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MASS TRANSFER EFFECTS ON MHD UNSTEADY FREE CONVECTIVE WALTER'S MEMORY FLOW WITH CONSTANT SUCTION AND HEAT SINK

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ABSTRACT

Free convection MHD memory flow of an incompressible and electrically conducting fluid past an infinite vertical plate with heat and mass in the presence of constant suction and heat sink has been studied. The dimensionless governing equations are solved using multi-parameter perturbation technique. The results are obtained for mean velocity, mean temperature,Nusselt number of mean temperature and skin friction of mean velocity. The effect of various material parameters are discussed on flow variables and presented by graphs and table.

Keywords: *Constant Suction, Free convection, Vertical plate, Heat transfer, memory flow, sink, Mass transfer and MHD*

INTRODUCTION:

The propagation of thermal energy through mercury and electrolytic solution in the presence of external magnetic field and heat absorbing sinks has wide range of application in chemical and aeronautical engineering, atomic propulsion, space science etc. The effect of magnetic field on free convective flow of electrically conducting fluids past a semi-infinite flat plate has been analysed by Gupta[1], Singh and Cowling[2],Nanda and Mohanty [4] and Vajravelu et al[5]. Raptis et al [8] and Geindreau et al [12] studied the effect of magnetic field in flow through porous medium. Raptis, Tzivonidis and Kafousias [6] and Raptis, Kafousias and Massalas [7] have studied the steady free convection and mass transfer through porous medium. Mohapatra and Senapati [9] have considered the steady MHD free convection flow through a porous medium with mass transfer. Mohapatra and Senapati [10, 11] have investigated the unsteady MHD free convection flow with mass transfer through porous medium past a vertical plate. Unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system was studied by Sharma [13]. MHD convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption was studied by Rahman et al. [14]. Ramana Murthy et al. [15] have studied the MHD unsteady free convective walter's memory flow with constant suction and heat sink.

It is proposed to study the mass transfer effects on MHD unsteady free convective Walter's memory flow with constant suction and heat sink for mercury (Pr=1) and electrolytic solution (Pr=0.025) .

FORMULATION OF THE PROBLEM:

An unsteady two dimensional free convective memory flow of an electrically conducting and incompressible fluid past an infinite vertical porous plate with constant suction and heat sink has been considered. X_1-axis is taken along the vertical plate in upward direction and the Y_1-axis is taken normal to the plate in the direction of applied uniform magnetic field of strength Ho. The magnetic permeability μ_e is constant throughout the field. There exist free convection current in the vicinity of the plate. It is assumed that a fluid has constant properties and the variation of density with temperature and mass concentration are considered only in the body force term.Joulean dissipation and induced magnetic field are neglected. All the variables in this flow are the function of y_1 and time t_1 only as the plate is infinite length. Initially, the temperature and mass concentration at the plate are respectively.T_P and C_P also the temperature and mass concentration of fluid are respectively T_∞ and C_∞ . At time $t_1 > 0$, it is assumed that the temperature and mass concentration at the plate rise to$T_1 = T_P + \epsilon(T_P - T_\infty)e^{iw_1t_1}$ and $C_1 = C_P + \epsilon(C_P - C_\infty)e^{iw_1t_1}$ Applying usual Boussinesq's approximation the unsteady flow is governed by the following equations:

$$\frac{\partial v_1}{\partial t_1} = 0 \;\Rightarrow\; v_1 = V_0 \tag{1}$$

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$$\frac{\partial u_1}{\partial t_1} + v_1 \frac{\partial u_1}{\partial y_1} = g\beta(T_1 - T_\infty) + g\beta_c(C_1 - C_\infty) + v\frac{\partial^2 u_1}{\partial y_1^2} - \frac{\sigma B_0^2 u_1}{\rho} - B_1\left(\frac{\partial^2 u_1}{\partial t \partial y_1^2} + v_1 \frac{\partial^2 u_1}{\partial y_1^2}\right) \tag{2}$$

$$\frac{\partial T_1}{\partial t_1} + v_1 \frac{\partial T_1}{\partial y_1} = k\frac{\partial^2 T_1}{\partial y_1^2} + S_1(T_1 - T_\infty) + \frac{v}{C_P}\left(\frac{\partial u_1}{\partial y_1}\right)^2 \tag{3}$$

$$\frac{\partial C_1}{\partial t_1} + v_1 \frac{\partial C_1}{\partial y_1} = D\frac{\partial^2 C_1}{\partial y_1^2} \tag{4}$$

The initial and boundary conditions of the problem are

$$\begin{aligned} &u_1 = V_0\,, T_1 = T_P + \epsilon(T_P - T_\infty)e^{iw_1 t_1}, C_1 = C_P + \epsilon(C_P - C_\infty)e^{iw_1 t_1} \quad at\ y_1 = 0 \\ &u_1 \to 0\,, T_1 \to T_\infty\,, C_1 \to C_\infty \quad as\ y_1 \to \infty \end{aligned} \tag{5}$$

where ρ is the density, g acceleration due to gravity, β is the co-efficient of thermal expansion, k is the thermal conductivity, v the kinematic viscosity, σ is electrical conductivity,$B_0(= H_0\mu_e)$ is the electromagnetic induction β_c the coefficient of expansion of mass and D is the diffusion constant.

On introducing the following non-dimensional quantities and parameters,

$$u = \frac{u_1}{V_0}\,, y = \frac{V_0 y_1}{v}\,, t = \frac{t_1 V_0^2}{v}, T = \frac{T_1 - T_\infty}{T_P - T_\infty}\,, C = \frac{C_1 - C_\infty}{C_P - C_\infty}\,, P_r = \frac{v}{k}\,, M = \frac{\sigma v B_0^2}{\rho V_0^2}\,, S = \frac{4 s_1 v}{V_0^2}\,, \omega = \frac{4\omega_1 k}{V_0^2}\,,\ G_r = \frac{g\beta v(T_P - T_\infty)}{V_0^2},$$
$$G_m = \frac{g\beta_C v(C_P - C_\infty)}{V_0^2}\,, \mathrm{E_C} = \frac{V_0^2(T_P - T_\infty)}{C_P}\,, R_m = \frac{B_1 V_0^2}{v^2}\,, S_C = \frac{v}{D}$$

Where $B_1, \rho, k, \mathrm{C_P}, \mathrm{P_r}, \mathrm{G_r}, \mathrm{G_m}, \mathrm{S}, \mathrm{S_C}, \mathrm{E_C}$, M and $\mathrm{R_m}$ are coefficient of volumetric expansion, density, thermal conductivity, specific heat at constant pressure, Prandtl number, Grashoff number, modified Grashoff number, Sink strength, Schmidt number, Eckert number, Hartmann number and Magnetic Reynolds number respectively.Using equation (6) ,equations (2) to (4) with boundary conditions (5) become

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + G_r T + G_m C - Mu - R_m\left(\frac{1}{4}\frac{\partial^2 u}{\partial t \partial y^2} - \frac{\partial^2 u}{\partial y^2}\right) \tag{7}$$

$$\frac{1}{4}\frac{P_r \partial T}{\partial t} - \frac{P_r \partial T}{\partial y} = \frac{\partial^2 T}{\partial y^2} + \frac{P_r S T}{4} + E_C P_r\left(\frac{\partial u}{\partial y}\right)^2 \tag{8}$$

$$\frac{1}{4}\frac{S_C \partial C}{\partial t} - \frac{S_C \partial C}{\partial y} = \frac{\partial^2 C}{\partial y^2} \tag{9}$$

With corresponding boundary conditions

$$\begin{aligned} &u = 0\,, T = 1 + \epsilon e^{i\omega t}\,, C = 1 + \epsilon e^{i\omega t} \quad at\ y = 0 \\ &u \to 0\,, T \to 0\,, C \to 0 \quad as\ y \to \infty \end{aligned} \tag{10}$$

To solve equations (7) to (9), we assume ω to be very small and velocity ,Temperature and mass concentration in the neighborhood of the plate as

$$\begin{aligned} u(y,t) &= u_0(y) + \epsilon e^{i\omega t} u_1(y) \\ T(y,t) &= T_0(y) + \epsilon e^{i\omega t} T_1(y) \\ C(y,t) &= C_0(y) + \epsilon e^{i\omega t} C_1(y) \end{aligned} \tag{11}$$

Where $u_0, T_0\ and\ C_0$ are mean velocity , mean temperature and mass concentration , respectively .Substituting (11) in equations (7) to (9) ,equating harmonic and non-harmonic terms for mean velocity , mean temperature and mass concentration after neglecting co-efficient of ϵ^2 ,we get

$$R_m u_0'' + u_0'' + u_0' - M u_0 = -G_r T_0 - G_m C_0 \tag{12}$$

$$T_0'' + P_r T_0' + \frac{P_r S T_0}{4} = -P_r E_C (u_0')^2 \tag{13}$$

$$C_0'' + S_C C_0' = 0 \tag{14}$$

As the equation (12) is third order differential equation presence of elasticity, therefore u_0 is expanded using Beard and Walters rule [3], i.e.

$$u_0 = u_{0_0} + R_m u_{0_1} \tag{15}$$

and substitute in equation (12),equating the zeroth and first order co-efficient of R_m, we get

$$u_{0_0}'' + u_{0_0}' - Mu_{0_0} = -G_r T_0 - G_m C_0 \tag{16}$$

$$u_{0_1}'' + u_{0_1}' - Mu_{0_1} = -u_{0_0}'' \tag{17}$$

Using multiparameter perturbation technique and assuming Ec<<1, we write

$$\begin{aligned} u_{0_0} &= u_{00_0} + E_C u_{00_1} \\ u_{0_1} &= u_{01_1} + E_C u_{01_2} \\ T_0 &= T_{0_0} + E_C T_{0_1} \\ C_0 &= C_{0_0} + E_C T_{0_1} \end{aligned} \tag{18}$$

Using equation (18) in equation (13),(14) ,(16) and (17),equating the zeroth and first order co-efficient of Ec,we get the following differential equations

Zero-order of Ec :

$$\begin{aligned} &u_{00_0}'' + u_{00_0}' - Mu_{00_0} = -G_r T_{0_0} - G_m C_{0_0} \\ &u_{01_1}'' + u_{01_1}' - Mu_{01_1} = -u_{00_0}'' \\ &T_{0_0}'' + P_r T_{0_0}' + \frac{P_r S T_{0_0}}{4} = 0 \\ &C_{0_0}'' + S_C C_{0_0}' = 0 \end{aligned} \tag{19}$$

First-order of Ec :

$$\begin{aligned} &u_{00_1}'' + u_{00_1}' - Mu_{00_1} = -G_r T_{0_1} - G_m C_{0_1} \\ &u_{01_2}'' + u_{01_2}' - Mu_{01_2} = -u_{00_1}'' \\ &T_{0_1}'' + P_r T_{0_1}' + \frac{P_r S T_{0_1}}{4} = -P_r (u_{00_0}')^2 \\ &C_{0_1}'' = 0 \end{aligned} \tag{20}$$

With corresponding boundary conditions

$$\begin{aligned} &y = 0: \quad u_{00_0} = u_{00_1} = u_{01_1} = u_{01_2} = 0\,, T_{0_0} = 1, T_{0_1} = 0, C_{0_0} = 1, C_{0_1} = 0 \\ &y \to \infty: \quad T_{0_0} \to T_{0_1} \to 0\,, C_{0_0} \to C_{0_1} \to 0 \end{aligned} \tag{21}$$

METHOD OF SOLUTION:

Solving these differential equations from (19-20), using boundary conditions (21), and then making use of equation (18).Finally with the help of equation(15) we obtain the mean velocity u_0 ,mean temperatureT_0 ,mean mass concentration C_0 as follows

$$\begin{aligned} u_0 = {} & A_{13} e^{-(t_2 y)} + A_{11} e^{-(t_1 y)} + A_{12} e^{-(S_C y)} + E_C [A_{28} e^{-(t_2 y)} + A_{21} e^{-(t_1 y)} + A_{22} e^{-2(t_2 y)} + A_{23} e^{-2(t_1 y)} + \\ & A_{24} e^{-2(S_c y)} + A_{25} e^{-((t_1+t_2)y)} + A_{26} e^{-((S_c+t_2)y)} + A_{27} e^{-((S_c+t_1)y)} + A_{31} e^{-(t_1 y)} + A_{29} e^{-(S_c y)} + A_{30} e^{-(t_1 y)} + \\ & A_{39} e^{-(t_2 y)} + A_{32} e^{-(t_1 y)} + A_{33} e^{-2(t_2 y)} + A_{34} e^{-2(t_2 y)} + A_{35} e^{-2(S_c y)} + A_{36} e^{-((t_1+t_2)y)} + A_{37} e^{-((S_c+t_2)y)} + \\ & A_{38} e^{-((S_c+t_1)y)}] \end{aligned} \tag{22}$$

$$\begin{aligned} T_0 = {} & e^{-(t_1 y)} + E_C [A_{20} e^{-(t_1 y)} + A_{14} e^{-2(t_2 y)} + A_{15} e^{-2(t_1 y)} + A_{16} e^{-2(S_c y)} + A_{17} e^{-((t_1+t_2)y)} + A_{18} e^{-((S_c+t_2)y)} + \\ & A_{19} e^{-((S_c+t_1)y)}] \end{aligned} \tag{23}$$

$$C_0 = e^{-S_c y} \tag{24}$$

Where $t_1 = \frac{P_r + \sqrt{P_r^2 - P_r S}}{2}$, $t_2 = \frac{1+\sqrt{1+4M}}{2}$

$$A_{11} = \frac{-G_r}{\left[2P_r^2 - P_rS + 2P_r\sqrt{(P_r^2 - P_rS)}\right) - 2P_r - 2\sqrt{(P_r^2 - P_rS) - 4M}} \ , \ A_{12} = \frac{-G_m}{S_C^2 - S_C - M} \ ,$$

$$A_{13} = -(A_{11} + A_{12}) \ , A_{14} = \frac{-P_r A_{13}^2}{4t_2^2 - 2t_2P_r + \frac{P_rS}{4}} \ , A_{15} = \frac{-P_r A_{11}^2}{4t_1^2 - 2t_1P_r + \frac{P_rS}{4}} \ , A_{16} = \frac{-P_r A_{12}^2}{4S_C^2 - 2S_CP_r + \frac{P_rS}{4}}$$

$$A_{17} = \frac{-2P_r A_{13} A_{11}}{(t_1+t_2)^2 - (t_1+t_2)P_r + \frac{P_rS}{4}}$$

$$A_{18} = \frac{-2P_r A_{13} A_{12}}{(S_C+t_2)^2 - (S_C+t_2)P_r + \frac{P_rS}{4}}$$

$$A_{19} = \frac{-2P_r A_{11} A_{12}}{(S_C+t_1)^2 - (S_C+t_1)P_r + \frac{P_rS}{4}}$$

$$A_{20} = -(A_{14} + A_{15} + A_{16} + A_{17} + A_{18} + A_{19})$$

$$A_{21} = \frac{A_{20}}{t_1^2 - t_1 - M} \ , A_{22} = \frac{A_{14}}{4t_2^2 - 2t_2 - M} \ , A_{23} = \frac{A_{15}}{4t_1^2 - 2t_1 - M} \ \ A_{24} = \frac{A_{16}}{4S_C^2 - 2S_C - M} \ , A_{25} = \frac{A_{17}}{(t_1+t_2)^2 - (t_1+t_2) - M} \ ,$$

$$A_{26} = \frac{A_{18}}{(S_C+t_2)^2 - (S_C+t_2)P_r - M} \ , A_{27} = \frac{A_{19}}{(S_C+t_1)^2 - (S_C+t_1)P_r - M} \ , A_{28} = -(A_{21} + A_{22} + A_{23} + A_{24} + A_{25} + A_{26} + A_{27})$$

$$A_{31} = -(A_{30} + A_{29}) \ \ , A_{30} = \frac{t_1^3 A_{11}}{t_1^2 - t_1 - M} \ , A_{29} = \frac{S_C^3 A_{12}}{S_C^2 - S_C - M} \ , A_{32} = \frac{t_1^3 A_{21}}{t_1^2 - t_1 - M} \ , A_{33} = \frac{8t_2^3 A_{22}}{4t_2^2 - 2t_2 - M} \ , A_{34} = \frac{8t_1^3 A_{23}}{4t_1^2 - 2t_1 - M} \ ,$$

$$A_{35} = \frac{8S_C^3 A_{24}}{S_C^2 - 2S_C - M} \ , A_{36} = \frac{(t_1+t_2)^3 A_{25}}{(t_1+t_2)^2 - (t_1+t_2) - M} \ , A_{37} = \frac{(S_C+t_2)^3 A_{26}}{(S_C+t_2)^2 - (S_C+t_2) - M} \ , A_{38} = \frac{(S_C+t_1)^3 A_{27}}{(S_C+t_1)^2 - (S_C+t_1) - M} \ ,$$

$$A_{39} = -(A_{32} + A_{33} + A_{34} + A_{35} + A_{36} + A_{37} + A_{38})$$

The mean skin friction/shearing stress at the plate in dimensional form is given by

$$\tau_0 = (\frac{\partial u_0}{\partial y})_{y=0} = -[A_{13}t_2 + A_{11}t_1 + A_{12}S_C + E_C[A_{28}t_2 + A_{21}t_1 + A_{22}2t_2 + A_{23}2t_1 + A_{24}2S_C + A_{25}(t_1 + t_2) + A_{26}(S_C + t_2) + A_{27}(S_C + t_1) + A_{31}t_1 + A_{29}S_C + A_{30}t_1 + A_{39}t_2 + A_{32}t_1 + A_{33}2t_2 + A_{34}2t_2 + A_{35}2S_C + A_{36}(t_1 + t_2) + A_{37}(S_C + t_2) + A_{38}(S_C + t_1)] \tag{25}$$

Similarly the mean rate of heat transfer at the plate / Nusselt Number is given by

$$Nu_0 = -(\frac{\partial \tau_0}{\partial y})_{y=0} = t_1 + E_C[A_{20}t_1 + A_{14}2t_2 + A_{15}2t_1 + A_{16}2S_C + A_{17}(t_1 + t_2) + A_{18}(S_C + t_2) + A_{19}(S_C + t_1)] \tag{26}$$

and the mean rate of mass concentration transfer at the plate/Sherwood Number is given by

$$Sh_0 = S_C \tag{27}$$

DISCUSSION OF RESULTS:

In this paper we have studied the effect of Mass transfer on MHD unsteady free convective Walter's memory flow with constant suction and heat sink. . The effect of the parameters Gr, Gm, M, Rm,Ec ,S, Pr and Sc on flow characteristics have been studied and shown by means of graphs . In order to have physical correlations ,we choose suitable values of flow parameters. To obtain the graphs the mean velocity ,mean temperature, mean mass concentration ,Nusselt number of mean temperature and skin friction of mean velocity are taken w.r.t parameters(y) and (Gm) as per need .

Velocity profiles: The mean velocity profiles are depicted in Figs 1-3. Figure-(1))shows the effect of the parameters Pr ,Sc and M on mean velocity at any point of the fluid, when Ec=0.001,Pr=0.025,Gr=5,Rm=1,S=-0.05 and Gm=5. It is noticed that the mean velocity decreases with the increase of Prandtl number (Pr), Schmidt number (Sc) and magnetic field strength (M).

Figure-(2) shows the effect of the parameters S ,Ec, and Rm on mean velocity at any point of the fluid **,**when Sc=0.22,Pr=0.025,Gr=5,Gr=5,M=1 and Gm=5. It is noticed that the velocity decreases with the increase of sink strength (S) , Magnetic Reynolds number (Rm)and Eckert number (Ec).

Figure-(3) shows the effect of the parameters Gr and Gm on mean velocity at any point of the fluid, when Ec=0.001,Pr=0.025,Sc=0.22,Rm=1,M=1 and S=-0.05. It is noticed that the velocity increases with the increase of Grashoff number (Gr) and modified Grashoff number(Gm).

Temperature profile: The mean temperature profiles are depicted in Figs 4-6. Figure-(4) shows the effect of the parameters S ,Gr and M on mean Temperature profile at any point of the fluid **,**when Ec=0.001,Pr=0.025,Sc=2and Gm=5. It is noticed that the temperature rises in the increase of Grashoff number(Gr) and magnetic field strength (M) but falls for the increase of sink strength (S).

Figure-(5) shows the effect of the parameters Ec and Sc on mean Temperature profile at any point of the fluid, when Pr=0.025,S=-0.5,Gm=5,M=1 and Gr=5. It is noticed that the temperature falls (near the plate)upto 1.5 units and then rises (away from the plate) when Eckert number (Ec) increases and rises in the increase of Schmidt number(Sc).
Figure-(6) shows the effect of the parameters Pr and Gm on mean Temperature profile at any point of the fluid, when Ec=0.001,Sc=2,S=-0.5 ,M=1 and Gr=5. It is noticed that the temperature falls when Pr increases and rises in the increase of modified Grashoff number (Gm).

Shearing stress of mean velocity: The Shearing stresses of mean velocity are depicted in Figs 7-8. Figure-(7) shows the effect of the parameters Pr, M and S on shearing stress of mean velocity at the plate of the fluid w.r.t. Gm, when Ec=0.001,Sc=0.22,Gr=5 and Rm=1 . . It is noticed that shearing stress at plate decreases with the increase of Prandtl number(Pr), magnetic field strength (M) and magnitude of sink strength(S).

Figure-(8) shows the effect of the parameters Ec,Sc ,Gr and Rm on shearing stress at the plate of the fluid w.r.t. Gm **,**when Pr=0.025, ,S=-0.5 and M=1. It is noticed that the shearing stress of mean velocity at the plate increases with the increase of Grashoff number (Gr) and Magnetic Reynolds number (Rm),where as it decreases in the increase of Eckert number (Ec) and Schmidt number (Sc).

Nusselt number of mean Temperature**:** Table-(1) shows the effect of the parameters S ,M ,Pr and Ec on the mean rate of heat transfer for mercury and electrolytic solution at the plate ,It is observed that the mean rate of heat transfer increases with the increase in magnetic field strength(M) and decreases with the increase in sink strength(S) both for mercury and electrolytic solution ,where as it increases for mercury and decreases for electrolytic solution with the increase in magnetic Eckert number (Ec).

Table-1. Values of mean rate of heat transfer Nu_0 for fixed values of Gr = 5.0,

Pr when Gm=5, Sc=1	**M**	**S**	**Ec**	**Nu_0**
Mercury (Pr = 0.025)	1.0	-0.05	0.001	0.0322
	5.0	-0.05	0.001	0.0341
	5.0	-0.1	0.001	0.0404
	10	-0.2	0.001	0.0500
	10	-0.2	0.1	0.0485
	5	-0.1	0.1	0.0471
Electrolytic solution (Pr = 1.0)	1.0	-0.05	0.001	1.0121
	5.0	-0.05	0.001	1.0123
	5.0	-0.10	0.001	1.0244
	1.0	-0.05	0.1	0.9903
	1.0	-0.05	0.5	0.9019

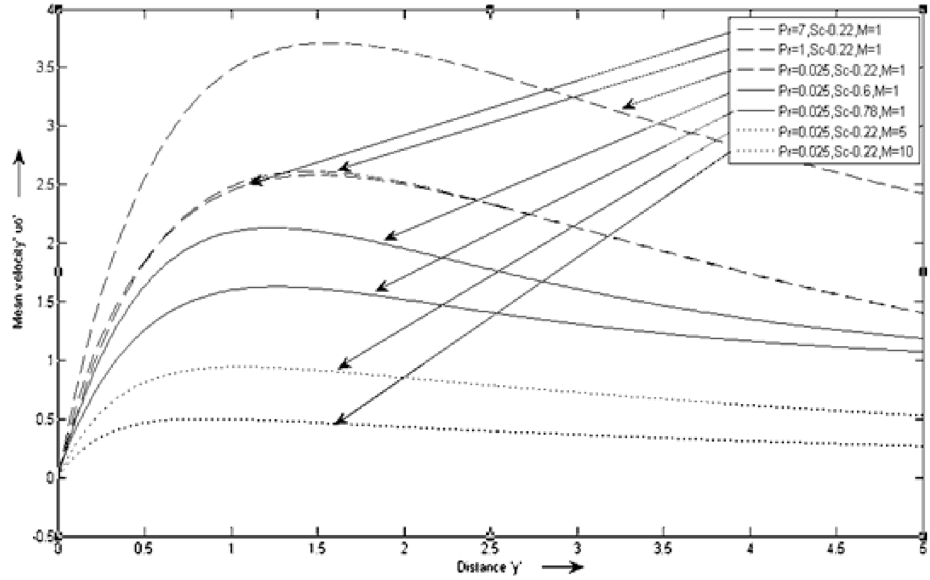
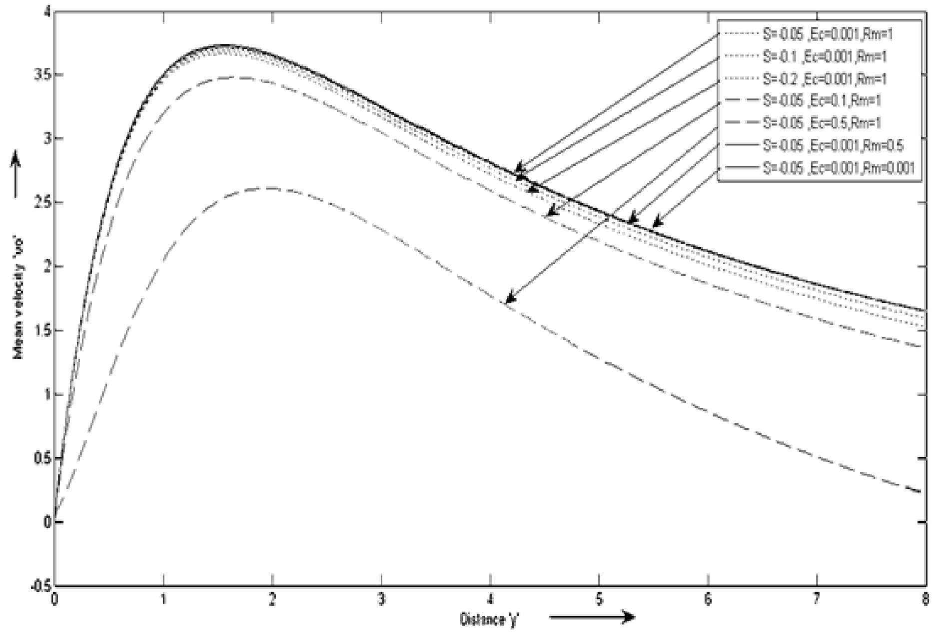


Fig-(1): Effect of Sc, Pr and M on Mean Velocity profile when Ec=0.001,Pr=0.025,Gr=5, Rm=1, S=-0.05 and m=5.



Fig(2): Effect of S , Ec and Rm on Mean Velocity profile when Sc=0.22, Pr=0.025, Gr=5, Gr=5, M=1and Gm=5.

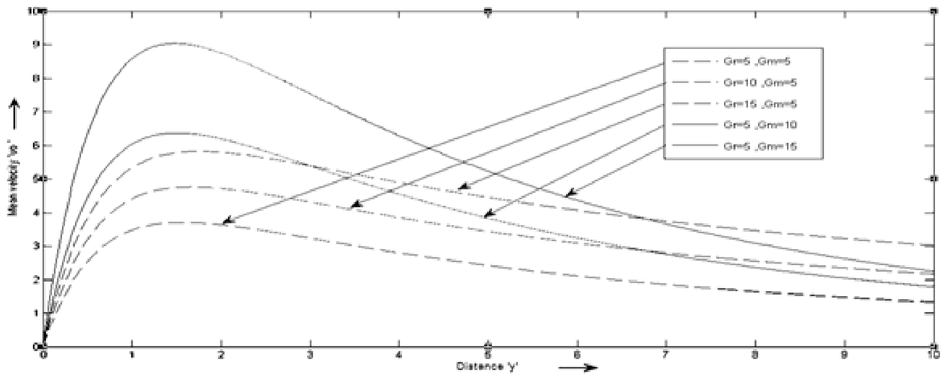


Fig (3): Effect of Gr and Gm on Mean Velocity profile when Ec=0.001, Pr=0.025, Sc=0.22, Rm=1, M=1 and S=-0.05.

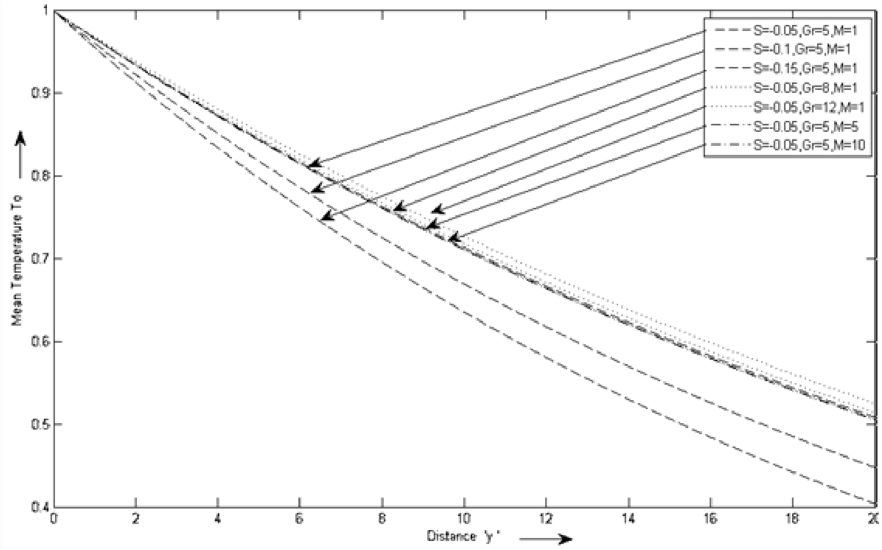


Fig-(4): Effect of S, Gr and M on Mean Temperature profile when Ec=0.001, Pr=0.025, Sc=2 and Gm=5.

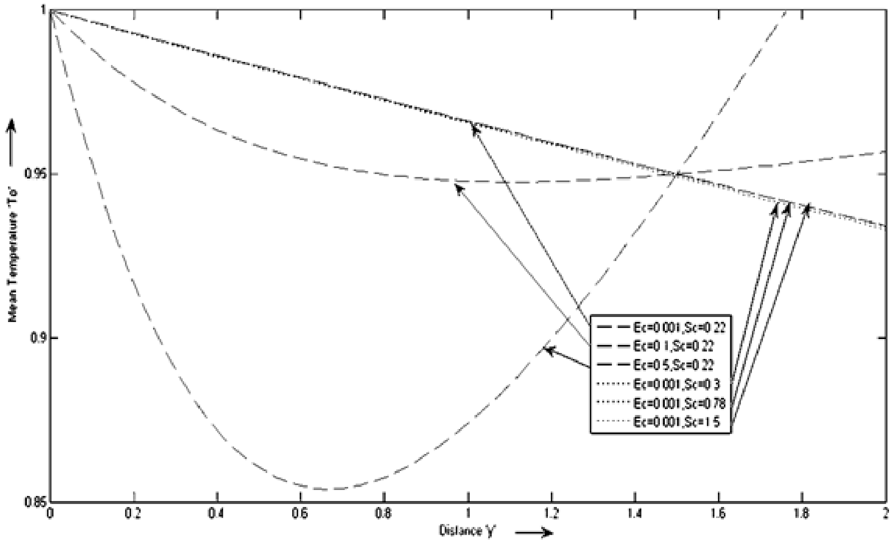


Fig-(5): Effect of Ec and Sc on Mean Temperature profile when Pr=0.025, S=-0.5, Gm=5, M=1 and Gr=5.

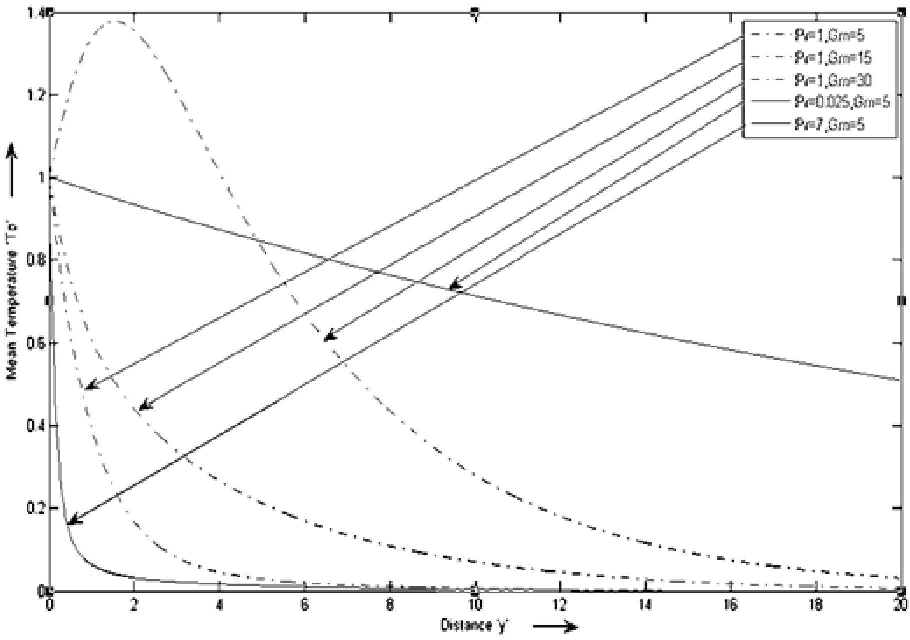


Fig-(6): Effect of Pr and Gm on Mean Temperature profile when, Ec=0.001, Sc=2, S=-0.5, M=1 and Gr=5.

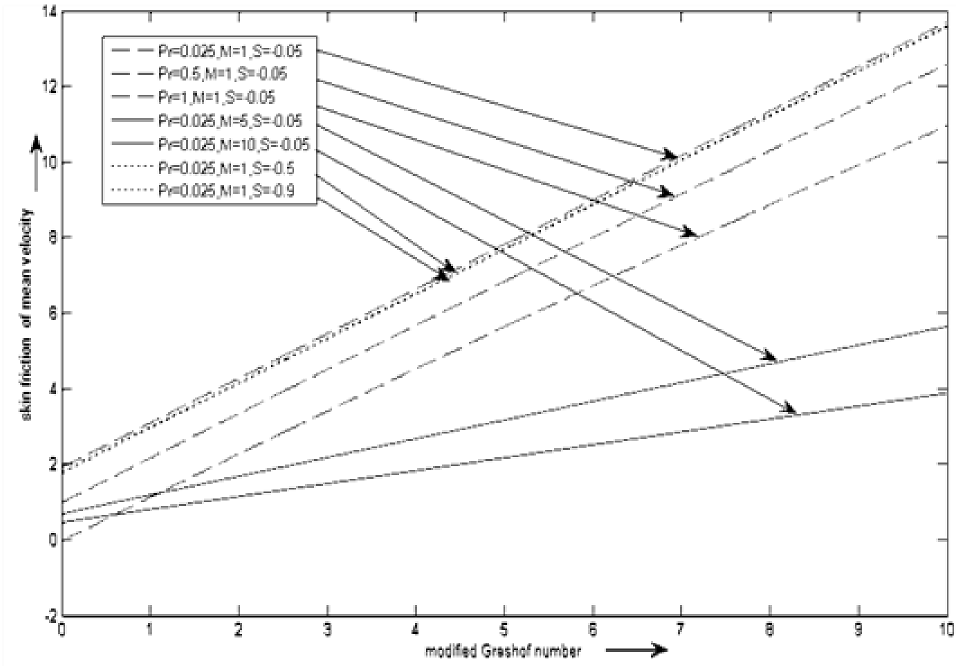


Fig-(7): Effect of Pr, S and M on skin friction of mean velocity when, Ec=0.001, Sc=0.22, Gr=5 and Rm=1 .

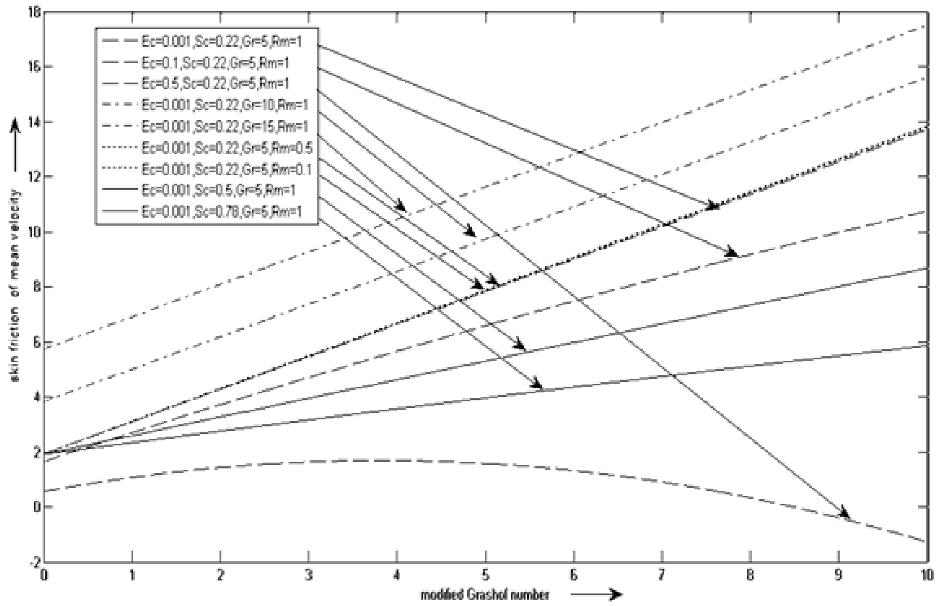


Fig-(8): Effect of Ec, Sc, Gr and Rm on skin friction of mean velocity when, Pr=0.025, S=-0.5 and M=1.

CONCLUSION:

In this study, the following conclusions for mercury (Pr=1) and electrolytic solution (Pr=0.025) are set out:

i. The mean velocity increases with the increase in Gr and Gm, also decreases with the increase in of M, Pr, Sc, S, Rm and Ec.
ii. The mean heat profile decreases for the increasing of Pr, Sc and S; increases with the increase in of Gr, M and Gm; but initially decrease and then increase with the increase of Ec.
iii. The skin-friction of mean velocity at plate increases with an increase in Gr and Rm, while it decreases with an increase in Sc, M Pr, Ec and S.
iv. The mean rate of heat transfer increases with the increase M and decreases with the increase in S.

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