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THREE DIMENSIONAL CONVECTIVE SQUEEZING FLOW IN A ROTATING CHANNEL WITH HALL EFFECT AND THERMAL RADIATION

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ABSTRACT

We analyze MHD effects on the three dimensional squeezing flow of an electrically conducting in a rotating channel and its heat transfer characteristics with hall effect. The governing equations are reduced to set of ordinary differential equations and then numerically solved by employing Runge-Kutta-Fehlberg fourth-fifth order method. Effect of pertinent parameters on velocity, temperature fields is examined through the plots. Nusselt number for different variations are studied numerically.

Keywords: *Thermal Radiation, Squeezing flow, Hall Effect, Rotating Channel.*

1. INTRODUCTION

An unsteady squeezing flow of an electrically conducting fluid occurs in many engineering and industrial applications such as lubrication, food industries, transient loading of mechanical components, power transmission, polymer processing, compression and injection modelling. The squeezing flow of a fluid was first introduces by Stefan [53], Following this work, many researchers have investigated such flow with different aspects. Numerical solution for a fluid film squeezed between two parallel plane surfaces have been reported by Hamza and Macdonald [23]. Domairry and Aziz [15] studied the squeezing flow of viscous fluid between parallel disks with suction or blowing analytically. Heat and mass transfer in the unsteady squeezing flow between parallel plates is analyzed by Mustafa *et al.* [36], Hamza [22] discussed the effect of suction and injection on the squeezing flow between parallel plates. It is noted that very little attention has been given to study the three-dimensional flow in a rotating channel. Munawar *et al.* [35] studied the three-dimensional flow in a rotating channel of lower stretching sheet in the presence of MHD effects. The mathematical equations are modelled with the help of Navier-Stokes equation and then they are solved numerically. Hayat *et al.* [24] have discussed an unsteady mixed convection three-dimensional squeezing flow of an incompressible Newtonian fluid between two vertical parallel planes. Mahantesh *et al.* [31] have discussed the heat and mass transfer effects on the mixed convective flow of chemically reacting nanofluid past a moving / stationary vertical plate. Mahanthesh *et al.* [31] have studied mixed MHD convection squeezing three-dimensional flow in a rotating channel filled with nanofluid.

The motion of rotation fluids enclosed with in a body or vice versa, was given by Greenspan [21], discussed these problems relating to the boundary layers and their interaction in rotating flows and gave so many examples relating to such interaction. The rotating viscous flow equation yields a layer known as Eckman boundary layer after the Swedish oceanographer Eckman who discovered it. Attempts to observe the structure of the Eckman layer in the surface layers of the sea have been successful. Eckman layers are easy to produce and observe in the laboratory. Such boundary layers or similar ones are required to connect principally geotropic flow in the interior of the fluid to the horizontal boundaries where conditions like a prescribed horizontal stress or no slip on a solid bottom are given. In a similar way other kinds of various boundaries have been studies so as to connect geotropic flow to vertical boundaries (for example a vertical well along which the depth varies) on which boundary conditions consistent with geotropic flow are given. Rao *et al.* [38] made an investigation of the combined free and forced convective effects on an unsteady Hydro magnetic viscous incompressible flow in a rotating porous channel. This analysis has been extended to porous boundaries by Sarojamma and Krishna [45]. An initial value investigation of the hydro magnetic and convective flow of a viscous electrically conducting fluid through a porous medium in a rotating channel has been made by Krishna *et al.* [28]. In all these papers the viscous dissipative effect has not been considered. But the viscous dissipation has its importance when the

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natural convection flow fixed is of extreme size or the temperature is low or in higher gravity field. The problem of steady laminar micro polar fluid flow through porous walls of different permeability had been discussed by Agarwal and Dhanpal [5]. Steady and unsteady hydro magnetic flow of viscous incompressible electrically conducting fluid under the influence of constant and periodic pressure gradient in the presence of include magnetic field had been investigated by Ghosh [20] to study the effect of slowly rotating systems with low frequency of oscillation when the conductivity of the fluid is low and the applied magnetic field is weak. El-Mistikawy *et al.* [18] were discussed the rotating disk flow in the presence of strong magnetic field and weak magnetic field. Hazim Ali Attia [25] was developed the MHD flow of incompressible, viscous and electrically conducting fluid above an infinite rotating porous disk was extended to flow starting impulsively from rest. The fluid was subjected to an external uniform magnetic field perpendicular to the plane of the disk. The effects of uniform suction or injection through the disk on the unsteady MHD flow were also considered. Circar and Mukherjee [12] have analyzed the effect of mass transfer and rotation on flow past a porous plate in a porous medium with variable suction in a slip flow regime. Balasubramanyam [7] and Madhusudhana Reddy [30] have investigated convective heat and mass transfer flow in horizontal rotating fluid under different conditions. Singh and Mathew [52] have studied on oscillatory free convective MHD flow in a rotating vertical porous channel with heat sources. Madhavi *et al.* [29] have investigated heat and mass transfer flow of a rotating fluid in a vertical channel with stretching and stationary walls. Sukanya *et al.* [54] have studied the effect of non-uniform heat sources on convective heat and mass transfer flow in vertical channel bounded by Stretching walls.

The heat transfer flow of an electrically conducting fluid in the presence of transverse magnetic field also finds a variety of applications such as MHD generators, pumps, flow meters, nuclear reactors, accelerators and in metallurgical industries. Its relevance is also seen in many practical applications in geophysical and astrophysical situations. Sarpkya [46] was the first to study the effectiveness of MHD flows in fluids.

The effect of radiation on MHD flow and heat transfer problem have become more important industrially. At high operation temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and a knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering areas. Bestman [8] examined the natural convection boundary layer with suction and mass transfer in a porous medium. His results confirmed the hypothesis that suction stabilizes the boundary layer and affords the most efficient method in boundary layer control yet known. Abdul Sattar and Hamid Kalim [2] investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Mankinde [32] examined the transient free convection interaction with thermal radiation of an absorbing-emitting fluid along moving vertical permeable plate. Recently Ibrahim *et al.* [26] have studied non classical thermal effects in Stokes second problem for micropolar fluids by used perturbation method.

Raptis [41] analyzed the thermal radiation and free convection flow through a porous medium by using perturbation technique. Bakier and Gorla [6] investigated the effect of thermal radiation on mixed convection from horizontal surfaces in saturated porous media. Satapathy *et al.* [47] studied the natural convection heat transfer in a Darcian porous regime with Rosseland radiative flux effects. With regard to thermal radiation heat transfer flows in porous media, Chamkha [9] studied the solar radiation effects on porous media supported by a vertical plate. Forest fire spread also constitutes an important application of radiative convective heat transfer. More recently Chitraphiromsri and Kuznetsov [11] have studied the influence of high-intensity radiation in unsteady thermo fluid transport in porous wet fabrics as a model of fire fighter protective clothing under intensive flash fires. Impulsive flows with thermal radiation effects and in porous media are important in chemical engineering systems, aerodynamic blowing processes and geophysical energy modeling. Such flows are transient and therefore temporal velocity and temperature gradients have to be included in the analysis. Raptis and Singh [42] studied numerically the natural convection boundary layer flow past an impulsively started vertical plate in a Darcian porous medium. The thermal radiation effects on heat transfer in magneto – aerodynamic boundary layers has also received some attention, owing to astronautical re-entry, plasma flows in astrophysics, the planetary magneto-boundary layer and MHD propulsion systems. Mosa [34] discussed one of the first models for combined radiative hydromagnetic heat transfer, considered the case of free convective channel flows with an axial temperature gradient. Nath *et al.* [37] obtained a set of similarity solutions for radiative – MHD stellar point explosion dynamics using shooting methods. Abd-El-Naby *et al*. [1] presented a finite difference solution of radiation effects on MHD unsteady free convection flow over a vertical porous plate. Shateyi *et al.* [49] have analyzed the Thermal Radiation and Buoyancy Effects on Heat and Mass Transfer over a Semi-Infinite stretching Surface with Suction and Blowing. Dulal Pal *et al.* [16] have discussed Heat and Mass transfer in MHD non-Darcian flow of a micropolar fluid over a stretching sheet embedded in a porous media with non-uniform heat source and thermal radiation. Dulal Pal *et al.* [17] have analyzed unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Rajesh *et al*. [39] have considered the radiation effects on MHD flow through a porous medium with variable temperature or variable mass diffusion. Soret & Dufour effect, Rawat *et al.* [43] have discussed the finite element study of natural convection heat and mass transfer in a micropolar fluid-saturated porous regime with. Ganesam and Loganathan [19] studied the effect of the radiation and mass transfer effects on flow past a moving vertical cylinder using Rosseland approximation by the crank–Nicolsan finite difference method. Seddeek.M.A *et al.* [48] have discussed the effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation. Devikarani *et al* [14] have considered oscillatory mixed convection in horizontal channel with heat sources and radiation effect.

With the fuel emergency extending everywhere throughout the world, there is an awesome worry to use the gigantic power underneath the world's outside layer in the geothermal region. Fluid in the geothermal area is an electrically conducting liquid because of high temperature. Hence the study of interaction of the geomagnetic field with the fluid in the geothermal region is of awesome interest, in this way prompting enthusiasm for the investigation of MHD convection courses through permeable medium. Keeping these applications in view the MHD convective heat and mass flow of a electrically conducting fluid past a stretching sheet has been considered by a few analysts [4, 13, 27, 44].

Hall currents are essential and they have a marked effect on the magnitude and direction of the current density and subsequently on the magnetic forceterm. The issue of MHD free convection flow with Hall currents has many important engineering applications, for example, in control generators, MHD accelerators, refrigeration coils, transmission lines, electric transformers, warming components and so on., several authors [3,10,40,51,50,55] have studied hall current effects on MHD convective heat transfer in different configurations.

2. MATHEMATICAL FORMULATION

Consider an unsteady three-dimensional squeezing flow of an electrically conducting incompressible viscous fluid in a vertical rotating channel. The plane positioned at $y = 0$ is stretched with velocity $U_{wo} = ax/(1 - \alpha t)$ in x-direction and maintained at the constant temperature T_0. The temperature at the other plane is T_h and located at a variable distance $h(t) = \sqrt{\nu_f (1-\alpha t)}$. In negative y-direction, the fluid is squeezed with a time dependent velocity

$V_h = dh/dt = -\alpha/2\sqrt{\nu_f/\alpha(1-\alpha t)}$.

The fluid and the channel are rotated about y-axis with angular velocity $\vec{\Omega} = \omega\hat{j}/(1-\alpha t)$. The transverse magnetic field is assumed to be variable kind $\vec{B} = B_0/\sqrt{(1-\alpha t)}$ and it is applied along y-axis. The fluid is sucked/injected from the plane located at $y = 0$ as shown in figure 1. The magnetic Reynolds number is assumed to be small thus induced magnetic field is negligible. In addition, effects of Hall current, viscous dissipation and Joule heating are taken into account.

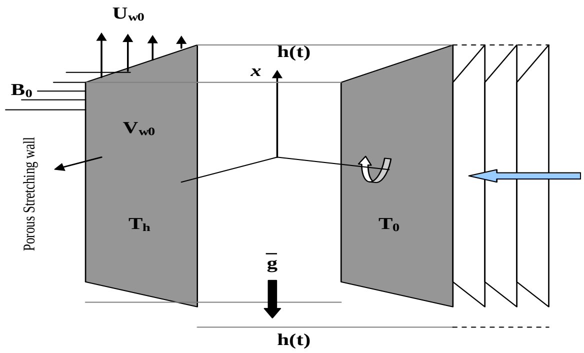

Fig. 1 : Flow configuration and coordinate

Under those assumptions, the governing equations for the velocity and temperature fields in the presence of internal heating source/sink are given by [*Hayat et al.* 24, *Munawar et al* 35].

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + 2\frac{\omega}{1-\alpha t}w = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\sigma B_0^2}{\rho(1-\alpha t)}(u + mw) + \frac{g\beta_T}{\rho}(T - T_0), \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right), \tag{3}$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} - 2\frac{\omega}{1-\alpha t}u = \nu_{rf}\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) - \frac{\sigma B_0^2}{\rho(1-\alpha t)}(w - mu), \tag{4}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k_f}{(\rho C_p)}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) - \frac{1}{(\rho C_p)}\frac{\partial(q_R)}{\partial y} - 2\mu\left(\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2\right) + \frac{\sigma B_0^2}{1+m^2}(u^2 + w^2) \tag{5}$$

where u, v and w are velocity components along x, y and z directions respectively, p is pressure. B_0 is the magnetic field, σ is the electrical conductivity, g is the magnitude of acceleration due to gravity, α is characteristic parameter with the dimension of reciprocal of time t and $\alpha t < 1$. T is temperature of the fluid, k_f and (ρC_p) are thermal conductivity and heat capacity of the fluid respectively.ρ_f is the density of fluid, μ_f is the dynamic viscosity of the fluid, The approximate boundary conditions for the present problem are;

$$u(x,y,t)=U_{w0}, \quad v(x,y,t)=V_{w0}, \quad w(x,y,t)=0, \quad T(x,y,t)=T_0, \quad \text{at } y=0 \tag{6}$$

$$u(x,y,t)=0, \quad v(x,y,t)=V_h, \quad w(x,y,t)=0, \quad T(x,y,t)=T_h \quad \text{at } y=h(t) \tag{7}$$

where $T_h = T_0 + T_0/(1-\alpha t),\ V_{w0} = -V_0/(1-\alpha t)$. Here V_0 is constant, $V_{w0} < 0$ corresponds injection whereas $V_{w0} > 0$ corresponds wall suction.
To reduce the governing equations into a set of similarity equations, introduce the following similarity transformations [*Munawar et al* 35].

$$\psi = \sqrt{\frac{\alpha v_f}{1-\alpha t}}\, x f(\eta), \quad \eta = \frac{y}{h(t)}, T = T_0 + \frac{T_0}{1-\alpha t}\theta(\eta),$$
$$u = U_{w0} f_\eta \eta, \quad v = -\sqrt{\frac{\alpha v_f}{1-\alpha t}}\, f(\eta), \quad w = U_{w0} g(\eta), \tag{8}$$

where a suffix η denote the differentiation with respect to η and v_f is the kinematic viscosity of the fluid. Using the above transformations (8), the equation (1) is automatically satisfied, while the equation (2) – (4) are respectively reduces to the following nonlinear ordinary differential equations;

$$f_{\eta\eta\eta} - \left[f\ f_{\eta\eta} - f_\eta^2 - \beta\left(f_\eta \frac{\eta}{2} f_{\eta\eta}\right) - 2Rg - \frac{M^2}{1+m^2}(f_\eta + m\,g) + G(\theta)\right] = \frac{(1-\alpha t)^2}{\rho\, a^2 x}\frac{\partial p}{\partial x}, \tag{9}$$

$$f_{\eta\eta} - \left[-f\ f_\eta + \frac{\beta}{2}\left(f\ + \eta f_\eta\right)\right] = -\frac{1-\alpha t}{\rho v_f a}\, p_\eta, \tag{10}$$

$$g_{\eta\eta} + \left[f\ g_\eta - f_\eta\, g - \beta\left(g\ \frac{\eta}{2} g_\eta\right) + 2Rf_\eta\right] - \frac{M^2}{1+m^2}(g - m\, f_\eta) = 0, \tag{11}$$

$$\left(1+\frac{4Rd}{3}\right)\theta_{\eta\eta} + \Pr\left[\ \left\{\beta\left(\theta + \frac{\eta}{2}\theta_\eta\right) + f\theta_\eta\right\}\right] + \frac{\Pr EcM^2}{1+m^2}(f_\eta^2 + g^2) + \Pr Ec(f_{\eta\eta}^2 + g_\eta^2) = 0\,. \tag{12}$$

The modified boundary conditions are;

$$f_\eta = 1, \quad f = fw, \quad g = 0, \quad \theta = 0, \quad \text{at} \quad \eta = 0$$
$$f_\eta = 0, \quad f = \tfrac{\beta}{2}, \quad g = 0, \quad \theta = 1, \quad \text{at} \quad \eta = 1 \tag{13}$$

where

$\beta = \alpha/\alpha$ is the squeezing parameter, $R = \omega/\alpha$ is rotation parameter, $M^2 = \sigma B_0^2/\alpha\rho_f$ is magnetic parameter, $Gr = G/Re^2$ is mixed convection parameter, $G = g\beta_T T_0 x^3/v_f^2(1-\alpha t)$ is Grashaf number, $Re = xU_{w0}/v_f$ is Reynolds number, $Pr = (\mu c_p)_f / k_f$ is the Prandtl number.

It is important to mention that, $\beta = 0$ represents plates are stationary, $\beta > 0$ corresponds to the plate which is located at $y = h(t)$ moves towards the plate which is located at $y = 0$ and $\beta < 0$ corresponds to the plate at $y = y(t)$ moves apart with respect to the plate at $y = 0$.

Now in order to reduce the number of independent variables by cross differentiation; the set of equations (9)-(12) takes the following form;

$$f_{\eta\eta\eta} - \left[\frac{\beta}{2}\left(3 f_{\eta\eta} + \eta f_{\eta\eta\eta}\right) f_\eta f_{\eta\eta} - f\ f_{\eta\eta\eta} + 2Rg_\eta\right] - \frac{M^2}{1+m^2}(f_{\eta\eta} + m\, g_\eta) + G(\theta_\eta) = 0 \tag{14}$$

$$g_{\eta\eta} + \left[f\ g_\eta - f_\eta g - \beta\left(g + \frac{\eta}{2} g_\eta\right) + 2R\ f_\eta\right] - \frac{M^2}{1+m^2}(g - m\ f_\eta) = 0 \tag{15}$$

$$\left(1+\frac{4Rd}{3}\right)\theta_{\eta\eta} - \Pr\left(\ \left\{\beta\left(\theta + \frac{\eta}{2}\theta_\eta\right) + f\theta_\eta\right\}\right) + \frac{\Pr EcM^2}{1+m^2}(f_\eta^2 + g^2) + \Pr Ec(f_{\eta\eta}^2 + g_\eta^2) = 0 \tag{16}$$

For engineering and industrial point of view, one has usually less interest in velocity and temperature profiles nature than in the value of the skin-friction and rate of heat transfer. Therefore expression for the local Nusselt number at both the walls are defined as;

$$Nu^*_{\text{ at } y=0} = \sqrt{\frac{v_f}{a}}\frac{(q_{xy})_{y=0}}{k_f T_0}, \qquad Nu^*_{\text{ at } y=h(t)} = \sqrt{\frac{v_f}{a}}\frac{(q_{xy})_{y=h(t)}}{k_f T_0}, \tag{17}$$

where τ_{xy} is the shear stress, q_{xy} is the heat flux, and m_{xy} is the mass flux which are given by

$$q_{xt} = -k_{\eta f}\left(\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y}\right) \tag{18}$$

In view of equation (18) and similarity transformations (8); equations (14)-(15) will takes the following form;

$$Nu_{\text{ at } y=0} = (1-\alpha t)^{1,5}\ Nu^*_{\text{ at } y=0} = -\theta_\eta(0),$$

$$Nu_{\text{ at } y=h(t)} = (1-\alpha t)^{1,5}\ Nu^*_{\text{ at } y=h(t)} = -\theta_\eta(1) \tag{19}$$

3. NUMERICAL METHOD AND VALIDATION

A set of non-similar equations (14)-(16) are nonlinear in nature and possess no analytical solution, thus, a numerical treatment would be more appropriate. These set of ordinary differential equations together with the boundary conditions (13) are numerically solved by employing fourth-fifth order Runge-Kutta-Fehlberg scheme with the help of Maple. This algorithm in Maple is proven to be precise and accurate and which has been successfully used to solve a wide range of nonlinear problem in transport phenomena especially for flow and heat transfer problems. In this study, we set the relative error tolerance to 10^{-6}. Comparison results are recorded in table 1 and are found to be in excellent agreement. The effects of development of the squeezing three-dimensional flow and heat transfer in a rotating channel utilizing nanofluid are studied for different values of squeezing parameter, rotation parameter, magnetic parameter, suction/injection parameter, mixed convection parameter, radiation parameter, Prandtl number. In the following section, the results are discussed in detail with the aid of plotted graphs and tables.

We make an investigation of the three dimensional squeezing convective flow, heat transfer flow of An electrically conducting fluid in a rotating channel. In our numerical simulation the default values of the parameters are considered as, R = 0.5, β = 0.5, Pr = 0.71. In order to analyse the effects of various pertinent parameters on velocity, temperature profiles, several graphs are plotted.

Fig.2a-2d represent the effect of Hall current on f, f′, g, θ .It can be found from the profiles that the normal velocity (f), axial velocity (f′), the transverse velocity (g) enhances with increasing Hall parameter (m) (figs.2a-2c). The thickness of the thermal boundary layers reduces with increase in m which results in a fall in the temperature in the flow region (figs.2d).

The influence of rotation parameter (R) on f, f′, g, θ can be observed from the figs.3a-3d. The normal velocity (f) and transverse velocity (g) enhances with increase in R. The axial velocity (f′) enhances in the left half(0,0.5) and reduces in the right half (0.5,1.0) of the channel. The temperature distributions experience an enhancement in the entire flow region with increase in rotation parameter (R). This is due to the fact thickness of the thermal boundary layers increase with R.

Fgs.4a-4d show the influence of thermal radiation(Rd) on f, f′, g, θ .It can be seen from the profiles(figs.4a-4d) that there is a significant depreciation in the magnitude of the velocity components f, f ′and g in the presence of thermal radiation throughout the flow region. The radiation parameter is found to reduce the hydrodynamic boundary layers along x and y-directions. The presence of the thermal radiation is very significant on the variation of temperature. It is seen that the temperature increases rapidly in the presence of thermal radiation parameter throughout the flow region. This may be attributed to the fact that as the Roseland radiative absorption parameter R*diminishes the corresponding heat flux diverges and thus rising the rate of radiative heat transfer to the fluid causing a rise in the temperature of the fluid. The thickness of the thermal boundary layer also increases with increase in Rd (fig.4d).

Figs.5a-5d represents the effect of Eckert number (Ec) on f, f′ g, θ from the velocity profile we find that the normal velocity (f) enhances while axial and transverse velocity component depreciate in magnitude in the flow region (figs.5a-5c). From fig.5d we notice an enhancement in temperature in entire flow region. It may be attributed to the fact that higher dissipation larger the thickness of the thermal boundary layer.

Figs.6a-6d present the typical profiles namely, f, f′, g, θ respectively for different values of the squeezing parameter (β). From figs.6a & 6b show that the magnitude of the normal velocity (f) is an increasing function and the transverse velocity (g) is a decreasing function of squeezing parameter. This implies that squeezing effect on flow field is accumulated by it The axial velocity (f ′) reduces in the left half (0,0.3) and enhances in the right half (0.32,1.0) of the channel. with increase in β.An increase in β leads to a reduction in the temperature (figs.6d).

The effect of Prandtl number (Pr) on f, f′, g, θ can be seen from figs.7a-7d. From the profiles we find that all the velocity components experience an enhancement with increase in Pr. Also lesser the thermal diffusivity larger the thickness of the thermal boundary layer in the entire flow region (figs.7d).

The rate of heat transfer (Nu) at $\eta = 0,1$ are shown in table.1. An increase in Hall parameter (m) or R or Rd reduces Nu at the left wall and enhances at the right wall. Higher the dissipation (Ec) or squeezing parameter (β) smaller Nu at η=0 and larger at η=1. The rate of heat transfer reduces at the left wall and enhances at the right wall with increase in R or β or Pr. An increase in Prandtl number reduces Nu at η=1 and enhances at η=0.

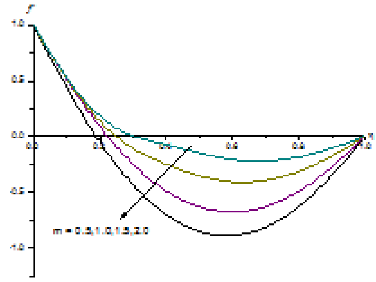

Fig.2b Variation of f' with m
R=0.5,Rd=0.5,Ec=0.1,β=0.2,Pr=0.71

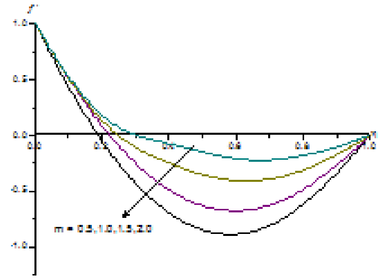

Fig.2b Variation of f' with m
R=0.5,Rd=0.5,Ec=0.1,β=0.2,Pr=0.71

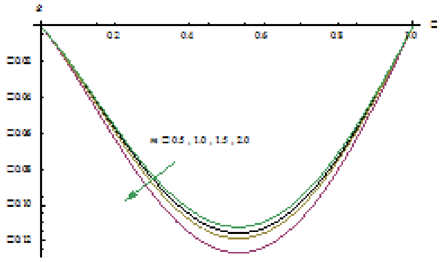

Fig.2c Variation of g with m
R=0.5,Rd=0.5,Ec=0.1,β=0.2,Pr=0.71

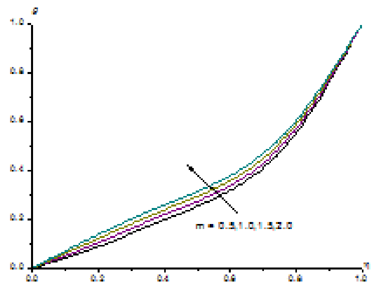

Fig.2d Variation of θ with m
R=0.5,Rd=0.5,Ec=0.1,β=0.2,Pr=0.71

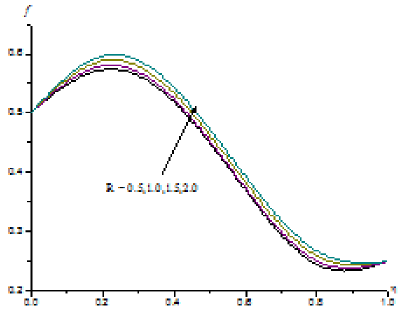

Fig.3a Variation of f with R
m=0.5, Rd=0.5, Ec=0.1,β=0.2Pr=0.71

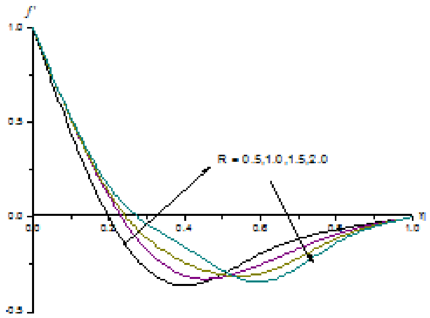

Fig.3b Variation of f' with R
m=0.5, Rd=0.5, Ec=0.1,β=0.2Pr=0.71

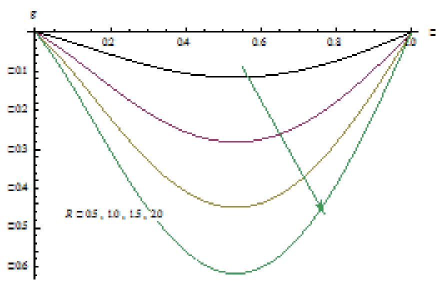

Fig.3c Variation of g with R
m=0.5, Rd=0.5, Ec=0.1,β=0.2Pr=0.71

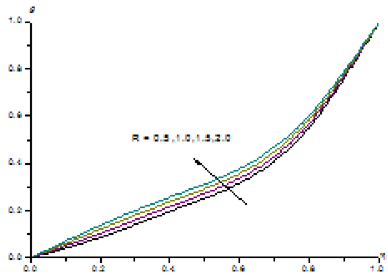

Fig.3d Variation of θ with R
m=0.5, Rd=0.5, Ec=0.1,β=0.2Pr=0.71

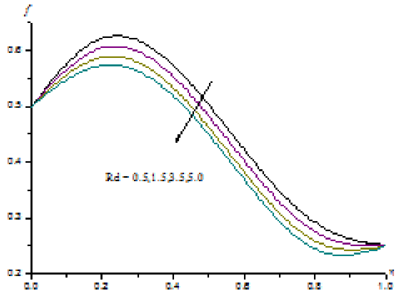

Fig.4a Variation of f with Rd
m=0.5, R=0.5,Ec=0.1,β=0.2, Pr=0.71

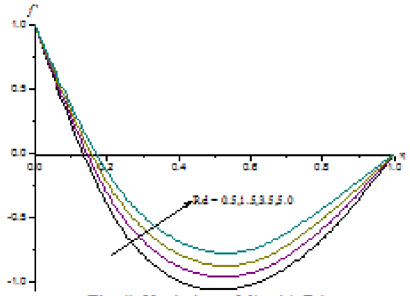

Fig.4b Variation of f' with Rd
m=0.5, R=0.5,Ec=0.1,β=0.2, Pr=0.71

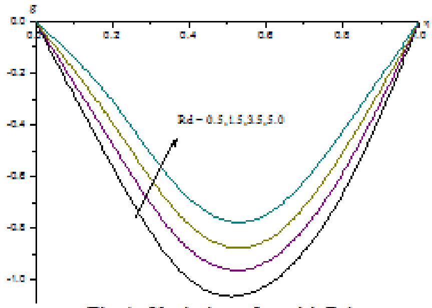

Fig.4c Variation of g with Rd
m=0.5, R=0.5,Ec=0.1,β=0.2, Pr=0.71

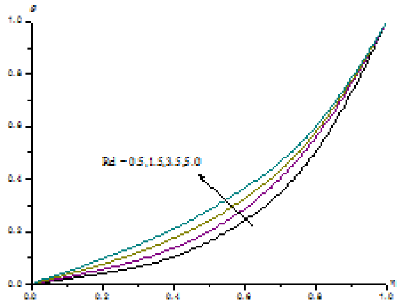

Fig.4d Variation of θ with Rd
m=0.5, R=0.5,Ec=0.1,β=0.2, Pr=0.71

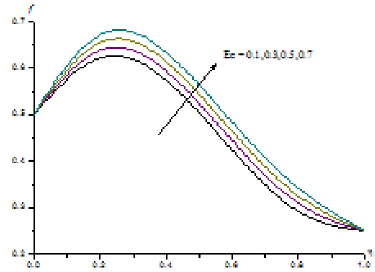

Fig.5a Variation of f with Ec
m=0.5, R=0.5,Rd=0.5,β=0.2, Pr=0.71

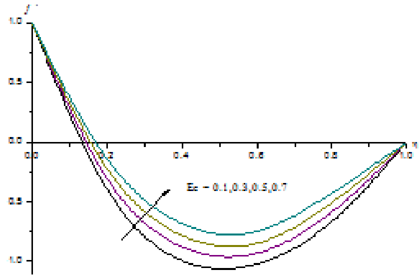

Fig.5b Variation of f' with Ec
m=0.5, R=0.5,Rd=0.5,β=0.2, Pr=0.71

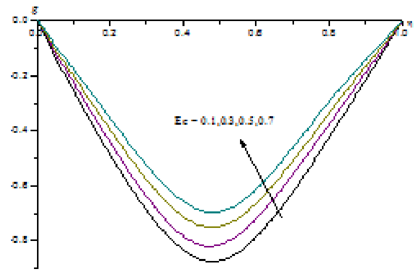

Fig.5c Variation of g with Ec
m=0.5, R=0.5,Rd=0.5,β=0.2, Pr=0.71

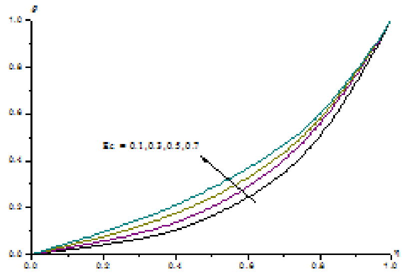

Fig.5d Variation of θ with Ec
m=0.5, R=0.5,Rd=0.5,β=0.2, Pr=0.71

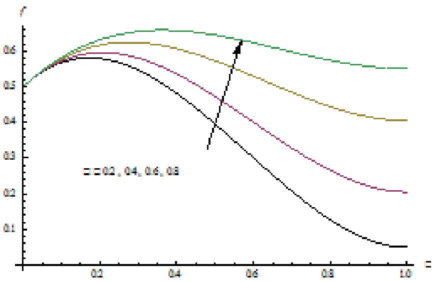

Fig.6a Variation of f with β
m=0.5, R=0.5,Rd=0.5,Ec=0.1, Pr=0.71

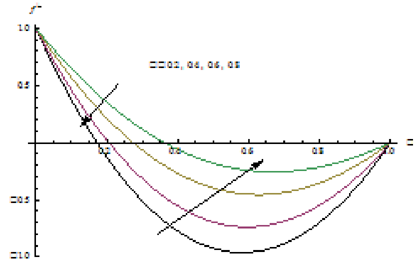

Fig.6b Variation of f' with β
m=0.5, R=0.5,Rd=0.5,Ec=0.1, Pr=0.71

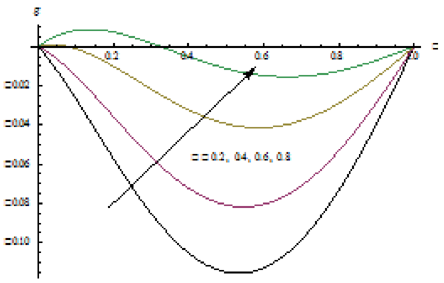

Fig.6c Variation of g with β
m=0.5, R=0.5,Rd=0.5,Ec=0.1, Pr=0.71

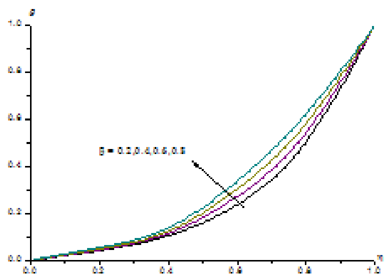

Fig.6d Variation of θ with β
m=0.5, R=0.5,Rd=0.5,Ec=0.1, Pr=0.71

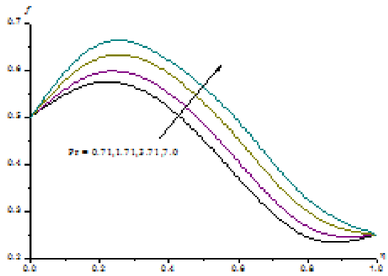

Fig.7a Variation of f with Pr
m=0.5, R=0.5,Rd=0.5,Ec=0.1,β=0.2

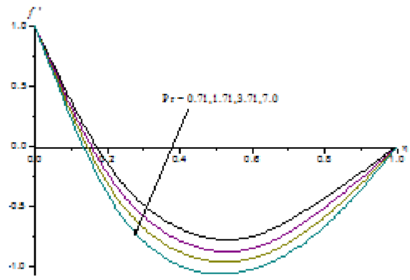

Fig.7b Variation of f' with Pr
m=0.5, R=0.5,Rd=0.5,Ec=0.1,β=0.2

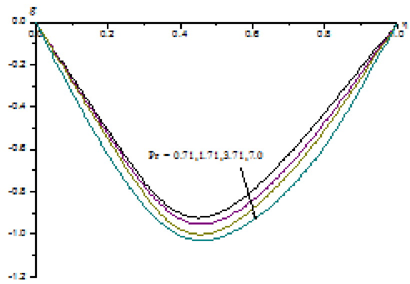

Fig.7c Variation of g with Pr
m=0.5, R=0.5,Rd=0.5,Ec=0.1,β=0.2

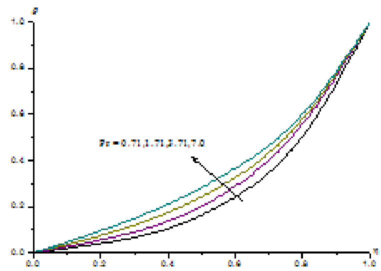

Fig.7d Variation of θ with Pr
m=0.5, R=0.5,Rd=0.5,Ec=0.1,β=0.2

Table – 2: Nusselt number(Nu) at $\eta = 0$

Parameter		**Nu(0)**	**Nu(1)**	**Parameter**		**Nu(0)**	**Nu(1)**
m	**0.5**	-0.999841	-1.00005	Ec	**0.1**	-0.999745	-1.00015
	1.0	-0.998857	-1.00032		**0.3**	-0.998231	-1.00104
	1.5	-0.99939	-1.00045		**0.5**	-0.99756	-1.00214
	2.0	-0.998316	-1.00055		**0.7**	-0.996221	-1.00305
R	**0.5**	-0.999841	-1.00005	β	**0.2**	-0.999165	-1.00108
	1.0	-0.998858	-1.00031		**0.4**	-0.998989	-1.00145
	1.5	-0.999392	-1.00045		**0.6**	-0.998813	-1.00182
	2.0	-0.998316	-1.00055		**0.8**	-0.998637	-1.00218
Rd	**0.5**	-0.999841	-1.00005	**Pr**	**0.71**	-1.00012	-0.999896
	1.5	-0.997252	-1.00139		**1.71**	-1.00029	-0.999749
	3.5	-0.996392	-1.00295		**3.71**	-1.00047	-0.999603
	5.0	-0.991122	-1.00519		**7.0**	-1.00064	-0.999456

4. CONCLUSIONS

The effect of rotation, Hall currents, squeezing, thermal radiation and heat source on convective heat and mass transfer of an electrically conducting fluid in a vertical channel has been analysed .It is found that an increase in Hall parameter (m) increases f, f′ and g while squeezing parameter (β) enhances f and reduces f ′ & g. The temperature enhances with Rotation and Hall parameter, reduces with squeezing parameter (β). Higher the thermal radiation/dissipation larger the temperature in the flow region. The Nusselt number enhances at η=1 and reduces at η=0, with increase in m, R, Rd, Ec, β.

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