Combined Influence of Thermal Radiation, Thermo-Diffusion, Radiation Absorption on Mixed Convective Heat and Mass Transfer Flow of a Micropolar Fluid in a Vertical Channel with Variable Temperature in the presence of Heat Sources

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Abstract

The purpose of the present chapter is to analyze the thermal radiation, radiation absorption and thermo-diffusion 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. The non-linear governinmg equations have been solved by employing Galerkin finite element technique with three nodded line segments.The velocity ,micro-rotation temperature and concentration have been analysed for different variations of Rd,Sr,Q1 ,α and Δp.

Keywords: *Thermal Radiation (Rd), Thermo-Diffusion (Sr), Radiation Absorption (Q1), Micropolar Fluid(R), Heat Source(Δ_p)*

1. Introduction:

The micropolar fluid model introduced by Eringen [4] 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.

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 [10] 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 [2] 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. The problem of fully developed free convection of a micropolar fluid in vertical channels has been discussed by Chamkha *et al.* [3] and many more researchers (Srinivasacharya *et al.* [12], Gorla *et al.* [5], Nigam *et al.* [8], Lukaszewicz [7], Tulasi *et al.* [15], Kumar *et al.* [6], Sulochana et al[14]) 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.

In all the above works,the effect of thermal radiation on the flow characteristics has not been provided.The effect of radiation on MHD flow,heat and mass transfer problems has become important industrially.At high operating temperatures,radiation effect can be quite significant, many processes in engineering areas occur at high temperatures and knowledge of radiation heat and mass transfer ecomr very important for design of reliable equipment ,nuclear plants,gas turbines and various oropulsion devices or aircfarcts,missiles, satellites, and space vehilcles.Abo-eldohad and Ghomaim[1] analysed the radiation effects on heat transfer of a micropolar fluid through a porous medium. Rahman and Sultana[9] have studied the steady convective flow of a micropolar fluid past a vertical porous flat plate in the presence of radiation with variable heat flux in porous medium.The effects of thermal radiation.

From the scientific point of view, flow arising from temperature and material difference is applied in chemical engineering, geothermal reservoirs, aeronautics and astrophysics. In some applications, magnetic forces are present, and at other times, the flow is further complicated by the presence of radiation absorption, an excellent paradigm of this is in the planetary atmosphere where there is radiation absorption from nearby stars.The influence of magnetic field on the flow of an electrically conducting viscous fluid with mass transfer and radiation absorption is also useful planetary atmosphere research (Shercliff [11]). Umavathi And Malasetty [16] have studied the problem of combined mixed convection flow in a vertical channel with symmetric and asymmetric boundary heating in the presence of viscous and joulean dissipations.The effect of chemical reaction and radiation absorption in the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with a heat source and suction were studied (Sudheer Babu[13]).

The purpose of the present chapter is to analyze the combined influence of chemical reaction, thermal radiation, radiation absorption and thermo-diffusion 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 analyse a fully developed laminar convective heat and mass transfer flow of a viscous, electrically conducting micropolar 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 cx and mcx being the temperature of the left (y=0) 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.

The governing equations of this type of flow with thermal radiation and Boussinesqu approximation are

Momentum:

$$(\mu+k)\frac{d^2u}{dy^2}+k\frac{d\omega}{dy}-\frac{dP}{dx}+\rho_e g(\beta T+\beta^* C)-(\frac{\mu}{k})u-(\frac{\sigma\mu_e^2H_o^2}{\rho_e})u=0 \qquad (2.1)$$

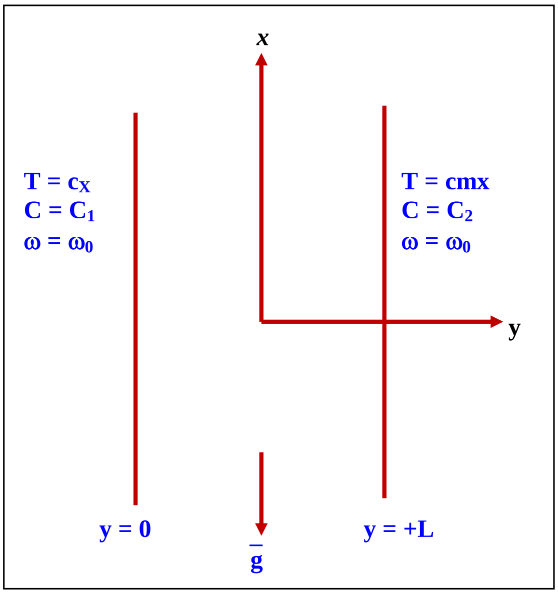

Fig.1. : Configuration of the Problem

Angular Momentum:

$$\gamma \frac{d^2\omega}{dy^2} - k\frac{du}{dy} - 2k\omega = 0 \qquad (2.2)$$

Energy equation:

$$k_f \frac{d^2T}{dy^2} + (\mu + \frac{k}{2})(\frac{du}{dy})^2 + \frac{k}{2}(\frac{du}{dy} + 2\omega)^2 + \gamma(\frac{d\omega}{dy})^2 - Q_H T + + Q_1^{'} C + \frac{16\sigma^{\bullet} T_\infty^3}{3\beta_R}\frac{\partial^2 T}{\partial y^2} = 0 \qquad (2.3)$$

Diffusion equation:

$$D_m \frac{d^2C}{dy^2} - k_c C + \frac{D_m K_T}{T_m}\frac{d^2T}{dy^2} = 0 \qquad (2.4)$$

$$N(x,o) = -s(\frac{\partial u}{\partial y})_{y=0} \qquad (2.5)$$

where s is the surface condition parameter and varies from 0 to 1.

The appropriate physical boundary conditions are given by

$$\left.\begin{array}{lllll} u = 0 & , \omega = \omega_o & T = cx & C = C1 & on \quad y = 0 \\ u = 0 & , \omega = \omega_o & T = cmx & C = C2 & on \quad y = +L \end{array}\right| \qquad (2.6)$$

where m is the wall temperature ratio parameter and c is the varying temperature.
Introducing the dimensionless functions f, g,θ and ϕ.defined by

$$\eta = \frac{y}{L}, u = \frac{U_0}{S} f, T = \frac{cL}{S}\theta, C = \frac{L}{S}\phi, N = \frac{U_o}{LS} g, U_0 = \frac{\rho\beta g_e L^3 c}{\mu}, S = \frac{\mu U_o^2}{k_f cl} \qquad (2.7)$$

Wherex,y, u,T,C,μ,k, D_m K_T T_m ,Cp,Cs,L,Uo, β , β^* ,No,N1,θ,ϕ,ω,η,C1,C2,kf,s,Q_H, $Q_1^{'}$ are defined in the Nomenclature of the thesis.

The set of differential equations (5.1)-(5.4) can be written in the following form:

$$(1+\Delta)\frac{d^2 f}{d\eta^2} + \Delta\frac{dg}{d\eta} + (\theta + N\varphi) - (D^{-1} + M^2) f = \frac{\mu U_o^2}{k_f \rho g_e \beta (cL)^2}\frac{dP}{dx} \qquad (2.8)$$

$$A\frac{d^2g}{d\eta^2}-\frac{df}{d\eta}-2g=0 \qquad (2.9)$$

$$(1+\frac{4Rd}{3})\frac{d^2\theta}{d\eta^2}+(1+\frac{R}{2})(\frac{df}{d\eta})^2+\frac{\Delta}{2}(\frac{df}{d\eta}+2g)^2+A\Delta(\frac{dg}{d\eta})^2-\alpha\theta+Q_1\varphi=0 \qquad (2.10)$$

$$\frac{d^2\varphi}{d\eta^2}-\gamma\varphi+ScSo\frac{d^2\theta}{d\eta^2}=0 \qquad (2.11)$$

Where R=k/μ is the dimensionless micropolar parameter, $A=\frac{\gamma}{kL^2}$ is the dimensionless micro rotation parameter, $\Delta P=\frac{\mu U_o^2}{k_f\rho g_e\beta(cL)^2}\frac{dP}{dx}$ is the pressure gradient parameter, $D^{-1}=\frac{L^2}{k_1}$ Is the Darcy parameter, $Sc=\frac{\nu}{D_m}$ is the Schmidt number, $N=\frac{\beta^*\Delta C}{\beta\Delta T}$ is the buoyancy ratio , $Rd=\frac{4\sigma^\bullet T_e^3}{\beta_R k_f}$ is the radiation parameter, $So=\frac{D_mK_T(T_1-T_2)}{T_m(C_1-C_2)}$ is the Soret parameter 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 tranasformed boundary conditions are

$$\begin{aligned} &f=0\ ,\ g=\frac{LS}{U_o}N_0=g_o,\theta=\frac{x}{L}S\ ,\ C=1\quad on\ \eta=0\\ &f=0\ ,\ g=\frac{LS}{U_o}N_0=g_o,\theta=m\frac{x}{L}S\ ,\ C=0\quad on\ \eta=+1\end{aligned} \qquad (2.12)$$

The differential equations (2.8)-(2.11) with the boundary conditions as those given in (5.12) have been solved numerically using the finite element technique for the different parameters, namely the pressure gradient parameter ΔP, micropolar parameter R, Surface condition parameter go, Magnetic parameter M, Darcy parameter D^{-1}, Schmidt number Sc, heat source parameterα, Radiation parameter Rd, Radiation absorption parameter Q1 and the variable x.

3. Method of Solution:

The set of differential equations given in equations (2.8)-(2.11) 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.

4. Shear Stress, Nusselt Number and Sherwood Number:

The shear stress on the boundaries $y=0,1$ in the non-dimensional form is $\tau_{y=0,1}=(\frac{df}{dy})_{y=0,1}$

The rate of micro rotation (Couple stress)on the boundaries $y = 0,1$ in the non-dimensional form is $Cw_{y=0,1} = (\frac{dg}{dy})_{y=0,1}$

The rate of heat transfer (Nusselt Number) is given by $Nu_{y=0,1} = (\frac{d\theta}{dy})_{y=0,1}$

The rate of mass transfer (Sherwood Number) is given by $Sh_{y=0,1} = (\frac{d\phi}{dy})_{y=0,1}$

5. Results and Discussion :

The velocity, micro rotation, temperature and concentration have been evaluated by employing the finite element method and the results as shown graphically in Fig.2a–2d to 7a – 7d . The values of material constants S, L 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 Δp, micropolar parameter R, heat source parameter α, radiation absorption parameter Q_1 ,thermal radiation parameter Rd and Soret parameter Sr.

A velocity, and temperature reduces, micro rotation, concentration enhance with increase in the strength of the heat source(α) while f', θ enhance. ω, C reduce with increase in heat absorption source (α<0) (figs.2a-2d). Nusselt and Sherwood numbers decrease η=0 with increase in α>0 while reversed effect is noticed with α<0, a couple stress reduces η=0 and enhances at η=1 with α>0 (table 1).

Higher the radiative heat flux larger the micro-rotation and concentration and smaller the velocity, temperature in the entire flow region (figs.3a-3d). The skin friction,Nuselt and Sherwood number reduces ,couple stress enhances at the left wall with increase in Rd.At the right wall Nusselt and Sherwood numbers, couple stress reduces,skin friction enhances with increase in Rd(table.1).

An increase in micropolar parameter R, leads to an increase in the velocity (f) (Figs.(4a,4a). An increase in R reduces the micro-rotation in the first half and enhances in the second half of the channel (fig.4b). An increase in micro-rotation parameter R reduces the concentration in the first half and enhances in the second half of the channel(fig.4d). The rate of micro rotation (Cw) enhances with increase in R at η=0.At η=1,Cw reduces with R. Nu enhances with increase in R at both the walls .With respect to micro rotation parameter Nu enhances at η=0 and reduces at η=1. The rate of mass transfer (Sherwood number) enhances with R at η = 0, 1(table.1)

Higher the thermo-diffusion effects larger the micro-rotation(fig.5b) and smaller the temperature and concentration in the flow region(5c,5d).The velocity reduces in the left half and enhances in the right half of the channel(fig.5a). The skin friction enhances,Nusselt and Sherwood number reduces with increase in Sr at the left wall.At the right wall,the skin friction,Sherwood number enhances ,the Nusselt number reduces with increase in Sr.Higher the thermo-diffusion effects,smaller |Cw| at η=0 and larger at η=1(table.1).

The velocity decreases with increase in pressure gradient. The micro-rotation,temperature and concentration enhances in the left half and reduces in the right half of the channel with Δp(figs.6a-6d).The skin friction enhances at η=0 and reduces at η=1.The couple stress, Nusselt and Sherwood number reduces at η=0 and enhances at η=1 with increae in pressure gradient Δp (table.1)

An increase in the radiation absorption parameter Q_1 leads to an enhancement in the velocity, temperature(figs.7a,7c) and reduction in the concentration in the entire flow region(fig.7d).The micro-rotation reduces in the left half and enhances in the right half half of the channel(fig.7b). An increase in the radiation absorption parameter Q_1 reduces |Cw| at η = 0,1(table.1)

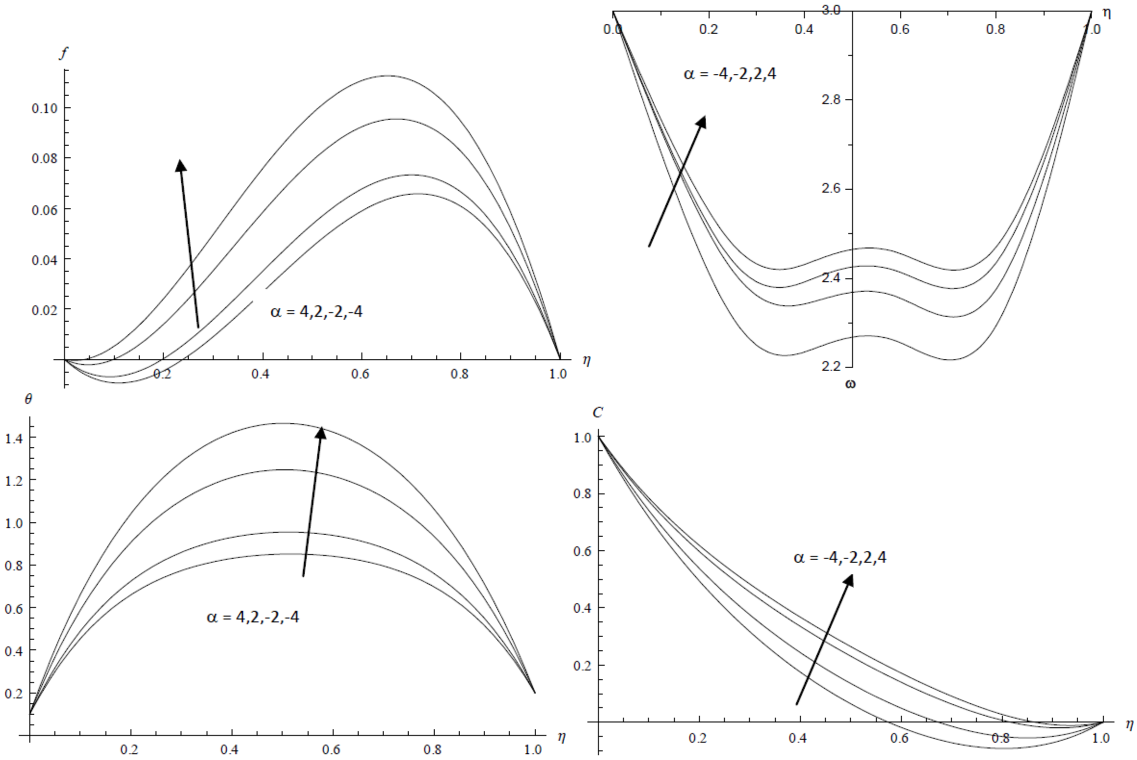

Fig.2: Variation of [a] f' , [b]ω, [c] θ, [d] C with α

Rd=0.5, R=1, Sr=0.5, Q_1=0.5, Δ_p=1

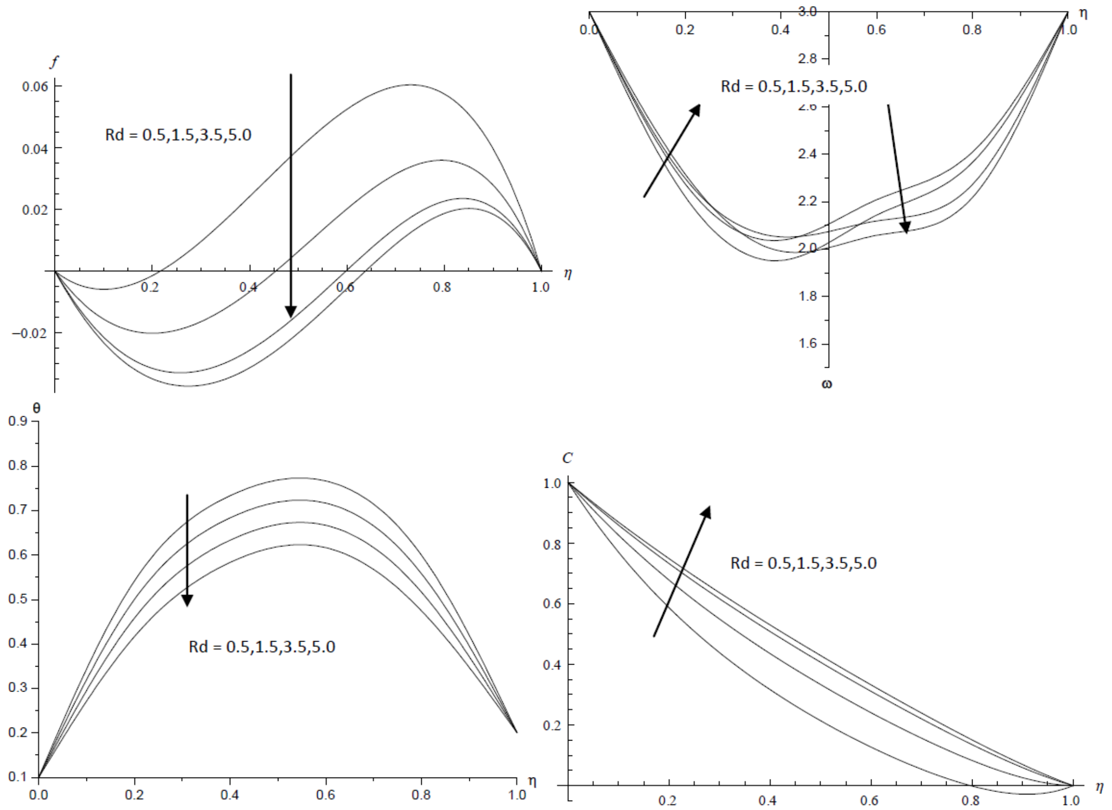

Fig.3: Variation of [a] f' , [b]ω, [c] θ, [d] C with Rd

α=2, R=1, Sr=0.5, Q_1=0.5, Δ_p=1

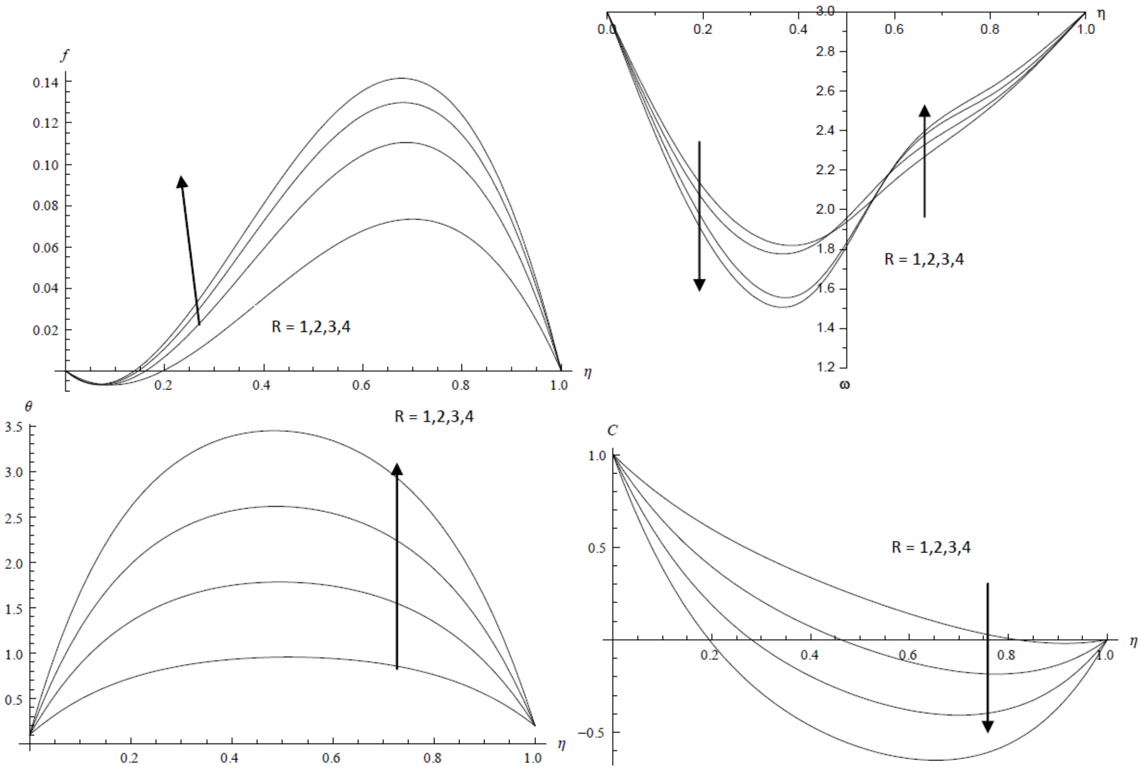

Fig.4: Variation of [a] f' , [b]ω, [c] θ, [d] C with R

Rd=0.5, α=2, Sr=0.5, Q_1=0.5, Δ_p=1

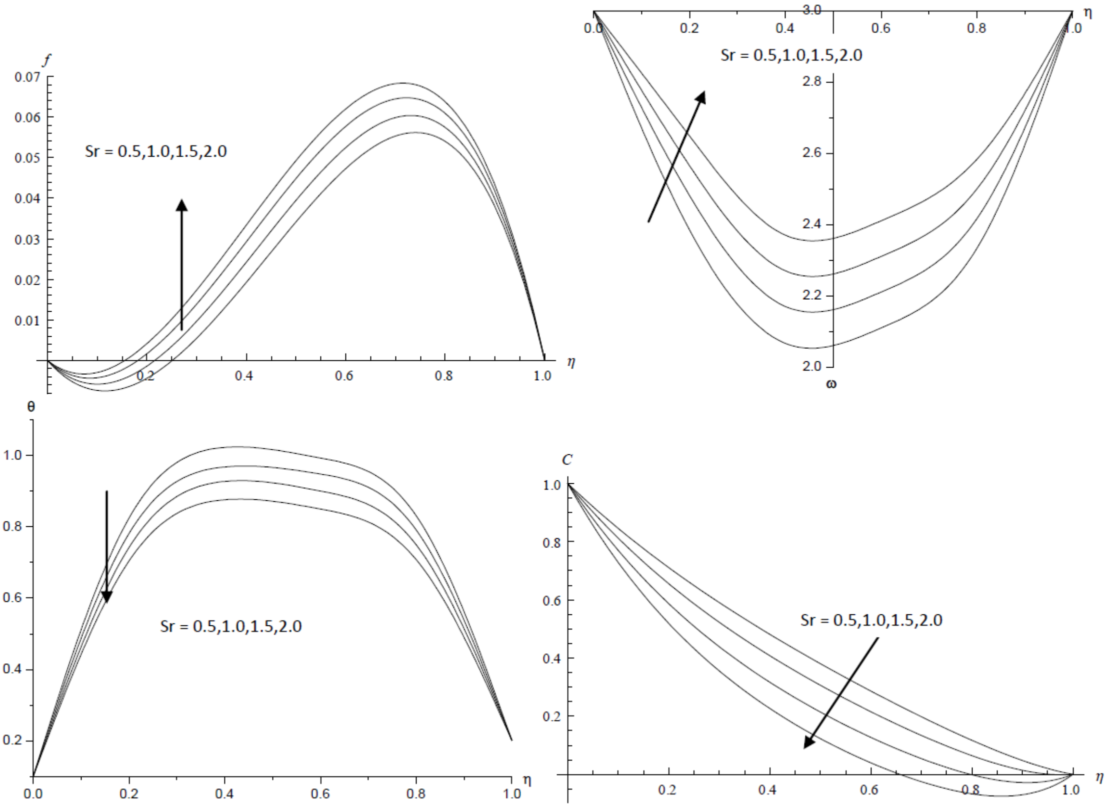

Fig.5: Variation of [a] f', [b]ω, [c] θ, [d] C with Sr

Rd=0.5, α=2, R=1, Q_1=0.5, Δ_p=1

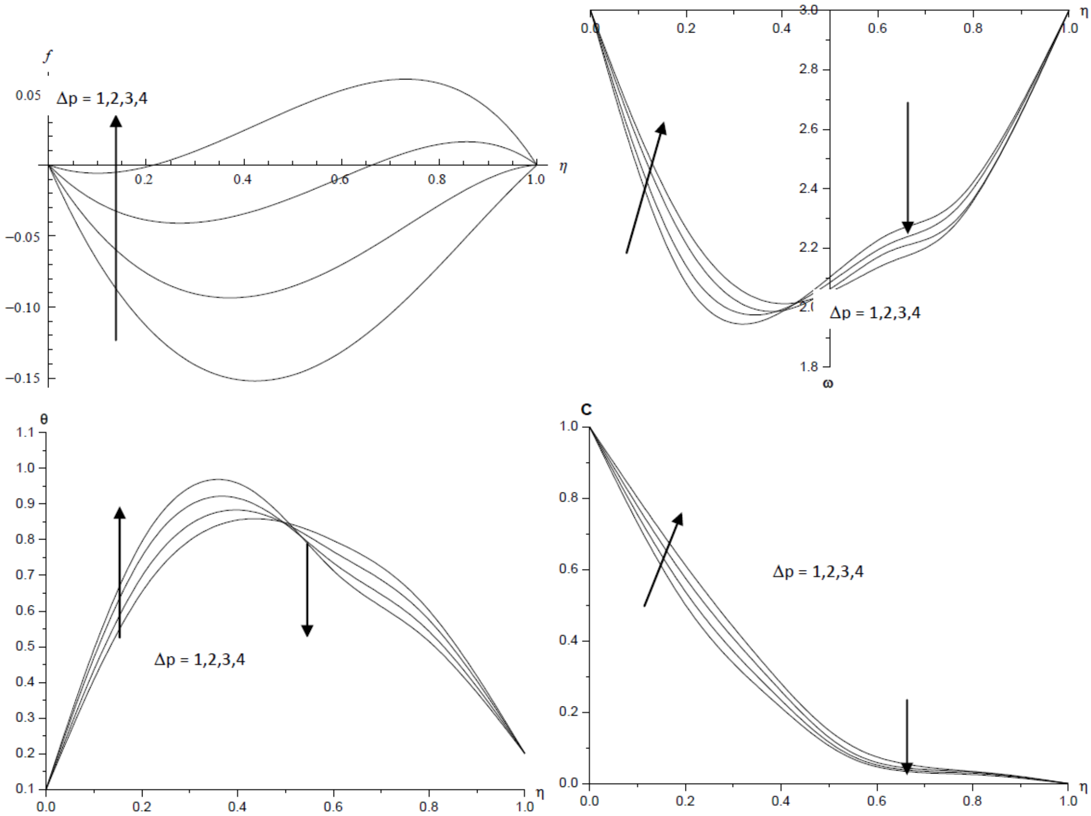

Fig.6: Variation of [a] f' , [b]ω, [c] θ, [d] C with Δ_p
Rd=0.5, α=2, R=1, Sr=0.5, Q_1=0.5

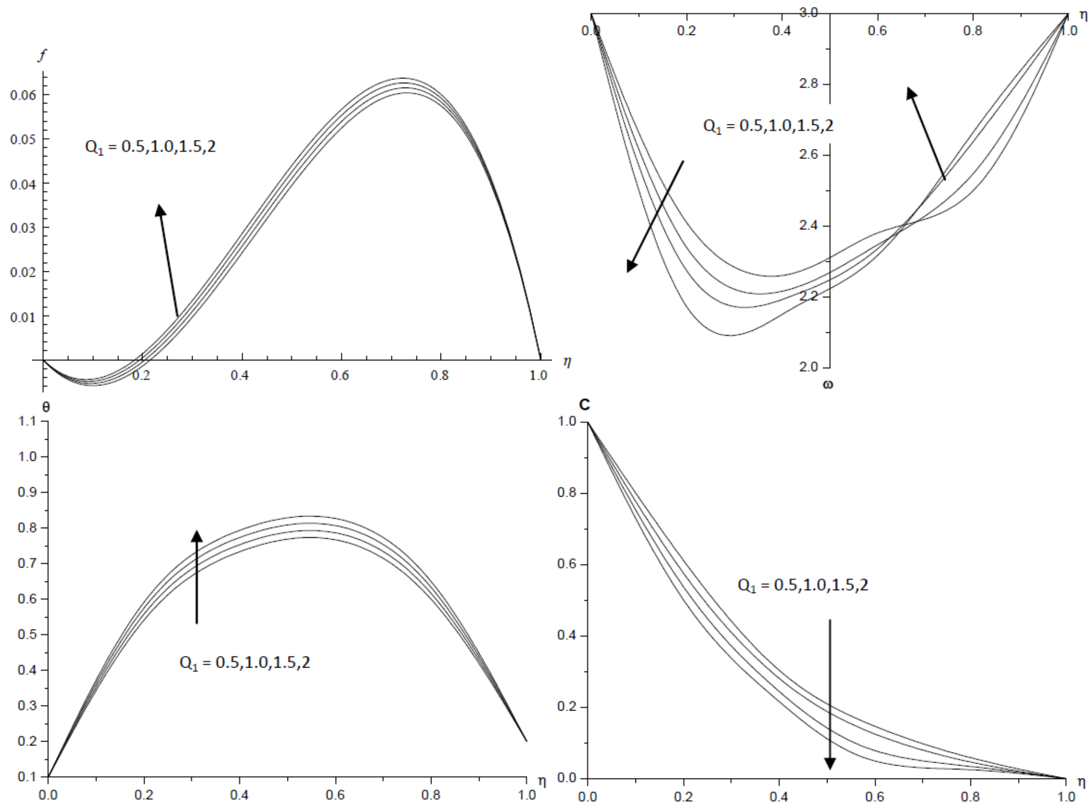

Fig.7: Variation of [a] f' , [b]ω, [c] θ, [d] C with Q1
Rd=0.5, α=2, R=1, Sr=0.5, Δ_p=1

Table. 1

Skin friction(τ),Couple stress,Nusselt number(Nu),Sherwood Number(Sh) at η=0&1

Parameter		τ(0)	τ(1)	cw(0)	cw(1)	Nu(0)	Nu(1)	Sh(0)	Sh(1)
α	2	-0.0818777	-0.648579	-4.65566	4.45089	-7.96613	7.05815	3.61554	-1.36397
	4	-0.0940002	-0.629654	-4.64613	4.46014	-7.09801	6.22991	3.33188	-1.09345
	-2	0.14121256	-0.941395	-4.74812	4.35442	-10.8083	9.32914	4.54438	-2.10463
	-4	0.27903645	-1.084855	-4.80523	4.29696	-13.1561	11.5524	5.37681	-2.76429
Rd	0.5	-0.0818777	-0.648579	-4.65665	4.45089	-7.96613	7.05815	3.61554	-1.36397
	1.5	-0.0421476	-0.698558	-4.66859	4.43684	-7.92859	6.93837	3.60335	-1.32468
	3.5	-0.0401476	-0.728558	-4.69859	4.40684	-7.82859	6.23837	3.40335	-1.30468
	5.0	-0.0659241	-0.741846	-4.75597	4.35143	-7.73662	7.29023	3.20584	-1.27455
Sr	0.5	-0.0818777	-0.648579	-4.65566	4.45089	-7.96613	7.05815	3.61554	-1.36397
	1.0	-0.0883703	-0.638957	-4.64941	4.45665	-7.82034	6.94761	5.25546	-2.86773
	1.5	-0.1334325	-0.580485	-4.63066	4.47603	-7.71562	6.55706	6.86266	-4.41518
	2.0	-0.2024337	-0.453837	-4.59905	4.51032	-7.41851	6.32013	8.43161	-6.11835
Q_1	0.5	-0.0818777	-0.648579	-4.65665	4.45089	-7.96613	7.05815	3.61554	-1.36397
	1.0	-0.0374547	-0.702257	-4.67021	4.43531	-8.09967	6.94361	3.65959	-1.32628
	1.5	-0.0329582	-0.845733	-4.60174	4.40387	-8.26715	6.9473	3.71463	-1.32737
	2.0	-0.0227105	-0.641864	-4.56044	4.44722	-8.33535	7.29649	3.76978	-1.27626
Δp	1	-0.0421476	-0.698558	-4.66859	4.43684	-7.92859	6.93837	3.60335	-1.32468
	2	-0.2653772	-0.415625	-4.58991	4.51822	-7.65646	7.14346	3.51381	-1.39237
	3	-0.4893075	-0.133113	-4.51135	4.59946	-7.39377	7.35899	3.42736	-1.46352
	4	-0.7123306	0.148963	-4.43292	4.68057	-7.14045	7.58509	3.34399	-1.53813
R	1	-0.0421476	-0.698558	-4.66859	4.43684	-7.92859	6.93837	3.60335	-1.32468
	2	-0.0223474	-0.977546	-4.71912	4.37451	-16.0632	13.7309	6.27077	-3.54991
	3	-0.0059588	-1.112151	-4.74603	4.34227	-24.3005	20.4394	8.97197	-5.74735
	4	0.0060747	-1.191153	-4.76269	4.32261	-32.5862	27.1143	11.6877	-7.93374

6. Conclusions:

An attempt has been in this chapter to analyse the combined influence of thermal radiation,thermo-diffusion and radiation absorption on MHd convective heat and mass transfer flow of an electriucally conducting fluid in a vertical channel with variable wall temperature in the presence of heat sources.The non-linear governinmg equations have been solved by employing Galerkin finite element technique with three nodded line segments.The velocity ,micro-rotation temperature and concentration have been analysed for different variations of Rd,Sr,Q1 ,α and Δp.The skin friction,couple stress,rate of heat and mass transfer on the walls are evauated for different variations.It can be observed from the profiles that the velocityreduces with increases in radiation parameter(Rd) and enhances with radiation absorption parameter(Q1).higher the thermo-diffusion effects smaller the velocity in the left half and larger in the right half of the channel.The temperature reduces with increase in Sr and Rd and enhances with Q1.The concentration reduces with Q1&Sr and enhances with Rd.The skin friction reduces with rd and Q1 and enhances with Sr and Δp.The couple stress experience a depreciation with increase in Q1,Sr, Δp and enhances with Rd on the wall η=0.The rate of heat and mass transfer enhances with Q1 and reduces with Rd&Δp.

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