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Variable Viscosity Effect on Heat Transfer over a Continuous Moving Surface with Variable Internal Heat Generation in Micropolar Fluids

M. Modather M. Abdou and E. Roshdy EL-Zahar

Department of Mathematics
College of Science and Humanity Studies
Salman Bin AbdulAziz University
Al-Kharj, Saudi Arabia
m_modather@yahoo.com

Abstract

The effect of temperature-dependent viscosity on heat transfer over a continuous moving surface with variable internal heat generation in micropolar fluids is studied. The fluid viscosity is assumed to vary as inverse linear function of temperature. The governing equations are transformed into dimensionless forms using the stream function and suitable variables then solved numerically using the Runge-Kutta numerical integration, procedure in conjunction with shooting technique.

A parametric study illustrating the influence of the viscosity parameter, heat source generation and micropolar parameter on the velocity, microrotation and temperature profiles skin friction, couple stress as well as the Nusselt are investigated. The results of the parametric study are shown in graphic and tabulated.

Keywords: micropolar fluids, internal heat generation, heat transfer, temperature dependent viscosity

Nomenclature

A	Dimensionless parameter measure of the unsteadiness
B	Dimensionless parameter
C_f	Local skin friction
c_P	Specific heat
f	Dimensionless velocity
g	Dimensionless microrotation
h	Local heat transfer coefficient
j	Microinertia per unit mass
K	Vortex viscosity
k	Thermal conductivity of fluid
m_w	Local wall couple stress
N	Angular velocity
Nu	Local Nusselt number, =hx/k
Pr	Prandtl number
q_w	Wall heat flux
Q	Volumetric rate of heat generation
Re	Local Reynolds number
T	Temperature
T_∞	Ambient temperature
T_w	Wall temperature
u	Velocity component in x –direction
x	Horizontal co-ordinate
y	Vertical co-ordinate

Greek symbols

β	Thermal expansion coefficient
χ	Spin-gradient viscosity
η	Dimensionless co-ordinate
λ	Heat source or sink parameter
μ	Absolute viscosity
μ_∞	Dynamic viscosity of the ambient fluid
υ	Kinematic viscosity
θ_r	Viscosity variation parameter
θ	Dimensionless temperature
ψ	Stream function
ρ_∞	Density of the fluid

Subscripts

w	at the wall
∞	condition far away from the surface

Superscript

'	Differentiation with respect to η;

1- Introduction

Most studies of the problems of heat transfer are based on the constant physical properties of the ambient fluid. However, it is known that these properties may change with temperature, especially for fluid viscosity. To accurately predict the flow and heat transfer rates, it is necessary to take account of this variation of viscosity.

The flow over a stretching surface is an important problem in many engineering processes with applications in industries such as extrusion, melt-spinning, the hot rolling, wire drawing, glass fiber production, manufacture of plastic and rubber sheets, cooling of a large metallic plate in a bath, which may be an electrolyte, etc. In industry, polymer sheets and filaments are manufactured by continuous extrusion of the polymer from a die to a windup roller, which is located at a finite distance away.

Crane [1] and Gupta and Gupta [2] have analyzed the stretching problem with constant surface temperature, while Soundalgekar and Ramana [3] investigated heat transfer past a continuous moving plate with variable temperature. Grubka and Bobba [4] have analyzed the stretching problem for a surface moving with a linear velocity and with variable surface temperature. Ali [5] has reported flow and heat characteristics on a stretched surface subject to power-law velocity and temperature distributions. The flow field of a stretching wall with a power-law velocity variation was discussed by Banks [6]. Heat transfer over a stretching surface with internal heat generation or absorption is examined by Elbashbeshy and Bazid [7].

In all of the above mentioned studies the viscosity of the fluid was assumed to be constant. However it is known that this physical property may change significantly with temperature. To accurately predict the flow behavior, it is necessary to take into account this variation of viscosity. Elbashbeshy and Bazid [8] studied the effect of temperature-dependent viscosity on heat transfer over a continuous moving surface. The same authors [9] studied the influence of a variable viscosity on the heat transfer over a stretching surface with internal heat generation. EL-Kabeir and Gorla [10] studied the heat transfer with temperature dependent viscosity in a viscous fluid over stretching sheet in the presence of viscous dissipation and internal heat generation. El-Hakiem [11] has studied the effects transverse flows with variable viscosity in micropolar fluid. Mohammadein et al. [12] have studied variable viscosity effects on natural convection in a micropolar fluid at an axisymmetric stagnation point. Modather and El-Hakiem [13] examined the influence of variable viscosity and a transverse magnetic field on natural convection in micropolar fluids. Modather and EL-Kabeir [14] study the effect of nonlinear MHD flow with heat and mass transfer characteristics of an incompressible, viscous, electrically conducting and Boussinesq fluid on with chemical reaction and heat generation. Modather et al. [15] investigated the effects of temperature-dependent viscosity and thermal conductivity on an unsteady two-dimensional laminar flow of a micropolar fluid from a non-isothermal stretching sheet.

In the present work we study the effect of temperature-dependent viscosity on heat transfer over a continuous moving surface with variable internal heat generation in micropolar fluids. The fluid viscosity is assumed to vary as inverse linear function of temperature. The governing equations are transformed into dimensionless forms using the stream function and suitable variables then solved numerically using the Runge-Kutta numerical integration, procedure in conjunction with shooting technique. Numerical result are presented in terms of local skin friction coefficient, rate of heat transfer and wall couple stress for various values of heat source generation λ, variable viscosity θ_r parameters against micropolar parameter Δ. The effect of variation in λ, θ_r and Δ on the dimensionless velocity, temperature and microrotation distribution are also depicted graphically.

2- Mathematical Formulation

Consider a steady, two-dimensional laminar flow of a viscous incompressible micropolar fluid on a continuous, stretching surface with uniform surface temperature T_w and velocity U_w moving axially through a stationary fluid. The x-axis runs along the continuous surface in the direction of the motion and y-axis is perpendicular to it.

According to the assumption, the two-dimensional boundary layer equations for the flow of the fluid over a continuous moving surface are as flows:

Mass:

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

Momentum:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{\rho_\infty}\frac{\partial}{\partial y}\left[(\mu+K)\frac{\partial u}{\partial y}\right]+\frac{K}{\rho}\frac{\partial N}{\partial y} \tag{2}$$

Angular momentum:

$$u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}=\frac{\chi}{\rho_\infty j}\frac{\partial^2 N}{\partial y^2}-\frac{K}{\rho j}\left[2N+\frac{\partial u}{\partial y}\right]. \tag{3}$$

Energy:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho_\infty c_p}\frac{\partial^2 T}{\partial y^2}+Q(T-T_\infty). \tag{4}$$

In the above equations u and v are the components of fluid velocity in the x and y directions respectively, ρ_∞ is the density away from the hot plate, N is the component of microrotation, T is the fluid temperature in the boundary layer region. μ and k are respectively the dynamic viscosity and the thermal conductivity, c_p is the specific heat at constant pressure, T_∞ is the free stream temperature and Q is the volumetric rate of heat generation.
With the associated boundary conditions:

$$y = 0: \quad u = U_w, \quad v = 0, \quad T = T_w, \quad N = -\frac{1}{2}\frac{\partial u}{\partial y},$$
$$y \to \infty: \quad u = 0, \quad T = T_\infty, \quad N = 0. \tag{5}$$

The case $N = -\frac{1}{2}\frac{\partial u}{\partial y}$ results in the vanishing of the anti-symmetric part of the stress tensor and represents weak concentrations [16]. Ahmadi suggested that the particle spin is equal to the fluid vorticity at the boundary for fine particle suspensions.
For a viscous fluid, Ling and Dybbs [17] suggest a viscosity dependence on temperature T of the form following are given as below:

$$\frac{1}{\mu} = \frac{\mu_\infty}{\left[1 + \gamma(T - T_\infty)\right]} \tag{6}$$

So that viscosity is an inverse linear function of temperature T.
Equation (6) can be written as:

$$\frac{1}{\mu} = \alpha\left(T - T_r\right) \tag{7}$$

Where $\alpha = \gamma / \mu_\infty$ and $T_r = T_\infty - 1/\gamma$ (8)
In the above relations (8), both α and T_r are constant and their values depend on the reference state and γ thermal property of the fluid.
The equation of continuity is satisfied if we choose a stream function $\psi(x,y)$ such that

$$u = \frac{\partial \psi}{\partial y}, \qquad v = -\frac{\partial \psi}{\partial x}$$

We introduce the following dimensionless coordinates:

$$\psi(x, y) = \sqrt{2\upsilon_\infty U_w x}\, f(\eta), \quad \eta = y\sqrt{\frac{U_w}{2\upsilon_\infty x}}, \quad \upsilon_\infty = \frac{\mu_\infty}{\rho_\infty},$$

$$N(x,y)=U_w\sqrt{\frac{U_w}{2\upsilon_\infty x}}\,g(\eta),\quad \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}\ \text{ or }\ \theta(\eta)=\frac{T-T_r}{T_w-T_\infty}+\theta_r. \tag{9}$$

Where $\theta_r=\dfrac{T_r-T_\infty}{T_w-T_\infty}=-\dfrac{1}{\gamma(T_w-T_\infty)}=\text{constant}$

And its value is determined by the viscosity/temperature characteristics of the fluid and the operating temperature difference $\Delta T=T_w-T_\infty$.

Substituting equation (9) into equations (2), (3), (4) and (5), the governing equations become:

$$\left[1+\frac{\Delta(\theta_r-\theta)}{\theta_r}\right]f'''+\frac{(\theta_r-\theta)}{\theta_r}ff''+\frac{\theta'}{(\theta_r-\theta)}f''+\frac{\Delta(\theta_r-\theta)}{\theta_r}g'=0, \tag{10}$$

$$\left(1+\frac{\Delta}{2}\right)g''-\Delta.B\left(f''+2g\right)+fg'+gf'=0, \tag{11}$$

$$\theta''+\Pr\left(f\,\theta'+\lambda\theta\right)=0. \tag{12}$$

The corresponding boundary conditions transform to:

$$f(0)=0,\quad f'(0)=1,\quad g(0)=-\frac{1}{2}f''(0),\quad \theta(0)=1,$$

$$f'(\infty)=0,\quad g(\infty)=\theta(\infty)=0. \tag{13}$$

Where $\Delta=\dfrac{K}{\rho_\infty\upsilon_\infty}$, $B=\dfrac{2\upsilon_\infty x}{jU_w}$, $\Pr=\dfrac{\rho_\infty\upsilon_\infty c_p}{k}$, $\lambda=\dfrac{2Qx}{U_w}$. (14)

Where B is dimensionless parameter, Δ is a micropolar parameter, λ is the heat source or sink parameters, *Pr* is the Prandtl number and the primes denote differentiation with respect to η.

The quantities of physical interested, namely, the local skin friction C_f ,the wall couple stress, m_w and the rate of heat transfer in terms of local Nusselt number Nu_x are prescribed by:

$$C_f=\frac{2\tau_w}{\rho_\infty U_w^2} \tag{15}$$

$$m_w=\gamma\frac{U_w^2}{2\upsilon_\infty x}g'(0) \tag{16}$$

$$Nu=\frac{q_w x}{k(T_w-T_\infty)} \tag{17}$$

where τ_w is the skin friction and q_w is the heat transfer from the sheet are given by:

$$\tau_w=\left[(\mu+K)\frac{\partial u}{\partial y}+KN\right]_{y=0}=\rho_\infty\mu_\infty\left(\frac{\Delta}{2}+\frac{\theta_r}{\theta_r-1}\right)f''(0)$$

$$q_w=-k\left(\frac{\partial T}{\partial y}\right)_{y=0}.$$

$$C_f \operatorname{Re}^{\frac{1}{2}} = \sqrt{2}\left(\frac{\Delta}{2} + \frac{\theta_r}{\theta_r - 1}\right) f''(0)$$

$$Nu / \operatorname{Re}^{1/2} = -\theta'(0).$$

3-Results and Discussion

Equations (10-12) with the boundary conditions (13) are solved numerically, employing the sixth order implicit Rung-Kutta-Butcher initial value problem solver along with Nachtsheim-Swigert iteration technique. Here, solutions are obtained, up to the third level of truncation.

Calculations were carried out for the value of Prandtl number $\Pr = 0.78,\ 7.0$, the viscosity variation parameter θ_r ranged from -8.0 to 8.0, the heat source or sink parameter λ ranged from 0.0 to 0.6 and the micropolar parameter $\Delta = 0.0, 1.0, 2.0, 3.0, 5.0$ are summarized with $B = 0.5$.

Tables (1-6) displays the results for the values of the skin friction factor, Nusselt number and the wall couple stress respectively to show the effect temperature dependent viscosity and internal heat generation in the flow of micropolar fluids over continuous moving surface. We compared these results that we have obtained with the results in Elbashbeshy and Bazid [9] and it is found that they are in good agreement.

In the case $T_w - T_\infty$ is positive, θ_r is negative for liquid and positive for gases since c has the positive sign in each of these cases. Indeed the variable viscosity μ can be rewritten in the form:

$$\mu = \frac{\mu_\infty}{1 - \theta\theta_r^{-1}}$$

Since θ varies from zero at the edge of the boundary layer to one at the surface, the largest change in the fluid viscosity from its free-stream value μ_∞, occurs at the wall, where

$$\mu = \frac{\mu_\infty}{1 - \theta_r^{-1}}$$

Then cannot take values between zero and one and that the constraints, $\theta_r > 1$ for gases and $\theta_r < 0$, for liquids.

These tables indicate that as heat source or sink parameter λ increases leads to a significant change in Nusselt number but slight change in the value of skin friction factor and wall couple stress. We also notice from these tables that the viscosity variation parameter θ_r has a significant effect on skin friction factor, local Nusselt number and wall couple stress. In cases gases (Pr=0.78) and liquids (Pr=7.0), as the viscosity variation and heat source or sink parameters increase, the thermal boundary layer thickness decreases and thus the rate of the heat transfer increases. The viscosity variation parameter also has a noticeable effect on the local skin friction coefficient and wall couple stress, increasing the viscosity within the boundary layer leads to decreasing in the velocity within the layer and thus decrease the local skin friction coefficient and wall couple stress decreases for both gases (Pr=0.78) and liquids (Pr=7.0). The results indicate also, as the micropolar parameter Δ increases both Nusselt number and local skin friction coefficient increase while the value of wall couple stress decrease for gases and increases for liquids.

The effect of heat source or sink parameter, λ=0.0,0.2,0.4,0.6. on velocity, temperature and microrotation fields against η at θ_r =2.0, -2.0 for the fluid with Pr=0.78, 7.0 and Δ=3.0 is shown in figures (1-6), it can be seen that, for gases, the velocity, temperature and microrotation distributions increase with λ while for liquids, the temperature increases, whereas the velocity and microrotation decrease slightly as λ increases.

The effect of changes in the viscosity parameter, θ_r =-8.0,-6.0-4.0, -2.0,2.0.4.0,6.0,8.0 on velocity, temperature and microrotation fields g against η at λ =0.2 for the fluid with Pr=0.78, 7.0 and Δ=2.0 is shown in figures (7-12). It can be seen that in case of liquids, the velocity and microrotation increase slightly whereas the temperature decreases slightly as θ_r decreases, while for gases velocity and microrotation decrease whereas the temperature increases as θ_r increases.

The effect of micropolar parameter, Δ=0.0,1.0,2.0,3.0,5.0 on velocity, temperature microrotation fields against η at θ_r =6.0, -6.0 for the fluid with Pr=0.78, 7.0 and λ=0.3 is shown in figures (13-18), it can be seen that, for gases, the velocity and temperature distributions of the fluid increase as micropolar parameter Δ increases while the microrotation distribution decreases. On the other hand for liquids the velocity increases as micropolar parameter increases whereas the temperature and microrotation decrease.

4- Concluding Remarks

In the present work we introduced theoretically study the effect of temperature-dependent viscosity on heat transfer over a continuous moving surface with variable internal heat generation in micropolar fluids is studied. These results indicate that as heat source or sink parameter λ increases leads to a significant change in Nusselt number but slight change in the value of skin friction factor and wall couple stress. In cases gases (Pr=0.78) and liquids (Pr=7.0), as the viscosity variation and heat source or sink parameters increase, the thermal boundary layer thickness decreases and thus the rate of the heat transfer increases. The viscosity variation parameter also has a noticeable effect on the local skin friction coefficient and wall couple stress, increasing the viscosity within the boundary layer leads to decreasing in the velocity within the layer and thus decrease the local skin friction coefficient and wall couple stress decreases for both gases and liquids. The results indicate also that as the micropolar parameter Δ increases both

Nusselt number and local skin friction coefficient increase while the value of wall couple stress decrease for gases and increases for liquids.

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Table 1:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =0.78, B=0.5, Δ=3.0 and θ_r=2.0.

λ	$-f''(0)$	$-\theta'(0)$	$g'(0)$
0.0	0.31196	0.61569	0.02885
0.2	0.31367	0.48001	0.02727
0.4	0.31636	0.30317	0.02483
0.6	0.32198	0.02244	0.01983

Table 2:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =7.0, B=0.5, Δ=3.0 and θ_r=-2.0.

λ	$-f''(0)$	$-\theta'(0)$	$-g'(0)$
0.0	0.44255	2.01209	0.01786
0.2	0.44209	1.67580	0.01746
0.4	0.44150	1.28635	0.01697
0.6	0.44074	0.81693	0.01632

Table 3:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =0.78, B=0.5, Δ=2.0 and λ=0.2

θ_r	$-f''(0)$	$-\theta'(0)$	$g'(0)$
2.0	0.33616	0.46502	0.03379
4.0	0.40157	0.44836	0.01290
6.0	0.41756	0.44376	0.00795
8.0	0.42477	0.44160	0.00574

Table 4:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =7.0, B=0.5, Δ=2.0 and λ=0.2

θ_r	$-f''(0)$	$-\theta'(0)$	$-g'(0)$
-8.0	0.46339	1.66672	0.00725
-6.0	0.46928	1.66534	0.00942
-4.0	0.48023	1.66275	0.01343
-2.0	0.50758	1.65603	0.02334

Table 5:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =0.78, B=0.5, λ=0.6 and θ_r=6.0.

Δ	$-f''(0)$	$-\theta'(0)$	$g'(0)$
0.0	0.56612	0.15822	0.00000
1.0	0.47533	0.29765	0.00977
2.0	0.41810	0.34868	0.00756
3.0	0.37777	0.37805	0.00582
5.0	0.32340	0.41205	0.00377

Table 6:
Values of $f''(0), \theta'(0)$ and $g'(0)$ with Pr =7.0, B=0.5, λ=0.6 and θ_r=-6.0.

Δ	$-f''(0)$	$-\theta'(0)$	$-g'(0)$
0.0	0.70073	0.62014	0.00000
1.0	0.55025	0.73670	0.01146
2.0	0.46845	0.79458	0.00884
3.0	0.41480	0.83030	0.00674
5.0	0.34851	0.87211	0.00432

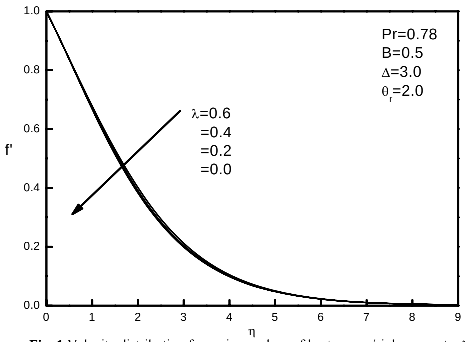

Fig. 1 Velocity distribution for various values of heat source/sink parameter λ

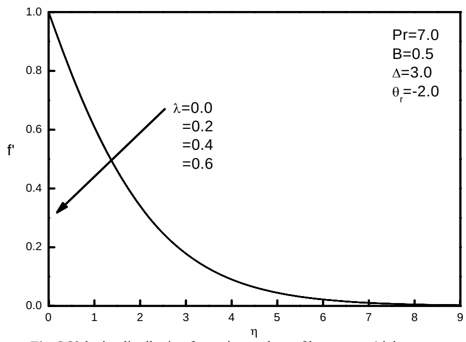

Fig. 2 Velocity distribution for various values of heat source/sink parameter λ

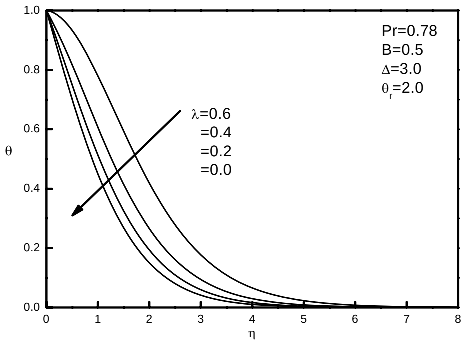

Fig. 3 Temperature distribution for various values of heat source/sink parameter λ

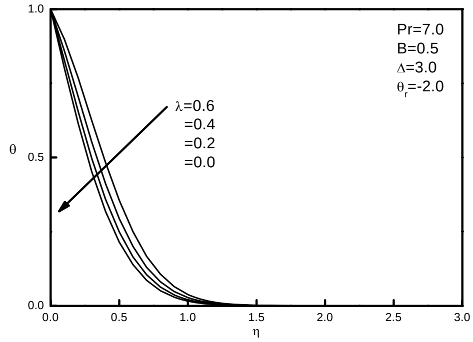

Fig. 4 Temperature distribution for various values of heat source/sink parameter λ

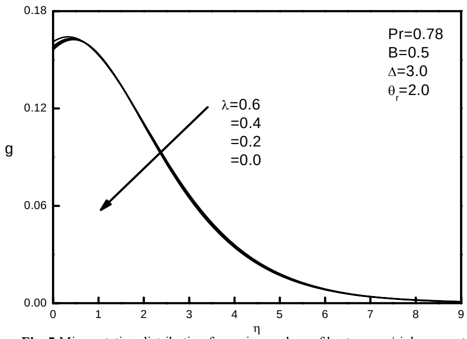

Fig. 5 Microrotation distribution for various values of heat source/sink parameter λ

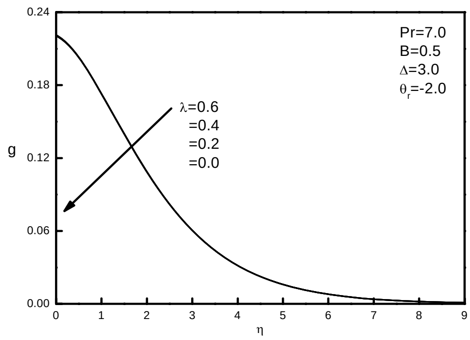

Fig. 6 Microrotation distribution for various values of heat source/sink parameter λ

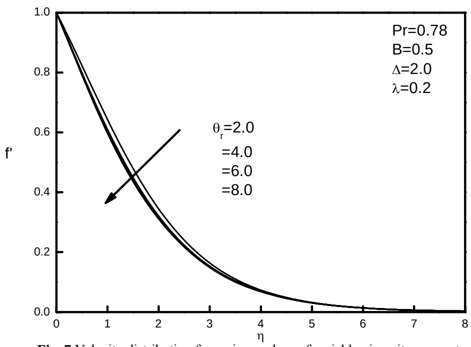

Fig. 7 Velocity distribution for various values of variable viscosity parameter θ_r

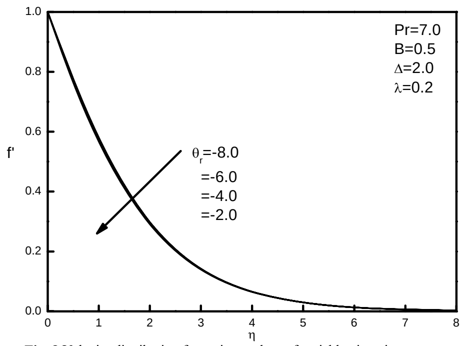

Fig. 8 Velocity distribution for various values of variable viscosity parameter θ_r

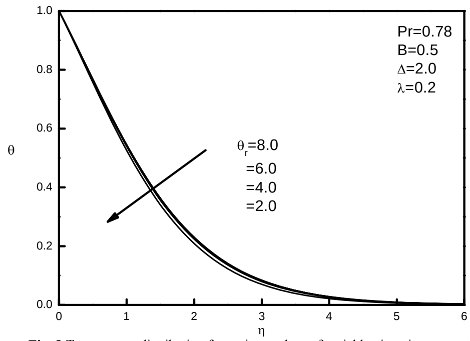

Fig. 9 Temperature distribution for various values of variable viscosity parameter θ_r

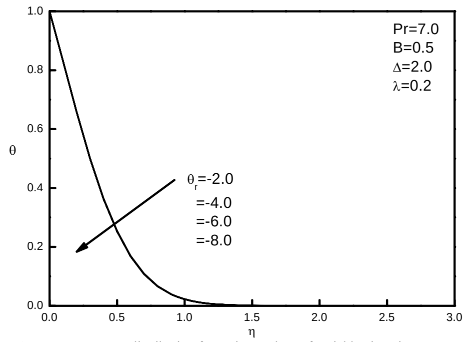

Fig. 10 Temperature distribution for various values of variable viscosity parameter θ_r

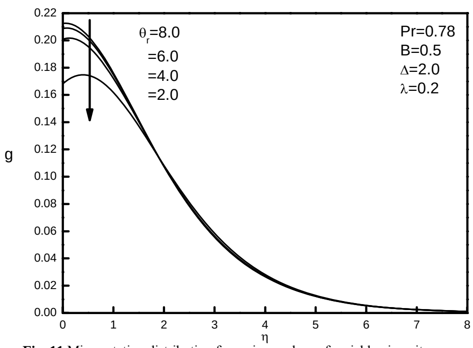

Fig. 11 Microrotation distribution for various values of variable viscosity parameter θ_r

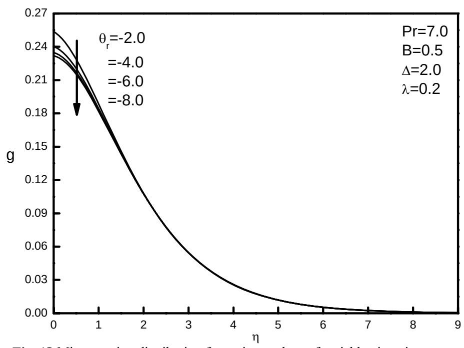

Fig. 12 Microrotation distribution for various values of variable viscosity parameter θ_r

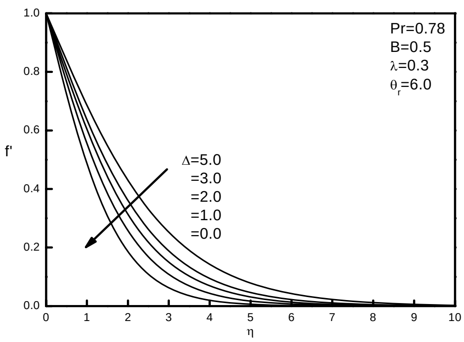

Fig. 13 Velocity distribution for various values of micropolar parameter Δ

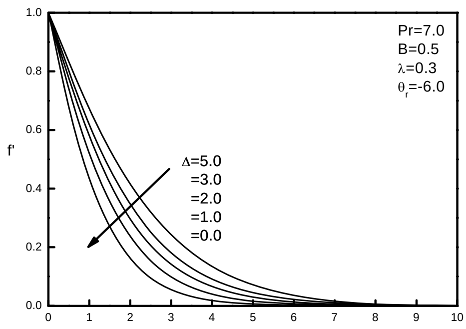

Fig. 14 Velocity distribution for various values of micropolar parameter Δ

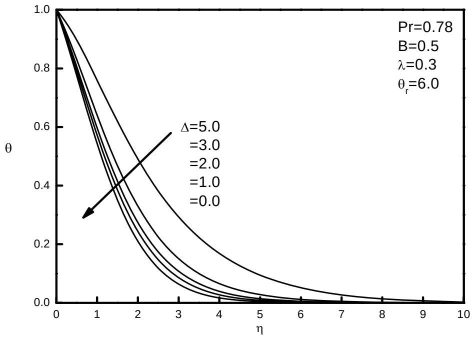

Fig. 15 Temperature distribution for various values of micropolar parameter Δ

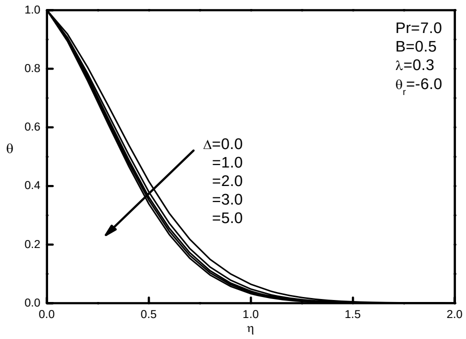

Fig. 16 Temperature distribution for various values of micropolar parameter Δ

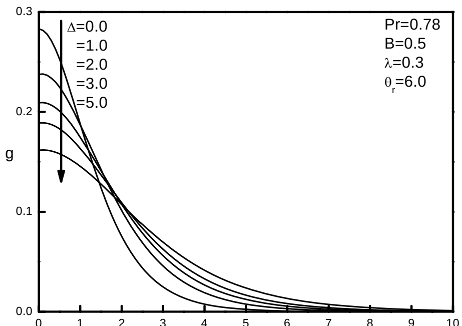

Fig. 17 Microrotation distribution for various values of micropolar parameter Δ

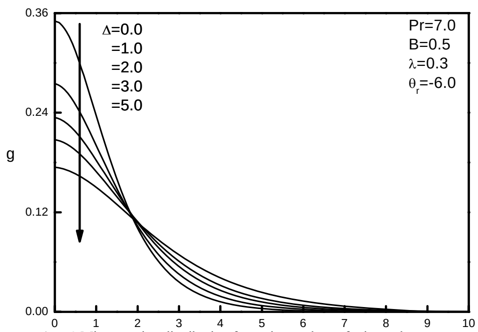

Fig. 18 Microrotation distribution for various values of micropolar parameter Δ

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