Mhd And Radiation Effect On Heat Transfer In A Non-Newtonian Maxwell Fluid Over An Unsteady Stretching Sheet With Heat Source/Sink

S.Vijaya Lakshmi*, T.Amaranatha Reddy** and M. Suryanarayana Reddy***

*Lecturer in Mathematics NTR Govt.degree College Valmikipuram, A.P, India.
**Department of Physics , Aditya College of Engineering , Madanapalle-517325 , A.P , India
***Department of mathematics, JNTUA College of engineering, Pulivendula-516 390.A.P, India

ABSTRACT

The effects of variable heat flux on the flow and heat transfer of a non-Newtonian Maxwell fluid over an unsteady stretching sheet in the presence of, MHD, heat source/sink and radiation effects have been studied. The governing differential equations are transformed into a set of coupled non-linear ordinary differential equations and then solved with a numerical technique using appropriate boundary conditions for various physical parameters. The numerical solution for the governing non-linear boundary value problem is based on applying the fourth-order Runge–Kutta method coupled with the shooting technique using appropriate boundary conditions for various physical parameters. The effects of various parameters like the viscosity parameter, thermal conductivity parameter, unsteadiness parameter, radiation parameter, heat source/sink parameter, Deborah number, and Prandtl number on the velocity and temperature profiles as well as on the local skin-friction coefficient and the local Nusselt number are presented and discussed.

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Keywords: non- Newtonian Maxwell fluid, unsteady stretching sheet, radiation, variable fluid properties, variable heat flux.

1. Introduction

The flow of non-Newtonian fluids over a stretching surface has received considerable attention during the last several decades because of its numerous applications in engineering problems, such as chemical engineering and particularly, polymer fluids, manufacturing of plastic and rubber sheets, solidification of liquid crystals, glass blowing, hot rolling, crystal growing, continuous cooling and fibres' spinning, exotic lubricants, and suspension solutions. Crane [1] was the first to study the motion set up in the ambient fluid due to a linearly stretching surface. Gupta and Gupta [2] have subsequently explored various aspects of the accompanying heat transfer occurring in the infinite fluid medium surrounding the stretching sheet. The flow field of a stretching wall with a power-law velocity variation was discussed by Banks.[3]. The self-similar boundary flow with identically vanishing skin friction induced by a continuous plane surface with stretching velocity is considered by Magyari and Keller.[4]. Mahapatra and Gupta [5] analyzed stagnation-point flow towards a stretching surface in the presence of free stream velocity. Megahed [6] studied the variable fluid properties and variable heat flux effects on the flow and heat transfer in a non-Newtonian Maxwell fluid over an unsteady stretching sheet with slip velocity.

The magnetohydrodynamic (MHD) problems of flow of an electrically conducting fluid over a stretching porous plate in a porous medium with an external transverse uniform magnetic field has many applications in petroleum industry, purification of crude oil and fluid droplets sprays wire and fiber coating and polymer technology, production of plastic sheets and foils, and cold drawing of plastic sheets. All these processes depend on the physical/rheological properties of the fluid around the sheet. Many studies to understand the features of the flow over a stretching sheet had been done traditionally for Newtonian fluids, although the fluids used in industrial purposes are non-Newtonian. The MHD flow and heat transfer over a stretching sheet is one of the very important problems in fluid mechanics. It had been discussed for the first time by Sakiadis [7]. In last decades the applications of this problem has been widely speeded in metallurgical industry, polymer processing, and paper production [8-10]. Liao [11, 12] introduced the analytic solution of the steady state non-Newtonian MHD fluid flow over a stretching sheet by means of HAM. Hayat et al. [13] analyzed the MHD boundary layer flow of an upper convected Maxwell fluid over a porous stretching sheet by means of homotopy analysis method. The effect of Hall currents on flow and heat transfer over an unsteady stretching surface in the presence of a strong magnetic field has been analyzed by El-Aziz.[14]. Abdallah [15] studied the homotopy analytical solution of MHD fluid flow and heat transfer problem. Bataller [16] studied the magnetohydrodynamic flow and heat transfer of an upper-convected Maxwell fluid due to a stretching sheet.

The effects of radiation on unsteady free convection flow and heat transfer problem have become more important industrially. At high operating temperature, radiation effect can be quite significant. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for design of reliable equipments, nuclear plants, gas turbines and various propulsion devices or aircraft, missiles, satellites and space vehicles. Das [17] studied the effect of chemical reaction and thermal radiation on heat and mass transfer flow of MHD micropolar fluid in a rotating frame of reference. Ishak [18] discussed thermal boundary layer flow over a stretching sheet in a micropolar fluid with radiation effect. The influence of thermal radiation on hydromagnetic Darcy-Forchheimer mixed convection flow was presented by Pal and Mondal [19]. Mukhopadhyay et al. [20] considered forced convection flow and heat transfer over a porous plate in a Darcy-Forchheimer porous medium in presence of radiation. Olajuwon and Oahimire [21] studied the unsteady free convection heat and mass transfer in an MHD micropolar fluid in the presence of thermo diffusion and thermal radiation. Prabir Kumar et al. [22] studied the MHD micropolar fluid flow with thermal radiation and thermal diffusion in a rotating frame.

The heat source/sink effects in thermal convection are significant where there may exist high temperature differences between the surface (e.g. space craft body) and the ambient fluid. Heat generation is also important in the context of exothermic or endothermic chemical reaction. Tania et al [23] has investigated the Effects of radiation, heat generation and viscous dissipation on MHD free convection flow along a stretching sheet. Moalem [24] studied the effect of temperature dependent heat sources taking place in electrically heating on the heat transfer within a porous medium. Vajravelu and Nayfeh [25] reported on the hydro magnetic convection at a cone and a wedge in the presence of temperature dependent heat generation or absorption effects. The effect of the unsteadiness parameter on heat transfer and flow field over a stretching surface with and without heat generation was considered by Elbashbeshy and Bazid,[26,27] respectively. Swati Mukhopadhyay [29] analyze the heat transfer analysis of the unsteady flow of a Maxwell fluid over a stretching surface in the presence of a heat source/sink.

The present study contains an analysis of the effects of magnetohydrodynamic flow of a non-Newtonian Maxwell fluid over an unsteady stretching sheet by taking heat source/sink, radiation into account. Using the similarity transformations, the governing equations have been transformed into a set of ordinary differential equations, which are nonlinear and cannot be solved analytically, therefore, fourth order Runge-Kutta method along with shooting technique has been used for solving it. The results for velocity and temperature functions are carried out for the wide range of important parameters namely, magnetic parameter, unsteadiness parameter, viscosity parameter, thermal conductivity parameter, heat source/sink parameter and radiation parameter. The skin friction and rate of heat transfer have also been computed.

2. MATHEMATICAL FORMULATION

Consider an unsteady, two-dimensional laminar boundary layer flow of a non-Newtonian Maxwell fluid over a stretching sheet immersed in an incompressible and radiative fluid. The flow is in the region $y > 0$ and is subjected to a non-uniform magnetic field of strength $B = B_0/\sqrt{1-at}$ applied normally to the surface, B_0 is the initial strength of the magnetic field. The unsteady fluid and heat flows start at $t = 0$. The sheet emerges out of a slit at origin ($x = 0$, $y = 0$) and moves with non-uniform velocity $U(x,t) = bx/1-at$, where b and a are positive constants with dimensions of (time)$^{-1}$, we must observe that our problem is valid only for $at<1$, b is the initial stretching rate. The surface of the sheet is held at a surface heat flux $q_w(x, t)$. It is assumed that the magnetic Reynolds number is very small and as there is no electric field, the electric field due to polarization of charges is neglected. Under these assumptions along with the Boussinesq and boundary layer approximations, the system of equations, which models the flow is given by

Continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2.1}$$

Linear momentum equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{1}{\rho}\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) - \frac{\sigma B^2}{\rho}u - \lambda_1\left[u^2\frac{\partial^2 u}{\partial x^2} + v^2\frac{\partial^2 u}{\partial y^2} + 2uv\frac{\partial^2 u}{\partial x \partial y}\right] \tag{2.2}$$

Energy equation

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{\rho c_p}\frac{\partial}{\partial y}\left(\kappa\frac{\partial T}{\partial y}\right) - \frac{\partial q_r}{\partial y} + \frac{Q_0}{\rho c_p}(T - T_\infty) \tag{2.3}$$

The boundary conditions for the velocity, temperature and concentration fields are

$$u = -U(x,t) = -\frac{bx}{1-at}, v = v_w, \frac{\partial T}{\partial y} = -\frac{q_w}{k_\infty} \text{ at } y = 0$$
$$u \to 0, T \to T_\infty \quad \text{as} \quad y \to \infty \tag{2.4}$$

where u and v are the velocity components along x and y directions, respectively, ρ is the fluid density, T is the temperature of the fluid, λ_1 is the relaxation time, c_p is the specific heat at constant pressure, μ is the fluid viscosity, k is the fluid thermal conductivity, q_r is the radiative heat flux, Q_0 is the heat source/sink constant, κ_∞ is the thermal conductivity at the ambient, and T_∞ is the free stream temperature.

By using the Rosseland approximation the radiative heat flux q_r is given by

$$q_r = -\frac{4\sigma_s}{3k_e}\frac{\partial T^4}{\partial y} \tag{2.5}$$

Where σ_s is the Stefan -Boltzmann constant and k_e is the mean absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically thick fluids. If temperature differences within the flow are significantly small, then equation [2.5] can be linearised by expanding T^4 into the Taylor series about T_∞, which after neglect higher order terms takes the form:

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{2.6}$$

In view of equations [2.6] and [2.7], eqn. [2.3] reduces to

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{1}{\rho c_p}\frac{\partial}{\partial y}\left(\kappa\frac{\partial T}{\partial y}\right) + \frac{16\sigma_s T_\infty^3}{3k_e \rho c_p}\frac{\partial^2 T}{\partial y} + \frac{Q_0}{\rho c_p}(T - T_\infty) \tag{2.7}$$

The continuity equation (2.1) is satisfied by the Cauchy Riemann equations

$$u = \frac{\partial \psi}{\partial y} \quad \text{and} \quad v = -\frac{\partial \psi}{\partial x} \tag{2.8}$$

where $\psi(x, y)$ is the stream function.

In order to transform equations (2.2) and (2.7) into a set of ordinary differential equations, the following similarity transformations and dimensionless variables are introduced.

$$\psi = \left(\frac{\mu_\infty b}{\rho}\right)^{1/2}(1-at)^{-1/2}xf(\eta), \eta = \left[\frac{b}{(\mu_\infty/\rho)}\right]^{1/2}(1-at)^{-1/2}y$$
$$T = T_\infty + T_0\left(\frac{dx^2}{\kappa_\infty\sqrt{\rho b/\mu_\infty}}\right)(1-at)^{-3/2}\theta(\eta), \theta(\eta) = \frac{T - T_\infty}{\Delta T}, S = \frac{a}{b}$$
$$\Delta T = T_0\left(\frac{dx^2}{\kappa_\infty\sqrt{\rho b/\mu_\infty}}\right)(1-at)^{-3/2}, M = \frac{\sigma B_0^2}{\rho b}, N = \frac{16\sigma_s T_\infty^3}{3k_e k \rho c_p}$$
$$Q = \frac{Q_0}{1-at}, De = \frac{\lambda_1(t)b}{\lambda_0(1-at)} = b\lambda_0, \lambda_1(t) = \lambda_0(1-at), \Pr = \frac{\mu_\infty c_p}{\kappa_\infty} \tag{2.9}$$

where $f(\eta)$ is the dimensionless stream function, θ - dimensionless temperature, η - similarity variable, M - Magnetic parameter, S - unsteadiness parameter, μ_∞ - viscosity at the ambient, T_0 - is a (positive or negative; heating or cooling), d is a constant, De - Deborah number, λ_0 - is a constant,

Q - heat source/sink parameter, *N*- radiation parameter, *Pr*- Prandtl number.
The viscosity μ and thermal conductivity κ of the fluid are assumed to vary with the temperature as follows:[30]

$$\mu = \mu_\infty e^{-\alpha\theta} \qquad (2.10)$$
$$\kappa = \kappa_\infty (1+\varepsilon\theta)$$

where α is the viscosity parameter, and κ is the thermal conductivity parameter.
The surface heat flux *q(x, t)* at the stretching sheet varies with the power of distance x from the slit and with the power of time factor t [30]

$$q(x,t) = -\kappa_\infty \frac{\partial T}{\partial y} = T_0 \frac{dx^2}{(1-at)^2} \qquad (2.11)$$

In view of Equations (2.8) - (2.11), the Equations (2.2) and (2.7) transform into

$$e^{-\alpha\theta}\left(f''' - \alpha\theta' f''\right) + ff'' - f'^2 - Mf'$$
$$-S\left(f' + \frac{1}{2}\eta f''\right) - De\left(f^2 f''' - 2ff'f''\right) = 0$$

(2.12)

$$\left((1+\varepsilon\theta)\theta'' + \varepsilon\theta'^2\right)(1+N)$$
$$+\Pr(f\theta - 2f'\theta + Q\theta - S\left(\frac{3}{2}\theta + \frac{1}{2}\eta\theta'\right) = 0$$

(2.13)

The corresponding boundary conditions are:

$$f(0) = fw,\ f'(0) = 1, \theta'(0) = -1$$
$$f' \to 0, \theta \to 0 \quad \text{as} \quad \eta \to \infty$$

(2.14)

where the primes denote differentiation with respect to η

The physical quantities of interest are the skin friction coefficient C_f, the local Nusselt number Nu which are defined as

$$C_f = -2\,\mathrm{Re}_x^{-1/2} f''(0),\ Nu = -\frac{\mathrm{Re}_x^{1/2}}{\theta(0)} \qquad (2.15)$$

3 SOLUTION OF THE PROBLEM

The set of coupled non-linear governing boundary layer equations (2.12) and (2.13) together with the boundary conditions (2.14) are solved numerically by using Runge-Kutta fourth order technique along with shooting method. First of all, higher order non-linear differential Equations (2.12) and (2.13) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique (Jain *et al*.[32]). The resultant initial value problem is solved by employing Runge-Kutta fourth order technique. The step size $\Delta\eta$=0.05 is used to obtain the numerical solution with five decimal place accuracy as the criterion of convergence. From the process of numerical computation, the skin-friction coefficient and Nusselt number, which are respectively proportional to $f''(0)$ and $1/\theta(0)$, are also sorted out and their numerical values are presented in a tabular form.

4 RESULTS AND DISCUSSION

The governing equations (2.11) - (2.14) subject to the boundary conditions (2.15) are integrated as described in section 3. In order to get a clear insight of the physical problem, the velocity and temperature have been discussed by assigning numerical values to the parameters encountered in the problem. The effects of various parameters on velocity profiles in the boundary layer are depicted in Figs. 1-5. The effects of various parameters on temperature profiles in the boundary layer are depicted in Figs. 6-13.

Fig.1 illustrates the effect of the unsteadiness parameter (*S*) on the velocity field. It is seen that as the unsteadiness parameter increases, the velocity field decreases. The effect of suction parameter (*fw*) on the velocity is illustrated in Fig.2. It is noticed that the velocity decreases with increasing values of the suction parameter. Fig. 3 shows the variation of the velocity with the Deborah number (*De*). It is noticed that the velocity thickness decreases with an increase in the Deborah number.

Fig.4 illustrates the effect of heat source/sink parameter on the velocity. It is noticed that as the heat source/sink parameter increases, the velocity increases. Fig. 5 shows the variation of the velocity with the viscosity parameter (α). It is noticed that the velocity thickness decreases with an increase in the viscosity parameter.

Fig. 6 depicts the thermal boundary-layer with the unsteadiness parameter. It is noticed that the thermal boundary layer thickness decreases with an increase in the unsteadiness parameter. Fig. 7 depicts the thermal boundary-layer with the suction parameter. It is noticed that the thermal boundary layer thickness decreases with an increase in the suction parameter.

Fig.8 illustrates the effect of the Deborah number on the temperature. It is noticed that as the Deborah number increases, the temperature increases. Fig. 9 shows the variation of the thermal boundary-layer with the Prandtl number *(Pr)*. It is noticed that the thermal boundary layer thickness decreases with an increase in the Prandtl number. Fig. 10 shows the variation of the thermal boundary-layer with the radiation parameter *(N)*. It is observed that the thermal boundary layer thickness increases with an increase in the radiation parameter. Fig. 11 shows the variation of the thermal boundary-layer with the heat source/sink parameter (*Q*). It is observed that the thermal boundary layer thickness increases with an increase in the heat source/sink.

The effect of viscosity parameter on the temperature field is illustrated Fig.12. As the viscosity parameter increases the temperature is found to be increasing. The effect of conductivity parameter on the temperature field is illustrated Fig. 13. It is noticed that the thermal boundary layer thickness increases with an increase in the conductivity parameter.

The correctness of the present numerical method is checked with the results obtained by Abel et al. [33] and Megahed [6] for the values of Skin friction coefficient in the limiting condition. Thus, it is seen from Table 1.

5 CONCLUSIONS

In the present prater, the unsteady magnetohydrodynamic (MHD) laminar flow and heat transfer in a non-Newtonian Maxwell fluid over stretching sheet with prescribed surface heat flux by taking MHD, heat source/sink and radiation effects into account, are analyzed. The governing equations are approximated to a system of non-linear ordinary differential equations by similarity transformation. Numerical calculations are carried out for various values of the dimensionless parameters of the problem. It has been found that

1. The velocity decreases as well as temperature increases with an increase in the magnetic parameter.
2. The velocity and temperature decreases with an increase in the suction parameter.
3. The heat source/sink enhances the velocity and temperature.

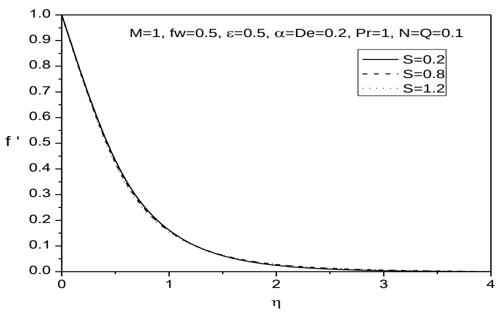

Fig.1 Velocity profiles for different values of *S*

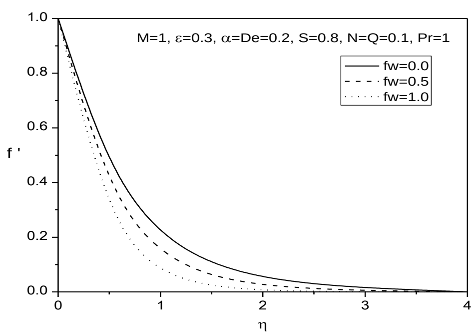

Fig.2 Velocity profiles for different values of f_w

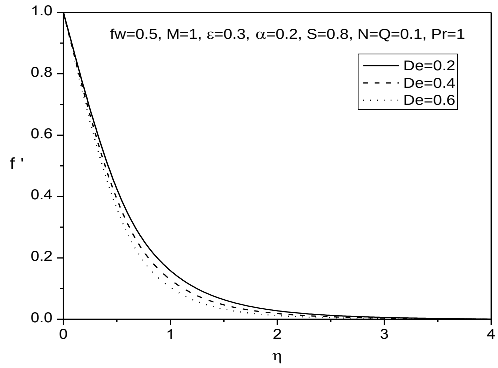

Fig.3 Velocity profiles for different values of *De*

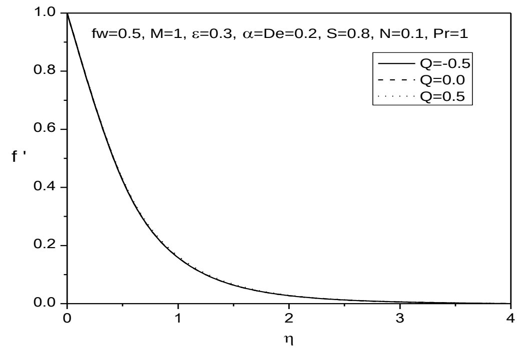

Fig.4 Velocity profiles for different values of *Q*

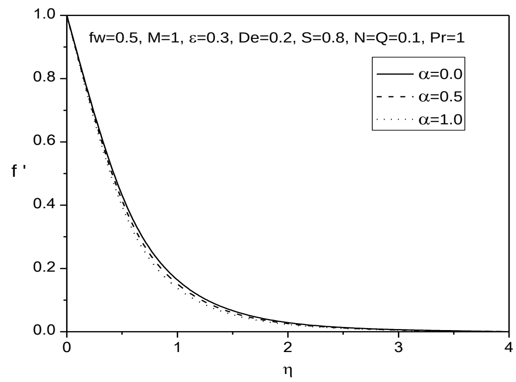

Fig.5 Velocity for different values of *α*

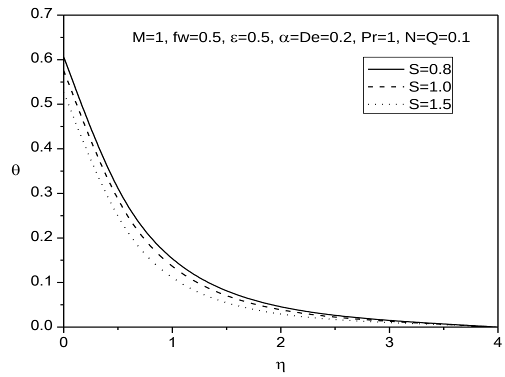

Fig.6 Temperature for different values of *S*

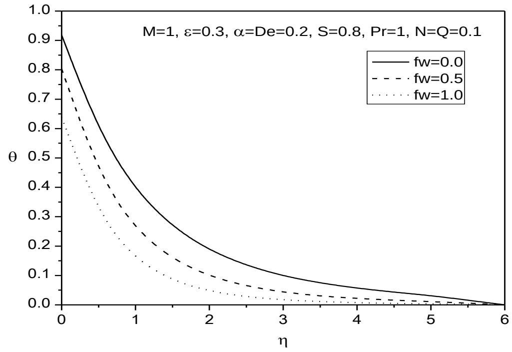

Fig.7 Temperature for different values of f_w

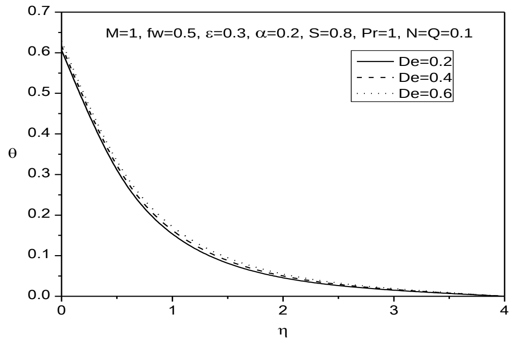

Fig.8 Temperature for different values of *De*

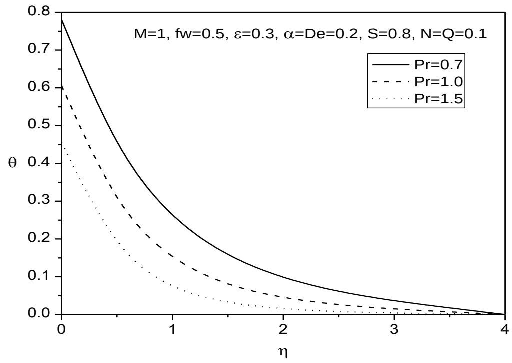

Fig.9 Temperature profiles for different values of *Pr*

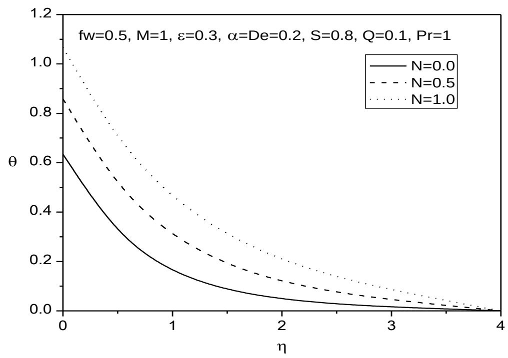

Fig.10 Temperature profiles for different values of *N*

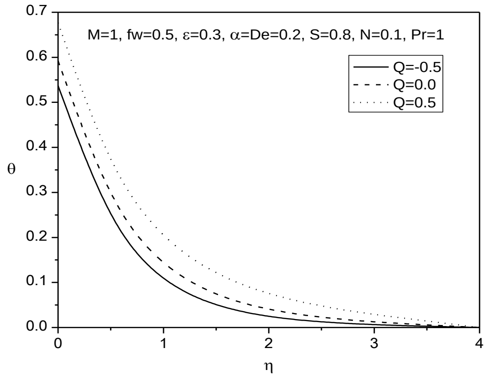

Fig.11 Temperature for different values of *Q*

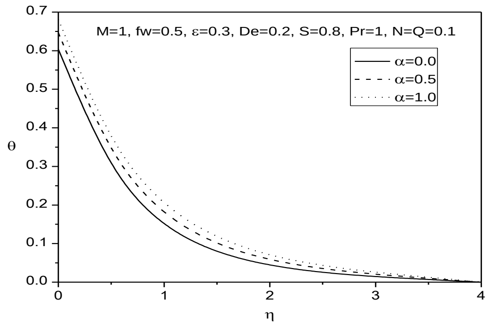

Fig.12 Temperature for different values

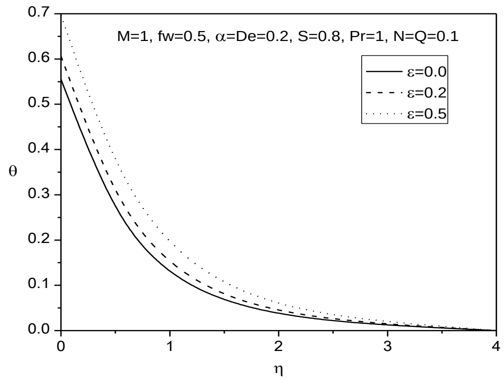

Fig.13 Temperature for different values of *ε*

Table 1 Numerical values of $-f''(0)$ at the sheet for different values of *De* when *S=M=fw=N=Q=0*, Comparison of the present results with that of Abel et al. [33] and Megahed [6]

De	Present study	Abel et al. [33]	Megahed [6]
0.0	0.999978	0.999962	0.999978
0.2	1.051945	1.051948	1.051945
0.4	1.101848	1.101850	1.101848
0.6	1.150160	1.150163	1.150160
0.8	1.196690	1.196692	1.196690
1.2	1.285253	1.285257	1.285253
1.6	1.368641	1.368641	1.368641
2.0	1.447616	1.447617	1.447616

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