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MHD AND UNSTEADY FLOW OF RIVLIN-ERICKSEN FLUID IN A PERMEABLE MEDIA WITH THERMAL AND MASS TRANSPORT OVER A CHANNEL THAT IS INCLINED AND COMPRISES OF TWO RECTANGULAR PARALLEL PLATES IN OSCILLATION.

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Abstract:

The research paper goal is to investigate the impact of the heat and mass transport on a Rivlin-Ericksen fluid's unsteady MHD flow through a channel that is inclined having two rectangular plates placed in parallel and oscillating subject to the impact of magnetic field which includes sources of heat generation or sinks that absorb heat, while one plate is adiabatic and the other non- adiabatic in porous medium. The equations with fluid conservation laws were solved by applying perturbation method and the expressions for velocity, temperature and concentration were obtained. The effect of various pertinent parameters on fluid velocity, temperature and concentration are shown with the graphic representation.

Key words: Rivlin-Ericksen fluid, Oscillatory flow, porous medium, Perturbation method, inclined channel, adiabatic.

Introduction:

MHD and oscillatory Rivlin Ericksen fluid flow is of vital interest due to vast array of applications in the scientific and technical disciplines which include electronic component cooling systems, chemical engineering, underground waste water disposal, oil exploration, nuclear fuel cooling, geothermal power recovery, thermal power storage, bio medical engineering applications which include blood flow dynamics.

Bhattacharjee A. and Borkakati A. K[1].have examined the thermal transfer between the permeable disks, one in motion and another stationary, within a magnetohydrodynamic flow including continuous suction, while the bottom plate remains adiabatic. (given by

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Schlitchting[9]). The impact of thermal transmission on MHD flow of dusty Rivlin-Ericksen fluid filled with porous medium via an inclined conduit was studied by Chakraborty S. and Borkakati A. K[3]. Badosa G.and Borkakati A. K[2]. examined the heat transmission and MHD transient Rivlin-Ericksen fluid flow via a conduit that is inclined, with two rectangular plates placed in parallel while one of which remains adiabatic. Ujwanta I. J.and Hussaini A[11]. studied the impact of mass transport on electrically conducting fluids passing across a permeable plate that is infinitely vertical with periodic suction in an unstable hydromagnetic free convection of a Rivlin Ericksen fluid. Reddy P. R. et., al[8]. focused on Rivlin-Ericksen fluid heat transport and MHD flow via an inclined conduit with oscillatory motion.. Reddy P. R. et., al[7]. studied the of Rivlin-Ericksen fluid heat transmission via a channel which is inclined in a permeable medium with oscillatory motion. Purna Chander Rao D. et., al[5]. extended the work of P.R. Reddy et., al[8]. and discussed the impact of thermal transmission and mass transport. Omeshwer Reddy et., al[6]. focused on the two -dimensional natural convection flow of unsteady Rivlin Ericksen fluid over an inclined plane with thermal diffusion and heat and mass transfer effects.. Malleswari D[4]. examined the two- dimensional heat absorbing unsteady flow of viscous, incompressible, electrically conducting fluid flow via a vertical semi-infinite vertical porous plate in a boundary layer by considering double diffusion, magnetic field and free convection.

The present investigation is the continuation of the work of Purna Chander Rao D. et., al[5]. This work focusses on the impact of the heat and mass transport on a Rivlin-Ericksen fluid's unsteady MHD flow through a channel that is inclined having two rectangular plates placed in parallel and oscillating when exposed to the magnetic field which includes sources of heat generation or sinks that absorb heat, while one plate is adiabatic and the other non- adiabatic in porous medium.

Mathematical Formulation:

Consider the oscillatory flow of a fluid that conducts electrically, which is viscous and incompressible over a channel that is inclined having two rectangular plates placed in parallel and located 2h and oscillating subject to a uniformly strong magnetic field two flat parallel plates in oscillatory motion located 2h apart. We assert that the x^*-axis is aligned between the middle of the plates in straight line, while the y^*-axis is orthogonal to it. A constant magnetic field strength B_0 is applied along y^*-axis. Assume that every other components of velocity are zero and that u^* is the component of velocity with respect to the x^*-axis.

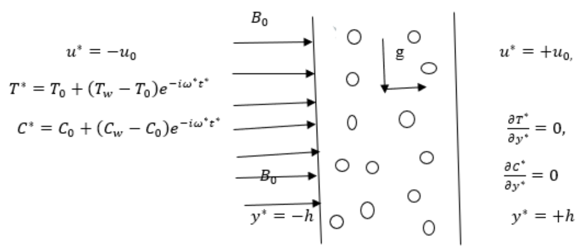

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Fig. 1 **Physical model**

Listed below criteria are taken into consideration when writing out the equations governing the flow.

(i). The plates length is infinite, therefore the velocity u^* is solely depends on y^* and t^*.

(ii). All fluid particles have the same temperature and the fluids equation of momentum takes the buoyancy force into account.

(iii). There is a complete development of the flow across the two plates.

(iv). This is a presumption that the fluid has a very low conductivity to disregard the magnetic field that is induced [G. W. Sutton [1]].

(v). It is presumed that viscous dissipation and Hall effect are ignored.

(vi). Only the Lorenz force is taken in to account.

The equations governing the continuity, motion, energy, and concentration for the unsteady electrically conducting incompressible viscoelastic fluid over two parallel, non-conductive plates when a magnetic field is present are as follows.

$$\frac{\partial u^*}{\partial x^*} = 0 \qquad (1)$$

$$\frac{\partial u^*}{\partial t^*} = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \nu\frac{\partial^2 u^*}{\partial y^{*2}} + \frac{k_0}{\rho}\frac{\partial^3 u^*}{\partial t^* \partial y^{*2}} - \sigma\frac{{B_0}^2}{\rho}u^* + g\sin\theta + g\beta(T^* - T_0) + g\,\beta_c(C^* - C_0) - \frac{\mu u^*}{K} \qquad (2)$$

$$\frac{\partial T^*}{\partial t^*} = \frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}} + S^*(T^* - T_0) \qquad (3)$$

$$\frac{\partial C^*}{\partial t^*} = D\,\frac{\partial^2 C^*}{\partial y^{*2}} - D_1\frac{\partial^2 T^*}{\partial y^{*2}} \qquad (4)$$

The fluid flow has the following boundary conditions:

$$\left.\begin{array}{l} t^* > 0;\ u^* = -u_0,\ \ T^* = T_0 + (T_w - T_0)e^{-i\omega^* t^*}, \\ \quad C^* = C_0 + (C_w - C_0)e^{-i\omega^* t^*}\ \ at\ y^* = -h \\ \quad u^* = +u_{0,}\frac{\partial T^*}{\partial y^*} = 0,\ \ \frac{\partial C^*}{\partial y^*} = 0 \quad at\ y^* = +h \end{array}\right\} \qquad (5)$$

In order to provide the necessary characteristics of this problems equations, we now take into the dimensionless parameters which Shih-Pai[2] stated.

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$$\begin{gathered} x=\frac{x^*u_0}{v}, y=\frac{y^*u_0}{v},\ u=\frac{u^*}{u_0}, \\ t=\frac{t^*{u_0}^2}{v},\ M=\frac{\sigma {B_0}^2 v}{\rho {u_0}^2}, \\ T=\frac{T^*-T_0}{T_w-T_0}, P_r=\frac{\mu C_p}{k}, \omega=\frac{v\omega^*}{{u_0}^2}, \\ S=\frac{S^*v}{{u_0}^2},, p=\frac{p^*}{\rho {u_0}^2}, Fr=\frac{{u_0}^2}{gh}, \\ Re=\frac{u_0 h}{v},\ \frac{hu_0}{v}=1, \\ C=\frac{C^*-C_0}{C_w-C_0},\ Rc=\frac{k_0{u_0}^2}{\rho v^2}, \\ Sc=\frac{\mu}{\rho D}, Gr=\frac{vg\beta(T_w-T_0)}{u_0^3}, \\ Gm=\frac{vg\beta_c(C_w-C_0)}{u_0^3}, S_0=\frac{D_1(T_w-T_0)}{C_w-C_0}, \\ Da=\frac{K{u_0}^2}{v^2}, \end{gathered} \tag{6}$$

where T_w and T_o represents the temperature of the plates, C_w and C_o represent the concentration at the plates, ρ fluid's density, B_0 a uniform magnetic field strength that is applied in a transverse direction to the plate, fluid's electrical conductivity σ, kinematics viscosity coefficient υ, fluid's specific heat c_p, coefficient thermal expansion coefficient β, Solutal expansion coefficient β_c, gravitational acceleration g, pressure p, elasticity coefficient k_0, the source or sink parameter S, D, chemical molecular diffusivity, D_1 Mass diffusivity, M , magnetic parameter, Pr, Prandtl number, Fr, Froude's number, Re, Reynold's number, R_c, elastic parameter, G_r, Grashof number with respect to temperature, Sc, Schmidt number , S_0,Soret number, Gm, Solutal Grashof number, Da, Permeability parameter and $\omega > 0$ denoting the decay factor.

Replacing the dimensionless parameters in (1), (2), (3) and (4) equations we get,

$$\frac{\partial u}{\partial x} = 0 \tag{7}$$

$$\frac{\partial u}{\partial t}=-\frac{\partial p}{\partial x}+\frac{\partial^2 u}{\partial y^2}+Rc\frac{\partial^3 u}{\partial t\partial y^2}-(M+Da^{-1})u+\frac{\sin\theta}{FrRe}+ GrT+GmC \tag{8}$$

$$\frac{\partial T}{\partial t} = \frac{1}{Pr}\frac{\partial^2 T}{\partial y^2}+ ST \tag{9}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-S_0 \tag{10}$$

The unitless boundary conditions are

$$\left.\begin{gathered} t>0;\ u=-1, T=e^{-i\omega t}, \\ C=e^{-i\omega t}\ at\ y=-1 \\ u=1,\ \frac{\partial T}{\partial y}=0, \frac{\partial C}{\partial y}=0\ at\ y=1 \end{gathered}\right\} \tag{11}$$

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From eq.(7) we have u is a either a constant or only a function of y and t. Additionally eq. (8) indicates that the velocity u is independent of x, hence u is in terms of only y and t. Hence the expression, $\frac{\partial p}{\partial x}$ must be either vary only with time or constant.

Let $\frac{\partial p}{\partial x} = \quad -h(t)$ (12)

Then eq. (8) becomes

$$\frac{\partial u}{\partial t} = h(t) + \frac{\partial^2 u}{\partial y^2} + Rc\frac{\partial^3 u}{\partial t \partial y^2} - (M + Da^{-1})u + \frac{\sin\theta}{FrRe} + GrT + GmC \quad (13)$$

Solution of the problem:

With the imposed boundary conditions (11), the equations (9),(10) and (13) can be solved by considering $u = f(y)e^{-i\omega t}$, $T = g(y)e^{-i\omega t}$,

$$h = h_0 e^{-i\omega t},\ C = l(y)e^{-i\omega t} \quad (14)$$

The boundary conditions (11) are transformed to

$$\left.\begin{array}{r} t > 0\,;\ at\ y = -1, f(-1) = -e^{i\omega t}, \\ g(-1) = 1, l(-1) = 1 \\ at\ y = +1, f(+1) = e^{i\omega t}, \\ g'(+1) = 0, l'(+1) = 0 \end{array}\right\} \quad (15)$$

and equations (13), (9) and (10) are transformed to

$$(1 - i\omega Rc)f''(y) - (M + Da^{-1} - i\omega)f(y)$$
$$= -h_0 - \frac{\sin\theta}{FrRe}e^{i\omega t} - Grg(y) - Gml(y) \quad (16)$$

$$g''(y) + Pr(S + i\omega)\, g = 0 \quad (17)$$

$$l''(y) + ScS_0 g''(y) + i\omega Scl = 0 \quad (18)$$

Now, separating real and imaginary parts and solving (16), (17) and (18) with (15), we get

$$f(y) = f_R(y) + if_I(y) \quad (19)$$

where

$$f_R(y) = \cos\omega t\, B_{44}e^{-(\sqrt{B_{18}})y} - B_{45}e^{-(\sqrt{B_{18}})y} + B_{46}sinh\left(\sqrt{B_{18}}\right)y - B_{47}sinh\left(\sqrt{B_{18}}\right)y + B_{48}cosh\left(\sqrt{B_{18}}\right)y + B_{24}y + B_{26}\cos(m_1 y) \quad (20)$$

$$f_I(y) = (B_{42}\sin\omega t - B_{40}\cos\omega t)e^{m_2 y} + (B_{43}\sin\omega t - B_{41}\cos\omega t)e^{-m_2 y} + B_{34} \quad (21)$$

$$g(y) = B_2\cos(m_1 y) + B_1\sin(m_1 y) \quad (22)$$

$$l(y) = B_{17} + B_{15}y - B_6\cos(m_1 y) - B_7\sin(m_1 y) \quad (23)$$

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Substituting the values of $f,\ g$ and l in $u,\ T$ and C we get,

$u \ = \ u_R + iu_I$ (24)

$T = T_R + iT_I$ (25)

$C \ = \ C_R + iC_I$ (26)

where

$u_R = f_R(y)\cos\omega t + f_I(y)\sin\omega t$ (27)

$u_I = f_I(y)\cos\omega t - f_R(y)\sin\omega t$ (28)

$T_R = B_1\cos(m_1 y)\cos\omega t + B_2\sin(m_1 y)\cos\omega t$ (29)

$T_I = -B_2\cos(m_1 y)\sin\omega t - B_1\sin(m_1 y)\sin\omega t$ (30)
(30)

$C_R = (B_{17} + B_{15}y - B_6\cos(m_1 y) - B_7\sin(m_1 y))\cos\omega t$ (31)

$C_I = -(B_{17} + B_{15}y - B_6\cos(m_1 y) - B_7\sin(m_1 y))\sin\omega t$ (32)

The magnitude of fluid velocity, fluid temperature and fluid concentration are given by

$|u| = \sqrt{u_R{}^2 + u_I{}^2}$ (33)

$|T| \ = \sqrt{T_R{}^2 + T_I{}^2}$ (34)

$|C| \ = \sqrt{C_R{}^2 + C_I{}^2}$ (35)

Where $m_1 = \sqrt{PrS}$, $m_2 = \sqrt{\frac{1}{Rc}}$, $B_1 = \frac{\sin m_1}{\cos 2m_1}$, $B_2 = B_1\sin m_1\cos m_1$, $B_3 = ScS_0$, $B_4 = B_3 m_1{}^2$, $B_5 = B_1B_3$, $B_6 = B_2B_3$, $B_7 = \cos m_1$, $B_8 = \sin m_1$, $B_9 = m_1B_7$, $B_{10} = m_1B_8$, $B_{11} = B_5B_9$, $B_{12} = B_5B_8$, $B_{13} = B_6B_7$, $B_{14} = B_6B_{10}$, $B_{15} = B_{11} - B_{14}$, $B_{16} = B_{12} - B_{13}$, $B_{17} = B_{15} - B_{16}$, $B_{18} = M + Da^{-1}$, $B_{19} = h_0 + GmB_{17}$, $B_{20} = GmB_{15}$, $B_{21} = GrB_2 + GmB_6$, $B_{22} = GrB_1 - GmB_7$, $B_{23} = \frac{B_{19}}{B_{18}}$, $B_{24} = \frac{B_{20}}{B_{18}}$, $B_{25} = B_{18} + m_1{}^2$, $B_{26} = \frac{B_{21}}{B_{25}}$, $B_{27} = \frac{B_{22}}{B_{25}}$, $B_{28} = B_{23} + B_{24} + B_{26}B_7$, $B_{29} = B_{27}B_8$, $B_{30} = B_{28} + B_{29}$, $B_{31} = \frac{\cosh\sqrt{B_{18}}}{\sinh\sqrt{B_{18}}}$, $B_{32} = \sinh(2m_2)$, $B_{33} = \frac{\sinh(m_2)}{B_{32}}$, $B_{34} = \frac{Rc\sin\theta}{\omega FrRe}$, $B_{35} = \frac{1}{2B_{32}}$, $B_{36} = B_{34}B_{35}$, $B_{37} = (B_{34} + 1)e^{m_2}$, $B_{38} = (B_{36})e^{2m_2}$, $B_{39} = B_{35}e^{3m_2}$, $B_{40} = B_{35}e^{m_2}$, $B_{41} = B_{35}e^{-m_2}$, $B_{42} = -B_{37} + B_{38} - B_{39}$, $B_{43} = -B_{36} - B_{40}$, $B_{44} = e^{-\sqrt{B_{18}}}$, $B_{45} = B_{30}B_{44}$, $B_{46} = 2B_{31}$, $B_{47} = 2B_{29}B_{31}$, $B_{47} = 2B_{28}$.

Results and discussion:

Impact of various significant parameters on fluid velocity:

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Fig.2 shows the effect of Hartmann number M on transient velocity. As the Hartmann number M increases from M=0.1 to 0.3, the fluid velocity is seen to reduce. The fluid velocity escalates as we move from nonadiabatic plate to adiabatic plate. The graph clearly shows that a resistive force is applied to the transient velocity when the perpendicularly oriented magnetic field (M) is present. An electrically conducting fluid moves more slowly as a result of this force, known as the Lorentz force influencing the fluid velocity, Fig.3 plots the velocity profile with respect to the Prandtl number. It is noticed that as the Prandtl number rises at both the plates, the fluid velocity reduces Fig. 4 depicts that velocity of fluid rises with the rise in Grashoff number Gr at non adiabatic plate and no significant change in the fluid velocity is observed near the adiabatic plate. Fig.5 exhibits that as the elastic parameter Rc reduces, the fluid velocity rises at the adiabatic plate but no significant change in the fluid velocity is noticed at the nonadiabatic plate. Fig. 6 shows that rise in fluid velocity is due to rise in solutal Grashoff number Gm at both the plates. Fig. 7 examines the impact of Froude number Fr on velocity. It shows that velocity profile surges with the decline in the Froude number at both the plates. The fluid velocity at both plates increases as the Reynolds number Re decreases, as shown in Fig.8. As can be observed, rise in Da increases the fluid velocity near the non-adiabatic plate in Fig.9.Therefore rise in Da^{-1} decreases the velocity of the fluid. hence it indicates that velocity profile drops with the permeability coefficient near the nonadiabatic plate whereas velocity profile rises with the increase in permeability coefficient near the adiabatic plate. The impact of heat source parameter S is shown with respect to the variable y in Fig.10. It has been noticed that as S increases fluid velocity also boosts up near the nonadiabatic plate whereas it declines near the adiabatic plate. Fig. 11 shows that increase in Soret number S_0 rises the velocity near the adiabatic plate and no significant change is observed near the nonadiabatic plate. Fig. 12 shows that the velocity rises with the rise in Schmidt number Sc near both the plates.

Impact of various significant parameters on fluid temperature:

Fig.13 indicates that the fluid temperature boosts up with the rise in Prandtl number Pr near both the plates. Fig. 14 depicts that the rise in Source/Sink parameter S declines the fluid temperature near both the adiabatic and nonadiabatic plates.

Impact of various pertinent parameters on concentration of the fluid:

Fig. 15 plots the fluid concentration with respect to Prandtl number Pr. An increase in Prandtl number is found to raise the fluid concentration near both the plates. It shown from Fig. 16 that the fluid concentration rises with the surge in source/sink parameter S near the two plates. Fig. 17 depicts that decrease in Schmidt number Sc increases the fluid concentration at both the plates. It is identified from Fig.18 that the fluid concentration boosts up with the decline in Soret number S_0.

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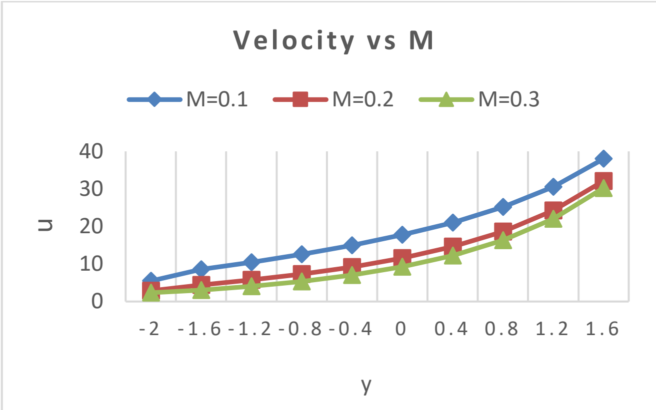

Fig.2

Pr=0.1, S=1.0, Rc=1.0, Fr=1.0, h_0=1, Re=1.0, ω=5.0, t=11/105, Gr=1 Gm=1, Sc=0.15, S_0 =1, Da=100 and $\theta=60^0$.

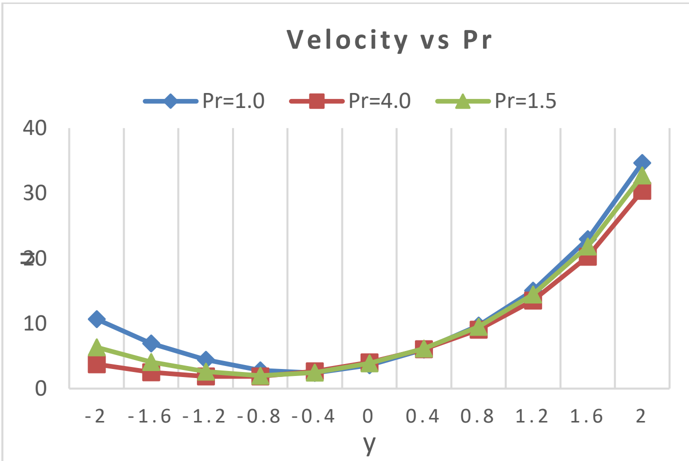

Fig.3

S=1, M=1, Rc=1, Fr=1, h_0=1, Re=1, ω=5, t=11/105, Gr=1, Gm=1, Sc=0.15, S_0 =1, Da =100 and $\theta=60^0$.

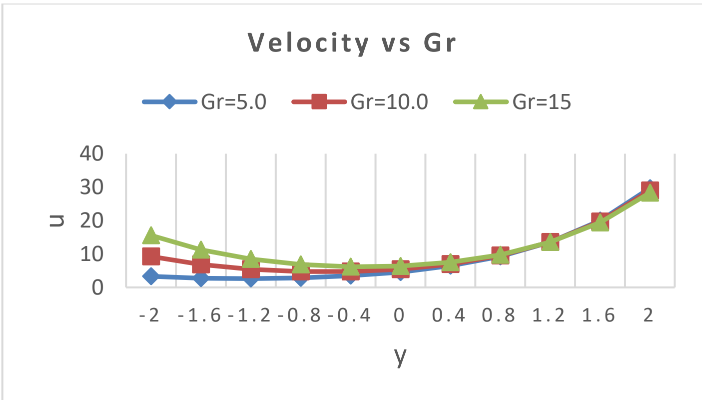

Fig.4

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Pr=0.1, S=1, M=1, Rc=1, Fr=1, h_0=1, Re=1, ω=5, t=11/105, Gm=1.0, Sc=0.15, S_0 =1.0 ,Da =100 and θ=60^0.

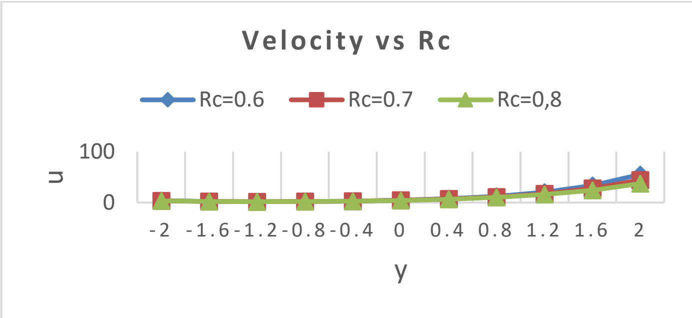

Fig.5

Pr=0.1, S=1.0, M=1.0, Fr=1.0, h_0=1, Re=1.0, ω=5.0, t=11/105, Gm=1.0,Gr=1.0 Sc=0.15, S_0 =1.0 ,Da =100 and θ=60^0.

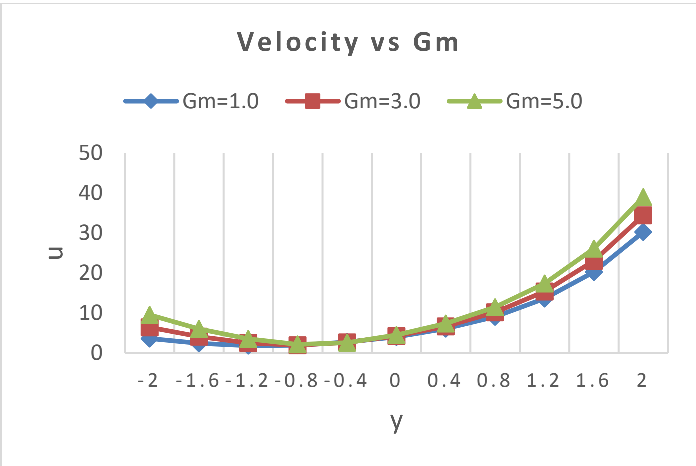

Fig.6

Pr=0.1, S=1, M=1, Fr=1, h_0=1, Re=1, Rc=1, ω=5, t=11/105, Gr=1.0 Sc=0.15, S_0 =1.0 ,Da =100 and θ=60^0.

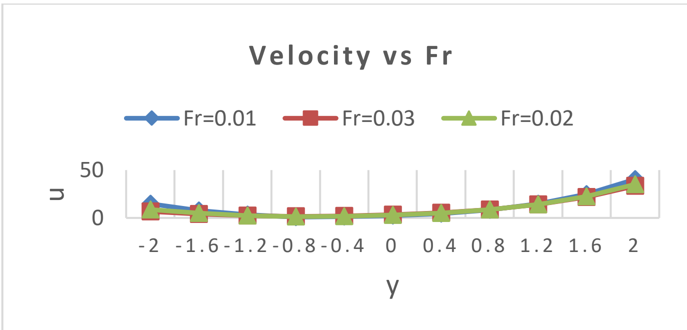

Fig.7

Pr=0.1, S=1.0, M=1.0, h_0=1, Re=1.0, Rc=1.0, ω=5.0, t=11/105, Gr=1, Gm=1, Sc=0.15, S_0 =1, Da =100 and θ=60^0.

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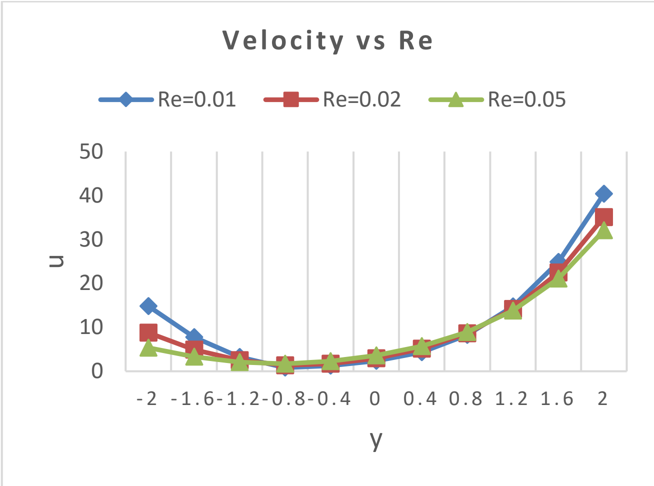

Fig.8

Pr=0.1, S=1.0, M=1.0, Fr=1.0, h_0=1, Rc=1.0, ω=5.0, t=11/105, Gr=1, Gm=1, Sc=0.15, S_0 =1, ,Da =100 and $\theta=60^0$.

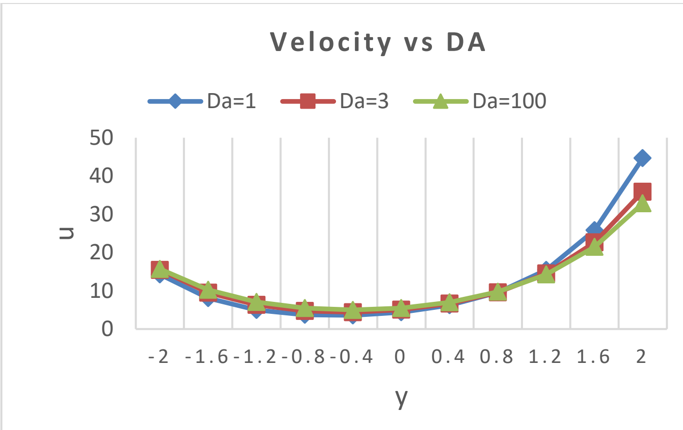

Fig.9

Pr=0.5, S=0.5, M=1.5, Fr=1.0, h_0=1, Re=2.0, Rc=1.0, ω=5.0, t=11/105, Gr=5.0, Gm=1.0, Sc=0.6, S_0 =1.0 and $\theta=60^0$.

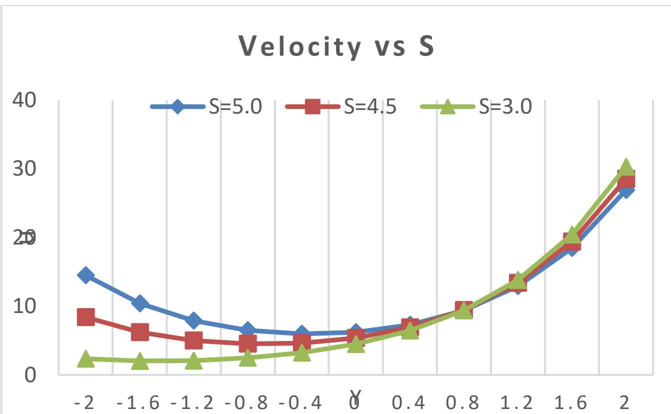

Fig.10

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Pr=0.1, M=1, Fr=1, h_0=1, Re=1, Rc=1, ω=5, t=11/105, Gr=1, Gm=1, Sc=0.15, S_0=1 ,Da =100 and θ=60^0.

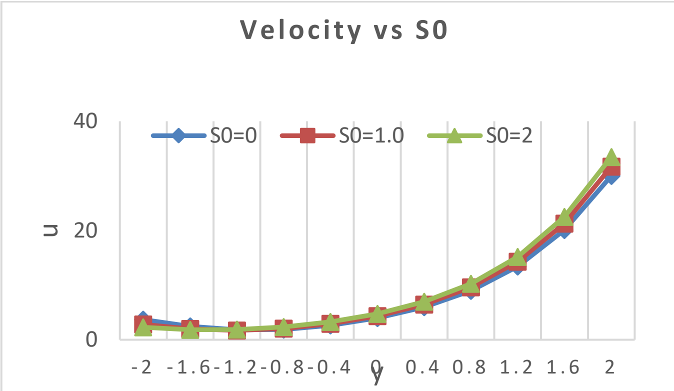

Fig.11

Pr=0.1, M=1, Fr=1, h_0=1, Re=1, Rc=1, ω=5, t=11/105, Gr=1, Gm=1, Sc=0.15, S=1, Da =100 and θ=60^0.

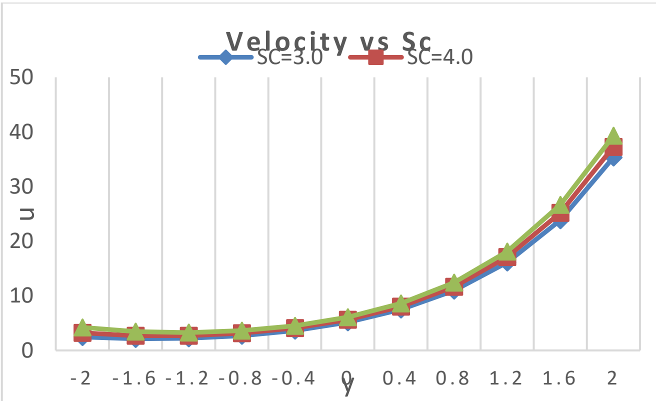

Fig.12

Pr=0.1,M=1, Fr=1, h_0=1, Re=1, Rc=1, ω=5, t=11/105, Gr=1.0, Gm=1.0, S=1.0, S_0 =1.0 ,Da =100 and θ=60^0.

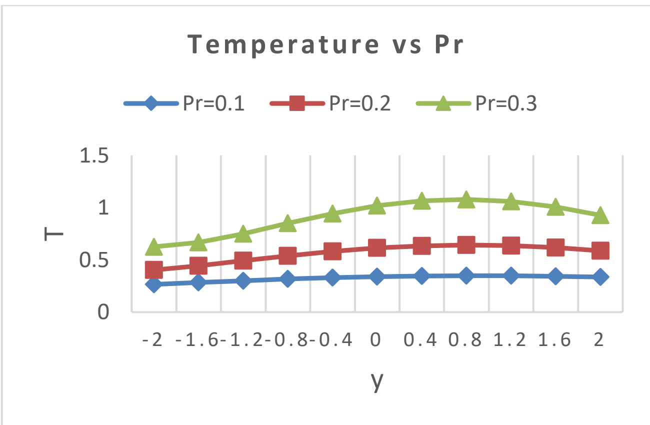

Fig. 13

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ω=5.0, t=11/105, S=1.0

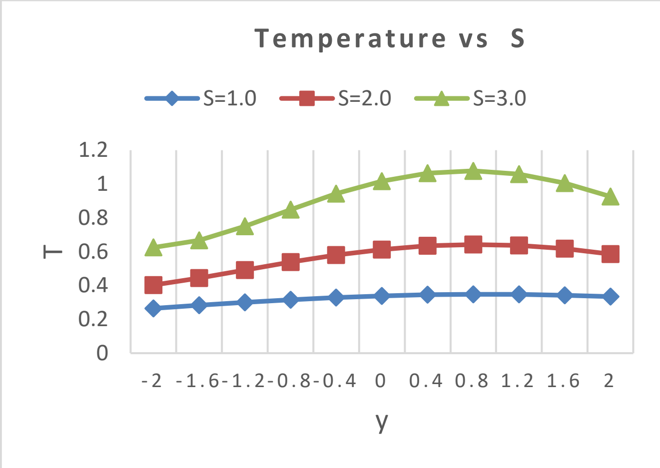

Fig. 14

ω=5.0, t=11/105, Pr =0.1

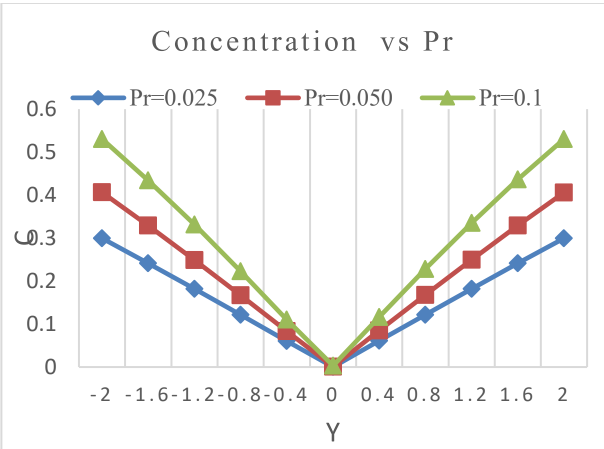

Fig. 15

ω=5.0, t=11/70, Sc=0.15, S=1.0

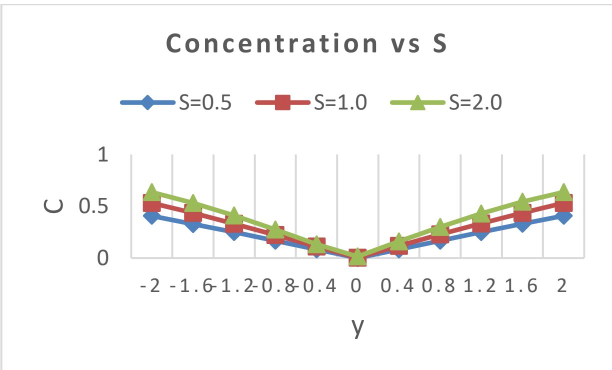

Fig.16

ω=5.0, Pr =0.1, t=11/70, Sc=0.15, S_0=1.0

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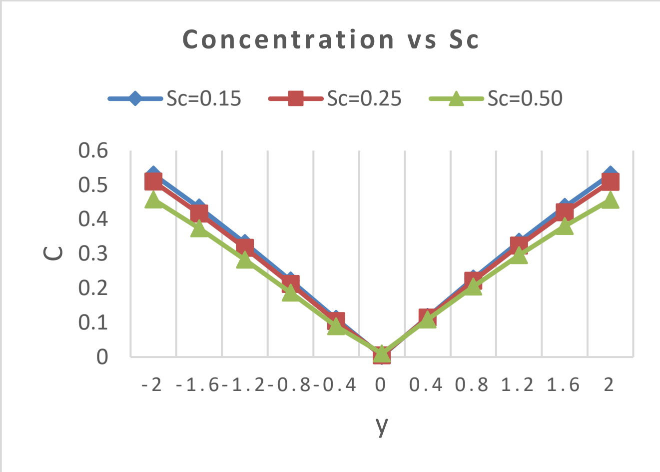

Fig.17

ω=5.0, Pr =0.1, t=11/70, S=1.0, S_0=1.0

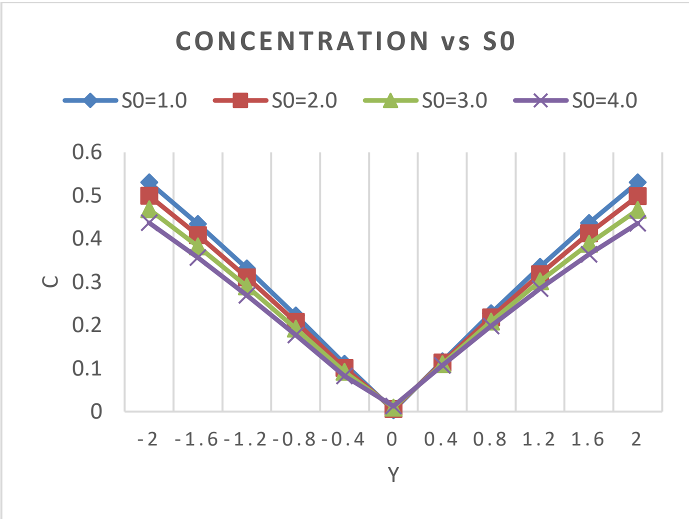

Fig.18

ω=5.0, Pr =0.1, t =11/70, S=1.0, Sc=0.15

Conclusions:

It is observed that velocity of the fluid decreases with the rise in M, Pr, Rc, Re, Fr where as it increases with the increases in Gr, Gm, S0 and Sc near both the adiabatic and non adiabatic plates. It is noticed that rise in porous medium parameter decreases the velocity of the fluid near non adiabatic plate and increases near adiabatic plate. It is seen that rise in heat source parameter increases velocity of the fluid near non adiabatic plate while it decreases near the adiabatic plate.

It is observed that fluid temperature rises with the rise in Pr and S near both the adiabatic and non adiabatic plates.

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It is identified that concentration of the fluid increases with rise in Pr and S whereas it decreases with the increase in Sc.

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