A NOTE ON HEAT TRANSFER OF MHD JEFFREY FLUID OVER A STRETCHING VERTICAL SURFACE THROUGH POROUS PLATE

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ABSTRACT

This research note's objective is to elaborate the study of MHD Jeffrey fluid over a stretching vertical surface an accelerated porous plate with heat source. The fluid flow phenomenon happens in a stretching vertical surface immersed in a porous medium. The mathematical model is presented with the system of the partial differential equations along with physical conditions. Appropriate dimensionless model is transformed into similarity transformations, which are solved numerically using finite difference scheme. The influences of various pertinent parameters on the flow involving in the governing differential equations are discussed through graphs.

KEYWORDS: Jeffrey fluid, Stretching surface, Porous plate, Heat transfer

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INTRODUCTION

The Jeffrey fluid model is capable of describing the stress relaxation property of no-Newtonian fluids, which the usual viscous fluid model cannot describe. Class of non-Newtonian fluids having the characteristic memory time scale, also known as the relaxation time, can be described well by the Jeffrey fluid model. The interest developing in the studies of non-Newtonian fluid in the last few years is owing to its implementation in industry and technology. Some of the common examples of the non-Newtonian fluid are honey, polymer solution, get, blood, macro-molecules solutions, and many others. The nonlinear rheological properties of the non-Newtonian fluid are one of the major aspects of its importance. Many rheological problem applications are observed in the field of geophysics, bioscience, cosmetics, during of paper, food processing, chemical plastic suggested explicating the rheological conduct of non-Newtonian fluids. In literature, many models have been suggested to explicate the rheological conduct of non-Newtonian fluids. In the amidst, Jeffrey fluid is noted as an important model of non-Newtonian fluid because of its simplicity. The Jeffrey fluid best explains the rheological viscoelastic fluids because it utilizes the time derivative preferably to convicted derivative. The linear viscoelastic behaviour of Jeffery fluids makes it more appealing in the polymer industries. An important role of Jeffrey fluid is observed in blood flow and fluid mechanics due to its viscoelastic behaviour. Newtonian fluid can be derived as a special case of Jeffrey fluid as it is a significant generalization of a Newtonian fluid. Several studies of the Jeffrey fluid flow under different conditions have been carried out by many researchers. In view of the above some researchers are (Hussain et. al, 2014) illustrated the radiative hydromagnetic flow of Jeffrey nanofluid by an exponentially stretching sheet, (Hyat and Mustafa, 2010) explained in detailed on influence of thermal radiation on the unsteady mixed convection flow of a Jeffrey fluid over a stretching sheet, (Idowu et. al, 2015) observed that on impact of heat and mass transfer on MHD oscillatory flow of Jeffery fluid in a porous channel with thermal conductivity, Dufour and Soret, (Zin et. al, 2016) has been considered the influence of thermal radiation on unsteady MHD free convection flow of Jeffrey fluid over a vertical plate with ramped wall temperature, (Zeeshan and Majeed, 2016) Heat transfer analysis of Jeffrey fluid flow over a stretching sheet with suction/injection and magnetic dipole effect, (Bhatti andZeeshan, 2016)studied an analytic study of heat transfer with variable viscosity on solid particle motion in dusty Jeffrey fluid, (Turkyilmazoglu, 2014) worked out on an unsteady convection flow of some nanofluids past a moving vertical flat plate with heat transfer, (Pourabdian et. al, 2014) The Jeffrey – Hamel flow and heat transfer of nanofluids by homotopy perturbation method and comparison with numerical results, (Kothandapani and Prakash, 2016) motivated study on convective boundary conditions effect on peristaltic flow of a MHD Jeffrey nanofluid, (Rajagopal, 1993) measured on mechanics of non-Newtonian fluids, very recently some of the authors considered (Chenna Kesavaiah et. a, 2022) Radiation and mass transfer effects on MHD mixed convective flow from a vertical surface with heat source and chemical reaction, (Chenna Kesavaiah et. al, 2022) Radiation, radiation absorption, chemical reaction and hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source.

The study of non-Newtonian fluids has gained interest because of their numerous technological applications, including performance of lubricants, manufacturing of plastic sheets and movement of biological fluids. In particular, the boundary layer flow of an incompressible non-Newtonian fluid over a stretching sheet has several industrial applications, for example, food processing, and extrusion of polymer sheet from a dye, oil recovery and drawing of plastic films. In view of their differences with Newtonian fluids, several models of non-Newtonian fluids have been proposed. Jeffery fluid (non-Newtonian fluid) is s type of non-Newtonian fluid that uses a relatively simpler linear model using time derivatives instead of convicted derivatives, which are used by most fluid models. Recently, this model of fluid has prompted active discussion. (Shehzad et.al, 2013)observed influence of thermo-phoresis and joule heating on the radiative flow of Jeffery fluid with mixed convection, (Nallapu and Radhakrishnamacharya, 2014) has been considered Jeffrey fluid flow through porous medium in the presence of magnetic field narrow tubes, (Kalidas Das et. al, 2015) explained radiative flow of MHD Jeffery fluid past a stretching sheet surface slip and melting heat transfer, (Prasad et. al, 2015) expressed mathematical study for laminar boundary layer flow heat and mass transfer of a Jeffery non-Newtonian fluid past a vertical porous plate, (Kartini Ahmed and Anuar Ishak, 2017) illustrated magnetohydrodynamic (MHD) Jeffery fluid over a stretching vertical surface in a porous medium, (Gbadeyan et. al, 2011) motivated study on heat and mass transfer for Soret and Dolour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid in the presence of magnetic field, (Fetecau et. al, 2009) a note on the second problem of Stokes for Maxwell fluids, (Vieru et. al, 2008) considered flow of a viscoelastic fluid with fractional Maxwell model between two side walls perpendicular to a plate, (Vieru and Rauf, 2012) Stokes flows of a Maxwell fluid with wall slip condition, (Dunn and Rajgopal, 1995) active research on fluid of differential tube: Critical review and thermodynamics analysis. Not long ago authors highlighted in some research domains as Chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties by (Chenna Kesavaiah et. al, 2022), MHD Effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface (Chenna Kesavaiah et. al, 2022), and (Chenna Kesavaiah et. al, 2022):Chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer.

Heat transfer accompanied by melting phenomenon has recently received considerable research attention. This is due to a large number of applications, including latent heat storage, material processing, crystal growth, castings of metals, glass industry, purification of materials, and others. The prediction of temperature distribution and meting solidification rate is very important in some modern technologies. This is in order to control the fundamentals parameters such as the speed of fabrication, incidence of defects as well as the influence on the final properties of products and the possibility of damage of the contact surface between the wall and phase change material. Melting heat transfer from a flat plate was discussed many authors; such as (Chenna Kesavaiah et. al, 2021) has been considered theradiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (Rami Reddy et. al, 2021) motivated study on Hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, (Chenna Kesavaiah and Venkateswarlu, 2020) observed that chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al, 2019) explained in detailed information on radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Srinathuni Lavanya and Chenna Kesavaiah, 2017) expressed their research innovation on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction,(Mallikarjuna Reddy et. al, 2018) illustrated the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (Chenna Kesavaiah and Sudhakaraiah, 2014) demonstrated on the effects of heat and mass flux to MHD flow in vertical surface with radiation absorption,(Rajaiah et. al, 2015). Represented the report on chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium, (Chenna Kesavaiah et. al, 2013) communicated a research report on natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, Chenna Kesavaiah and Satyanarayana, 2013) exhibited the effect of MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction,(ChennaKesavaiah et. al, 2013) showed evidence onradiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source, (Karunakar Reddy et. al, 2013) revealed on effect on MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, (Ch Kesavaiah et. al, 2013) conveyed the effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium, (Rajaiah and Sudhakaraiah (2015) extracted work on unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, (ChKesavaiah et. al, 2012) a research note on radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation.

The purpose of the present paper is to examine the effects of thermal radiation and melting heat transfer on the boundary layer stagnation point flow of an electrically conducting Jeffrey fluid over a semi infinite stretching sheet in the presence of magnetic field and surface slip with heat source. The model of Jeffery fluid flow is presented mathematically and has been solved numerically using finite difference method.

MATHEMATICAL FORMULATION

We considered unsteady two-dimensional incompressible Jeffery fluid in a porous medium over a vertical stretching sheet coinciding with the plate $y=0$ with the flow being confined to $y>0$. The surface is assumed to stretch with velocity $u_w = ax$ where a stretching constant. Here, the $x-$axis is chosen parallel to the vertical surface and the $y-$axis is taken normal to it. The plate temperature is $T_w = T_\infty + bx$, where T_w is the surface temperature is, T_∞ is the ambient fluid temperature and b is constant. $T_w > T_\infty$ and $T_w < T_\infty$ are for heated surface (assisting flow) and cooled surface (opposing flow), respectively. A uniform transverse magnetic field of strength B_0 is applied parallel to the $y-axis$. By invoking the boundary layer and Boussinesq approximation, the governing boundary layer equations for this problem can be written as

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\nu}{1+\lambda}\left[\frac{\partial^2 u}{\partial y^2}+\lambda_1\left(u\frac{\partial^3 u}{\partial x\partial y^2}+v\frac{\partial^3 u}{\partial y^3}+\frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial x\partial y}-\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2}\right)\right]+g\beta_T\left(T-T_\infty\right)-\frac{\nu}{\in}u-\frac{\sigma B_0^2}{\rho}u \qquad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{\kappa}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}-\frac{q}{\rho c_p}\left(T-T_\infty\right) \qquad (3)$$

Subject to the boundary conditions

$$u=u_w, v=0,\ T=T_w \quad at \quad y=0$$
$$u\to 0, \frac{\partial u}{\partial y}\to 0,\ T\to T_\infty \quad as \quad y\to\infty \qquad (4)$$

where u, v are velocity components in x and y directions respectively. λ is the ration of the relaxation and retardation times; λ_1 is the relaxation time and T is the fluid temperature, $\nu=\frac{\mu}{\rho}$ is the kinematic viscosity, where μ is the coefficient of fluid viscosity and ρ is the fluid density, $g, \beta_T, \in$ and σ are gravitational acceleration, thermal expansion coefficient, permeability coefficient of porous medium and fluid electrical conductivity, respectively.

Using the Rosseland approximation, the radiative heat flux is given by

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \qquad (5)$$

where σ_0 is the Stefan – Boltzmann constant and k_3 is the mean absorption coefficient.

We assume that the temperature differences within the flow are sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding T^{*4} in a Taylor series about T_∞^* and neglecting the higher order terms, we get

$$T^{*4} \cong 4T^{*}{}_{\infty}{}^{4}T' - 3T^{*4}_{\infty} \quad (6)$$

Using equation (5) and (6) into equation (3) yields

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \left(\alpha + \frac{16\sigma^* T_\infty^3}{3k^*}\right)\frac{\partial^2 T}{\partial y^2} - \frac{q}{\rho c_p}\left(T - T_\infty\right) \quad (7)$$

Setting

$$\eta = \sqrt{\frac{a}{\nu}}\, y, \psi = \sqrt{a\upsilon x}\, f(\eta), \quad \theta = \frac{T - T_w}{T_w - T_\infty} \quad (8)$$

and making $u = \frac{\partial \psi}{\partial y}$ *and* $v = -\frac{\partial \psi}{\partial x}$

Equation (1) automatically satisfied and equations (2), (7) reduced to

$$f''' + \beta\left(f''^2 - f^{iv}\right) + (1+\lambda)\left[f\,f'' - f'^2 - f'(\gamma + M) + \lambda\theta\right] = 0 \quad (9)$$

$$(1+Nr)\theta'' + \Pr\left(f\theta' - f'\theta - Q\theta\right) = 0 \quad (10)$$

And the transformed boundary conditions can be written as

$$f(0) = 0, f'(0) = 1, \theta(0) = 1 \;\; at \;\; \eta = 0$$
$$\left.\begin{array}{l} f'(\eta) \to 0, f'' \to (\eta) = 0, \\ \theta(\eta) \to 0 \end{array}\right\} as \;\; \eta \to \infty \quad (11)$$

where f is the dimensionless steam function, θ is the dimensionless temperature and the prime denotes differentiation with respect to η. Here β is the Deborah number, γ is the porosity parameter, M is the MHD parameter, Q is the heat source/sink parameter, $\Pr$ is the Prandtl number and $g, \beta_T, \in$ is the mixed convection parameter which is defined as

$$\beta = a\lambda_2, \gamma = \frac{\nu}{\in a}, M = \frac{\sigma B_0^2}{\rho a}, \Pr = \frac{\nu}{\alpha}, \quad Nr = \frac{16 T_\infty^3 \sigma_*}{3\kappa k^*}, \;\; \lambda = \frac{Gr}{\mathrm{Re}^2}, \;\; Q = \frac{q}{\nu\rho C_P} \quad (12)$$

where $Gr = \frac{g\beta(T_w - T_\infty)x^3}{\nu^3}$ *and* $\mathrm{Re} = \frac{u_w x}{\nu}$ are the local Grashof number and the local Reynolds number, respectively. It should be pointed out that $\lambda > 0$ and $\lambda < 0$ represent assisting flow (heated plate) and opposing flow (cooled plate), respectively, while $\lambda = 0$ corresponds to forced convection regime and λ corresponds to the free convection regime.It is worth mentioning that when equations (9), (10) reduce to those of (Gbadeyan et.al, 2011)when $K = N = Du = Le = 0$ as in their paper. The important physical quantities of interest are the skin friction C_f coefficient and the local Nusselt number Nu_x, the transformed forms of which are given by(Shehzad et.al, 2013) i.e.

$$C_f \operatorname{Re}_x^{\frac{1}{2}} = \frac{1+\beta}{1+\lambda} f''(0), \quad Nu_x \operatorname{Re}_x^{\frac{1}{2}} = -\theta'(0)$$

where $\operatorname{Re}_x = \frac{u_w x}{\nu}$ is the local Reynolds number

RESULTS AND DISCUSSION

In this article an MHD boundary layer problem for momentum and heat transfer in Jeffrey fluid flow over a non-isothermal stretching sheet in the presence of dissipative energy, thermal radiation and internal heat source/sink is carried out. The highly non-linear governing partial differential equations are reduced into a set of non-linear ordinary differential equations by applying suitable similarity transformation and their analytic solutions are obtained in the form hyper geometric function. For the purpose of discussing results, the numerical computations are carried out for various values of pertinent parameters like Deborah number (β), the porosity parameter (γ), the MHD parameter (M), the mixed convection parameter (λ), thermal radiation parameter (Nr) and the Prandtl number $(\Pr)$ with ratio of relaxation and retardation times (λ) , heat source/sink parameter (Q). For illustrations of the results, numerical values are plotted in figures (2) – (10). There are many parameters involved in the final form of the mathematical model. The problem can be extended on many directions, but the first once which seems to be considered, is the effect of in this simulation the default values of parameters are considered as $M=1, N=1, \gamma=1, \lambda=1, Q=1, \Pr=0.71$ unless otherwise specified.The graphical representations of the effect of λ for the purpose of the local Nusselt number $-\theta'(0)$ and surface stress $f'(0)$ are shown in figures (2) and (3), respectively. Figures (2) and (3) decided that an M increment will lead to decrement of surface shear stress $f'(0)$ and the reverse effect observed in local Nusselt number $-\theta'(0)$ for various values of Deborah number and porosity parameter. Figure (4) represent Nusselt number $-\theta'(0)$ for various values of porosity parameter. It is noticed that an increases values porosity parameter of the results decreases.The resulting profiles of the dimensionless velocity $f'(\eta)$ and the temperature distribution $\theta(\eta)$ for various values of the Deborah number displayed in figure (5) and (6) respectively. It is observed that the velocity and boundary layer thickness are increasing function of the Deborah number. It should be pointed out that $\beta=0$ represents Newtonian fluid and $\beta>0$ represents the Jeffery fluid parameter. However, opposing phenomenon is observed for the temperature profiles. The effect of the porosity parameter on flow velocity $f'(\eta)$ and temperature $\theta(\eta)$ can also be garnered form the same figures (7) and (8). It is obvious that an increase in the porosity parameter causes greater obstruction to the fluid flow, which culminates in the decrement of velocity as well as temperature profile. Figures (9) and (10) present the velocity $f'(\eta)$ and temperature profiles $\theta(\eta)$ for few values of the mixed convection parameter respectively. It is well known that $\lambda = 0$ corresponds to pure forced convection and the presence of thermal buoyancy $\lambda \neq 0$ will lead to stronger buoyancy force, which induces more flow along the surface. The consequences can be seen in the increase of the velocity $f'(\eta)$ as well as temperature profiles $\theta(\eta)$ mixed convection parameter increases. However, this phenomenon is more pronounced for flow with low Prandtl numbers. An overshoot peak in the velocity profile is observed near the surface for flow with low Prandtl number and for large values of the mixed convection parameter $(\lambda = 10)$ where the free convection is dominant. At the beginning of the motion $(0 \leq \eta \leq 0.5)$, the velocity increases until reaches a certain value and gradually decreases until it goes to 0 at the outside of the boundary layer, whereas the velocity for other profiles produce lower velocities toward the edge of the boundary layer starting from the beginning. Figure (11) – (12) illustrated the variation of the velocity and temperature profiles for distinct values of thermal radiation parameter when stretching sheet is melting at a steady rate, it shows that an enhancing radiation parameter rise in the fluid velocity, but the reverse effects are observed for same parameter in temperature profiles in figure (12). This is because rises in radiation have tendency to increase the conduction effects. Therefore a higher value of thermal radiation parameter implies higher surface heat flux and so, decrease the temperature at each point away from the surface. It is also observed that thermal boundary layer thickness decreases with increasing the values of thermal radiation parameter. The influence of heat generation/absorption parameter on the velocity profiles $f'(\eta)$, temperature $\theta(\eta)$ profiles is displayed in the figures (13) and (14). It is worth noting that for the case of $Q > 0$ the energy may be generates in the boundary layer, in consequences, the velocity and temperature profiles of the fluid increases. The numerical calculations we carried out for Deborah number (β) with fixed values of $M = 0.3, Nr = 0.2, \gamma = 0.2, \lambda = 0.5, Q = 0.5$ .Form table (1), we observed that an increase in the values of Deborah number (β) the Nusselt number increases. Form table (2); it is noticed that an increase in the values of Deborah number (β) the Nusselt number increases.

Table (1): The values of $f'(0)$ for several values of $\Pr$ and β				
β	$f'(0)$			
	$\Pr = 0.01$	$\Pr = 0.03$	$\Pr = 0.72$	$\Pr = 2.36$

0.1	-0.4992	-0.5120	-0.5568	-0.6932
0.2	-0.9425	-0.9245	-1.4563	-1.2404
0.3	-1.5987	-1.5864	-1.6457	-1.6987
0.4	-2.1156	-2.4245	-2.0965	-2.1987

Table (2): The values of $-\theta'(0)$ for several values of Pr and β

β	$-\theta'(0)$			
	$\mathrm{Pr}=0.01$	$\mathrm{Pr}=0.03$	$\mathrm{Pr}=0.72$	$\mathrm{Pr}=2.36$
0.1	-0.4992	1.0754	3.6458	5.1254
0.2	-0.9245	0.7856	3.5458	4.9685
0.3	-1.5864	0.6489	3.4566	4.4875
0.4	-2.0089	0.5256	3.3658	4.1256

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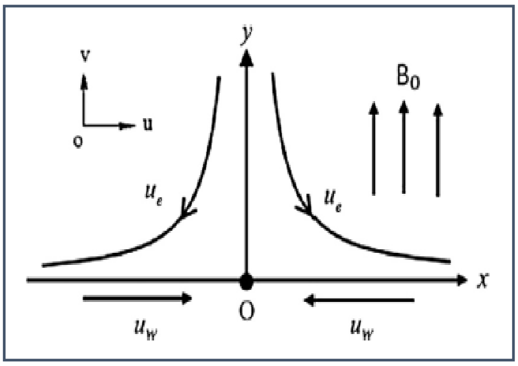

Fig. (1): Physical model of the problem

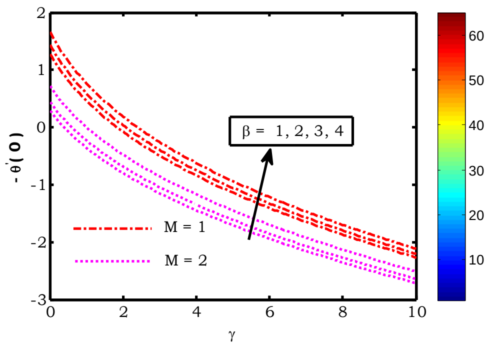

Fig. (2): Variations of $-\theta'(0)$ with γ selected values of M and β

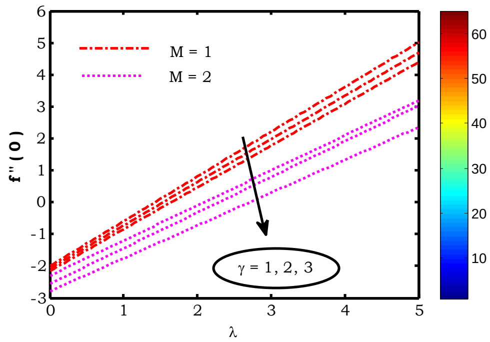

Fig. (3): Variations of $-f''(0)$ with λ selected values of M and γ

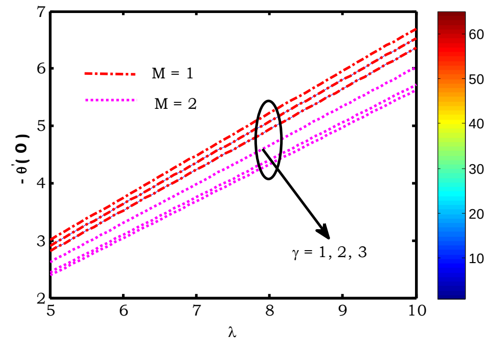

Fig. (4): Variations of $-\theta'(0)$ with λ selected values of M and γ

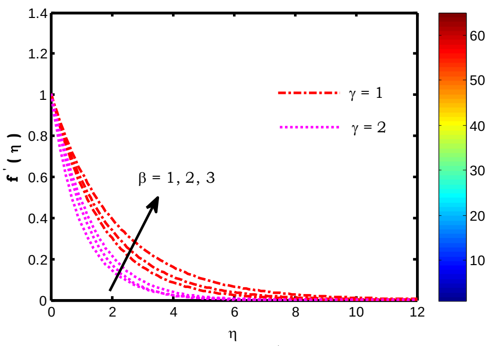

Fig. (5): Velocity profiles $f'(\eta)$ for β and γ

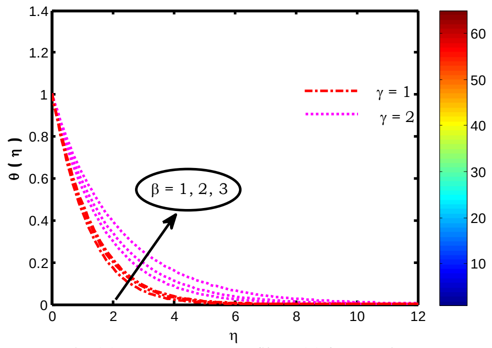

Fig. (6): Temperature profiles θ (η) for β and γ

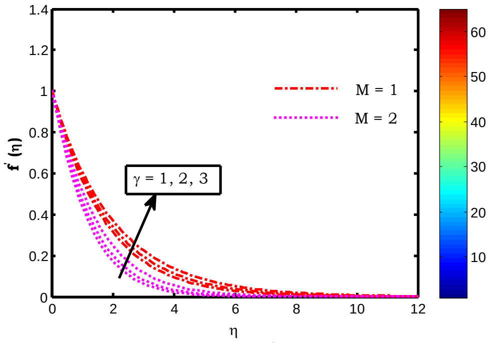

Fig. (7): Velocity profiles f′ (η) for M and γ

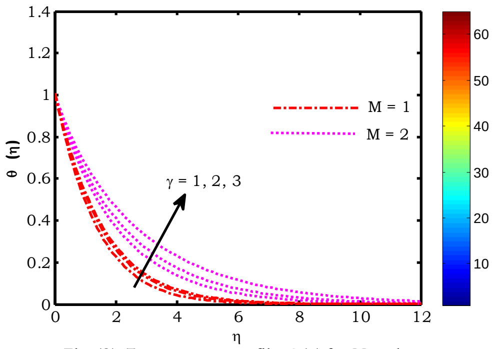

Fig. (8): Temperautre profiles θ (η) for M and γ

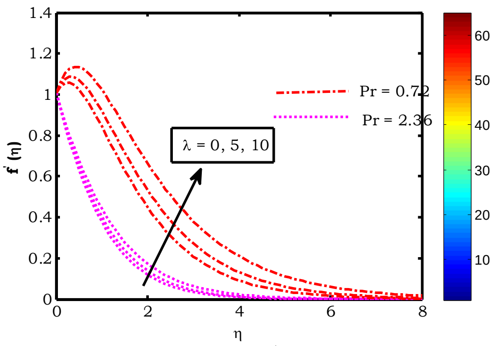

Fig. (9): Velocity profiles f′(η) for Pr and λ

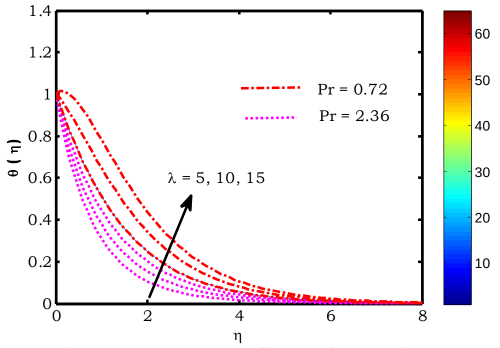

Fig. (10): Temperature profiles θ (η) for Pr and λ

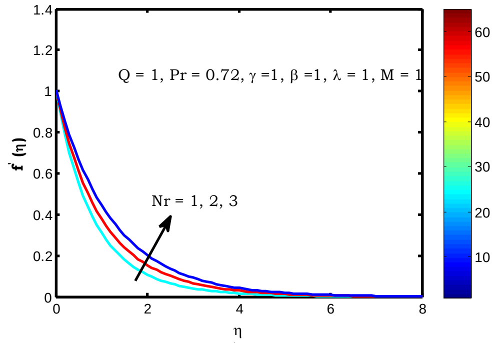

Fig. (11): Vellocity profiles f′(η) for different values of Nr

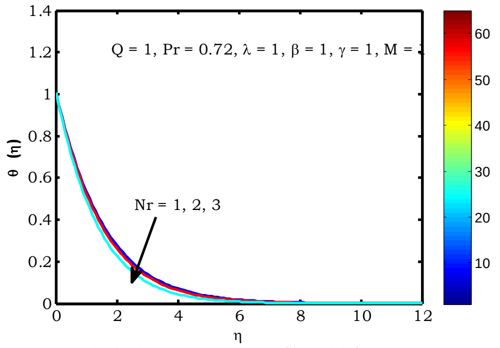

Fig. (12): Temperautre profiles θ (η) for Nr

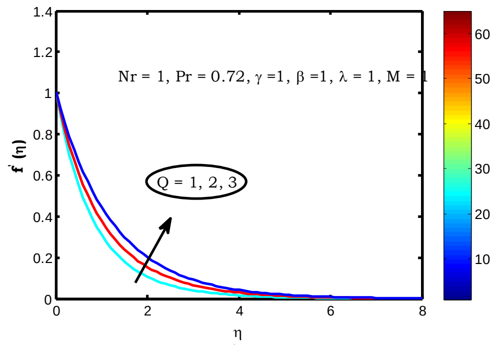

Fig. (13): Vellocity profiles f′(η) for different values of Nr

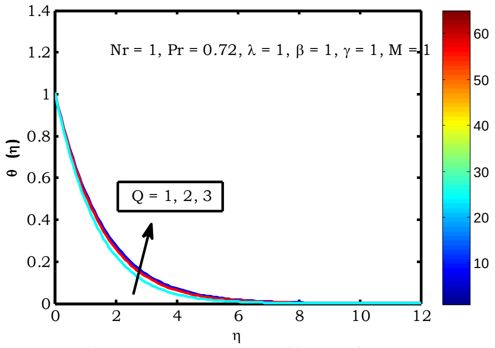

Fig. (14): Temperautre profiles θ (η) for Q