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***Journal of Scientific and Engineering Research*, 2018, 5(5):485-498**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Optimization for Effects of Heat Transfer on MHD Flow Over an Unsteady Stretching Surface in a Micropolar Fluid and a Porous Medium by Two Numerical Methods

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Abstract The objective of this paper is to study optimization for effect of the unsteady laminar on MHD flow of an incompressible, viscous, electrically conducting, micropolar fluid over a stretching sheet in a porous medium with prescribed surface heat flux by using two numerical methods. The governing partial differential equations are transformed into a system of ordinary differential equations, which are solved numerically using a finite-difference method and the Runge-Kutta integration scheme with a modified version of the Newton-Raphson shooting method and in this paper two numerical methods give us the same results for the problem (optimize of the solution). Approximate solutions have been derived for velocity, temperature and microrotation profiles. The effects of the flow parameters such as unsteadiness parameter(S), Boundary parameter (m), Prandtl number (Pr), Magnetic parameter (M), material parameter (Δ) and Permeability parameter (k_1) on the velocity, temperature and concentration profiles been studied.

Keywords Micropolar Fluid, Porous Medium

List of Symbols

$a,b,c,$	Constants
B_0	Magnetic induction
T	Fluid temperature
T_∞	Ambient temperature
N	Angular velocity
u	Velocity component in the x-direction
v	Velocity component in the y- direction
M	Magnetic parameter
Pr	Prandtl number
U_w	Stretching velocity
q_w	Surface heat flux
m	Boundary parameter
Δ	Material parameter
S	Unsteadiness parameter
$_1$	bility parameter

Greek Symbols

σ	Electric conductivity
η	Similarity variable
α	Thermal diffusivity of the fluid

k	Kortex viscosity
k_p	Permeability of the medium
j	microinertia per unit mass
γ	Spin gradient viscosity
μ	Dynamic viscosity coefficient
ν	Kinematical viscosity
ρ	Fluid density
ψ	Stream function
F	Dimensionless stream function
θ	Dimensionless temperature
h	Microrotation

Subscripts

W At the wall

∞ At infinity

x , y Cartesian coordinates along the surface and normal to it, respectively

Superscript

' Differentiation with respect to η only.

1. Introduction

The phenomenon of MHD flow with heat transfer in micropolar and electrically conducting fluid over stretching surface in a porous medium has attracted the attention of a good number of investigators because of its varied applications in many engineering problems such as MHD generators, plasma studies, nuclear reactors, oil exploration, geothermal energy extractions and in the boundary layer control in the field of aerodynamics. The quality of the final product depends on the rate of heat transfer at the stretching surface. Crane [1] first obtained an elegant analytical solution to the boundary layer equations for the problem of steady two-dimensional flow due to a stretching surface in a quiescent incompressible fluid. J. Anand Rao and S. Shivaiah [2] studied chemical reaction effects on an unsteady MHD free convective flow past an infinite vertical porous plate with constant suction and heat source. E. M. Abo-Eldahab et al. [3] have discussed the Viscous dissipation and blowing / suction effects on hydromagnetic natural convection from an inclined plate in a micropolar fluid with variable surface heat flux. The three dimensional case has been considered by Wang [4]. Roslinda Nazar et al. [5] initiated the Unsteady Boundary Layer Flow over a Stretching Sheet in a Micropolar Fluid. Kumari et al. [6] studied the unsteady free convection flow over a continuous moving vertical surface in an ambient fluid, and Ishak et al. [7] investigated theoretically the unsteady mixed convection boundary layer flow and heat transfer due to a stretching vertical surface in a quiescent viscous and incompressible fluid.

The problem of micropolar fluids past through a porous media has many applications, such as, porous rocks, foams and foamed solids, aerogels, alloys polymer blends and microemulsions. The Radiation effect on heat transfer of a micropolar fluid through a porous medium was studied by E. M. Abo-Eldahab and A.F. Ghonaim[8]. The simultaneous unsteady boundary layer flows of a micropolar fluid near the forward stagnation point of a plane surface were analyzed by Y.Y. Lok et al. [9]. A. Raptis[10] studied boundary layer flow of a micropolar fluid through a porous medium. Ali J. Chamkha [11] investigated MHD-free convection from a vertical plate embedded in a thermally stratified porous medium with Hall effects. Heat source effects on MHD flow past an exponentially accelerated vertical plate with variable temperature through a porous medium studied by V. Rajesh and S. V. K. Varma [12]. E. M. A. Elbashbeshy and M. A. Bazid [13] investigated the mixed convection along a vertical plate with variable surface heat flux embedded in porous medium. Several researchers have considered various stretching problems in micropolar fluids including the present authors (see Ishak et al. [14, 15], R. Nazar, et al. [16], R. Nazar, et al. [17], A.C. Eringen [18] and R.S. Agarwal et al. [19]). Many works have been reported on flow and heat transfer of electrically conducting fluids over a stretched surface in the presence of magnetic fluid (see for instance. V.M. Soundalgekar, et al. [20] initiated the Transient free convection flow of a viscous dissipative fluid past a semi-infinite vertical plate. M. Subhas Abel et al. [21] studied the boundary layer flow and heat transfer of a visco-elastic fluid immersed in a porous medium over a non-isothermal stretching sheet in the presence of temperature-dependent heat source). Mukhopadhyay et al. [22] studied the effects of variable viscosity on the boundary layer flow and heat transfer of the fluid flow through a porous medium towards a stretching sheet in the presence of heat generation or absorption. E. M. A. Elbashbeshy [23] investigated Heat Transfer over a Stretching Surface with Variable Surface Heat Flux. I. A. Hassanien et al. [24] studied the Flow and Heat Transfer in a Power -Law Fluid over a Nonisothermal Stretching Sheet. Motivated by the above-mentioned investigations and applications, in this present paper, we investigate the behavior of the boundary layer flow of an incompressible micropolar fluid over a stretching sheet in a porous medium with heat flux. The transformed governing partial differential equations in two variables are solved numerically using a finite-difference method and the Runge-Kutta method for some values of the physically governing parameters.

2. Mathematical Formulation

We consider unsteady two-dimensional flow of a laminar, viscous, electrically conducting, Incompressible micropolar fluid and heat-transfer over a stretching sheet in a porous medium. At time t=0, the sheet is impulsively stretched with velocity U_x (x, t) along the x-axis, keeping the origin fixed in the fluid of ambient temperature T_∞. The stationary Cartesian coordinate system has its origin located at the leading edge of the sheet with the positive x -axis extending along the sheet, while the y -axis is measured normal to the surface of the sheet. Under these assumptions, the equations that describe the physical situation are given by [5]:

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\left(\frac{\mu+k}{\rho}\right)\frac{\partial^2 u}{\partial y^2}+\frac{k}{\rho}\frac{\partial N}{\partial y}-\frac{\sigma B_0^2 u}{\rho}+\frac{\nu}{k_p}u \qquad (2)$$

$$\frac{\partial N}{\partial t}+u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}=\frac{\gamma}{\rho j}\frac{\partial^2 N}{\partial y^2}-\frac{k}{\rho j}\left(2N+\frac{\partial u}{\partial y}\right) \qquad (3)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2} \qquad (4)$$

Subject to the boundary conditions

$$\left.\begin{aligned} &u=U_w,\ v=0,\ N=-m\frac{\partial u}{\partial y},\quad \frac{\partial T}{\partial y}=-\frac{q_w}{k} \quad at \quad y=0 \\ &u\to 0,\quad N\to 0,\quad T\to T_\infty \qquad\qquad at \quad y\to\infty \end{aligned}\right\} \qquad (5)$$

Where m is the boundary parameter with $0 \le m \le 1$, u and v are the velocity components along the x - and y – axes, respectively, T is the fluid temperature in the boundary layer, N is the microrotation or angular velocity, j is the microinertia per unit mass, γ is the spin gradient viscosity, μ is the dynamic viscosity, κ is the vortex viscosity, ρ is the density of the fluid, α is the thermal diffusivity, ν is kinematic coefficient of viscosity, Kp is permeability of the medium, σ is the electrical conductivity of the fluid and B_0 is the applied magnetic field. It is assumed that the stretching velocity $U_w(x, t)$ and the surface heat flux $q_w(x, t)$ are of the form:

$$U_w(x,\ t)=\frac{ax}{1-ct},\quad q_w(x,\ t)=\frac{bx}{1-ct} \qquad (6)$$

Where a, b and c are constants with $a > 0$, $b > 0$ and $c \geq 0$(with $ct < 1$), and both a and c have dimension time $^{-1}$.It should be noticed that at $t = 0$ (initial motion), Eqs. (1) – (4) describes the steady flow over a stretching surface. This particular form of $U_w(x, t)$ and $q_w(x, t)$, has been chosen in order to be able to devise a new similarity transformation, which transforms the governing partial differential equations (1) – (4) into a set of ordinary differential equations, thereby facilitating the exploration of the effects of the controlling parameters. Relation (6) is invoked to allow the field of equations predicts the correct behavior in the limiting case when the microstructure effects become negligible and the total spin N reduces to the angular velocity.
The momentum, angular momentum and energy equations can be transformed into the corresponding ordinary differential equations by the following transformation:

$$\left.\begin{aligned} &\eta=\left(\frac{U_W}{\nu x}\right)^{1/2} y, && \theta(\eta)=\frac{k\left(T-T_\infty\right)}{q_w}\left(\frac{U_W}{\nu x}\right)^{1/2}, \\ &\psi=\left(\nu x U_w\right)^{1/2} f(\eta), && N=U_W\left(\frac{U_W}{\nu x}\right)^{1/2} h(\eta) \end{aligned}\right\} \rightarrow (7)$$

Where ψ is the stream function defined in the usual way as $u = \partial\psi / \partial y$ and $v = -\partial\psi / \partial x$, and identically satisfy (1) and η is the similarity variable. Substituting variables (7) into (2) - (4) gives:

$$(1+\Delta)F'''+F''F-F'^2+\Delta h'-(S+M+k_1)F'-\frac{1}{2}S\,\eta F''=0 \quad \rightarrow (8)$$

$$\left(1+\frac{1}{2}\Delta\right)h''+Fh'-F'h-\Delta(2h+F'')-\frac{S}{2}(3h+\eta h')=0 \quad \rightarrow (9)$$

$$\frac{1}{\Pr}\theta''+F\theta'-F'\theta-S\left(\theta+\frac{1}{2}\eta\theta'\right)=0 \quad \rightarrow (10)$$

Where $\Delta = \kappa/\mu$is the dimensionless viscosity ratio and is called the material parameter. Here γ and j are assumed to be given by $\gamma = (\mu+\kappa/2)j = \mu(1+\Delta/2)j$ and $j = v/c$, respectively. The boundary conditions (5) now become:

$$\left.\begin{aligned} &F(0)=0,\ F'(0)=1, && h(0)=-mF''(0), \theta'(0)=-1 \\ &F'(\infty)=0, && h(\infty)=0, \qquad \theta(\infty)=0 \end{aligned}\right\} \quad (11)$$

Where $Pr = \nu/\alpha$ is the Prandtl number, M is the magnetic parameter, k_1 is the permeability parameter and $S=c/a$ is the unsteadiness parameter. Thus, our task is to investigate how the governing parameters S, m, Δ, k_1, M and Pr influence these quantities.

3. Numerical Methods for Solution

3.1, Runge-Kutta Method

The transformed equations (8) - (10) subject to the boundary conditions (11) form a nonlinear two-point boundary value problem, which has been solved numerically using the Runge-Kutta integration scheme with a modified version of the Newton-Raphson shooting method. First of all, the higher order non-linear differential equations (8) - (10) are converted into simultaneous linear differential equation of first order and they are further transformed into initial value problem by applying the shooting technique. The resultant initial value problem is solved by employing Runge-Kutta fourth order method. The step size $\Delta\eta = 0.001$ is used to obtain the numerical solution with six decimal accuracy as criterion of convergence. The above mentioned third order and second order equations are written in terms of first order equations as follows:

$$F' = z, z' = p$$
$$p' = \left[\left(\frac{1}{2}s\eta - F\right)p + z^2 + (s + M + k_1)z - \Delta q\right] / (1+\Delta) \quad (12)$$
$$h' = q$$
$$q' = \frac{h(2z + 4\Delta + 3s) + q(\eta s - 2F) + 2\Delta P}{(2+\Delta)} \quad (13)$$
$$\theta' = L$$
$$L' = \Pr\left[L\left(\frac{s\eta}{2} - F\right) + \theta(z + s)\right] \quad (14)$$

With boundary conditions

$$F(0) = 0, F''(0) = 1, h(0) = 1, \theta(0) = 1 \quad (15)$$

In order to integrate equations (12)-(14) as initial value problem we require a value for $p(0)$ i.e. $F''(0)$ and $q(0)$ i.e. $h'(0)$ but no such values are given in the boundary. The suitable guess values for $F''(0)$ and $h'(0)$ are chosen and then integration is carried out. We take the series of values for $F''(0)$, $h'(0)$ and apply the fourth order Runge-Kutta method with different step-sizes
($\eta = 0.01, 0.001, etc.$) so that the numerical results obtained are independent of $\Delta\eta$. The above procedure is repeated until we get the results up to the desired degree of accuracy 10^{-6}.

3.2. The Finite Difference Method

The transformed equations (8) - (10) subject to the boundary conditions (11) form a nonlinear two-point boundary value problem, which has been solved numerically using the Finite Difference method. First of all, we start with introducing new independent variables $u(x,\eta), v(x,\eta), t(x,\eta), h(x,\eta), h = s(x,\eta), \theta = l(x,\eta)$, with $f' = u, u' = v, s' = t, \theta' = q$

So that equations (8)- (10) becomes:

$$(1+\Delta)v' + \left(f - \frac{1}{2}s\eta\right)v - (s + M + k_1)u - u^2 + \Delta t = 0 \quad (16)$$
$$\left(1 + \frac{1}{2}\Delta\right)t' + \left(f - \frac{1}{2}s\eta\right)t - \left(u + 2\Delta + \frac{3}{2}s\right)h - \Delta v = 0 \quad (17)$$
$$\frac{1}{\Pr}q' + \left(f - \frac{1}{2}s\eta\right)q - (u + s)\theta = 0 \quad (18)$$

We now consider the net rectangle in the $x - \eta$ plane and the net points defined as below:

$$x^0 = 0, x^n = x^{n-1} + k_n, \qquad n = 1, 2, \dots\dots, j$$
$$n_0 = 0, n_j = n_{j-1} + h_j, \qquad j = 1, 2, \dots\dots\dots, \text{j} \quad n_j = n_\infty \quad (19)$$

Where k_n is the $\Delta x -$spacing and h_j is the $\Delta\eta -$spacing. Here n and j are just sequences of numbers that indicate the coordinate location.

The derivatives in the x-direction are replaced by finite difference, for example the finite difference form any points are:

(a) $$(\ )_j^{n-\frac{1}{2}} = \frac{1}{2}\left[(\ )_j^n + (\ )_j^{n-1}\right], (\ )_{j-\frac{1}{2}}^n = \frac{1}{2}\left[(\ )_j^n + (\ )_{j-1}^n\right],$$

(b) $$\left(\frac{\partial u}{\partial x}\right)_{j-\frac{1}{2}}^{n-\frac{1}{2}} = \frac{(u)_{j-\frac{1}{2}}^n - (u)_{j-\frac{1}{2}}^{n-1}}{k_n}, \left(\frac{\partial u}{\partial \eta}\right)_{j-\frac{1}{2}}^{n-\frac{1}{2}} = \frac{(u)_j^{n-\frac{1}{2}} - (u)_{j-1}^{n-\frac{1}{2}}}{h_j}$$

We start writing the finite-difference form of equation for the midpoint $\left(x^n, n_{j-\frac{1}{2}}\right)$ using centered difference derivatives. This process is called centering about " $\left(x^n, n_{j-\frac{1}{2}}\right)$ ".

$$\left.\begin{aligned}
&f_j - f_{j-1} - \frac{h_j}{2}\left(u_j + u_{j-1}\right) = 0\\
&u_j - u_{j-1} - \frac{h_j}{2}\left(v_j + v_{j-1}\right) = 0\\
&s_j - s_{j-1} - \frac{h_j}{2}\left(t_j + t_{j-1}\right) = 0\\
&v_j - v_{j-1} + \frac{h_j}{4}\left(f_j + f_{j-1}\right)\left(v_j + v_{j-1}\right) - \frac{h_j}{4}\left(u_j + u_{j-1}\right)^2 = \left(R_1\right)_{j-\frac{1}{2}}\\
&ft_j - t_{j-1} + \frac{h_j}{4}\left(f_j + f_{j-1}\right)\left(t_j + t_{j-1}\right) = \left(R_2\right)_{j-\frac{1}{2}}
\end{aligned}\right\}(20)$$

We note that $\left(R_1\right)_{j-\frac{1}{2}}$ and $\left(R_2\right)_{j-\frac{1}{2}}$ involve only known quantities if we assume that the solution is known on $x = x^{n-1}$. In terms of the new dependent variables, the boundary conditions become:

$$\left.\begin{aligned}
&f\left(x,0\right) = 0, u\left(x,0\right) = 1, t\left(x,0\right) = -\gamma\left[1 + s\left(0\right)\right]\\
&u\left(x,\infty\right) = 0, s\left(x,\infty\right) = o
\end{aligned}\right\}(21)$$

4. Results and Discussion

The transformed Eqs.(8) - (10) subject to the boundary conditions (11) for prescribed surface heat flux are approximated by a system of ordinary differential equation replacing the derivatives with respect to η. which are solved numerically using a finite-difference method and the Runge-Kutta integration scheme with a modified version of the Newton-Raphson shooting method and in this paper two numerical methods give us the same results for the problem (optimize the solution). The resulting solutions for velocity, microrotation and temperature functions are shown graphically in the figures (1-16).The results are obtained for various values of the magnetic parameter M, Prandtl number Pr, permeability parameter k_1, unsteadiness parameter S**,** micropolar parameter Δ and Boundary parameter m. It is observed that these parameters affect the velocity, temperature and microrotation. Figs. (1-3) present the behavior of the velocity, temperature and microrotation for various values of the permeability parameter k_1. We observe that the velocity is increase with decreasing the permeability parameter $k_1$but the temperature and microrotation are increases with increasing the permeability parameter k_1**.**

Figs.(4-6) present the behavior of the velocity, temperature and microrotation for various values of the magnetic parameter M .The presence of magnetic field in an electrically conducting fluid tends to produce a body force against the flow. This type of resistive force tend to slow down the motion of the fluid in the boundary layer which in turn, reduce the rate of heat convection in the flow and this appears in increasing the flow temperature as the magnetic parameter M increases, also the microrotation increases as the magnetic parameter M increases and the velocity decreases while increasing the values of the magnetic parameter M.

Figs.(7-9) depict the influence of the material parameter Δ on the velocity, temperature and microrotation profiles in the boundary layer, respectively. We may conclude that the velocity is increase with increasing the values of the material parameter Δ,temperature and microrotation are increases with decreasing the values of the material parameter Δ.

Also, Figs.(10-12),describe the behavior of the velocity, temperature and microrotation with changes in the values of the boundary parameter m, the velocity is increase as decreasing the values of the boundary parameter m, but the temperature and microrotation are increases with decreasing the values of the boundary parameter m.

From Figs. (13-14), the velocity, and microrotation are no influence of the Prandtl number *Pr* and from fig.(15) we found that the temperature increase with decreasing the values of Prandtl number *Pr*.

The Figs. (17- 22) shown that the velocity, temperature and microrotation are increases with decreasing the values of unsteadiness parameter *S*.

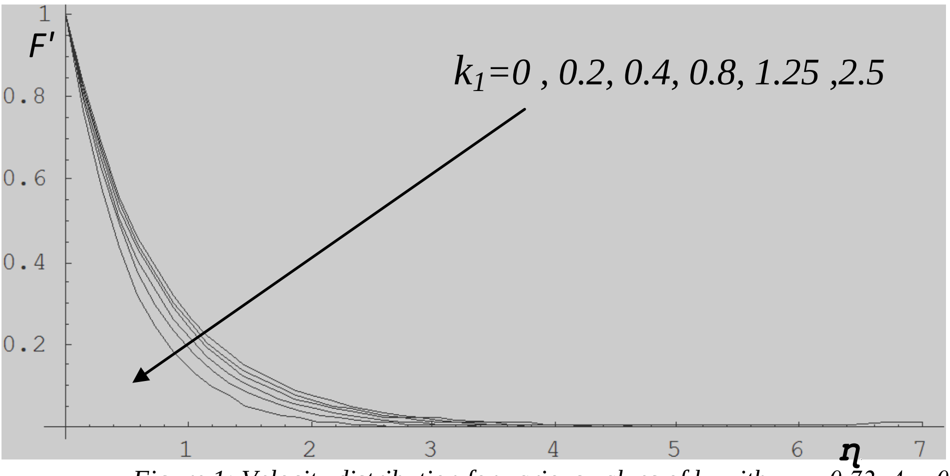

Figure 1: Velocity distribution for various values of k_1 with pr = 0.72, Δ = 0.5, S = 0.3, m = 0.5 and M = 1.

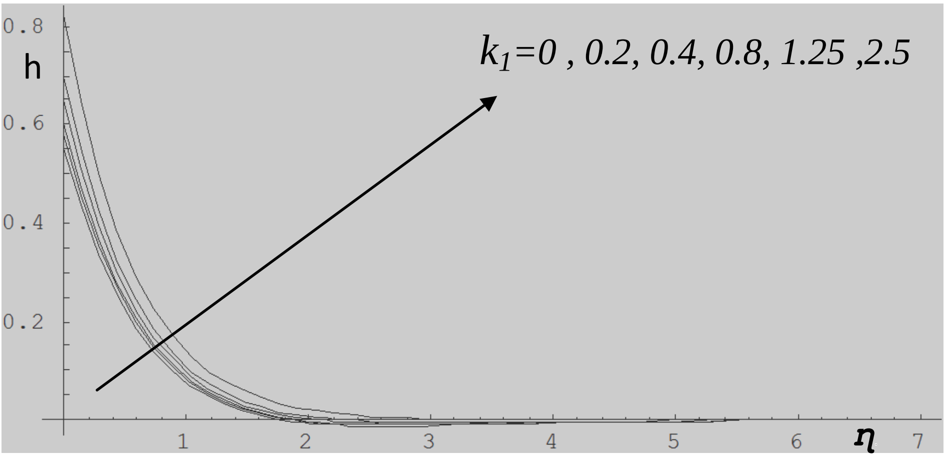

Figure 2: Microrotation distribution for various values of k_1 with pr = 0.72, Δ = 0.5, S = 0.3, m = 0.5 and M = 1.

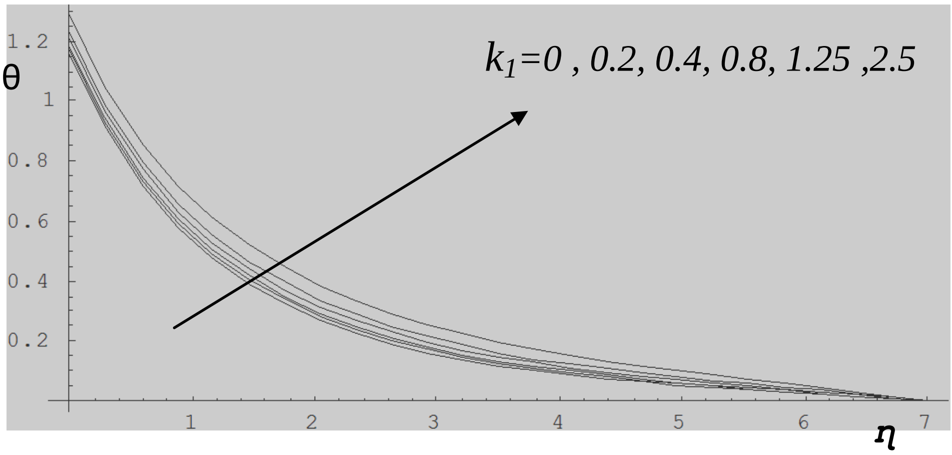

Figure 3: Temperature distribution for various values of k_1 with pr = 0.72, Δ = 0.5, S = 0.3, m = 0.5 and M = 1.

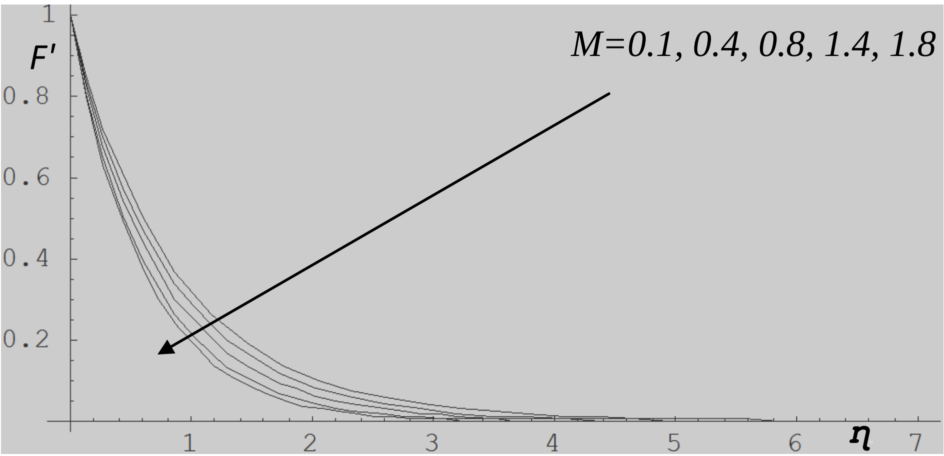

Figure 4: Velocity distribution for various values of M with $pr = 0.72$, $\Delta = 0.5$, $S = 0.3$, $m = 0.5$ and $A = 0.4$.

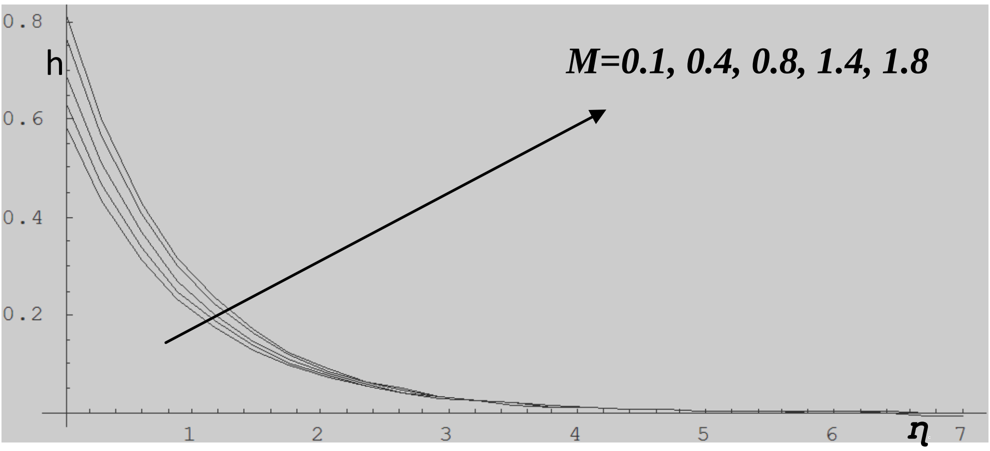

Figure 5: Microrotation distribution for various values of M with $pr = 0.72$, $\Delta = 0.5$, $S= 0.3$, $m = 0.5$ and $A = 0.4$.

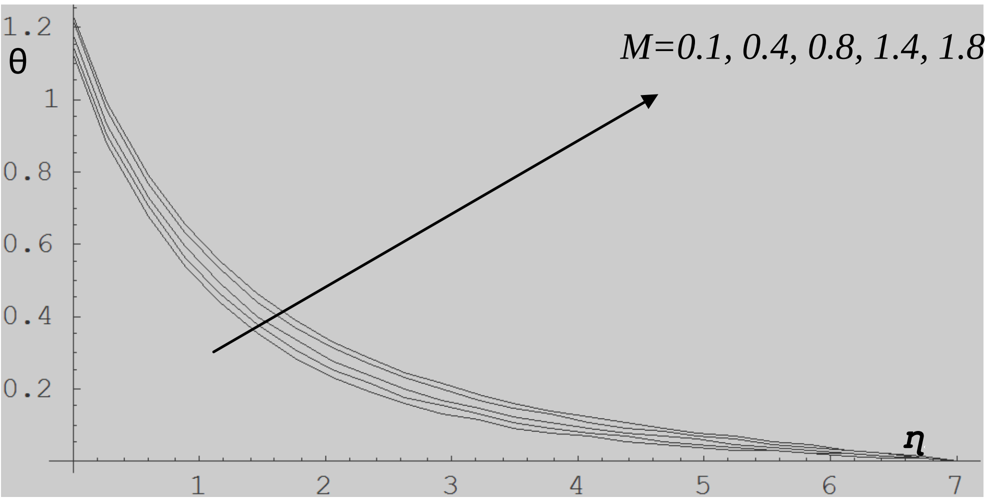

Figure 6: Temperature distribution for various values of M with $pr = 0.72$, $\Delta = 0.5$, $S = 0.3$, $m = 0.5$ and $A = 0.4$.

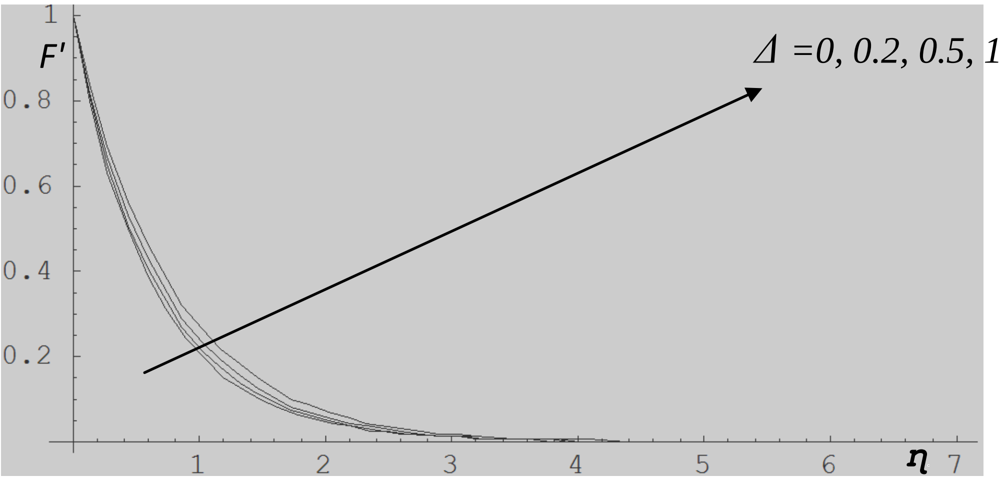

Figure 7: Velocity distribution for various values of Δ with pr = 0.72, S = 0.3, m = 0.5, M = 1 and A = 0.4

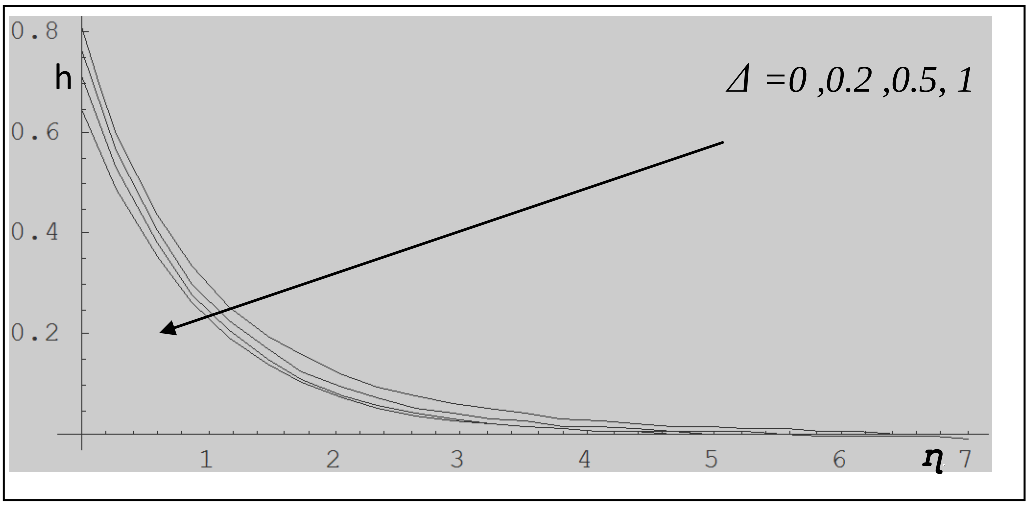

Figure 8: Microrotation distribution for various values of Δ with pr = 0.72, S = 0.3, m = 0.5, M = 1 and A = 0.4.

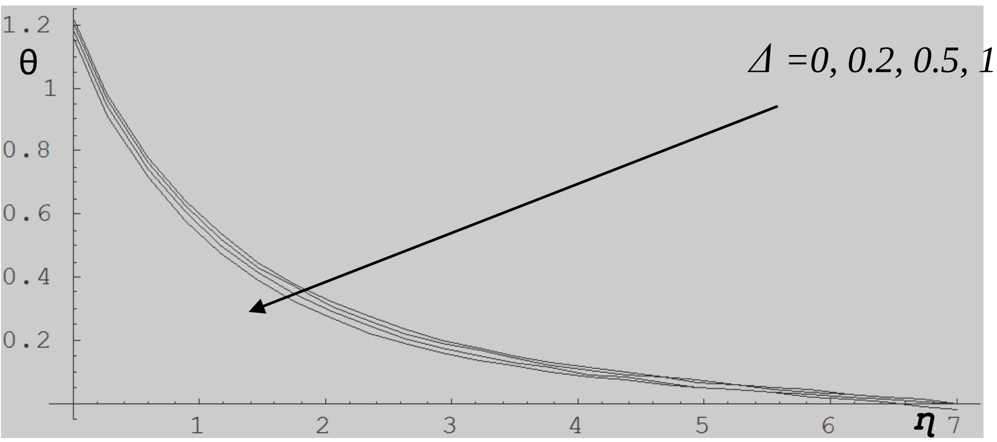

Figure 9: Temperature distribution for various values of Δ with pr = 0.72, S = 0.3, m = 0.5, M = 1 and A = 0.4.

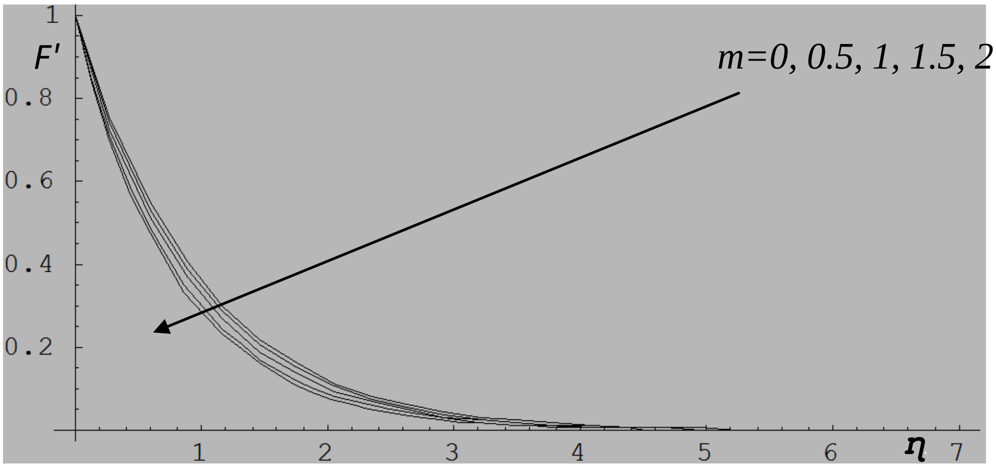

Figure 10: Velocity distribution for various values of m with pr = 0.72, Δ = 0.5, S = 0.3, M = 1and A = 0.4.

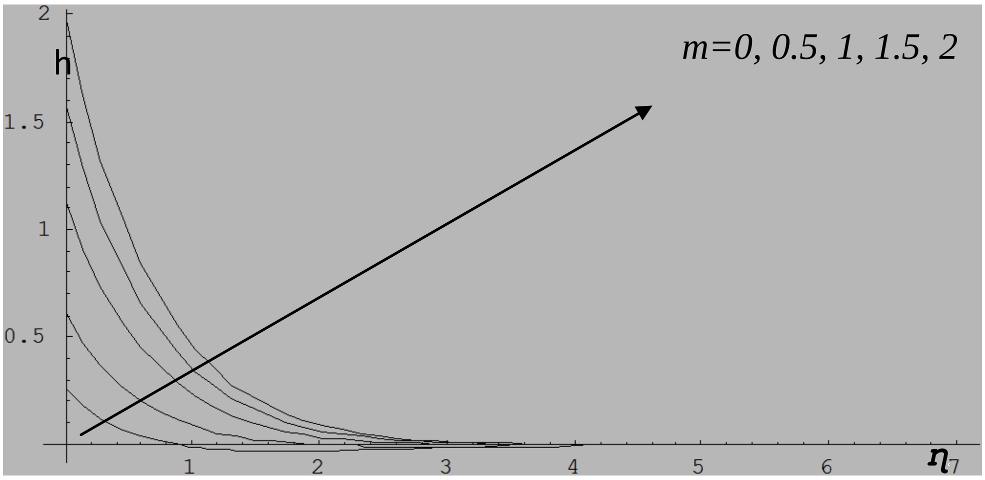

Figure 11: Microrotation distribution for various values of m with pr = 0.72, Δ = 0.5, S = 0.3, M = 1and A = 0.4.

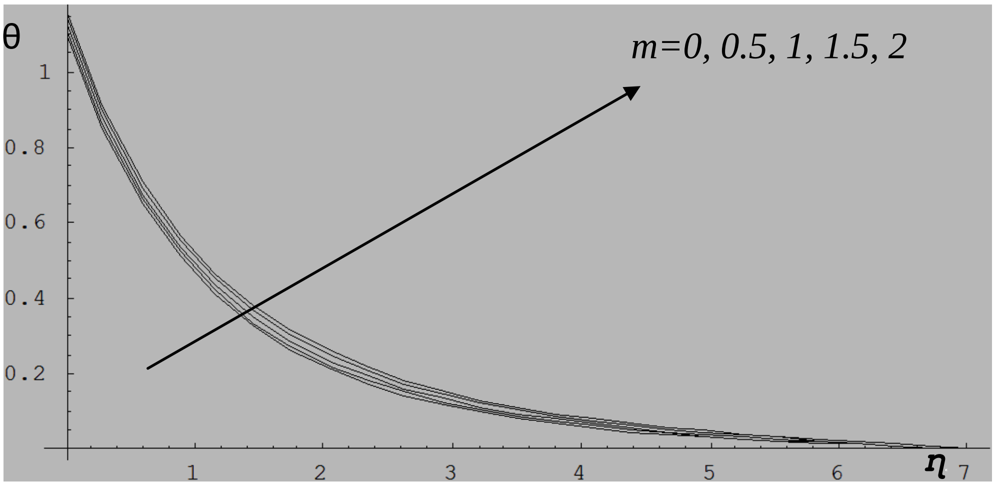

Figure 12: Temperature distribution for various values of m with pr = 0.72, Δ = 0.5, S = 0.3, M = 1and A = 0.4.

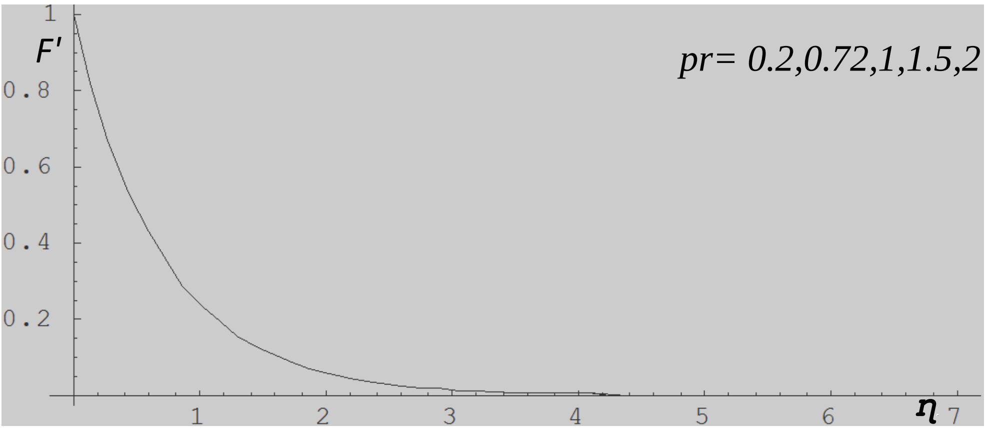

Figure 13: Velocity distribution for various values of Pr with $\Delta = 0.5$, $S = 0.3$, $m = 0.5$, $M = 1$ and $A = 0.4$.

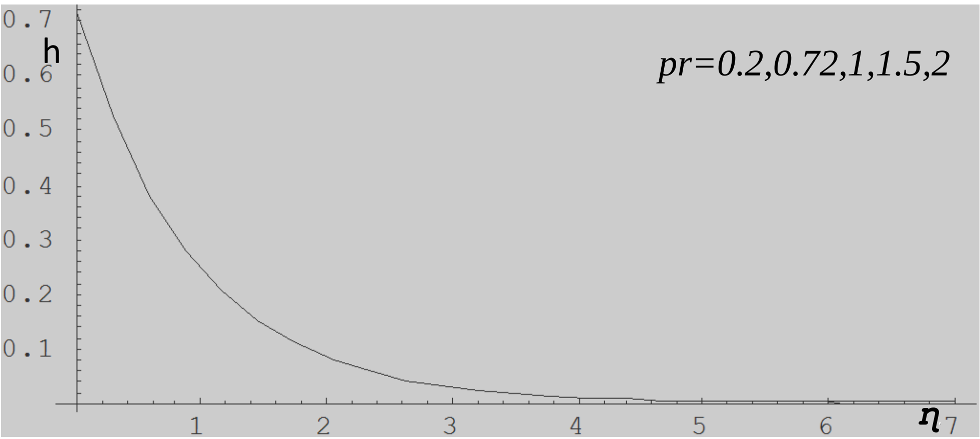

Figure 14: Microrotation distribution for various values of Pr with $\Delta = 0.5$, $S = 0.3$, $m = 0.5$, $M = 1$ and $A = 0.4$.

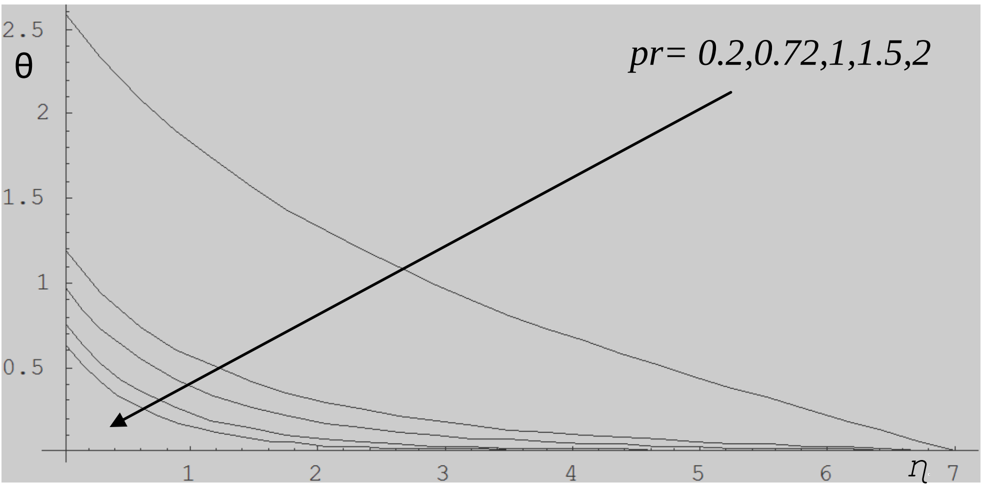

Figure 15: Temperature distribution for various values of Pr with $\Delta = 0.5$, $S = 0.3$, $m = 0.5$, $M = 1$ and $A = 0.4$

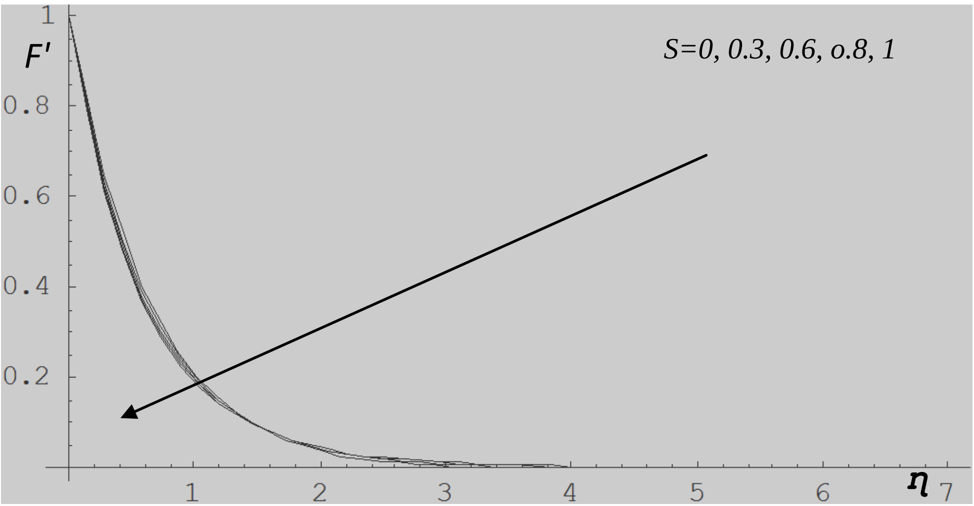

Figure 16: Velocity distribution for various values of S with pr = 0.2, Δ = 0.2, m = 1, M = 1 and A = 0.4.

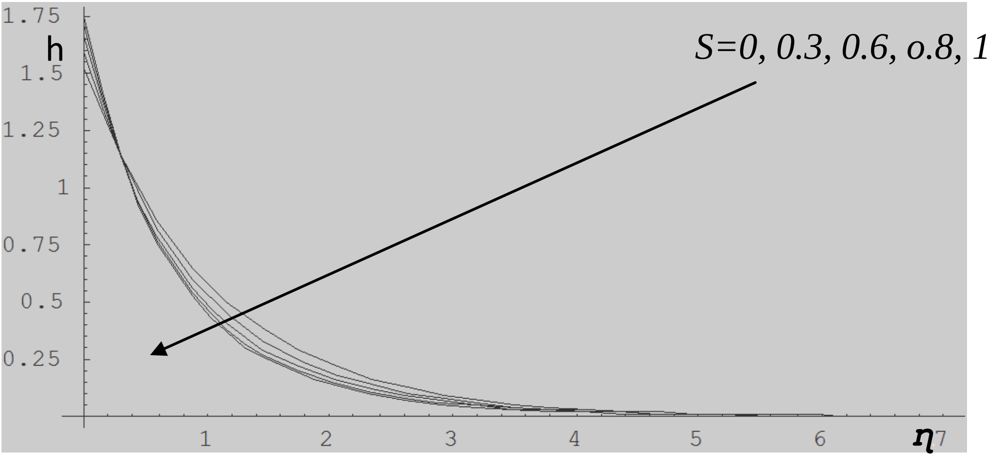

Figure 17: Microrotation distribution for various values of S with pr = 0.2, Δ = 0.2, m = 1, M = 1 and A = 0.4.

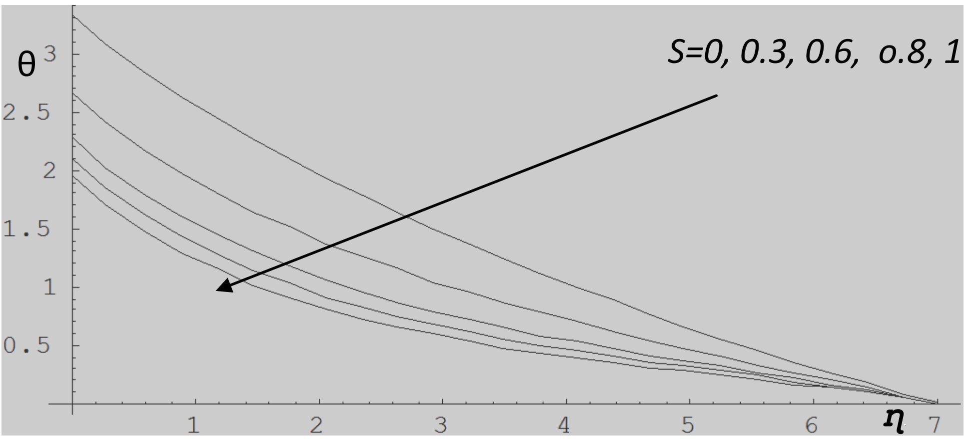

Figure 18: Temperature distribution for various values of S with pr = 0.2, Δ = 0.2, m = 1, M = 1and A = 0.4.

5. Conclusion

In this paper, we presented optimization for effect of the unsteady laminar on MHD flow of an incompressible, viscous, electrically conducting, micropolar fluid over a stretching sheet in a porous medium with prescribed surface heat flux by two numerical methods. The governing equations for the flow are obtained by using suitable transformations and solved numerically. Numerical results for the velocity, temperature and mirorotation profiles are presented graphically for various parametric conditions.

From all the above investigations we find that the velocity is increase as increasing the values of the Material parameter *Δ*, but the velocity is decreasing as the values of the Permeability parameter *k1*, Magnetic parameter *M*, Boundary parameter *m* and unsteadiness parameter *S* are increases.

The mirorotation is increasing with the Permeability parameter *K1*, Magnetic parameter *M* and Boundary parameter *m* are increases. Also the mirorotation is increasing as the unsteadiness parameter *S* and Material parameter *Δ* are decreases.

Finally the temperature is increasing as the Permeability parameter K_1, Magnetic parameter *M* and Boundary parameter *m* are increases, and the temperature is increasing as the Material parameter *Δ*, Prandtl number *pr* and unsteadiness parameter *S* are decreases. The use of the magnetic field in micropolar fluids could serve as an effective drag reducing mechanism.

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