Heat and Mass Transfer of Free Convective Chemically Reacting Flow Past a Low -Heat - Resistance Sheet under Magnetic Effect

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Abstract—*In the present manuscript an attempt has been taken to study the heat and mass transfer of free convective MHD – Chemically reacting fluid flow problem which is passed through a low heat resistance sheet with internal heating. The physical viscous boundary layer problem is formulate in term of system of partial differential equations which is transformed into the set of coupled ordinary differential equation using similarity transformation which well documented in the book of fluid dynamics. The set of coupled differential equations solved numerically using Spectral collocation method. The Effect of different physical parameter using the wide range of respective parameters is shown graphically. The asymptomatic behavior of velocity , temperature and concentration is discussed. The parametric convergence parameters for the large value of is investigated in the present manuscript.*

Keywords*: SEM, Magnetic effect, Chemical reaction, Free convection.*

1. INTRODUCTION

The study of convective flow with heat and mass transfer under the influence of magnetic field and chemical reaction with heat source has practical applications in many areas of science and engineering. Possible applications of this type of flow can be found in many industries. Many natural phenomena and engineering applications are susceptible to magneto-hydrodynamic (MHD) analysis. From technological point of view, magneto-hydrodynamic flow finds application in the fields of stellar and planetary magneto-spheres, aeronautics, meteorology, solar physics, cosmic fluid dynamics, chemical engineering, electronics, MHD generators, MHD accelerators, construction of turbine and other centrifugal machines. Very often, along with the free convection currents caused by the temperature difference, the flow is also affected by the difference in concentration of material constituents. In engineering application, the concentration differences are created either by injecting foreign gases or by coating a substrate with a material, and subsequently heating it, so that the material evaporates.

Analysis of transport processes and their interaction with chemical reaction has the greatest contributions to many areas of chemical science. The effect of chemical reaction on different geometry of the problem has been investigated by many authors. Anjalidevi and Kandasamy [1] have examined the effect of a chemical reaction on the flow in the presence of heat transfer and magnetic field. Mansour et al.[2] analyzed the effect of chemical reaction and viscous on MHD natural convection flows saturated in porous Medium. The analysis of MHD mixed convection interaction with thermal radiation and higher order chemical reaction is carried out by Makinde [3]. Aziz [4] theoretically examined a similarity solution for a laminar thermal boundary layer over a flat plate with a convective surface boundary condition. He found an interesting result that a similarity solution is possible if the convective heat transfer along with the hot fluid on the lower surface of the plate is inversely proportional to the square root of the axial distance.

Das et al. [5] have studied the effect of mass transfer flow past an impulsively started infinite vertical plate with heat flux and chemical reaction. The chemical reaction effect on heat and mass transfer flow along a semi infinite horizontal plate has been studied by Anjalidevi and Kandaswamy [6] and later it was extended for Hiemenz flow by Seddeek et al. [7] and for polar fluid by Patil and Kulkarni [8]. Salem and Abd El-Aziz [9] have reported the effect of hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation or absorption. Ibrahim et al. [10] studied the effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. A detailed numerical study has been carried out for unsteady hydromagnetic natural convection heat and mass transfer with chemical reaction over a vertical plate in rotating system with periodic suction by Parida et al. [11] , Rajeswari et al. [12] have investigated chemical reaction, heat and mass transfer on nonlinear MHD boundary layer flow through a vertical porous surface in presence of suction.Mahdy [13] has studied the effect of chemical reaction and heat generation or absorption on double diffussive convection from vertical truncated cone in a porous media with variable viscosity. Pal and Talukdar [14] have studied perturbation analysis of unsteady magnetohydrodynamic convective heat mass transfer in boundary layer slip flow past a vertical permeable plate with a thermal radiation and chemical reaction. Further the effect of thermal radiation, heat and mass transfer flow of a variable viscosity fluid past a vertical porous plate in presence of transverse magnetic field was investigated by Makinde and Ogulu [15]. Recently, the combined effects of an exponentially decaying internal heat generation and a convective boundary condition on the thermal boundary layer over a flat plate are investigated by Olanrewaju et al. [18]. In their study authors have neglected the Sherwood effect. Similar analysis has been carried out by Makinde [19, 20] without heat source and with heat source [21], neglecting chemical reaction effect. There has been considerable interest in studying the effect of chemical reaction [22] and heat source effect on the boundary layer flow problem with heat and mass transfer of an electrically conducting fluid in different geometry [23]. In context of that [24-25]an attempt has also taken find the solution of boundary layer problem which included chemical reaction and raditive heat transfer. where it is found that Heat source and chemical reaction effects are crucial in controlling the heat and mass transfer. The present paper attempts to investigate the influence of chemical reaction and the combined effects of internal heat generation and the convective boundary condition on the MHD heat and mass transfer flow. Recently Rawat and Kapoor [26-27] attempted to find the numerical solution of MHD flow with chemical reaction and two phase flow using finite element method. Keeping in view of that here we attempted to discuss the flow dynamics using the spectral method.

2. MATHEMATICAL MODEL

Let us consider the problem of cooling of a low-heat-resistance sheet that moves downwards in a viscous fluid when the velocity of the fluid far away from the plate is equal to zero. The variation of surface temperature are linear. The flow configuration and coordinate system is shown in Fig.1. All the fluid properties are assumed to be constant except for the density variations in the buoyancy force term of linear momentum. The magnetic Reynolds number is assumed to be small, so that the induced magnetic field is neglected. Electric field is assumed to exists and both viscous and magnetic dissipation are neglected. The Hall Effect, viscous dissipation and the joule heating term are neglected. Under these assumption along with the Bousineque approximation, the boundary layer equation for the problem

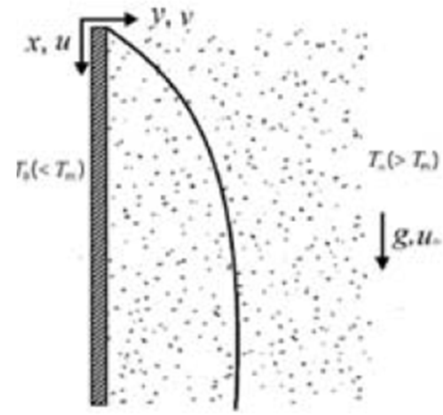

Fig. 1: Physical Model of the Problem

2.1 GOVERNING EQUATIONS

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_\infty)+J\times B \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\kappa\frac{\partial^2 T}{\partial y^2}+Q_0(T-T_\infty) \quad (3)$$

$$u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=\sigma\frac{\partial^2 S}{\partial y^2}-\Gamma S \quad (4)$$

Where J is Current density, Γ is the chemical reaction rate parameter. Negle-cting the displacement current , the Maxwell equation and Ohm's law becomes

$$div\,B=0, Curl\,B=\mu_e J\,, Curl\,E=-\frac{\partial B}{\partial t} \quad (5)$$

Where B is magnetic field strength

$$J=\sigma\,(E+V\times B) \quad (6)$$

Where σ is electrical conductivity

and μ_e is the magnetic permeability ,E is the electric field

The imposed and induced electric field are assume to be negligible under the assumption of low magnetic Reynolds number

$$J\times B=-\sigma\,\mu_e^2 H_0^2 u \quad (7)$$

i.e equations reduce to

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \quad (8)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\left(\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_\infty)-\sigma\,\mu_e^2 H_0^2 u \quad (9)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\kappa\frac{\partial^2 T}{\partial y^2}+Q_0(T-T_\infty) \quad (10)$$

$$u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=\sigma\frac{\partial^2 S}{\partial y^2}-\Gamma S \quad (11)$$

Subject to the boundary conditions

$$u = 0,\ \ v = 0,\ \ T = T_0\, , S = S_0 \text{ at } y = 0 \tag{12}$$

$$u \to 0,\ \ T \to \infty\ , S \to \infty \text{as } y \to \infty, \tag{13}$$

$$\psi = [g\beta(T - T_\infty)v^2 x_0^3]^{\frac{1}{4}} f(\eta), \tag{14}$$

$$T = T_\infty + (T - T_\infty)\left[\frac{x_0}{x_0 - x}\right]^3 \theta(\eta), \tag{15}$$

$$S = S_\infty + (S - S_\infty)\left[\frac{x_0}{x_0 - x}\right]^3 \emptyset(\zeta) \tag{16}$$

$$\eta = \left[\frac{g\beta(T - T_\infty)x_0^3}{v^2}\right]\frac{y}{(x_0 - x)}, \tag{17}$$

$$\zeta = \left[\frac{g\beta(S - S_\infty)x_0^3}{v^2}\right]\frac{y}{(x_0 - x)} \tag{18}$$

$$f''' - (f' + M)f' + \theta = 0, \tag{19}$$

$$\frac{1}{\mathrm{Pr}}\theta'' - 3f'\theta + Q\theta = 0. \tag{20}$$

$$\frac{1}{\mathrm{Sc}}\emptyset'' - 3f'\emptyset - Kr\emptyset = 0 \tag{21}$$

The corresponding boundary conditions are

$$f(0) = 0,\ \ f'(0) = 0,\ \ f'(\infty) \to 0, \tag{22}$$

$$\theta(0) = 1,\ \ \theta'(0) = 0\ \ \theta(\infty) \to 0, \tag{23}$$

$$\emptyset(0) = 1, \emptyset'(0) = 0\ \ \emptyset(\infty) \to 0 \tag{24}$$

3. NUMERICAL TECHNIQUE USED

The Spectral collocation method is adopted to find the numerical solution of the nonlinear coupled differential Equations (19)-(21) under the boundary condition (22)-(24) The comparison is also made with the finite difference technique which is available in literature.

The equation (19)-(21) may be written as

$$\frac{d^3 f}{d\eta^3} - \left(\frac{df}{d\eta} + M\right)\frac{df}{d\eta} + \theta = 0 \tag{25}$$

$$\frac{1}{Pr}\frac{d^2\theta}{d\eta^2} - 3\frac{df}{d\eta}\theta + Q\theta = 0 \tag{26}$$

$$\frac{1}{Sc}\frac{d^2\emptyset}{d\eta^2} - 3\frac{df}{d\eta}\emptyset - Kr\emptyset = 0 \tag{27}$$

η is the dimensionless y-coordinate, Kr is the local dimensionless chemical reaction rate parameter. $Pr = \frac{\vartheta}{\alpha}$ is the Prandtl Number ,$Sc = \frac{v}{D}$ is the Schmidt Number, $\theta$is the dimensionless temperature and $\emptyset$ is the dimensionless concentration. f is the dimensionless stream function. To approximate the field variables Suppose f and θ by Chebyshev polynomials the range [0,4] of the independent variable , η is mapped in to [-1,1] by using the function

$$2 - 2\xi = \eta \tag{28}$$

Here the maximum value of η is fixed to be 4 for the sake of connivance of the solution of flow dynamics. The governing equation (25)-(27) and the corresponding boundary condition in terms of Chebyshev ξ

$$\frac{d^3 f}{-2d\xi^3} + \frac{1}{2}\left(\frac{df}{-2d\xi} + M\right)\frac{df}{d\xi} + \theta = 0 \tag{29}$$

$$-\frac{1}{Pr}\frac{d^3\theta}{2d\xi^2} + \frac{3}{2}\frac{df}{d\xi}\theta + Q\theta = 0 \tag{30}$$

$$-\frac{1}{2\,Sc}\frac{d^3\emptyset}{d\xi^2} + \frac{3}{2}\frac{df}{d\xi}\emptyset - Kr\emptyset = 0 \tag{31}$$

The boundary conditions (4) becomes

$$\theta = f = \emptyset = 0\ \ at\ \xi = 1\ and\ \frac{df}{d\xi} = \frac{d\theta}{d\xi} = \frac{d\emptyset}{d\xi} = 0\ at\ \xi = -1 \tag{32}$$

Now the equations becomes

$$-\frac{1}{2}\sum_{k=0}^{n} C_{jk} f_k + \frac{1}{2}\left(-\frac{1}{2}\sum_{k=0}^{n} A_{jk} f_k + M\right)\sum_{k=0}^{n} A_{jk} f_k + \theta = 0 \tag{33}$$

$$-\frac{1}{2Pr}\sum_{k=0}^{n} B_{jk}\theta_k + \frac{3}{2}\sum_{k=0}^{n} A_{jk} f_k\ \theta + Q\theta = 0 \tag{34}$$

$$-\frac{1}{2\,Sc}\sum_{k=0}^{n} B_{jk}\emptyset_k + \frac{3}{2}\sum_{k=0}^{n} A_{jk} f_k\ \emptyset - Kr\emptyset = 0 \tag{35}$$

Where j=1,2,3…n-1

$$A_{jk} = \begin{cases} \dfrac{c_j(-1)^{k+j}}{c_k(\xi_j - \xi_k)}, & j \neq k \\ \dfrac{\xi_j}{2(1 - \xi_j^2)}, & 1 \le j = k \le n - 1 \\ \dfrac{2n^2 + 1}{6}, & j = k = 0 \\ -\dfrac{(2n^2 + 1)}{6}, & j = k = n \end{cases}$$

And $B_{jk} = A_{jm}A_{mk}$, $C_{jk} = B_{jm}A_{mk}$. In the above $c_j = \begin{cases} 2, & j = 0, n \\ 1, & 1 \le j \le n - 1 \end{cases}$ And $\xi_j - \frac{cos\pi j}{n}, for\ 0 \le j \le n$ are chebyshev collocation points .

4. RESULTS AND DISCUSSION

Figs. 1-3 have been plotted to show the effect of velocity exponent m on velocity, temperature and concentration profiles. As expected, the velocity, temperature and concentration profiles increase with the increase in velocity exponent m which is graphically demonstrated by Figs 1,2 and 3. Figs. 4-5 present the velocity and temperature profiles for different values of Magnetic number M=m. It is a well known fact that the application of uniform magnetic field normal to the flow direction gives rise to a force called Lorentz force. This force has a tendency to slow the motion of the fluid and make it warmer as it move over the stretching sheet causing velocity U to decrease and temperature θ to increase. These behaviours are clearly illustrated in figs. 4 and 5. The influence of Prandtl number Pr on temperature distribution can be seen in Fig. 6. The Prandtl number is a dimensionless number approximating the ratio of momentum diffusivity and thermal diffusivity. When *Pr* is small, it means that the heat diffuses very quickly compared to the velocity (momentum) resulting in a thicker boundary layer. Our computations also indicate that a rise in Pr substantially reduces the temperature.

Fig. 7 plots the influence of chemical reaction parameter Kr on the mass transfer function ϕ. It is observed that as Kr increases from 0 to 4, the concentration profile decreases noticeably. For the non-reactive case, Kr = 0, concentration profile shows approximately a linear decay from a maximum at the wall (vertical stretching surface i.e. at $\eta = 0$) to zero at the free stream (i.e. at $\eta = 8$), these end values being a direct result of the imposed boundary conditions. As Kr is increased, the profiles become more monotonic in nature; in particular the gradient of the profile becomes much steeper for Kr = 4 than for lower values of it. Thus chemical reaction parameter has a considerable influence on both magnitude and rate of species (mass) transfer function, since physically this corresponds to *faster* rates of reaction. The effect of Schmidt number, Sc, on the concentration ϕ profiles is illustrated in fig. 8. Schmidt number is a dimensionless number defined as the ratio of momentum diffusivity (viscosity) and mass diffusivity. It physically relates the relative thickness of the hydrodynamic layer and mass-transfer boundary layer. Thus a lower value of Schmidt number indicate a thicker boundary layer as is illustrated in Fig. 8. As Sc increases, for the reactive flow case, ϕ values are strongly reduced, since larger values of Sc are equivalent to a reduction in the chemical molecular diffusivity i.e. less diffusion therefore takes place by mass transport. Although the trends of influence of Sc on the concentration profiles for the non-reactive flow case are similar to that of the reactive flow case, the profiles are less decreased with a rise in Sc, in the absence of chemical reaction. For Sc = 0.2, there is almost a linear decay for the non-reactive case whereas it is considerably more parabolic for the reactive case, indicating lower values of ϕ throughout the flow domain for the reactive case. We can therefore infer that in consistency with our earlier computations, chemical reaction decreases mass transfer markedly throughout the porous medium

5. CONCLUSION

On the basis of the above work the following are the concluding remark of this study

i) The Spectral collocation method gives much similar result as we obtained in Finite difference method

ii) Both gives more accurate solution rather then the Keller box technique which is used by others

iii) Every profile (Velocity or temperature) has shows an asymptomatic behavior and converges for the large value of η

iv) W.r.t the characteristic length all profiles are nearly flat while keep on increasing Pr

v) The velocity profiles are found to increase to a certain maximum point and then reduce asymptotically to zero. As Prandtl number increases, the temperature profile and the thermal boundary layer thickness decrease.

vi) The internal heat source is not effected in case of low heat resistance sheet

vii) The magnetic number help in dragging the flow mechanism.

viii) Mass transfer function, Φ, substantially decreases with a rise in chemical reaction parameter (Kr).

ix) Increasing Schmidt number reduces mass transfer function both in the reactive and non-reactive flow cases, although mass transfer function values are always higher for any Sc value in the non-reactive case (Kr = 0).

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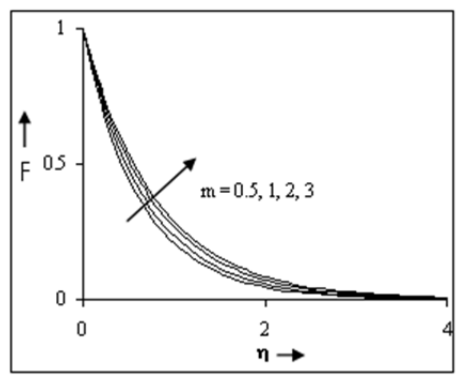

Fig. 1: Effect of velocity exponent m on velocity f

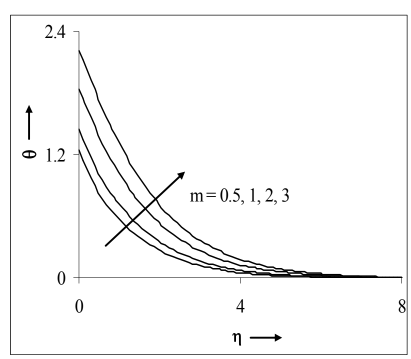

Fig. 2: Effects of velocity exponent m on temperature θ

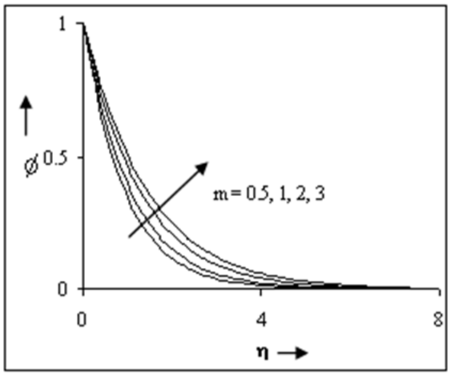

Fig. 3: Effects of velocity exponent m on concentration ϕ

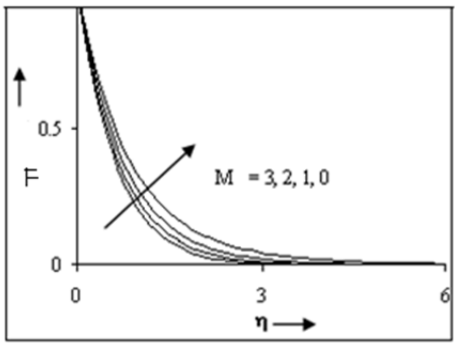

Fig. 4: Effects of Magnetic number M_x on velocity F

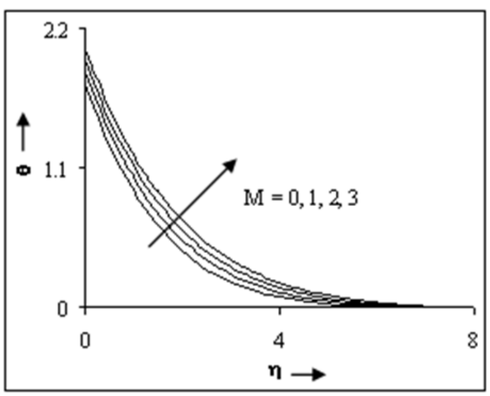

Fig. 5: Effects of Magnetic number M_x on temperature θ

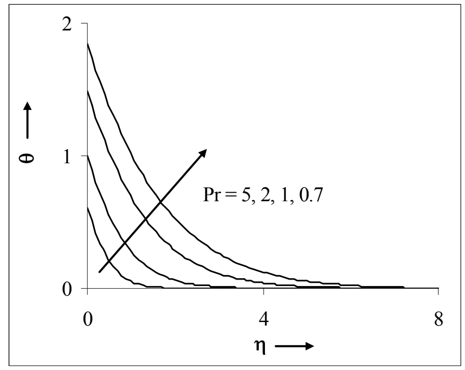

Fig.6 Temperature profiles for various values of Pr

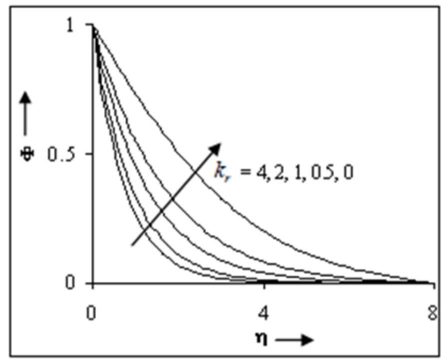

Fig. 7: Effects of Chemical reaction parameter Kr on concentration ϕ

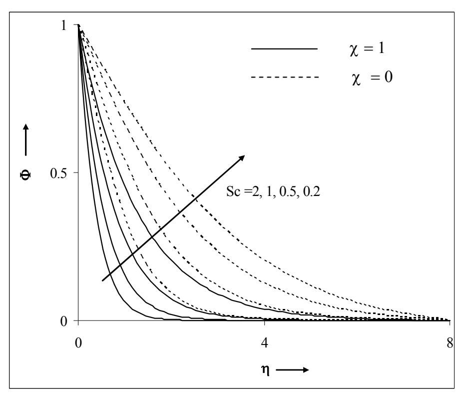

Fig. 8: Effects of Schmidt number Sc on concentration ϕ, both in the presence and absence of Chemical reaction parameter