Chemical Reaction and Thermal Radiation Effects on MHD Mixed Convective Oscillatory Flow Through a Porous Medium Bounded by Two Vertical Porous Plates

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Abstract: In this paper, we studied an oscillatory magneto hydrodynamic mixed convection flow of a Newtonian fluid flow through a porous medium bounded by two vertical parallel vertical porous plates is investigated. The presence of thermal diffusion, homogeneous chemical reaction and thermal radiation is considered. A magnetic field of uniform strength is applied perpendicular to the plate. The expressions for velocity, temperature and concentration are obtained by solving the non- dimensional governing equations by a regular perturbation technique. With the aid of these the expressions for Skin friction, Nusselt number and Sherwood number are derived. The effects of various emerging parameters on the velocity, temperature, concentration, skin friction, the rate of heat and mass transfer coefficients are studied in detail with the aid of graphs and tables.

Key words: MHD · Chemical reaction · Thermal radiation · Oscillatory

INTRODUCTION

MHD is applied to study the stellar and solar structure, interstellar matter, radio propagation through ionosphere etc. The ionized gas or plasma can be made to interact with the magnetic field and can frequently alter heat transfer on the bounding surface. To study the underground water resources, seepage of water in river beds, the filtration and water purification processes in chemical engineering, one need the knowledge of the fluid flow through porous medium. The porous medium is in fact a non-homogeneous medium but for the sake of analysis, it may be possible to replace it with a homogeneous fluid saturated medium which has dynamical properties equal to those of non-homogeneous continuum. Chamkha [1] addressed the problem of unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Raju and Varma [2] investigated on unsteady MHD free convection oscillatory Couette flow through porous medium with periodic wall temperature. Makinde and Mhone [3] investigated the combined effects of transverse magnetic field and radiative heat transfer in unsteady flow of a conducting optically thin fluid through a channel filled with porous medium. Effect of heat and

mass transfer on flow past an oscillatory vertical plate with variable temperature was considered by Muttucumaraswamy [4]. Ram and Mishra [5] considered MHD flow of conducting fluid through porous media. Effect of oscillatory suction and heat source on heat and mass transfer in MHD flow along a vertical porous plate bounded by porous medium was investigated by Sharma and Sharma [6]. Injection/suction effect on an oscillatory hydromagnetic flow in a rotating horizontal porous channel was considered by Singh and Mathew [7].

Heat transfer by thermal radiation is of great importance when we are concerned with space applications, higher operating temperatures and power engineering. In the processes such as drying, evaporation at the surface of water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occurs simultaneously. Thermal radiation and buoyancy effects on hydromagnetic flow over an accelerating permeable surface with heat source or sink were discussed by Chamkha [8]. Radiation effects on free convection flow past a semi-infinite vertical plate with mass transfer were discussed by Chamkha *et al.* [9]. Chemical reaction and radiation effects on unsteady MHD free convection flow near a moving vertical plate was considered by Reddy *et al.* [10]. Analytical study of MHD

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free convictive, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction was considered by Raju *et al.* [11]. Magyari and Chamkha [12] discussed the full analytical solution for combined effect of heat generation or absorption and first-order chemical reaction on micropolar fluid flows over uniformly stretched permeable surface. Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction were discussed by Kesavaiah *et al.* [13]. Gireesh kumar *et al.* [14] addressed the effects of chemical reaction and mass transfer on MHD unsteady free convection flow past an infinite vertical plate with constant suction and heat sink. Satyanarayana [15] discussed chemical reaction and thermal radiation effects on an unsteady MHD free convection flow past an infinite vertical plate with variable suction and heat source or sink. Chemically reacting unsteady MHD oscillatory slip flow in a planer channel with varying concentration was addressed by Sivaraj and Kumar [16]. Effects of thermal radiation and space porosity on MHD mixed convection flow in a vertical channel using homotopy analysis method were considered by Srinivas and Muthuraj [17]. Flow and mass transfer effects on viscous fluid in a porous channel with moving/stationary walls in presence of chemical reaction was addressed by Srinivas *et al.* [18].

The Soret effect or thermophoresis is a phenomenon observed in mixtures of mobile particles where the different particle types exhibit different responses to the force of a temperature gradient. The term Soret effect most often applies to aerosol mixtures, but may also commonly refer to the phenomenon in all phases of matter. It has been used in commercial precipitators for applications similar to electro static precipitators, manufacturing of optical fibre in vapour deposition processes, facilitating drug discovery by allowing the detection of aptamer binding by comparison of the bound versus unbound motion of the target molecule. It is also used to separate different polymer particles in fluid flow fractionation. Influence of thermal radiation on unsteady flow over an expanding or contracting cylinder with thermal-diffusion and diffusion-thermo effects was addressed by Srinivas *et al.* [18] Raju *et al.* [19] considered Soret effects due to natural convection between heated inclined plates with magnetic field. Anghel and Takhar [20] investigated the Dufour and Soret effects on free convection boundary layer over a vertical surface embedded in porous medium. Ahmed [21] studied MHD convection with Soret and

Dufour effect in a three dimensional flow past an infinite vertical porous plate. Chand *et al.* [22] investigated the hydro magnetic oscillatory flow through a porous medium bounded by two vertical porous plates with heat source and Soret effect. Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating was studied by Ananda Reddy *et al.* [2]. Recently Mamtha *et al.* [23] considered thermal diffusion effect on MHD mixed convection unsteady flow of a micro polar fluid past a semi – infinite vertical porous plate with radiation and mass transfer.

In view of these, we studied the effects of thermal radiation and thermal diffusion on the hydromagnetic oscillatory flow through a porous medium bounded by two vertical porous plates with heat source and chemical reaction. The closed form solutions are obtained for velocity, temperature and concentration fields. Various effects of emerging parameters on the velocity, temperature, concentration, skin friction, the rate of heat and mass transfer coefficients are studied in detail with the aid of graphs.

Formulation of the Problem: Consider the flow of an electrically conducting, viscous incompressible fluid through porous medium bounded by two insulated vertical porous plates distance 'd' apart in the presence of the heat source and chemical reaction. We choose a Cartesian system with origin at the stationary plate which is subjected to a constant injection velocity 'V'. The other plate moves with uniform velocity U and is subjected to same constant suction velocity 'V'. A Homogenous magnetic field of strength 'Bo' is applied normal to the plane of the plates. The plates of the channel are assumed to be infinite in extent, hence all the physical properties of the fluid will be the functions of y^* and t^* only except the pressure [24, 25].

In this analysis the following assumptions are made
- The flow considered is unsteady and laminar.
- A magnetic field of uniform strength is applied normal to the plate.
- The magnetic Reynolds number is small enough so that the induced magnetic field is neglected.
- Hall current and Joule's dissipation are neglected.
- The fluid is finitely conducting and with constant physical properties.
- Thermal and concentration buoyancy effects are considered.
- Chemical reaction effects are assumed
- The fluid is heat absorbing.

Under the usual boussinesq approximation the flow is governed by the following equations

$$\frac{\partial v^*}{\partial y^*} = 0, v^* = V \tag{1}$$

$$\frac{\partial u^*}{\partial t^*} + V^* \frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho} \frac{\partial p^*}{\partial x^*} + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\upsilon}{K^*} u^* - \frac{\sigma B_0^2}{\rho} u^* + g\beta \left(T^* - T_0^*\right) + g\beta_c \left(C^* - C_0^*\right) \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} + V^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho c_p} \frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho c_p} \frac{\partial q^*}{\partial y^*} + \frac{Q^*}{\rho c_p} \left(T^* - T_0^*\right) \tag{3}$$

$$\frac{\partial C^*}{\partial t^*} + V^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} + D_1 \frac{\partial^2 T^*}{\partial y^{*2}} - k_1^* \left(C^* - C_0^*\right) \tag{4}$$

where t^* is the time, p^* is the pressure, ρ is the fluid density, υ is the kinematic viscosity, K^* is the permeability of porous medium, g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, β_c is the volumetric coefficient of concentration expansion, C_p is the specific heat at constant pressure, D is the mass diffusivity, q^* is the radiation heat flux, k_1^* is the chemical reaction parameter.

It is assumed that the fluid is optically thin with relatively low density and radiative heat flux is given by

$$\frac{\partial q^*}{\partial y} = 4\alpha^2 T^* \tag{5}$$

where α is the mean radiation absorption coefficient
The boundary conditions of the problem are

$$u^* = 0, \quad T^* = T_O^*, \quad C^* = C_O^* \quad \text{at} \quad y^* = 0 \tag{6}$$

$$u^* = U \quad T^* = T_W^* \quad C^* = C_W^* \quad \text{at} \quad y^* = d \tag{7}$$

On introducing the following non dimensional parameters

$$x = \frac{x^*}{d}, \eta = \frac{y^*}{d}, u = \frac{u^*}{U}, t = t^* \frac{V}{d}, \mathrm{T} = \frac{T^* - T_0^*}{T_w^* - T_0^*}, C = \frac{C^* - C_0^*}{C_w^* - C_0^*}, p = \frac{p^*}{\rho U V}, \mathrm{Re} = \frac{Vd}{\upsilon},$$

$$M = B_0 d \sqrt{\frac{\sigma}{\mu}}, Pe = \frac{\rho c_p V d}{k}, K = \frac{K^* V}{\upsilon d}, Gr = \frac{g\beta v(T_W^* - T_0^*)}{UV^2}, Gm = \frac{g\beta_c \upsilon(C_W^* - C_0^*)}{UV^2},$$

$$S = \frac{Q^* d}{\rho C_p V}, S_0 = \frac{D_1(T_w^* - T_0^*)}{\upsilon(C_W^* - C_0^*)}, Sc = \frac{\upsilon}{D}, N = 2\alpha \frac{d}{\sqrt{k}}, k_1^* = \frac{kr\upsilon}{d^2}$$

In equations (1) to (4) we get the following non dimensional governing equations

$$\frac{\partial u}{\partial t} + \frac{\partial u}{\partial \eta} = -\frac{\partial P}{\partial x} + \frac{1}{\mathrm{Re}} \frac{\partial^2 u}{\partial \eta^2} - \frac{1}{K} u - \frac{M^2}{\mathrm{Re}} u + Gr \operatorname{Re} T + Gm \operatorname{Re} C \tag{8}$$

$$\frac{\partial T}{\partial t} + \frac{\partial T}{\partial \eta} = \frac{1}{Pe} \frac{\partial^2 T}{\partial \eta^2} + ST - \frac{N^2}{Pe} T \qquad (9)$$

$$\frac{\partial C}{\partial t} + \frac{\partial C}{\partial \eta} = \frac{1}{Re} \left(\frac{1}{Sc} \frac{\partial^2 C}{\partial \eta^2} + S_0 \frac{\partial^2 T}{\partial \eta^2} - krC \right) \qquad (10)$$

The non dimensional boundary conditions are

$$u = 0, \quad T = 0, \quad C = 0 \quad \text{at} \quad \eta = 0 \qquad (11)$$

$$u = 1 \quad T = 1 \quad C = 1 \quad \text{at} \quad \eta = 1 \qquad (12)$$

Solution of the Problem: In order to solve equations (8) to (10) for purely oscillatory flow. we assume the solution of the form

$$-\frac{\partial P}{\partial x} = Pe^{i\omega t}, \; u(\eta,t) = u_0(\eta)e^{i\omega t}, \; T(\eta,t) = \theta_0(\eta)e^{i\omega t} \; \text{and} \; C(\eta,t) = \phi_0(\eta)e^{i\omega t} \qquad (13)$$

Where P is a constant and ω is the frequency of oscillations
Using equation (13) in equations (18) to (10) we get

$$u_0'' - Re u_0' - m_3^2 u_0 = -Re P - Gr Re^2 \theta_0 - Gm Re^2 \phi_0 \qquad (14)$$

$$\theta_0'' - Pe\theta_0' - m_2^2 \theta_0 = 0 \qquad (15)$$

$$\phi_0'' - Re Sc\phi_0' - m_1^2 \phi_0 = -S_0 Sc\theta_0'' \qquad (16)$$

The boundary conditions (11) and (12) are reduced to the following form

$$u_0 = 0, \quad \theta_0 = 0, \quad \phi_0 = 0 \quad \text{at} \quad \eta = 0 \qquad (17)$$

$$u_0 = 1 \quad \theta_0 = 1 \quad \phi_0 = 1 \quad \text{at} \quad \eta = 1 \qquad (18)$$

The solutions of equations (14) to (16) under boundary conditions (17) and (18) are obtained as

$$u(\eta,t) = \left\{ r_{14}e^{A_6\eta} + r_{13}e^{A_5\eta} - r_7 e^{A_4\eta} - r_8 e^{A_3\eta} - r_{12}e^{A_2\eta} + r_{11}e^{A_1\eta} + \frac{P Re}{m_3^2} \right\} e^{i\omega t} \qquad (19)$$

$$T(\eta,t) = \frac{e^{A_1\eta} - e^{A_2\eta}}{e^{A_1} - e^{A_2}} e^{i\omega t} \qquad (20)$$

$$C(\eta,t) = \left\{ r_4 e^{A_4\eta} + r_3 e^{A_3\eta} + r_2 e^{A_2\eta} - r_1 e^{A_1\eta} \right\} e^{i\omega t} \qquad (21)$$

Skin –Friction, Nusselt Number and Sherwood Number: The non dimensional skin friction at the moving plate of the channel is given by

$$\tau = -\mu \left(\frac{\partial u}{\partial \eta} \right)_{\eta=1} = \left\{ A_6 r_{14}e^{A_6} + A_5 r_{13}e^{A_5} - A_4 r_7 e^{A_4} - A_3 r_8 e^{A_3} - A_2 r_{12}e^{A_2} + A_1 r_{11}e^{A_1} \right\} e^{i\omega t} \qquad (22)$$

The rate of heat transfer at the moving plate of the channel in terms of non dimensional Nusselt number is given by

$$Nu = -\left(\frac{\partial T}{\partial \eta}\right)_{\eta=1} = \left\{\frac{A_2 e^{A_2} - A_1 e^{A_1}}{e^{A_1} - e^{A_2}}\right\} e^{i\omega t} \tag{23}$$

The rate of mass transfer coefficient at the moving plate of the channel in terms of non dimensional Sherwood number is given by

$$Sh = \left(\frac{\partial C}{\partial \eta}\right)_{\eta=1} = \left\{A_4 r_4 e^{A_4} + A_3 r_3 e^{A_3} + A_2 r_2 e^{A_2} - A_1 r_1 e^{A_1}\right\} e^{i\omega t} \tag{24}$$

RESULTS AND DISCUSSION

In order to have a physical insight into the problem, we have studied numerically the effects of various physical parameters on velocity, temperature, concentration and also skin friction (τ), rate of heat transfer (Nu) and rate of mass transfer (Sh). These numerical results are then presented in graphs and tables.

Velocity profiles are presented in Figures 1-3. From Fig. 1, it is observed that the velocity decreases with an increase in radiation parameter (N). This is due to an increase in radiation parameter which leads to decrease in the momentum boundary layer thickness. The effect of chemical reaction parameter (kr) on velocity is shown in Fig. 2, from this figure it is observed that velocity decreases with an increase in chemical reaction parameter (kr). This is due to the fact that hydrodynamic boundary layer becomes thin as the chemical reaction parameter increases. For the validity of our results, we compared our results with the existing results of Chand *et al*. [7] in the absence of radiation parameter (N) and chemical reaction parameter (kr) in Figure 3. From this figure, we observe that velocity increases with increasing values of Reynolds number (Re), which is in confirmation with the fact that for larger values of Re the inertial forces will be predominant and the effect of viscosity will be confined only to the thin region adjacent to the solid surface. The agreement between these results is excellent.

Temperature profiles are presented in Figures 4-5. From Fig. 4, it is clear that temperature decreases with increasing values of radiation parameter (N). From Fig. 5, it is observed that temperature increases with an increase in heat source parameter (S).
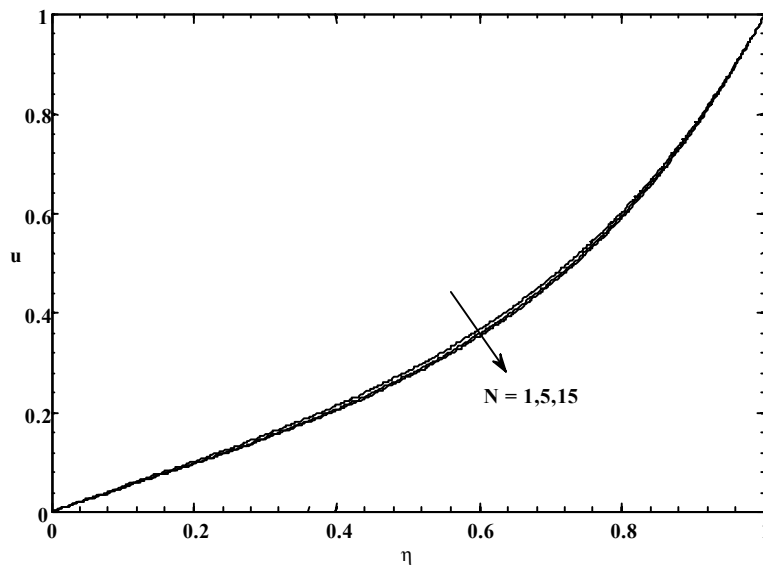

Fig. 1: Velocity profiles for different *N* with *P*=1, *K* = 0.5, *t* = 0, Re = 0.5, *M* = 2, *Pe* = 1, ω=5. *Gr* = 5, *Gm* = 5, *kr* = 0.5, *S* = 0.1, S_0 = 6.89 and *Sc* = 0.22.
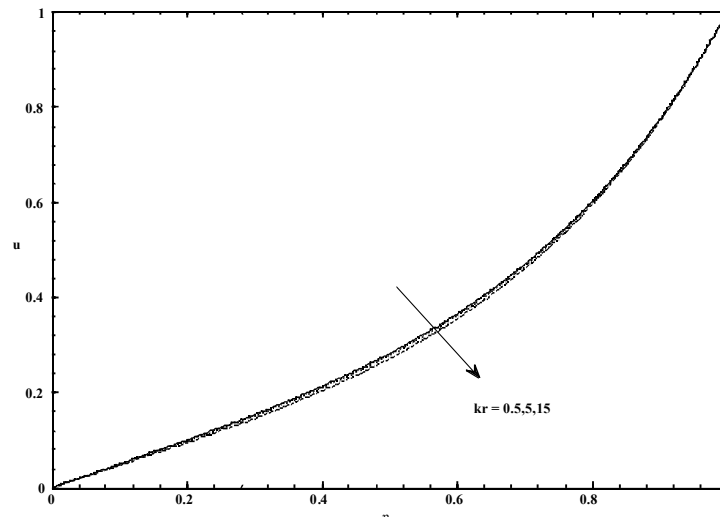
Fig. 2: Velocity profiles for different *kr* with *P*=1, *K* = 0.5, *t* = 0, Re = 0.5, *M* = 2, *Pe* = 1, *ω*=5. *Gr* = 5, *Gm* = 5, *N* = 1, *S* = 0.1, S_0 = 6.89 and *Sc* = 0.22.
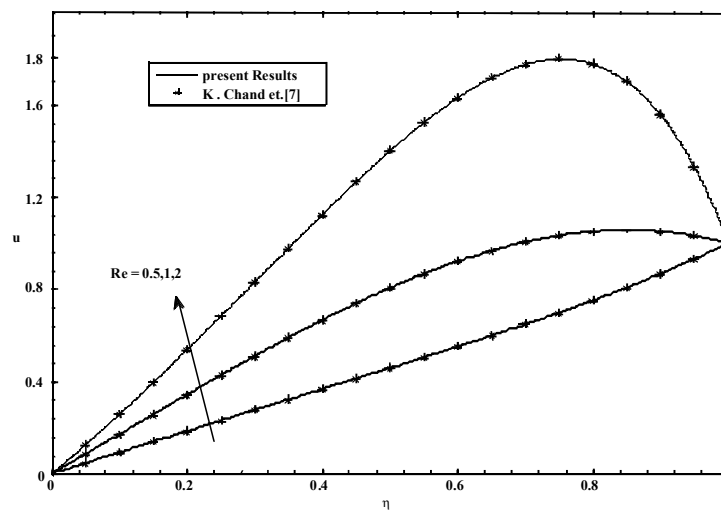
Fig. 3: Velocity profiles for for different Re with *P*=1, *K* = 0.5, *t* = 0, *M* = 2, *Pe* = 1, *ω*=5. *Gr* = 5, *Gm* = 5, *S* = 0.1, S_0 = 6.89 and *Sc* = 0.22 when *kr* = 0. *N* = 0.
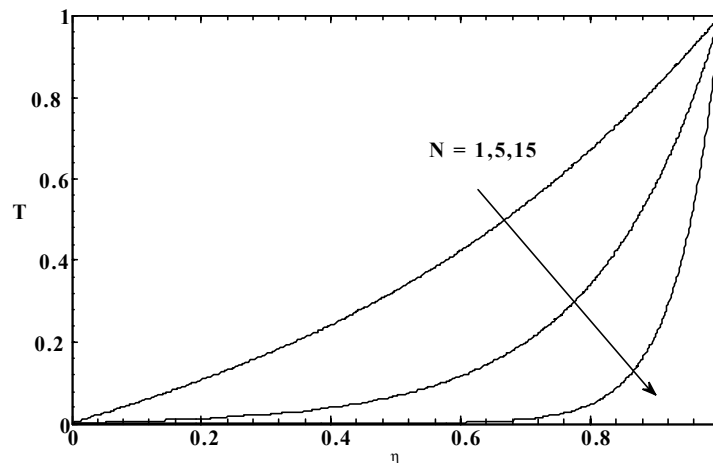
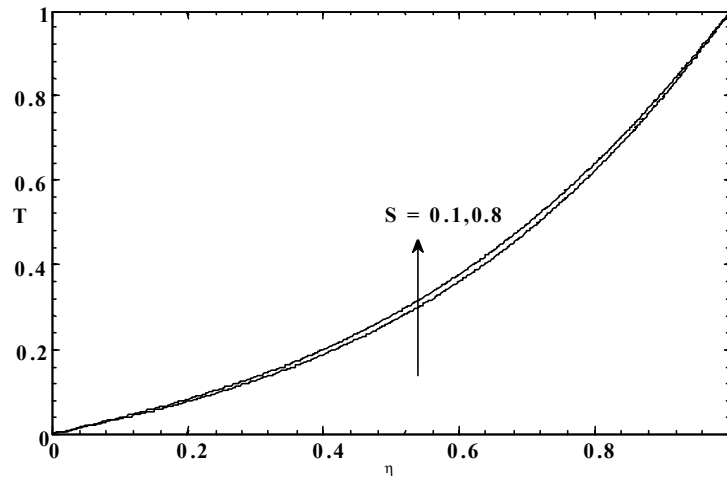Fig. 4: Temperature profiles for different *N* with *t* = 0, Re = 0.5, *Pe* = 1, *ω* = 5 and *S* = 0.1

Fig. 5: Temperature profiles for different *S* with *t* = 0, Re = 0.5, *Pe* = 1, ω = 5 and *N* = 1
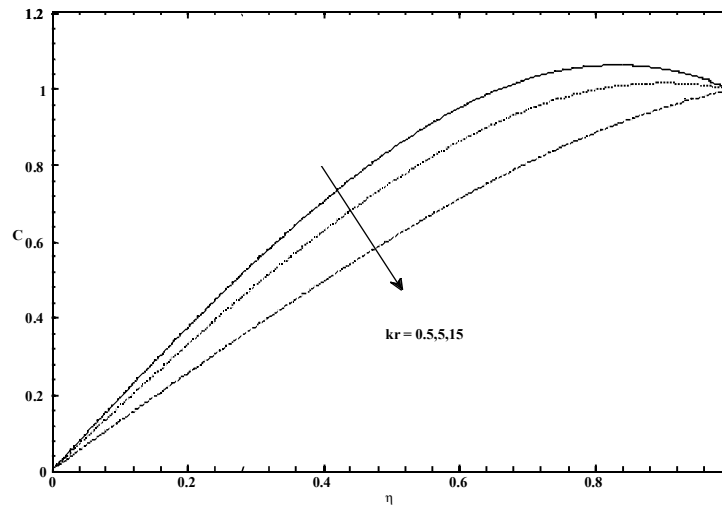

Fig. 6: Concentration profiles for different *kr* with S_0 =6.89, Re = 0.5, *Pe* = 1, ω = 5, *N* = 1, *S*=0.1. *P* = 1, S_0 = 6.89, *Sc* = 0.22 and *t* = 0
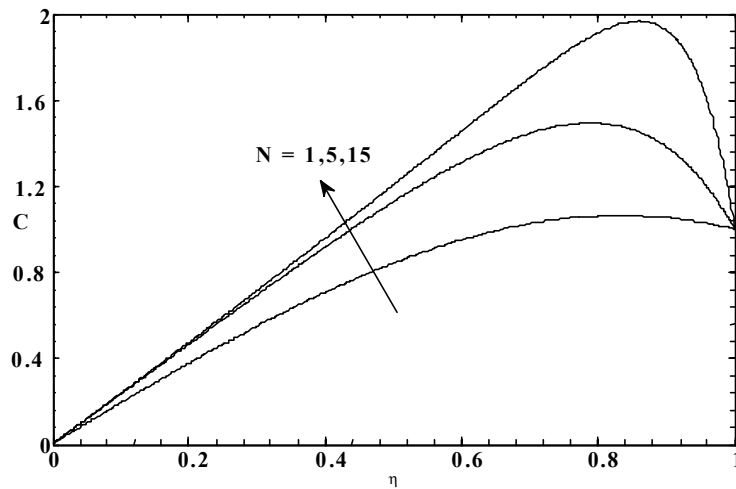

Fig. 7: Concentration profiles for different *N* with S_0 = 6.89, Re = 0.5, *Pe* = 1, ω = 5, *kr* = 0.5, *S*=0.1. *P* = 1, S_0 = 6.89, *Sc* = 0.22 and *t* = 0

Table: 1: Skin friction at t = 0

Re	kr	N	*Gm*	*Gr*	P	M	K	*Sc*	S	*Pe*	S_0	ω=0	ω=10	ω=20
0.5	0.5	1	5	5	5	2	0.5	0.22	0.1	1	6.89	0.8846	1.1314	1.7599
1	0.5	1	5	5	5	2	0.5	0.22	0.1	1	6.89	-1.7277	-0.4065	1.6286
0.5	5	1	5	5	5	2	0.5	0.22	0.1	1	6.89	0.9092	1.1625	1.7828
0.5	0.5	5	5	5	5	2	0.5	0.22	0.1	1	6.89	0.8239	1.1221	1.7687
0.5	0.5	1	10	5	5	2	0.5	0.22	0.1	1	6.89	0.4725	0.6299	1.2965
0.5	0.5	1	5	10	5	2	0.5	0.22	0.1	1	6.89	0.5980	0.9402	1.6348
0.5	0.5	1	5	5	1	2	0.5	0.22	0.1	1	6.89	1.6585	1.8440	2.3456
0.5	0.5	1	5	5	5	4	0.5	0.22	0.1	1	6.89	3.2725	3.3145	3.4896
0.5	0.5	1	5	5	5	2	1	0.22	0.1	1	6.89	0.7385	1.0103	1.6823
0.5	0.5	1	5	5	5	2	0.5	0.66	0.1	1	6.89	0.7431	0.8049	1.5716
0.5	0.5	1	5	5	5	2	0.5	0.22	0.8	1	6.89	0.8898	1.1306	1.7592
0.5	0.5	1	5	5	5	2	0.5	0.22	0.1	5	6.89	0.8266	1.0960	1.7478
0.5	0.5	1	5	5	5	2	0.5	0.22	0.1	1	2.5	0.9357	1.2560	1.8956

Table 2: Nusselt number at t = 0

Pe	S	N	ω=0	ω=10	ω=20
1	0.1	1	-1.85063	-2.8160	-3.7628
5	0.1	1	-5.1270	-7.8478	-9.8136
1	0.8	1	-1.6457	-2.7286	-3.7084
1	0.1	5	-5.5154	-5.6095	-5.8515

Table 3: compare the Nusselt number at t = 0 and N = 0

Pe	s	Present Result		K.Chand *et al.*[7]	
		ω=10	ω=20	ω=10	ω=20
1	0.1	-2.6921	-3.6855	-2.6921	-3.6855
5	0.1	-7.7950	-9.7772	-7.7950	-9.7772
1	0.8	-2.6096	-3.6328	-2.6096	-3.6328

Table 4: Sherwood number at t = 0

Re	*Sc*	S_0	N	Kr	S	*Pe*	ω=0	ω=10	ω=20
0.5	0.22	6.89	1	0.5	0.1	1	-0.2148	-1.7772	-3.1888
1	0.22	6.89	1	0.5	0.1	1	-0.1744	-1.7616	-2.8670
0.5	0.66	6.89	1	0.5	0.1	1	-2.6875	-7.6172	-10.6169
0.5	0.22	2.50	1	0.5	0.1	1	0.6181	0.0676	-0.3975
0.5	0.22	6.89	5	0.5	0.1	1	-5.7741	-5.8940	-6.1745
0.5	0.22	6.89	1	5	0.1	1	0.1693	-1.2866	-2.6475
0.5	0.22	6.89	1	0.5	0.8	1	0.1063	-1.6544	-3.1137
0.5	0.22	6.89	1	0.5	0.1	5	-5.1849	-9.3254	-12.1800

Concentration profiles are presented in Figures 6-7. Concentration is greatly influenced by chemical reaction parameter (kr) and radiation parameter (N). The influence of radiation parameter over the concentration is represented in Fig 6. From this figure it is clear that, concentration increases with an increase in radiation parameter (N). From Fig. 7, it is seen that concentration decreases with an increase in chemical reaction parameter (kr).

Table 1 shows the numerical values of the skin friction coefficient τ against frequency of oscillations at 0,10,20 for various values of Re, kr, N, Gm, Gr, K, S_c, S, Pe, S_o. We observed that as Re, Gm, Gr, Da, S_c, Pe increase, skin friction decreases. As kr and M increase, skin friction increases. An increase in N, the skin friction first decreases and then increases. As S increases skin friction first increases and then decreases. It is noticed that skin friction decreases for increasing values of P and S_0.

Table 2 shows the numerical values of heat transfer coefficient in terms of Nusselt number Nu for various of Pe, S, N. The Nusselt number decreases for increasing values of Pe and N. Whereas a reverse effect is shown in the case of S.

In the absence of radiation parameter these results are in good agreement with the results of K. Chand *et al.* [7]. It is evident from table 3 which gives the numerical values of heat transfer coefficient in terms of Nusselt number.

Table 4 represents the variation in the dimensionless rate of mass transfer coefficient i.e., the Sherwood number *Sh*. It is evident from this table that the rate of mass

transfer coefficient is increased for increasing values of Reynolds number (Re), chemical reaction parameter (*kr*) and heat source parameter (S) whereas the increase in the Schmidt number (*Sc*), Soret number (S_0) radiation parameter (N) and Peclet number (*Pe*) leads to reduction in the mass transfer.

CONCLUSION

In this chapter, we studyied the effects of chemical reaction and thermal radiation on MHD mixed convective oscillatory flow through a porous medium bounded by two vertical porous plates. The dimensionless governing equations are solved by analytical method. From the present investigation the following conclusions are drawn.

- Velocity decreases with increasing values of radiation parameter (N) and chemical reaction parameter (kr).
- Temperature decreases with increasing values of radiation Parameter N or the temperature increases with increasing values of heat source parameter S.
- Concentration decreases with increasing values of chemical reaction parameter or the concentration increases with increasing values of radiation parameter N.
- The skin friction is enhanced with the increase in chemical reaction parameter kr, pressure gradient or Hartmann number M.
- The rate of heat transfer is slightly increases for large values of heat source parameter S.

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