with $N$

$$N=0.5, -0.8$$

$\Delta P=1, M=0.5$
$$Sc=0.66, \alpha=0.5,$
$$\gamma=0.5, Q_{t}=0.5,$$
$$R_{1}=1, \theta_{0}=-3, x=0.1$$

Fig. 2b: $g$ with $N$

$$N=0.5, -0.8$$

$\Delta P=1, M=0.5$
$$Sc=0.66, \alpha=0.5,$$
$$\gamma=0.5, Q_{t}=0.5,$$
$$R_{1}=1, \theta_{0}=-3, x=0.1$$
Fig. 2c: $\theta$ with $N$

Fig. 3a: $f'$ with $\text{Sc}$

Fig. 3b: $g$ with $\text{Sc}$
Fig. 3c: $\theta$ With $Sc$

$\Delta P=1$, $M=0.5$, $N=1$, $\alpha=0.5$, $\gamma=0.5$, $Q=0.5$, $R=1$, $g=0$, $x=0.1$

$Sc=0.24, 0.6, 1.3, 2.01$

Fig. 3d: $\phi$ With $Sc$

$\Delta P=1$, $M=0.5$, $N=1$, $\alpha=0.5$, $\gamma=0.5$, $Q=0.5$, $R=1$, $g=0$, $x=0.1$

$Sc=0.24, 0.6, 1.3, 2.01$

Fig. 4a: $f'$ with $\alpha$

$\alpha=0.5, 1, 1.5, 2, 2.5, 3, 3.5$

$\Delta P=1$, $M=0.5$, $N=1$, $Sc=0.66$, $\gamma=0.5$, $Q=0.5$, $R=1$, $g=0$, $x=0.1$
\[ \Delta P = 1, \ M = 0.5, \ N = 1, \ Sc = 0.66, \ \gamma = 0.5, \ Q_1 = 0.5, \ R_1 = 1, \ g_0 = -3, \ x = 0.1 \]

\[ \alpha = 0.5, 1.5, 2.5, 3.5 \]

**Fig. 4b:** \( g \) with \( \alpha \)

\[ \Delta P = 1, \ M = 0.5, \ N = 1, \ Sc = 0.66, \ \gamma = 0.5, \ Q_1 = 0.5, \ R_1 = 1, \ g_0 = -3, \ x = 0.1 \]

\[ \alpha = 0.5, 1.5, 2.5, 3.5 \]

**Fig. 4c:** \( \theta \) with \( \alpha \)

\[ \Delta P = 1, \ M = 0.5, \ N = 1, \ Sc = 0.66, \ \gamma = 0.5, \ Q_1 = 0.5, \ R_1 = 1, \ g_0 = -3, \ x = 0.1 \]

\[ \alpha = 0.5, 1.5, 2.5, 3.5 \]

**Fig. 5a:** \( f' \) with \( \gamma \)

\[ \Delta P = 1, \ M = 0.5, \ N = 1, \ Sc = 0.66, \ \alpha = 0.5, \ Q_1 = 0.5, \ R_1 = 1, \ g_0 = -3, \ x = 0.1 \]

\[ \gamma = 0.5, 1.5, -0.5-1.5 \]
Fig. 6a: $f'$ with $Q_1$

Fig. 6b: $g$ with $Q_1$

Fig. 6c: $\theta$ With $Q_1$
Fig. 7a: $f'$ with $R_1$

$\Delta P=1, M=0.5, N=1, Sc=0.66, \alpha=0.5, \gamma=0.5, Q_i=0.5, g_0=-3, x=0.1$

Fig. 7b: $g$ with $R_1$

$\Delta P=1, M=0.5, N=1, Sc=0.66, \alpha=0.5, \gamma=0.5, Q_i=0.5, g_0=-3, x=0.1$

Fig. 7c: $\theta$ With $R_1$

$\Delta P=1, M=0.5, N=1, Sc=0.66, \alpha=0.5, \gamma=0.5, Q_i=0.5, g_0=-3, x=0.1$
Fig. 8a: $f'$ with $g_0$

Fig. 8b: $g$ with $g_0$

Fig. 8c: $\theta$ with $g_0$

$\Delta P=1$, $M=0.5$, $N=1$, $Sc=0.66$, $\alpha=0.5$, $\gamma=0.5$, $Q_1=0.5$, $R_1=1$, $x=0.1$
6. **Concluding remarks**: In this work, the combined influence of chemical reaction and radiation absorption on mixed convective heat and mass transfer flow of a micropolar fluid between two vertical parallel plates with varied temperature in the presence of heat sources. The governing differential equations have been solved by applying finite element analysis.

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Fig. 9a: $f'$ with $x$

Fig. 9b: $g$ with $x$

Fig. 9c: $\theta$ with $x$
with quadratic interpolation functions. The velocity, micro rotation and temperature functions are shown graphically. The effects of magnetic field; radiation and micropolar parameter are studied. It was found that the velocity reduces both in the degenerating and generating chemical reaction cases. An increase in the radiation absorption parameter results in an enhancement in the velocity. The micro rotation enhances in the first half region and reduces in the second half region in both degenerating and generating chemical reaction. It may be concluded that the rate micro rotation enhances in the degenerating chemical reaction case and enhances in the chemical reaction case at $\eta = +1$ while $\eta = -1$ $|g'|$ exhibited reversed effect. An increase in the radiation absorption parameter $Q_1$ reduces $|g'|$ at $\eta = +1$ and enhances $\eta = -1$. The rate of heat transfer reduces in the degenerating chemical reaction case & enhances in the generating chemical reaction case at both the walls. The rate of mass transfer enhances at $\eta = \pm 1$ in both the generating & generating reaction cases.

7. REFERENCE


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