Hydromagnetic free Convection from a Moving Permeable Vertical Surface through Porous medium with Heat Source and first order Chemical Reaction

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Abstract

An analysis is performed to study the momentum heat and mass transfer characteristics of MHD natural convection flow over moving permeable surface through porous medium taking into account the first order chemical reaction. The surface is maintained at linear temperature and concentration variations through porous medium. The non linear coupled boundary layer equations were transformed and the resulting ordinary differential equations were solved by perturbation technique. The solution is found to be dependent on several governing parameter, including the magnetic field, strength parameter, Prandtl number, Schmidt number, buoyancy ratio, porous medium, heat source, chemical reaction and suction /blowing parameter. A parametric study of all governing parameters is carried out and representative results for the dimensionless velocity profiles, the temperature profiles, the concentration profiles, the local friction coefficient and the local Nusselt number are presented for various combinations of parameters.

Key Words- *Heat source, Heat and Mass transfer, free convection, chemical reaction*

I. Introduction

The branch of continuum mechanics which deals with the flow of electrically conducting fluids in electric and magnetic fields is known as Magneto-hydrodynamic (MHD). Many usual phenomena and engineering problems are worth being subjected to an MHD analysis. In addition, magneto-hydrodynamic (MHD) has attracted the attention of a large number of researchers due to its assorted applications. In engineering it finds its application in MHD pumps, MHD bearings etc. Soundalgekar [1] studied the Hydromagnetic flow of a viscous incompressible fluid due to uniformly accelerated motion of an infinite flat plat in presence of a magnetic fixed relative to the plate and he found that the velocity at any point and at ant instant decreases when strength of magnetic field increased. Kafousias et.al. [2] discover the transverse magnetic effect on the free convective flow of incompressible, electrically conducting fluid past a non conducting and non magnetic, vertical limiting surface. Raptis, A. and Soundalgekar [3] investigated the MHD flow past a steadily moving infinite vertical porous plate with mass transfer and constant heat flux. some work are available in the subject of magnetohydrodynamics (MHD) convection in porous medium was studied by B.K.Jha and R.Prasad [4] MHD free convection and mass transfer flow through a porous medium with heat source. The problem of MHD natural convection about vertical incompressible flat plate is presented by Yih KA.[5] Free convection effect on MHD coupled heat and mass transfer of a moving permeable vertical surface. M.Abdelkhalek [6] discussed Unsteady MHD convection and mass transfer flow of micropolar fluids past a vertical permeable moving plate with heat absorption. Abdelkhalek.M [7]further work for the skin friction in the MHD mixed convection stagnation point with mass transfer.

The process of heat and mass transfer in free convection flow have attracted the attention of a number of scholars due to their application in many branches of science and engineering, viz. in the early stages of melting adjacent to a heated surface, in chemical engineering processes which are classified as a mass transfer process, in a cooling device aeronautics, fluid fuel nuclear reactor. The phenomenon of free convection arises in the fluid when temperature and mass concentration change cause density variation leading to buoyancy forces acting on the fluid elements. Analytical solutions of the problem of convective flows, which arise in the fluids due to interaction of the force of gravity and density differences caused by simultaneous diffusion of thermal energy and chemical species, have been presented by many authors due to application of such problems in Geophysics and Engineering. Some of them are Rapit and Kafousias [8], Trevisan and Bejan [9], Bejan and Khair [10], The study through porous medium has got its importance because of its occurrence in movement of water. Investigations of such problems also have importance in purification process, petroleum technology and in the field of agricultural engineering. The influence of a uniform transverse magnetic field on the motion of an electrically conducting fluid past a stretching sheet was investigated by Kumari et.al. [11]. Ram et al. [12] studied the heat and mass transfer of a viscous heat generating fluid with hall current. Hydromagnetic lows and heat transfer have become more important in recent years because of many important applications such that in many metallurgical processes which involve cooling of continuous strips or filaments, these elements are drawn through a quiescent fluid. Cheng and Huang [13] considered the problem of unsteady flows and heat transfer in the laminar boundary layer on a linearly accelerating surface with suction or blowing in the absence and presence of a heat source or sink. Xu and Liao[14]investigated the unsteady MHD flows of a non-Newtonian fluid over a non-impulsively stretching flat sheet and presented an accurate series solution. Some works are available in the subject of magnetohydrodynamic (MHD) convection in porous medium was studied.Thakar.et.al.[15] worked on the hydromagnetic convection flow of a heat generating fluid past a vertical plate with hall current and heat flux through a porous medium. Various researchers [16-17] worked on three-dimensional free convective MHD Flow and Heat Transfer through Porous Medium. Chaudhary and Jain [18] have studied the combined heat and mass transfer effects on MHD free convective flow through porous medium. Abdelkhalek, [19] also studied Heat and mass transfer in MHD free convection from a moving permeable vertical surface by a perturbation technique. Singh.[20] discover the heat and mass transfer in MHD boundary layer flow past an inclined plate with viscous dissipation in porous medium.

Many investigations have studied the effect of chemical reaction in different convective heat and mass transfer flows. The fluid flows with chemical reaction have attracted the attention of engineers and scientists in the recent times. The effect of chemical reaction on free-convective flow and mass transfer of a viscous, incompressible and electrically conducting fluid over a stretching sheet was investigated by Afify [21] in the presence of transverse magnetic field. Joneidi et al. [22] presented analytical treatment of MHD free convection flow over a stretching sheet with Chemical reaction. Mohmmed Nasser [23]discussed the effect of chemical reaction on the unsteady convection flow past an infinite vertical plate permeable moving plate with variable temperature.aim of present work is to study the hydromagnetic free convection from a coving permeable vertical surface through porous medium with heat source and first order chemical reaction by using perturbation technique There is always a molecular diffusion of species in the presence of chemical reaction within or at the boundary during several practical diffusive operations. There are two types of reactions, namely, homogeneous and heterogeneous. A homogeneous reaction takes place uniformly in the entire given phase whereas a heterogeneous reaction exists in a restricted region or within the boundary of a phase. The smog formation is an important example representing a first-order homogeneous chemical reaction. Several researchers in view of such facts are engaged in the discussion of flows with chemical reactions. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors, and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. S. Shateyi [24] studied the thermal radiation and buoyancy effect on heat and mass transfer over a semi-infinite stretching surface with suction bolwing. A. Seddeek [25] analyze The effect of radiation on MHD flow, heat and mass transfer becomes more important industrially.

Motivated by the above mentioned investigations and application, in this paper we investigate the heat and mass transfer with convective boundary condition for MHD, chemical reaction, viscous fluid flow in porous medium in presence of heat source. The perturbation method is used to solve the problem and the effect of related parameter discussed and presented by graphs.

II Formulation of the problem

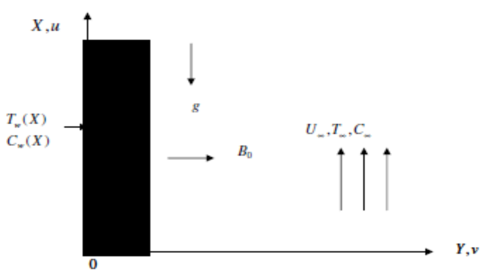


Fig. 1. Physical configuration and coordinates system.

Consider two dimensional free convection effects on the steady incompressible laminar MHD heat and mass transfer characteristics of a linearly moving permeable vertical surface when the velocity of the fluid far away from the plate is equal to zero. The variation of surface temperature and concentration are linear. The flow configuration and coordinate system are shown in the **above figure**. The entire fluid properties are assumed to be constant except for density variation in the buoyancy force term of linear momentum. The magnetic Reynolds number is assumed to be undersized, so that the induced magnetic field is neglected. No electric field is assumed to exist both viscous and magnetic dissipation are neglected. The Hall Effect, the viscous dissipation and the joule heating term are also neglected. Under these assumptions, along with Boussinesq approximation, the boundary layer equations for this problem can be written

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

$$\upsilon\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\xi\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta_c(C-C_\infty) \qquad (2)$$
$$-\sigma B_0^2\rho^{-1}u-\frac{\nu u}{k}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+Q(T-T_\infty) \qquad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-k_1(C-C_\infty) \qquad (4)$$

where u and v are the velocity components in X and Y directions, T is temperature β_T is the volumetric coefficient of the thermal expansion, α is acceleration due to gravity, ξ is kinematic viscosity, D is the coefficient of diffusion in the mixture, c is the species concentration, σ is electrical conductivity, B_0 is the externally imposed magnetic field in the Y-direction.

The relevant boundary conditions can be written as

$$y=0,\nu=-v_w,u=Bx,T=T_\infty+ax,$$
$$C=C_\infty+bx \qquad (5)$$
$$y\to\infty,u=0,T=T_\infty,C=C_\infty$$

where v_w is the uniform surface mass flux, B, a, and b are prescribed constant. .

We introduce now the following non-dimensional variable:

$$u=\frac{\partial\psi}{\partial y}\text{ and }v=-\frac{\partial\psi}{\partial x},\eta=\sqrt{\frac{\beta}{\xi}}y,$$
$$F(\eta)=\frac{\psi}{x\sqrt{\beta\xi}} \qquad (6)$$

$$\theta(\eta)=\frac{T-T_\infty}{T_w(x)-T_\infty},C(\eta)=\frac{C-C_\infty}{C_w(x)-C_\infty} \qquad (7)$$

Eq.(1) is identically satisfied and the partial differential equation (2)-(4) transform into ordinary differential equation (8)-(10).

$$F'''+FF''-(Z+F')F'=-G_{rT}Re^{-2}(\theta+NC) \qquad (8)$$

$$\theta''+Pr(F\theta'-F'\theta+Q\theta)=0 \qquad (9)$$

$$C'''+Sc(FC'-F'C-k_1C)=0$$
$$\text{where } Z=M+D \qquad (10)$$

where primes denote differentiation with respect to η. The appropriate flat plate, free convection boundary conditions are also transformed into the form,

$$\eta=0:F=F_w,F'=1,\theta=1,C=1$$
$$\eta\to\infty:F'=0,\theta=0,C=0$$

The velocity components are

$$u=B\ xF',\nu=-\sqrt{B\xi}\,F \qquad (11)$$

where $M=\sigma B_0^2\ B^{-1}\ \rho^{-1}$ is the magnetic parameter, $G_{rT}R_e^{-2}=g\beta_T\ aB^{-2}$ is the buoyancy parameter. When $G_{rT}R_e^{-2}=0$ the governing equation are reduced to forced convection limit. How ever as $G_{rT}R_e^{-2}\to\infty$ free convection is dominated. The buoyancy ratio $N=\beta_c b\beta_T^{-1}a^{-1}$ measure the relative importance of mass and thermal diffusion in the buoyancy driven flow, positive for thermally assisting flow, negative for thermally opposing flow, $Pr=\nu\alpha^{-1}$ is Prandtl number, and $Sc=\nu D^{-1}$ is the Schmidt number, $Fw = v_w/\sqrt{B\xi}$ is the suction/blowing parameter. For the case of suction, $v_w>0$ and hence Fw>0. For the case of blowing, $v_w<0$ and hence Fw<0.

The significant differential equations contain arbitrary parameters, the Prandtl number Pr, the magnetic field strength and the bouncy force, the ratio of Hartmann number is measure of the relative influence of the magnetic and bouncy force on the temperature and flow field. Solution of the semi infinite domain, non linear equation is the accomplished with three part series method [2].

The employed power series, equation (12), contain a term that satisfies the boundary condition and differential equation at the infinity, a second term that satisfies the boundary condition at zero and is the solution to the initial homogeneous differential equation, and additional term that will not initiate divergence of the numerical result:

$$F = A + \varepsilon F_1 + \varepsilon^2 F_2 + \varepsilon^3 F_3 + \cdots \qquad (12)$$

$$\Theta = \varepsilon \Theta_1 + \varepsilon^2 \Theta_2 + \varepsilon^3 \Theta_3 + \cdots \qquad (13)$$

$$C = \varepsilon C_1 + \varepsilon^2 C_2 + \varepsilon^3 C_3 + \cdots \qquad (14)$$

Subject to the boundary conditions which become,

$$\eta = 0, F_1'(0) = 1, F_2'(0) = F_3'(0) = 0, F_1(0) = F_w,$$
$$F_2(0) = F_3(0) = 0$$
$$\theta_1(0) = 1, \theta_2(0) = \theta_3(0) = 0, C_1 = 1, C_2 = C_3 = 0$$
$$\eta \to \infty, F_n'(\infty) = 0, \theta_n(\infty) = 0, C_n(\infty) = 0, n = 1,2,3 \qquad (15)$$

Equation (13), the temperature representation, along with the Equation (12)-(14) and the associated boundary conditions, Equation (15) contain an undetermined parameter ε which aids in the collection of terms for each set of the resulting linear differential equations in some problems, it will have a physical meaning which result in a power series in that parameters. However the present case ε equal to unity. Substitution of the series representation into the differential equation and collection of the terms by like power of ε result in the family of linear differential equations, and the first three sets are

$$F_1''' + AF_1'' - Z F_1' = -G_{rT} \operatorname{Re}^{-2}(\theta_1 + NG) \qquad (16)$$

$$\theta_1'' + \Pr(A\,\theta_1' + Q\theta_1) = 0 \qquad (17)$$

$$C_1'' + Sc\,(A\,C_1' - k\,C_1) = 0 \qquad (18)$$

$$F_2''' + AF_2'' + F_2F_1'' - Z F_2' - F_1'^2 = -G_{rT}\operatorname{Re}^{-2}(\theta_2 + NC_1) \qquad (19)$$

$$\theta_2'' + \Pr A\,\theta_2' + Q\,\theta_2 = \Pr[F_1'\theta_1 - \theta_1' F_1] \qquad (20)$$

$$C_2'' + Sc\,A\,C_2' - k\,C_2 = Sc\,[F_1'C_1 - F_1C_1'] \qquad (21)$$

$$F_3''' + AF_3'' - ZF_3' = 2F_1'F_2' - F_1F_2'' - F_2F_1'' - G_{rT}\operatorname{Re}^{-2}(\theta_3 + NC_3) \qquad (22)$$

$$\theta_3'' + \Pr A\theta_3' + Q\theta_3 = \Pr[F_1'\theta_2 + F_2'\theta_1 - F_1\theta_2' - F_2\theta_1'] \qquad (23)$$

$$C_3'' + Sc\,(AC_3' - kC_3) = Sc(F_1'C_2 + F_2'C_1 - F_1C_2' - F_2C_1') \qquad (24)$$

The solutions of equations are

$$\theta_1 = e^{-a_1\eta} \qquad (25)$$

$$C_1 = e^{-a_2\eta} \qquad (26)$$

$$F_1 = a_7 + a_6e^{-a_3\eta} + a_4e^{-a_1\eta} + a_5e^{-a_2\eta} \qquad (27)$$

$$\theta_2 = a_{17}e^{-a_8\eta} + a_{13}e^{-(a_1+a_3)\eta} + a_{15}e^{-(a_1+a_2)\eta} + a_{16}e^{-a_1\eta} \qquad (28)$$

$$C_2 = a_{22}e^{-a_{18}\eta} + a_{19}e^{-(a_2+a_3)\eta} + a_{20}e^{-(a_1+a_2)\eta} + a_{21}e^{-a_2\eta} \qquad (29)$$

$$F_2 = a_{39} + a_{38}e^{-a_3\eta} + a_{29}e^{-(a_1+a_2)\eta} + a_{30}e^{-(a_1+a_3)\eta} + a_{31}e^{-(a_2+a_3)\eta}$$
$$+ a_{32}e^{-a_1\eta} + a_{33}e^{-a_2\eta} + a_{34}e^{-a_3\eta} + a_{35}e^{-a_8\eta} + a_{36}e^{-2a_1} + a_{37}e^{-2a_2\eta} \qquad (30)$$

The solution of the first two sets when substituting into equation (12) – (14) provide the required representations for F, θ and C. Equation (25) – (30)

where

$$a_1 = \frac{(\Pr A + \sqrt{(\Pr A)^2 - 4\Pr Q})}{2}$$

$$a_2 = \frac{(Sc\,A + \sqrt{(Sc\,A)^2 + 4k})}{2}$$

III Result and Discussion

The series for θ, its first derivative θ'(0)(the wall temperature gradient),F' (the velocity profile) and F'(0)[the wall velocity gradient] were evaluated are and presented in the figures. The general results of the investigations are imposed magnetic field diminished the velocity field , wall shear, flow rate , and wall heat transfer , also the concept of free convection are retarded while the fluid temperature and the time required for the flow to each steady are increased. In addition, sizable influences on the flow and thermal field can be produced with moderate magnetic field strength only for liquid metal flow while the effect of induced magnetic field and Joule heating are very small. In the present study the following default parameter values are adopted for computation: G_{rT} =5.0,Pr=0.72,k=4.75,Sc=0.2,F_w=0,Re=50,N=0,1. All graph therefore correspond to these values unless specifically indicate on the related graphs. The magnetic field strength is to reduce the value of wall shear stress regardless of blowing and suction strength. Magnetic force is known to have a retardation effect: it increases the wall shear stress. Blowing has a similar effect which used aid the magnetic field in reducing the wall shear stress. However, suction has an opposite effect and increases the shear stress at the wall opposing the magnetic effect. In case of free convection , suction decreases wall shear stress, this may be because increasing suction will decreases the flow velocity and in turn diminishing the retardation effect of the magnetic field force. In order to get the physical insight into the problem, numerical calculation are carried out for different values of Prandtl number ,Hartmann number ,Schmidt number and Sherwood number.

Figure- 2 shows the influences of the Hartmann number M on the velocity profiles in the boundary layer. Application of magnetic field to an electrically conducting fluid gives rise to a resistive type force called the Lorentz force. This force has the tendency to slow down the motion of the motion of the fluid in the boundary layer. Also, the effect on the flow and thermal field become more so as the strength of the magnetic field increase. This is obvious from the decrease in the velocity profiles presented in figure2.

Figure-3 shows the velocity profile for different values of Grashof number Grt. It is noted that velocity increases with increasing G_{rT}. this is consistent with the fact that due to increase in G_{rT} buoyancy force increases which lead to increase in the velocity.

Figure 4-gives the velocity profile for different values of Schmidt number. It is observed that velocity decreases with increasing Schmidt number Sc.

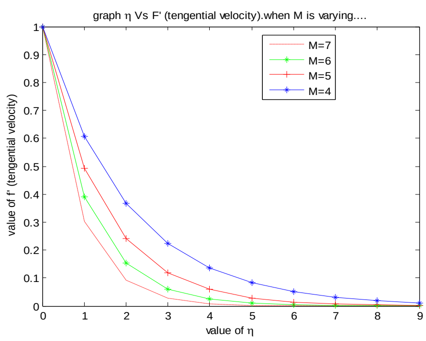
Figure- 5 shows the temperature profiles across the boundary layer and different values of the suction /injection parameter F_w. As mentioned suction corresponding to F_w >0, injection to F_w <0 and F_w = 0 to impermeable plate. It is known that imposition of wall fluid suction reduces both the hydrodynamic and thermal boundary layer which indicates reduction in temperature profile. However, the exact opposite behaviour is produced by imposition of wall fluid blowing or injection.

Figure 6-illustrate the effect of heat source on temperature profile. It noted that increasing heat source parameter temperature distribution decreases exponentially near the plate.

Figure-7 illustrates the influence of Schmidt number Sc on the concentration. As Schmidt number Sc increases, the mass transfer rates increase. Hence the concentration decreases with increasing Sc. It is evident from this figure that the concentration C takes its limiting value upto infinity.

Figure-8 depicts the effect of mass transfer, F_w on temperature gradient profiles. It should be noted that positive values of F_w indicate fluid suction at surface while negative values of F_w shows injunction. It is shown in the figure that increasing in suction parameter temperature decreases.

Figure-2



D=1;Pr=0.72;R=50;k=4.75;Sc=0.2;

G_{rT} =5;Fw=0;K=1;Q=.2

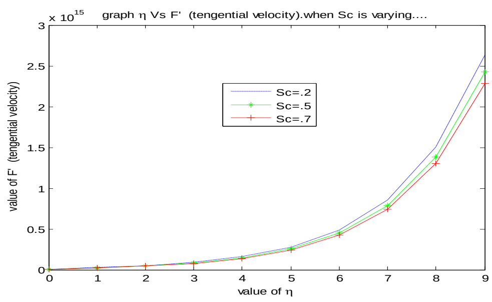
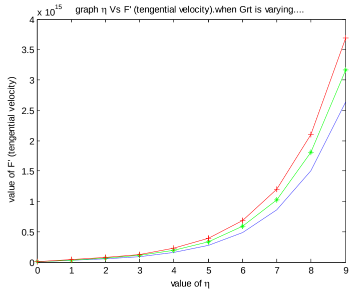


Figure-3



D=1;Pr=0.72;R=50;k=4.75;Sc=0.

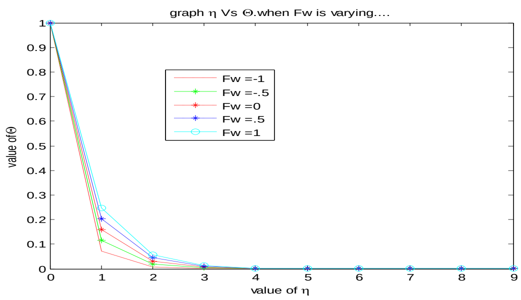
Fw=0;K=1;Q=.2;M=0,N=0,G_{rT} =5

Figure-4

D=1;Pr=0.72;R=50;k=4.75;M=0;

G_{rT} =5;Fw=0;K=1;Q=.2;N=0

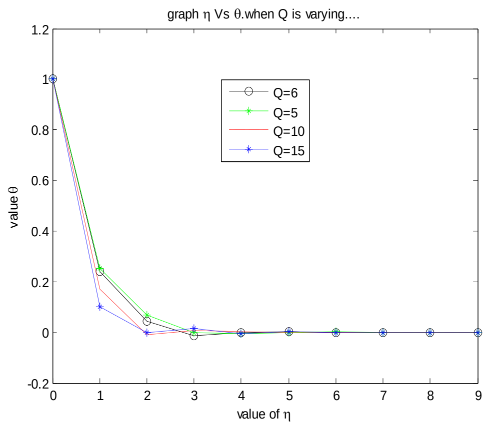
Figure-5



D=1;Pr=0.72;R=50;k=4.75;Sc=0.2;

SG_{rT} =5;M=0,N=0;K=1;Q=.2;

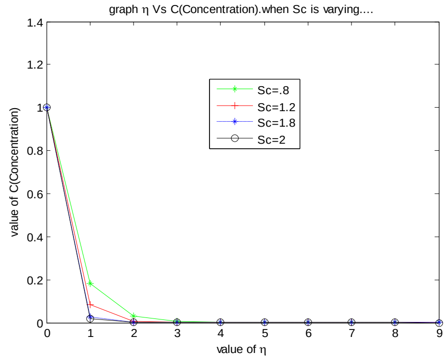
Figure-6



D=1;Pr=0.72;R=50;k=4.75;Sc=0.2;Grt=5

M=0,N=0;K=1;F_w=0, G_{rT}=5

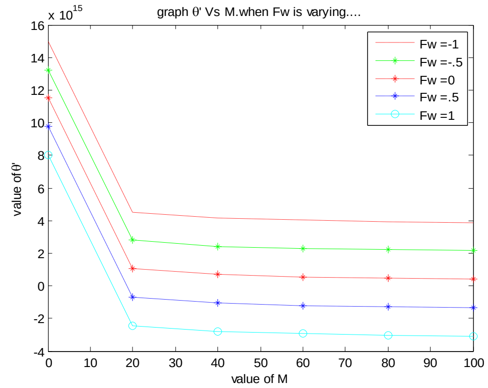
Figure-7



D=1;Pr=0.72;R=50;k=4.75;F_w=0.2;

G_{rT} =5;M=0,N=0;K=1;Q=.2

Figure-8



D=1;Pr=0.72;R=50;k=4.75;Sc=.2;

G_{rT} =5;M=0,N=0;K=1;Q=.2;

IV conclusion

The object of this paper is to investigate analytically, the heat and mass transfer in a hydromagnetic flow of a moving permeable vertical surface with heat source and first order chemical reaction. The plate surface is assumed permeable so as to allow for possible wall suction or injection. The resulting transformed governing equations are solved numerically by perturbation technique. The results are presented for the magnetic parameter, the Prandtl number, the dimensionless suction/blowing coefficient, Schmidt number and heat source. The conclusions have been reported:

- In the presence of a magnetic field, the velocity is found to be decreased, associated with a reduction in the velocity gradient at the wall, and it also noted that velocity increasing as Schmidt number decrease.
- Concentration profile decreases with increasing in Schmidt number.

- The effect of heat source on temperature profile, it noted that increasing heat source parameter temperature distribution decreases exponentially near the plate.

References

[1] Soundalgekar, V. M. (1965): Hydromagnetic flow near an accelerated plate in the presence of a magnetic field, Applied Scientific Research, Vol. 12, No. 1, pp. 151156.

[2] Kafousias, N. G. and Georgantopoulos, G. A. (1982): Magnetohydrodynamic free convection effects on the Stokes problem for an incompressible viscous fluid past an infinite vertical limiting surface, Astrophysics and Space Science, Vol. 85, No. 1-2, pp. 297-307.

[3] Raptis, A. and Soundalgekar, V. M. (1984): MHD flow past a steadily moving infinite vertical porous plate with mass transfer and constant heat flux, ZAMM Journal of Applied Mathematics and Mechanics, Vol. 64, No. 2, pp. 127-130.

[4] B.K.Jha and R.Prasad (1992):MHD free convection and mass transfer flow through a porous medium with heat source.J.Math.Phy.Sci.;26(1),1.

[5] Yih KA(1999) Free convection effect on MHD coupled heat and mass transfer of a moving permeable vertical surface. Int Commun Heat Mass Transfer ,26(1):pp.95–104.

[6] Mohamed M. Abdelkhalek (2006) Unsteady MHD convection and mass transfer flow of micropolar fluids past a vertical permeable moving plate with heat absorption. Indian J Phys;80(6):pp.625–35.

[7] Abdelkhalek MM.(2006) The skin friction in the MHD mixed convection stagnation point with mass transfer. Int Commun Heat Mass Transfe;33:pp.249–58.

[8] A. Rapits and N. Kafousias(1982) "Magneto Hydrodynamics Free Convective Flow and Mass Transfer through a Po- rous Medium Bounded by an Infinite Vertical Porous Plate with constant Heat Flux," Canadian Journal of Physics, Vol. 60, No. 12, pp. 1724-1729.

permeable vertical surface by a perturbation technique, Communications in Nonlinear Science and Numerical Simulation, Vol. 14, No. 5, pp. 2091-2102.

[20] Singh, P.K.(2012) Heat and Mass Transfer in MHD Boundary Layer Flow past an Inclined Plate with Viscous Dissipation in Porous Medium, International Journal of Scientific & Engineering Research, Volume 3, Issue 6, ISSN 2229-5518.

[21] Afify AA (2004) MHD free-convective flow and mass transfer over a stretching sheet with chemical reaction, Heat Mass Transf.40: 495-500.

[22] A.A.Joneidi, G.Domairry, and M.Babaelahi (2010) Analytical treatment of MHD free convective flow and mass transfer over a stretching sheet with chemical reaction, Journal of the Taiwan Institute of Chemical Engineers,vol.41,no.1,pp.35–43.

[23] F.Mohmmed Nasser El-Fayez (2012)effect of chemical reaction on the unsteady convection flow past an

[9] O. V. Trevisan and A. Bejan(1985) "Natural Convection with Combined Heat and Mass Transfer Buoyancy Effects in a Porous Medium," Heat and Mass Transfer, Vol. 28, No. 8, 1985, pp. 1597-1611.

[10] A. Bejan and K. R. Khair(1985) "Heat and Mass Transfer in Porous Medium," International Journal of Heat and Mass Transfer,Vol.28,No. 5, 902-918.

[11] Kumari M, Takhar HS and Nath G (1990) "MHD flow and heat transfer over a stretching surface with prescribed wall temperature or heat flux", Warme Stoffubertrag, 25: 331-336

[12] P.C.Ram, S.S.Singh and R.K.Jain(1990)Heat and mass transfer of a viscous heat generating fluid with hall current.AstroPhys.Space Sci.;168,209.

[13] Cheng WT, Huang CN. (2004) Unsteady flow and heat transfer on an accelerating surface with blowing or suction in the absence and presence of a heat source or sink. Chem Eng Sci; 59: 771–80.

[14] Xu H, Liao SJ. (2005) Analytic solutions of magnetohydrodynamic flows of non-Newtonian fluids caused by an impulsively stretching plate. J Non-Newton Fluid Mech ;159: 46–55.

[15] HS. Takhar, P.C. Ram , Garba EJD and J.K. Bitok,(1995) ; the hydromagnetic convection flow of a heat generating fluid past a vertical plate with hall current and heat flux through a porous medium. J. MHD Plasma Res.; 5(2/3), 185.

[16] U. N. Das, N. Ahmed and D. Sharma,(2000) "Three-Dimensional Free Convective MHD Flow and Heat Transfer through Porous Medium," FJAM, Vol. 4, No. 3, pp. 357- 369

[17] Choudhary, M.K., Islam, M.N. (2000) MHD free convection flow of visco-elastic fluid past an infinite vertical porous plate. Heat Mass transfer 36, 439-447.

[18] R. C. Chaudhary and A. Jain,(2007) "Combined Heat and Mass Transfer Effects on MHD Free Convection Flow Past an Oscillating Plate Embedded in Porous Medium," *Roma- nian Journal of Physics*, Vol. 52, No. 5-7, pp. 505- 524.

[19] Abdelkhalek, M. M. (2009): Heat and mass transfer in MHD free convection from a moving

infinite vertical plate permeable moving plate with variable temperature," Journal of Surface Engineering Materials and Advance Technology,Vol. 2 No.2,pp.100-109.

[24] S. Shateyi (2008)Thermal radiation and buoyancy effects on heat and mass transfer over a semi-infinite stretching surface with suction and blowing, Journal of Applied Mathematics, vol.2008, Article ID 414830, 12 pages, 2008.

[25] M. A. Seddeek and A. A. Almushigeh (2010) Effects of radiation and variable viscosity on MHD free convective flow and mass transfer over a stretching sheet with chemical reaction, "Applied Mathematics and Computation,vol.5,no.1,pp.181–197.

Where

$$a_1 = \frac{(\Pr A + \sqrt{(\Pr A)^2 - 4\Pr Q})}{2}$$

$$a_2 = \frac{(Sc A + \sqrt{(Sc A)^2 + 4k})}{2}$$

$$a_3 = \frac{A - \sqrt{A^2 + 4Z}}{2}$$

$$a_4 = \frac{-Gr_T \, Re^{-2}}{[(-a_2)^3 + Aa_2^2 + Za_2]}$$

$$a_5 = \frac{-Gr_T \, Re^{-2} N}{[(-a_2)^3 + Aa_2^2 + Za_2]}$$

$$a_6 = -\frac{(1 + a_1 * a_4 + a_2 a_5)}{a_3}$$

$$a_7 = F_w - a_6 - a_4 - a_5$$

$$a_8 = \frac{Pr\, A + \sqrt{(Pr\, A)^2 - 4Pr\, Q}}{2}$$

$$a_9 = -a_3 a_6 + a_1 a_6$$

$$a_{10} = 0$$

$$a_{11} = -a_2 a_5 + a_1 a_5$$

$$a_{12} = a_1 a_7$$

$$a_{13} = \frac{a_9}{[(a_1 + a_3)^2 - Pr\, A(a_1 + a_3) + Pt\, Q]}$$

$$a_{14} = \frac{a_{10}}{[4a_1^2 - 2Pra_1 A + Pr\, Q]}$$

$$a_{15} = \frac{a_{11}}{[(a_1 + a_2)^2 - Pr\, A(a_1 + a_2) + Pr\, Q]}$$

$$a_{16} = \frac{a_{12}}{(a_1^2 - PrAa_1 + Pr\, Q)}$$

$$a_{17} = -(a_{13} + a_{14} + a_{15} + a_{16})$$

$$a_{18} = \frac{(Sc + \sqrt{(Sc\, A)^2 + 4Sc\, k)}}{2}$$

$$a_{19} = \frac{(-a_3 a_6 + a_2 a_6)}{[(a_2 + a_3)^2 - Sc\, A(a_2 + a_3) - k\, Sc]}$$

$$a_{20} = \frac{(-a_1 a_4 + a_2 a_4)}{[(a_2 + a_1)^2 - Sc\, A(a_2 + a_1) - k\, Sc]}$$, and similar solutions.