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ANALYSIS OF NON –DARCY MHD BOUNDARY LAYER FLOW AND HEAT TRANSFER OVER A VERTICAL NONLINEAR PERMEABLE STRETCHING SHEET WITH COMBINED EFFECT OF HYDRODYNAMIC AND THERMAL SLIP IN A SATURATED POROUS MEDIUM

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ABSTRACT

*Numerical solutions of the equations of motion and energy for MHD boundary layer viscous incompressible fluid flow and heat transfer with combined effect of hydrodynamic and thermal slip over a permeable nonlinear stretching sheet in a saturated porous medium is presented in the present work. The electrically conducting fluid occupies a partially inestimable absorbent space.The non-linear partial differential equations and boundary conditions are condensed to a system of non-linear ordinary differential equations and boundary conditions by similarity transformations***.** *Runge-Kutta shooting method is implemented to solve the reduced system of equations.Graphs are depicted for dissimilar values of the budding parameters, such as stretching parameter n, magnetic parameter M, porosity parameter* $f_{w,}$ *buoyancy parameter* λ *,Prandtl number Pr,Eckert number Ec, hydrodynamic slip parameter* γ *, porous parameter* N_1 *,Inertia Coefficient* N_2 *and thermal slip parameter* δ *and discussed.*

Key words: Hydrodynamic slip; Thermal slip; Nonlinear stretching; Buoyancy parameter,;Prandtl number;Eckert number.

INTRODUCTION

In sight of tremendous applications in engineering mechanized processes, the problem of viscous fluid flow and heat carrying over stretching surfaces has enthralled the notice of fluid dynamics experts, for decades, has been the region under discussion of enormous curiosity in the accessible literature.

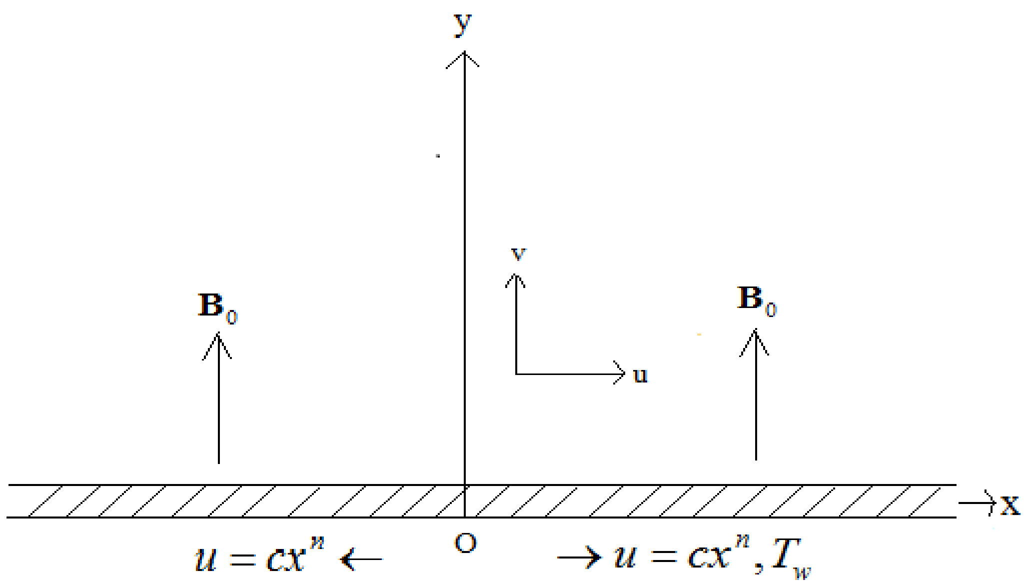
Some of the applications of flow past a stretching surface are, chemical and mechanized processes, hot rolling, paper production, metal revolving, drawing plastic films, glass blowing, annealing and tinning of copper wires, nonstop casting of metals and whirling of fibers, foodstuff dispensation, unbroken casting, portrayal of plastic sheets, and chemical dispensation apparatus, etc.

The fluid flow over a continuously poignant surface finds applications in manufacturing processes, crystal growing,liquid films in reduction course of action, etc., (refer,Fisher [1]). The investigations of Sakiadis [2] and Crane [3] are the most well-known investigations in boundary layer theory.The steadiness scrutiny of MHD flow over a stretching surface was well thought-out for study by H.S. Takhar etal[4]. MHD flow and heat transfer over a stretching surface was considered by H.I. Andersson[5]. MHD flow and heat transfer over a stretching surface with prearranged heat flux was considered by M Kumari etal[6].similarity solutions for MHD flow over continuosly poignant flat plate with hall effects was considered by Watanabe and Pop [7]. MHD flow over stretching surface with suction/Injection was considered by Pop and Na [8]. The MHD flow over porous stretching surface with changeable suction/injection was discussed byN.Chaturvedi[9].MHD flow and heat transfer past a stretching surface in a permeable medium was considered by G.A. Rao etal[10]. All the above mentioned researchers [4-10] have discussed concerning flow and heat transfer past a stretching sheet with no-slip condition at the surface. But though, in case of fluid being in the form of, particulate such as emulsions, suspensions,foams, and polymer solutions, the no-slip condition is no longer applicable, specially at the micro and nano scale, hence In such cases, one has to decide on for slip condition.

The problem concerns to Heat and mass transfer charecteristics of the MHD viscous incompressible fluid flow over a permeable stretching sheet with hydrodynamic and thermal slip is considered for investigation by M.Turkyilmazoglu, [11]. He solved the resulting boundary value problem analytically., and described the effects of various parameters on flow and heat transfer charecteristics. Analysis to study MHD stagnation point flow and heat transfer over a stretching/shrinking sheet with combined effects of velocity slip and heat generation/absorption was considered by Samir Kumar Nandy and Tapas Ray Mahapatra[12]. They have obtained the effects of slip and heat generation/absorption on flow and heat transfer and a comparative study was performed between the previously published research and the present work for a special case and are found to be well in agreement with the present study.The problem of nanofluid Flow and thermal transport charecteristics with hydrodynamic and thermal slip are solved analytically, resulting in providing unique and double solutions and also rigorous mathematical scaling is proposed, fecilitating the nano fluid analysis by M.Turkyilmazoglu,[13]. 2D and axisymmetric flows past a stretching surface with combined effects of magnetic field and porosity with second order slip was investigated by E.H Aly and K.Vajravelu[14]. Further the effects of first order slip, second order slip, magnetic field, and permeability of porous media on flow and thermal charecteristics are investigated.The prominent investigation concerned to the effects of partial slip and third grade fluid parameter on flow and heat transport charecteristics, are made by Bikas Sahoo etal[15]. Further they have shown that, the effect of third grade fluid parameter is to increase momentum boundary layer thickness and decreases the thermal boundary layer thickness.Steady two dimensional boundary layer flow and heat transfer over a vertical permeable stretching /shrinking surface was investigated by Alin V Rosca and Ioan Pop[16]. They have studied the effects of suction and mixed convection parameters, on flow and heat transport.Further they have discussed about stability analysis and have shown that the upper branch solutions are stable, and therefore not physically possible.The flow and radiation heat transfer of a nanofluid over a stretching sheet with velocity slip and temperature jump in porous medium is considered for study by Liancun Zheng etal[17]. They compared the numerical results with analytical HAM, and are found to be well in agreement with their results, and an analysis of MHD flow and heat transfer over permeable stretching/shrinking surfaces taking into account a second order slip model is considered in their study. The purpose is to obtain analytical solutions for the flow and heat transport valid under different physical conditions. A special attention is given for the effects of magnetic field on the second order slip flow conditions. The applied magnetic field play a prominent role in controlling momentum and heat transfers in the boundary layer flow of different fluids over a stretching/shrinking sheets. Considering the magnetic field effect, a variety of physical properties for the flow and heat transfer over stretching/shrinking sheet were analytically investigated in Turkyilmazoglu [19–20]. Recently, Fang et al. [21] considered the effects of second order slip on the flow of a shrinking as well as stretching sheet that was studied by Vajravelu et al. [22].

In case of slip-flow,if the separation of individual molecules occurs at the nanoscales,then one can explain main transport phenomena in nano fluidic systems with a theory depending on continuum and mean-field approaches[23].

Motivated by the above studies, an investigation concerned to the effect of hydrodynamic and thermal slip on the performance of fluid flow and thermal transport of Magneto hydrodynamic fluid over a permeable vertical nonlinear stretching sheet in the presence of viscous and Ohmic dissipations, in porous media is considered in this paper.



Schematic diagram of physical model for MHD flow past over a porous substrate attached to the nonlinearly stretching sheet.

Mathematical Formulation of the problem

In the present work, a Viscous incompressible fluid flow and heat transport of an electrically conducting fluid past a porous vertical nonlinear stretching sheet under the influence of transverse magnetic field, with hydrodynamic and thermal slip is considered for investigation. An uniform transverse magnetic field of strength B_0 is applied perpendicular to flow velocity.

Consider a stretching sheet that pulls out of a slit, and is stretched, as in a polymer extrusion process. Here the speed at a point on the sheet, is proportional to the power of its distance from the slit. In deriving the following equations, it is assumed that the induced magnetic field, the external electric field and the electric field due to the polarization of charges are negligible. The surface of the sheet is insulated, therefore is governed by partial slip condition.Further it is assumed that the sheet vary nonlinearly with the distance x from the leading edge, i.e. $U_w(x) = cx^n$

The Boussinesq approximation is employed and the homogeneity and local thermal equilibrium in the porous medium are assumed.Hence in view of the conditions as mentioned above, and the usual boundary layer approximations,the governing boundary layer equations of motion, and heat transport, with buoyancy ,viscous and Joules dissipation, hydrodynamic and thermal slip are

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty) - \frac{\sigma B_0{}^2}{\rho}u - \frac{\nu}{k'}u - \frac{c_b}{\sqrt{k'}}u^2 \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{\nu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\sigma B_0{}^2}{\rho c_p}\right)u^2, \tag{3}$$

Where $B_0 = cx^{\frac{n-1}{2}}$,

and are governed by the following boundary conditions

$$u(x, y) = L\frac{\partial u}{\partial y} + cx^n,\ v = v_w(x),,\ T = T_w + k_0\frac{\partial T}{\partial y} \quad \text{at} \quad y = 0,$$

$$u \to 0, , T \to T_\infty \quad \text{as} \quad y \to \infty, \tag{4}$$

Where $v_w(x) = -f_w\sqrt{\frac{\nu c(n+1)}{2}}x^{\frac{n-1}{2}}$

Here u and v are the horizontal and transverse velocity components. Further, μ , ρ, α, β, T, g , c_b, k' are the dynamic viscosity, fluid density, thermal diffusivity, thermal expansion coefficient, fluid temperature in the boundary layer, and acceleration due to gravity, drag coefficient and porosity respectively.

Introducing the following similarity trasformation, i.e

$$\eta = \left(\frac{(n+1)c}{2\nu}\right)^{1/2} x^{\frac{n-1}{2}} y, \qquad u(x,y) = cx^n f'(\eta),$$

$$v(x,y) = -\left(\frac{(\nu c x^{n-1}}{}\right)^{\frac{1}{2}} \left(\frac{n-1}{2}\eta f'(\eta) + \frac{n+1}{2} f(\eta)\right) \tag{5}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}. \tag{6}$$

The boundary layer flow, and heat transport equations, (2),(3), and (4), in view of the similarity transformation equations,(5) and (6) can be transformed into the following nonlinear ordinary differential equations.

$$f''' = ff'' - \left(\frac{2n}{n+1}\right) f'^2 - \left(\frac{2}{n+1}\right)\lambda\theta + Mf' + N_1 f' + N_2 f'^2 \tag{7}$$

$$\theta'' = P_r f \theta' - \left(\frac{2n}{n+1}\right) f'\theta - Ec.\Pr\left(f''^2 + Mf'^2\right) \tag{8}$$

In the same way, the boundary conditions (4) takes the form,

$$f(0) = f_w \quad f'(0) = 1 + \gamma f''(0), \qquad \theta(0) = 1 + \delta\theta'(0), f'(\infty) = 0, \theta(\infty) = 0. \qquad (9)$$

Where, $Ec = \dfrac{c^{\frac{5}{2}} x^{3n}}{\rho c_p}$, $\gamma = L\sqrt{\mathrm{Re}_x (1+n)}$, $\mathrm{Re}_x = \dfrac{cx^{n-1}}{\nu}$, $M = \dfrac{c\sigma}{\rho(n+1)}$

$\lambda = \dfrac{Gr_x}{(\mathrm{Re}_x)^2}$, and $Gr_x = \dfrac{g\beta(T_w - T_\infty)}{\nu^2}$, $N_1 = \dfrac{x\nu(1-n)}{k'\ c}$, $N_2 = \dfrac{2c_b x}{\sqrt{k'(n+1)}}$ $\delta = k_0\sqrt{\dfrac{(1+n)}{2}}\sqrt{\mathrm{Re}_x}$

NUMERICAL PROCEDURE

The highly nonlinear differential Eqs.(7) to(8), with boundary conditions (9) are solved numerically using Fourth-order Runge Kutta shooting technique.In the shooting procedure,guessing the values of $f''(0)$ and $\theta'(0)$, is very important. This method depends very much on our guesses. Numerical solutions are obtained for different values of the material parameters, i.e. magnetic parameter *M*, stretching parameter n, Prandtl number Pr, slip parameter γ, thermal slip parameter δ, Buoyancy parameter λ, Eckert number (Ec) , porous parameter N_1,Inertia Coefficient N_2, and suction/injection parameter f_w .The step size is taken as, $\Delta\eta = 0.01$ to have the convergence criterion to be 10^{-6} in these cases. The maximum value value of η_∞ was taken for each iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$ .The maximum value of η_∞ to each set of parameters is obtained when the value of the unknown boundary conditions at $\eta = 0$ is not changed to successful loop with error less than 10^{-6}.

RESULTS AND DISCUSSION

In order to analyze the physical idea of the problem, the velocity, and temperature profiles are assigned various numerical values to the parameter, that occur in the problem i.e. numerical calculations were carried out for different values of suction parameter f_w, magnetic parameter M, power law stretching parameter n, Prandtl number Pr, Eckert number Ec , buoyancy parameter λ, slip parameter γ ,and thermal slip parameter δ ,their effects on flow and heat transfer characteristics are discussed with the aid of graphs.

Fig 1 shows the effect of magnetic parameter M on dimensionless velocity profile $f'(\eta)$, and it is noticed that velocity profile of the fluid in the boundary layer significantly reduces with increase in values of M. This is because of the fact that, magnetic field introduces a retarding force which acts transverse to the direction of applied magnetic field. This force is Lorentz force, which decelerates the flow in the boundary layer, resulting in thickening momentum boundary layer and also it is noticed in increase of absolute value of velocity gradient at the surface of the sheet.The effect of suction/ injection parameter f_w ($f_w < 0$), f_w ($f_w > 0$), on horizontal velocity profiles are depicted in Fig2. It is noticed that the effect of suction parameter is to reduce horizontal velocity in the boundary layer, where as in case of injection, i.e f_w ($f_w > 0$), horizontal velocity increases. In case of large f_w , the boundary-layer assumptions do not admit a solution, where as it approaches the value unity resulting in boundary layer will almost be literally blown off at the surface of sheet, and the flow will be the same as that of stationery sheet.

Fig 3, shows the effect of suction/injection on dimensionless temperature profile. Here it is noticed that in case of increase of suction parameter($f_w < 0$), temperature decreases, in the thermal boundary layer, and the thickness of boundary layer decreases, where as for increase of injection parameter($f_w > 0$), there is decrease of thermal boundary layer thickness. Further it is observed that suction parameter ($f_w < 0$) enhances , heat transfer coefficient much more than injection parameter ($f_w > 0$). Thus, suction acts as a good means for cooling the surface than injection. Figs 4 and 5, represents respectively the behaviors of the horizontal velocity and temperature profiles for different values of power law stretching parameter n, and it is noticed that increase in m results in decrease of horizontal velocity profile which is more prominent for small values of n, where as temperature profile increases with the increase of stretching parameter n. it is noticed that, the sheet temperature variation has significant effect on thermal boundary layer. Further sheet temperature variation is observed to be more in the route of stretching rate.fig 6, exhibits the effect of the Prandtl number on temperature profile. The temperature profile and thermal boundary layer thickness quickly decrease with increasing values of Pr as well as both slip and no slip conditions. Prandtl number acts as a means to increase fluid viscosity resulting in lessen in the flow velocity and temperature. Here thermal boundary layer thickness decreases with increasing Prandtl number, which is consistent with the findings of various reasearchers.

Next, let us pay attention, how velocity slip parameter γ effects the horizontal velocity profile.The velocity profile $f'(\eta)$ for different values of the velocity slip parameter γ are shown in Fig 7. When there is slip, which means velocity is not zero at the surface of the sheet or the flow velocity adjacent to the sheet surface is not equal to the stretching sheet velocity. When γ increases, the fluid velocity increases. When the slip parameter γ increases in magnitude, more fluid is allowed to penetrate into the surface of stretching sheet. In the surrounding area of the sheet flow gets accelerated. however, far away from the sheet the flow is deccelerated. Further it is noticed that, increasing the value of γ will increase the flow velocity, only because due to the slip condition, the pulling of the stretching sheet is partially transmitted into the fluid. In fig 8, it is observed that,the effects of buoyancy parameter λ on horizontal velocity profile is shown graphically, and the effects of buoyancy force is found to be more effective for a lower Prandtl number fluid, which implies that lower Prandtl number fluid is more susceptible to the effects of buoyancy force.Buoyancy is observed to deplete velocity in convective flows and therefore the reduced buoyancy force will manifest a boost in $f'(\eta)$ as noticed in the figure. It is noticed from Fig 9, that Eckert number controls the fluid motion in the boundary layer, and when Ec=0, is the case of no viscous dissipation, i.e for the case of ideal fluid, where its viscosity is negligible. The prescence of Ec in the energy equation acts as an heat producing parameter due to the action of viscous stresses, where in dimensionless temperature overshoots at Ec=0.2. Further it is a well known fact that viscous dissipation is significant for those flows in which velocity gradient is large with fluids of high viscosity.In Fig 10, the effects of thermal slip parameter δ on temperature distribution is displayed. As the thermal slip increases, less heat is transferred from the sheet to the fluid and hence the temperature decreases, i.e increase in thermal slip parameter δ provides the decreasing behavior on temperature profile.Fig.11: Represents the effect of inertia coefficient N2 on velocity profile.From this we conclude thatN2,enhances the thickness of momentum boundary layer.Fig .12 Represents the effect of porous parameter N1 over velocity profile.As Porous parameter increases ,velocity decreases.Due to this,the velocity decreases in the boundary layer.

CONCLUSION

The analysis of non darcy MHD boundary layer flow and heat transfer over a vertical stretching sheet with combined effect of hydrodynamic and thermal slip in a saturated porous medium is studied.Numerical solutions for the governing boundary layer equations of motion is obtained,allowing the computation for flow and heat transfer charecteristics for different values of porosity parameter,nonlinear stretching parameter,Prandtl number,Eckert number etc.

The results indicate that increasing hydrodynamic slip enhances velocity profile resulting in decrease of boundary layer thickness,where as on the other hand increase of thermal slip reduces temperature in the thermal boundary layer region.

The velocity fileld is suppressed by increase in values of suction parameter resulting in enhancing skin friction coefficient, and the opposite results are noticed for injection.

The heat transfer rate at the surface of stretching sheet increases with increasing values of nonlinear stretching parameter, which results in increase of thermal boundary layer thickness.

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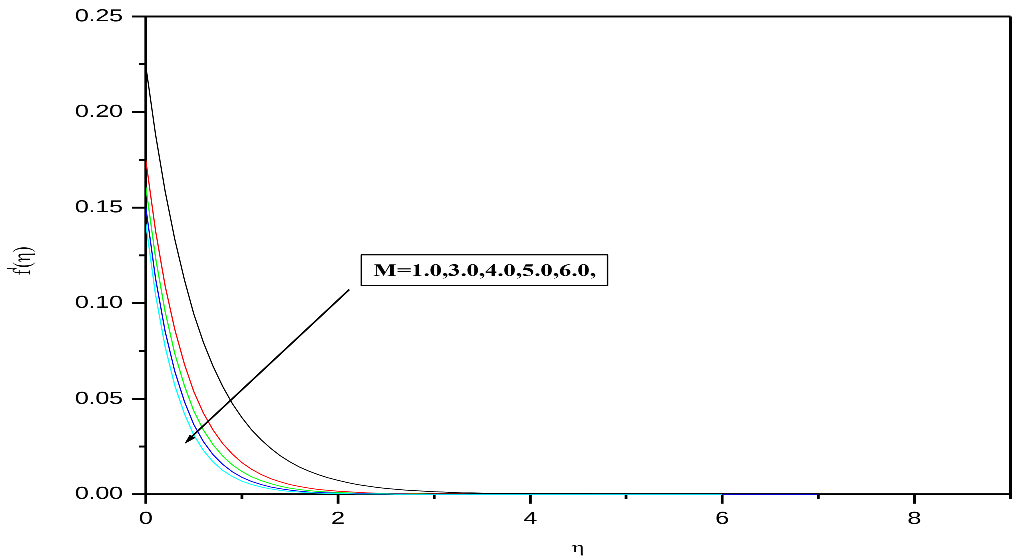

Fig 1 Velocity profile $f'(\eta)$ versus similarity variable η for various values of M when λ=3.0,

f_w =1.0,n=0.7,γ=2.0, $N_1 = 0.2, N_2 = 0.1.$

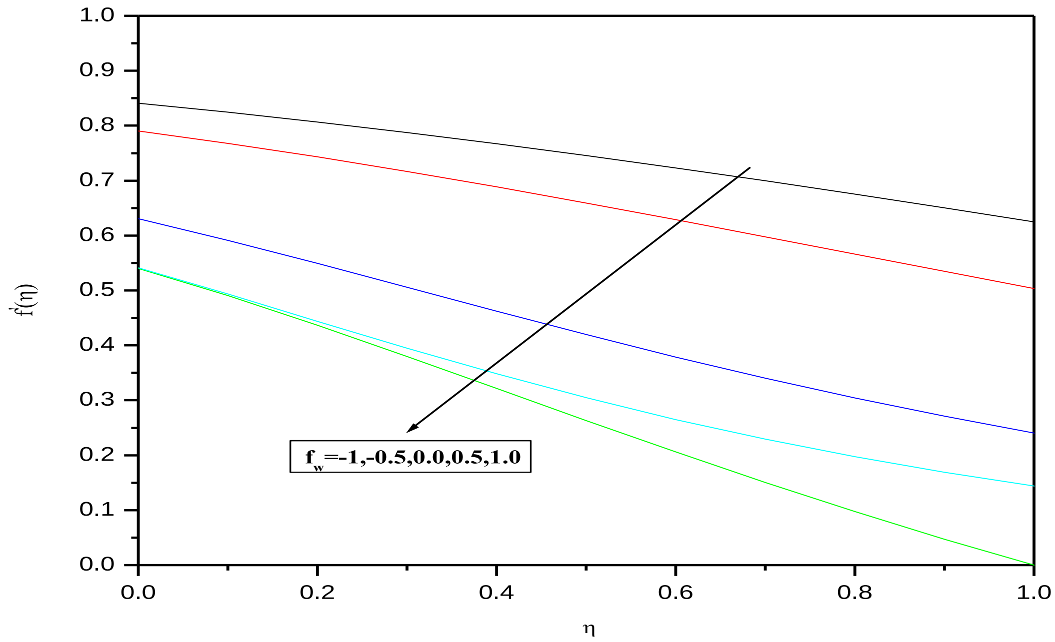

Fig 2 Velocity profile f' versus similarity variable η for various values of f_w When, $\lambda = 3.0, m = 0.7, M = 2.0,\ \gamma = 2.0,\ \mathrm{N}_1 = 0.2, N_2 = 0.1.$.

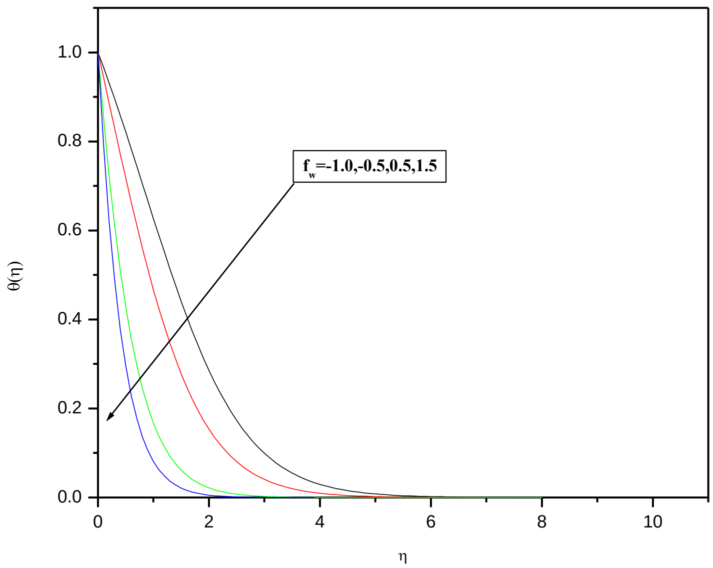

Fig 3 Temperature profile $\theta(\eta)$ versus similarity variable η for various values of f_w

when, $\mathrm{n} = 3.0, \mathrm{Pr} = 2.0, \ \gamma = 2.0, Ec = 2.0$.

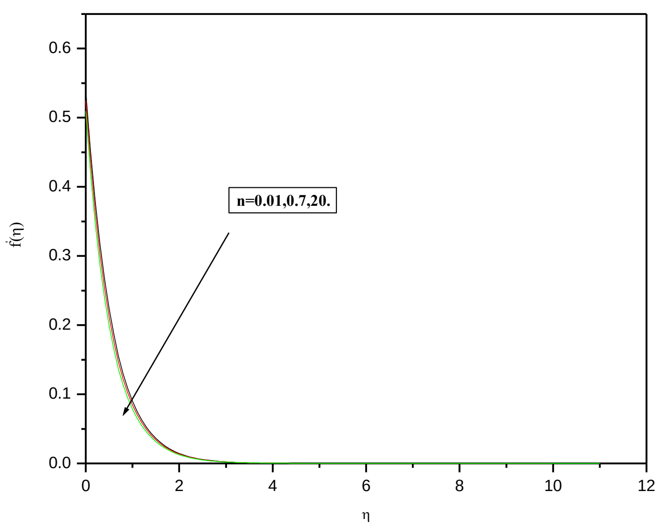

Fig 4 Velocity profile $f'(\eta)$ versus η for various values of n,when, $N_1 = 0.2, N_2 = 0.1.$

$M = 3.0, \lambda = 2.0, \ \gamma = 5.0, \ f_w = 2.0$

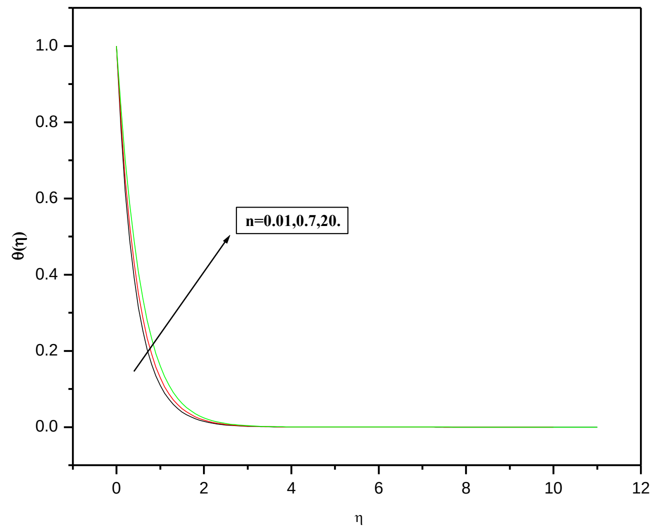

Fig 5 Temperature profile $\theta(\eta)$ versus η for various values of n when Pr=1.5,Ec=2.0, f_w=1.0, γ=0.5,

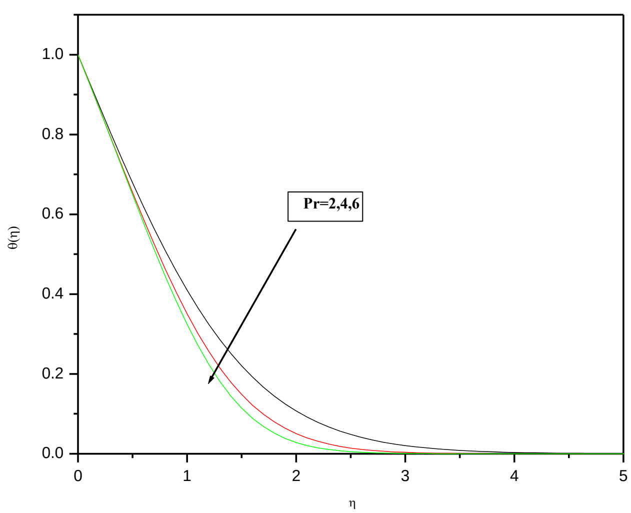

Fig 6 Temperature profile $\theta(\eta)$ versus similarity variable η for various values of Pr, when n=2.0, Ec=1.0, f_w=1.0, γ =1.0.

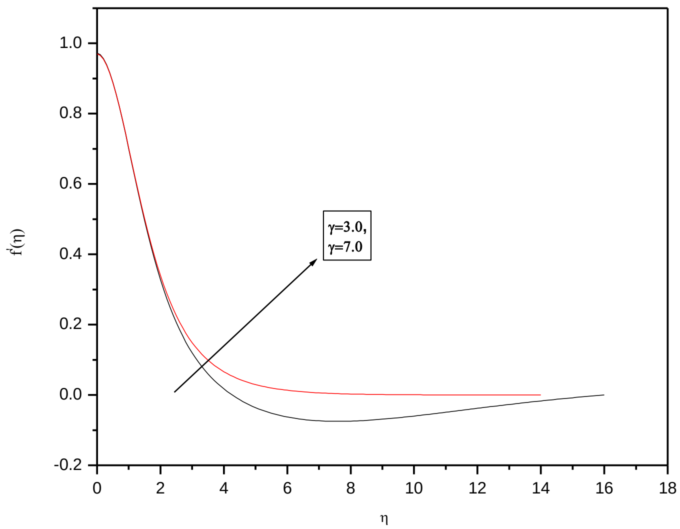

Fig 7 Velocity profile $f'(\eta)$ versus similarity variable η for various values of

n=2.0,M=2.0, λ=3.0, f_w=-1.0, $N_1 = 0.2, N_2 = 0.1$.

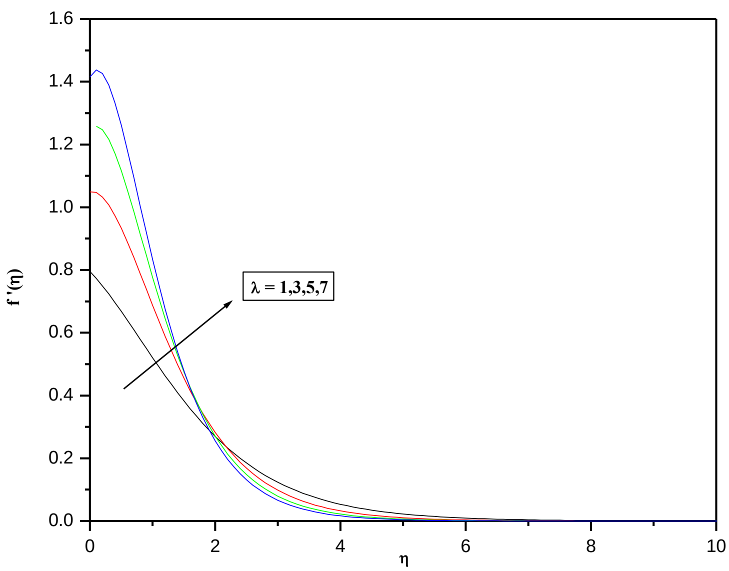

Fig 8, Velocity profile $f'(\eta)$ versus similarity variable η for various values of buoyancy parameter λ, when n=2.0,M=2.0, f_w=-0.5, γ=1.0, $N_1 = 0.2, N_2 = 0.1$.

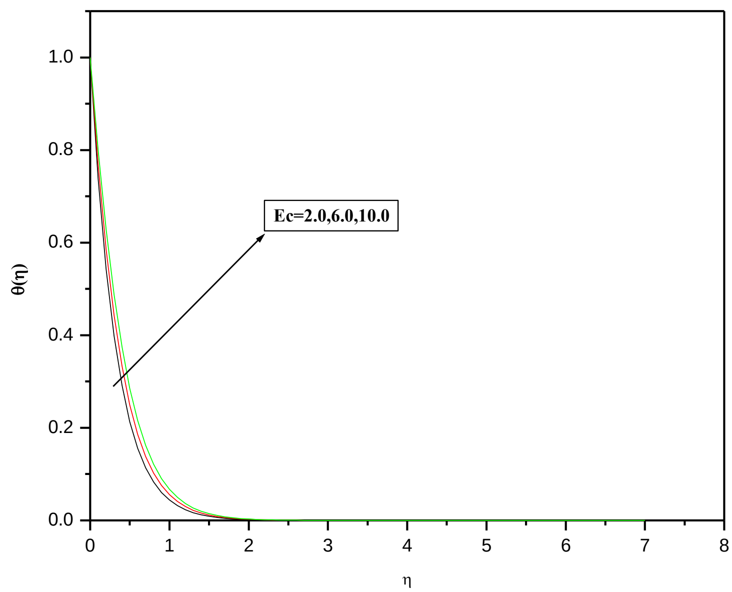

Fig 9 ,Temperature profile $\theta(\eta)$ versus similarity variable η for various values of Ec,

When n=2.0,Pr=3.0 f_w =1.0, δ =2.0.

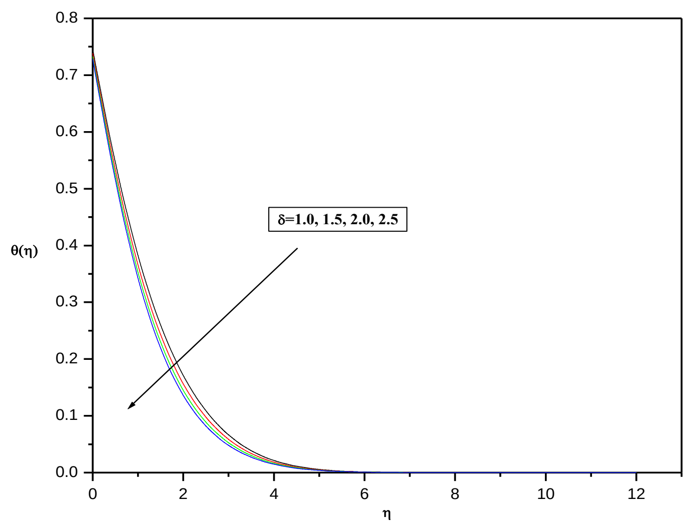

Fig 10, Temperature profile $\theta(\eta)$ versus similarity variable η for various values of δ,

When Ec=2.5, λ =3.0,Pr=1.5, γ =0.5.

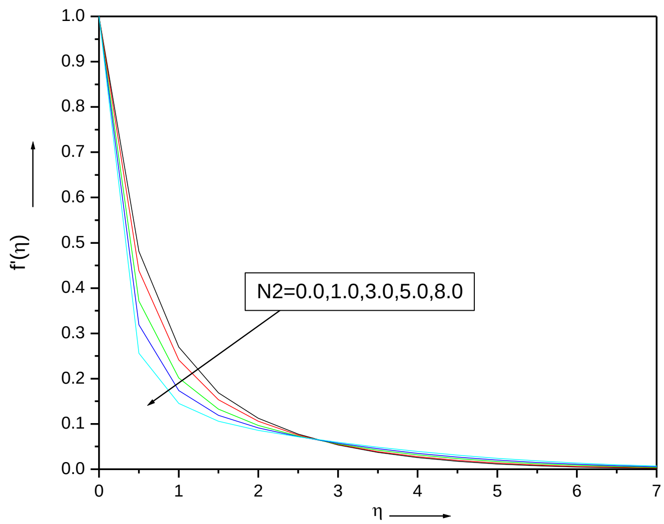

Fig 11, Velocity profile $f'(\eta)$ versus similarity variable η for various values of inertia coefficient N_2, when n=2.0,N1=2.0, f_w=-0.5, γ =1.0. $\lambda = 2.0$.

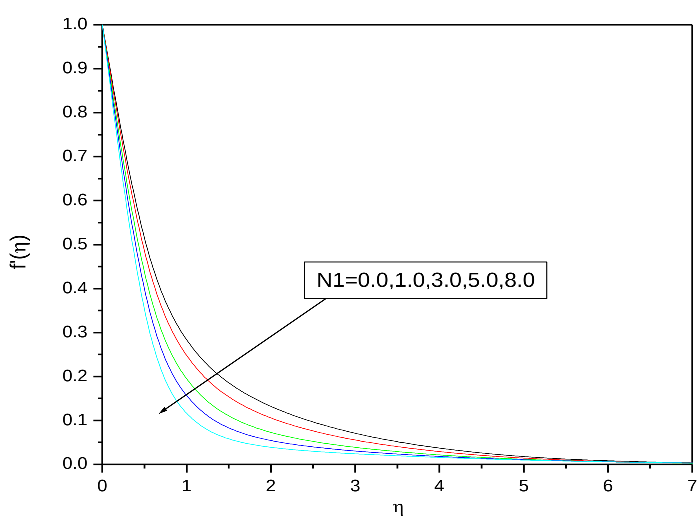

Fig 12 Velocity profile $f'(\eta)$ versus similarity variable η for various values of porous parameter N_1 when, n=2.0,M=2.0, λ =3.0, f_w=-1.0,N_2=1.0.