Effects of Variable Viscosity and Thermal Conductivity on MHD Flow of Micropolar Fluid in a Continuous Moving Flat Plate

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ABSTRACT
Effects of temperature dependent viscosity and thermal conductivity on magnetohydrodynamic flow and heat transfer over a continuous moving plate of a micropolar fluid have been studied. The fluid viscosity and thermal conductivity are assumed to be vary as inverse linear functions of temperature. Using similarity transformations the governing partial differential equations of motion are reduced to ordinary ones, which are solved numerically for prescribed boundary conditions using shooting method. Numerical results for the velocity, angular velocity, temperature profiles and magnetic field are shown graphically and the Skin friction and Nusselt number are presented in tabular form for various values of the parameters giving the flow and heat transfer characteristics.

Keywords
Magnetohydrodynamic flow, micropolar fluid, skin friction, shooting method.

1. INTRODUCTION
Micropolar fluids are the fluids which contain micro-constituents, belonging to a class of fluids with non-symmetrical stress tensor called polar fluids. These fluids can be defined as a viscous, non- Newtonian fluid, whose fluid elements exhibit micro-rotations.

The study of micropolar fluid is very important as the subject has wide applications in different branches of engineering sciences. The theory of micropolar fluid flow and heat transfer has important engineering applications e.g. in power generators, electric transformers, oil exploration, geothermal energy extractions, designing cooling system in nuclear reactors etc.

The theory of micropolar fluid has been a field of active research for the last few decades due to its multiple importances. It was originally developed by Eringen [1] who derived the constitutive laws of fluid with micro-structure. Eringen [2] also extended the theory of thermo micropolar fluid. Ishak *et al.* [3] discussed the problem of steady boundary layer flow and heat transfer of a micropolar fluid on an isothermal continuously moving surface. Gorla [4] studied the flow of a micropolar fluid over a flat plate. Modather M. *et al.* [5] analyzed variable viscosity effect on heat transfer over a continuous moving surface with variable internal heat generation in micropolar fluids. Modather M. *et al.* [6] studied influence of temperature dependent viscosity and thermal conductivity on the unsteady flow and heat transfer of a micropolar fluid over a stretching sheet. The effects of variable viscosity and thermal conductivity on non-Newtonian Micropolar fluid flow with heat generation were determined by Borgohain *et al*. [7]. Borthakur *et al.* [8] investigated the effects of variable viscosity and thermal conductivity on flow and heat transfer over an unsteady stretching sheet in a micropolar fluid with prescribed surface heat flux. Borgohain *et al.* [9] discussed the effects of variable viscosity and thermal conductivity on flow and heat transfer of a stretching surface in a rotating micropolar fluid with suction and blowing in presence of magnetic field. Effects of variable viscosity and thermal conductivity on MHD flow and heat transfer over a stretching surface with variable heat flux in micropolar fluid in presence of magnetic field were investigated by Thakur *et al.* [10]. Thakur *et al*.[11] also studied the effects of variable viscosity and thermal conductivity on unsteady free convection heat and mass transfer MHD flow of micropolar fluid with constant heat flux through porous medium. Assuming fluid viscosity as a linear function of temperature the effects of variable viscosity on MHD natural convection in micropolar fluids was investigated by Abd El-Hakiem M. *et al.* [12]. Effects of transverse magnetic field on a mixed convection in a micropolar fluid on a horizontal plate with vectored mass transfer were studied by Mohammeadein *et al* [13]. Hazarika *et al*.[14] studied the effects of temperature dependent viscosity and thermal conductivity on MHD flow and heat transfer over a continuous moving flat plate.

In this paper an attempt has been made to study the effects of temperature dependent viscosity and thermal conductivity on magnetohydrodynamic flow and heat transfer over a continuous moving surface of a micropolar fluid with viscous and Joule dissipation. The fluid viscosity and thermal conductivity are assumed to vary as an inverse linear function of temperature. Using similarity transformations the governing partial differential equations of motion are reduced to ordinary differential equations, which are solved numerically for prescribed boundary conditions by using shooting method.

2. MATHEMATICAL FORMULATION OF THE PROBLEM

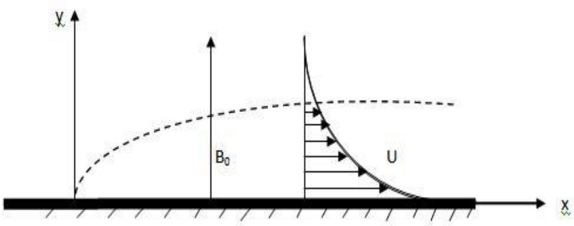

Fig 1: Flow Configuration

We consider the steady two dimensional flow of a viscous incompressible micropolar fluid over a continuous moving flat plate. Let, (u,v) be the velocity component along (x,y) direction respectively, where x-axis is considered along the plate and y-axis is taken as normal to the x- axis. The fluid properties are assumed to be constant, except for the fluid viscosity and thermal conductivity which are assumed to be inverse linear functions of temperature.

Let (H_x,H_y) be the component of magnetic field intensity along x and y where H_y is assumed to be constant and let, N is the micro-rotation component.

Under the boundary layer assumptions, the governing equations are given below:

The equation of continuity:

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

The momentum equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\frac{\partial \mu}{\partial y}\frac{\partial u}{\partial y}+\mu\frac{\partial^2 u}{\partial y^2}+\kappa\left(\frac{\partial^2 u}{\partial y^2}+\frac{\partial N}{\partial y}\right)-\frac{\sigma}{\rho_\infty}(E_Z+uB_y-vB_x)B_y \qquad \dots\ \dots\ (2)$$

The angular momentum equation:

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

The energy equation:

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=\frac{\partial \lambda}{\partial y}\frac{\partial T}{\partial y}+\lambda\frac{\partial^2 T}{\partial y^2}+(\mu+\kappa)\left(\frac{\partial u}{\partial y}\right)^2+\sigma(E_z+uB_y-vB_x)^2 \qquad \dots\ \dots\ (4)$$

The magnetic induction equation:

$$H_y\frac{\partial u}{\partial y}-v\frac{\partial H_x}{\partial y}-H_x\frac{\partial v}{\partial y}+\frac{1}{\rho\mu_e}\frac{\partial^2 H_x}{\partial y^2}=0 \qquad \dots\ \dots\ (5)$$

The boundary conditions are:

$$\left.\begin{array}{l} u=U, v=0, T=T_w, H_x=H_0,\ N=-\frac{1}{2}\frac{\partial u}{\partial y}\quad at\ y=0 \\ u\to 0, T\to T_\infty,\ H_x\to 0\quad N\to 0 \qquad as\quad y\to\infty \end{array}\right\} \qquad \dots\ \dots\ (6)$$

Here, j is the micro-inertia per unit mass, γ and κ are material parameters, λ is the thermal conductivity of the fluid, C_p is the specific heat at constant pressure and μ, σ, T, ρ, E_z and (B_x, B_y) are the viscosity, electrical conductivity, temperature, density, Z component of the electrical field strength and (x, y) component of magnetic field respectively.

Lai and Kulacki [16], has assumed the viscosity as

$$\left.\begin{array}{l} \frac{1}{\mu}=\frac{1}{\mu_\infty}[1+\delta(T-T_\infty)] \\ \text{or, } \frac{1}{\mu}=a\,(T-T_r) \\ \text{where } a=\frac{\delta}{\mu_\infty} \text{ and } T_r=T_\infty-\frac{1}{\delta} \end{array}\right\} \qquad \dots\ \dots\ (7)$$

where, μ_∞ is the viscosity at infinity, a and T_∞ are constants and their values depend on the reference state and thermal property of the fluid. T_r is transformed reference temperature related to viscosity parameter, δ is a constant based on thermal property of the fluid and $a<0$ for gas, $a>0$ for liquid.

Following Lai and Kulacki [16] we may assume the thermal conductivity as,

$$\left.\begin{array}{l} \frac{1}{\lambda}=\frac{1}{\lambda_\infty}[1+\xi(T-T_\infty)] \\ \frac{1}{\lambda}=b(T-T_k) \\ b=\frac{\xi}{\lambda_\infty},\ \text{and } T_k=T_\infty-\frac{1}{\xi} \end{array}\right\} \qquad \dots\ \dots\ (8)$$

where b and T_k are constants and their values depend on the reference state and thermal properties of the fluid, i.e. on ξ.

Let us introduce the following similarity transformations and parameters:

$$\left.\begin{array}{l} u=\frac{\partial\psi}{\partial y}=\nu_\infty\frac{Re}{x}f'(\eta), \\ v=-\frac{\partial\psi}{\partial x}=\frac{1}{2}\nu_\infty\frac{Re^{\frac{1}{2}}}{x}(\eta f'(\eta)-f(\eta)) \\ \theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\ H_x=H_0h(\eta) \\ \text{and } N=U\sqrt{\frac{U}{\nu_\infty x}g(\eta)} \\ \text{with } \psi=\nu_\infty Re^{\frac{1}{2}}f(\eta),\quad \eta=\frac{y}{x}Re^{\frac{1}{2}} \end{array}\right\} \qquad \dots\ \dots\ (9)$$

where $Re=\frac{Ux}{\nu_\infty}$ is the Reynolds number.

Using the above transformations the equation of continuity (1) is satisfied identically and rest of the equations (2), (3), (4) and (5) respectively reduced to:

$$f'''=\frac{1}{2}ff''\left(\frac{\theta-\theta_r}{\theta_r}\right)+\left(\frac{1}{\theta-\theta_r}\right)\theta'f''-K(f'''+g')\left(\frac{\theta-\theta_r}{\theta_r}\right)+Rm\left(\frac{\theta-\theta_r}{\theta_r}\right)[Rm(f'-Re)+\frac{1}{2}\frac{Mh(\eta f-f')}{Re}] \qquad \dots\ \dots\ (10)$$

$$g''=\frac{1}{G}(2g+f'')-\frac{1}{2\Delta}(f'g+fg') \qquad \dots\ \dots\ (11)$$

$$\theta''=\left(\frac{\theta'^2}{\theta-\theta_k}\right)-PrEc\left(\frac{\theta-\theta_k}{\theta_k}\right)\left[\left(\frac{\theta_r}{\theta-\theta_r}\right)+K\right]f''^2+\frac{Pr}{2}\left(\frac{\theta-\theta_k}{\theta_k}\right)f\theta'+PrR_HEcPm\left(\frac{\theta-\theta_k}{\theta_k}\right)[R_E\sqrt{Re}+\sqrt{Re}f'+\frac{1}{2}h(f-\eta f')]^2 \qquad \dots\ \dots\ (12)$$

$$h''=Pm[\frac{1}{2}\eta hf''-12h'(f-\eta f')-\sqrt{Re}f''] \qquad \dots\ \dots\ (13)$$

where,

$$\theta_r=\frac{T_r-T_\infty}{T_w-T_\infty}=\frac{1}{\delta(T_w-T_\infty)} \quad \text{and} \quad \theta_k=\frac{T_k-T_\infty}{T_w-T_\infty}=\frac{1}{\xi(T_w-T_\infty)}$$

are dimensionless reference temperature corresponding to viscosity and thermal conductivity respectively. It is to be noted that these values are negative for liquids and positive for gases when (T_w-T_∞) is positive (Lai and Kulacki [16]).

Here the dimensionless parameters are defined as:

$Pr=\frac{\nu_\infty}{\alpha}$ is the Prandtl number, where $\alpha=\frac{\lambda}{\rho C_p}$

$G=\frac{\kappa\mu_\infty x}{\rho\gamma U}$ is the micro-rotation parameter

$K=\frac{\kappa}{\mu_\infty}$ is the coupling constant parameter

$\Delta = \frac{\gamma}{\mu_\infty j}$ is the material constant

$M = \mu_e H_0 x \left(\frac{\sigma}{\mu}\right)^{\frac{1}{2}}$ is the Hartmann number

$R_H = \frac{\mu_e H_0^2}{\rho U^2}$ is the magnetic pressure number

$Rm = \sqrt{R_H R_\sigma}$ is the Magnetic number

$Pm = \frac{R_\sigma}{Re}$ is the magnetic Prandtl number

$R_E = \frac{E_Z}{U \mu_e H_0}$ is the electric field parameter

$Ec = \frac{U^2}{C_p (T_w - T_\infty)}$ is the Eckert number

The boundary conditions (6) reduce to:

$$\left.\begin{array}{l} \text{at } \eta = 0,\ f = 0,\ f' = 1,\ \theta = 1,\ h = 1,\ g = -\frac{1}{2}f'' \\ \text{as } \eta \to \infty,\ f' \to 0,\ \theta \to 0,\ h \to 0, g \to 0 \end{array}\right\} \quad \ldots\ \ldots (14)$$

The important physical quantities of interest in this problem are skin friction coefficient C_f and the Nusselt number *Nu* which are the rate of plate shear stress and the rate of heat transfer for the surface respectively. These are defined as:

$$C_f = \frac{2\tau_w}{\rho_\infty U^2},$$

where, τ_w is the shear stress which is given by

$$\tau_w = \left[(\mu + \kappa)\frac{\partial u}{\partial y} + \kappa N\right]_{y=0}$$

and, $Nu = \frac{x q_w}{\lambda_\infty (T_w - T_\infty)}$

where, q_w is the heat transfer from the surface given by,

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

Thus, $C_f Re^{\frac{1}{2}} = (\frac{2\theta_r}{\theta_r - 1} + K) f''(0)$.

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

3. RESULTS AND DISCUSSIONS

The differential equations (10) to (13) together with the boundary conditions (14) are solved numerically using Runge-Kutta fourth order method in conjunction with shooting technique. The numerical values of different parameters are taken as Pm = .5, R_E =1, Re = .1, Rm = .1, M = .5, Pr = .7, R_H =1, Ec = .01, $\theta_r = -12$, $\theta_k = -12$, G = 2, Δ= .5, K =.1 unless otherwise stated.

The variations in velocity profile, micro-rotation profile, temperature profile and magnetic field are illustrated in figure 1 to figure 18 for the variation of different parameters. Variations in velocity distribution are shown in figure 1 to figure 5. From the figure 1 and figure 4 it is clear that velocity increases with the increasing values of coupling constant parameter K and magnetic Prandtl number Pm. In figure 2, figure 3 and figure 5 we have seen that velocity decreases with the increase of micro-rotation parameter G, material constant Δ and viscosity parameter θ_r .

Figure 6 to 12 display the graphs obtained for micro-rotation profile with the variation of Δ, K, θ_k, θ_r, G, M and Pm. From the figure 6 and figure 9 it is observed that micro-rotation increases with the increase of material constant Δ and viscosity parameter θ_r.It is seen from the figure 7 and figure 11 that near the surface micro-rotation increases significantly but gradually its variations become smaller as the coupling constant parameter K and Hartmann number M increase. Figure 8 shows that the micro-rotation does not change significantly with the variation of thermal conductivity parameter θ_k. From the figure 10 and figure 12 we have found that micro-rotation decreases with the increasing values of micro rotation parameter G and magnetic Prandtl number Pm.

The variation of dimensionless temperature profile for various values of θ_k, K, M, θ_r is shown in the figure 13 to figure 16. It is seen from figure 13 that temperature decreases with the increase of thermal conductivity parameter θ_k while from the figure14, figure 15 and figure 16 we have found that temperature increases as the values of coupling constant parameter K, Hartmann number M and viscosity parameter θ_r increase.

From figure 17 it can be observed that magnetic field does not vary significantly with the variation of micro-rotation parameter G. Lastly figure 18 shows that magnetic field decreases as the values of magnetic Prandtl number Pm increases.

The missing values $f''(0)$, $g'(0)$, $\theta'(0)$ and the coefficient of skin friction C_f i.e. the wall shear stress and the Nusselt number *Nu* which represents the heat transfer rate are estimated for various combinations of parameters and presented in table 1 to table 4. From these tables we have seen that $f''(0)$ and Nusselt number *Nu* decrease and $g'(0)$ increases for the increasing values of viscosity parameter θ_r, thermal conductivity parameter θ_k and coupling constant parameter K while $f''(0)$ and Nusselt number *Nu* increase and $g'(0)$ decreases with the increase of micro-rotation parameter G. From the same tables it is found that $\theta'(0)$ increases for the increase of coupling constant parameter K and viscosity parameter θ_r whereas it decreases with the increase of G and θ_k. We can observe from the table 1 that the skin friction C_f decreases as the coupling constant parameter K and viscosity parameter θ_r increase but in the table 3 we have seen that its values increase for the increasing values of micro-rotation parameter G.

In the table 5 we have compared of missing values $f''(0)$ and $\theta'(0)$ with those of Hazarika *et al*. From this table we have observed that missing values $f''(0)$ and $\theta'(0)$ of micropolar fluid are less than non-micropolar fluid i.e, micro-rotation reduces both plate shear stress and rate of heat transfer at the plate.

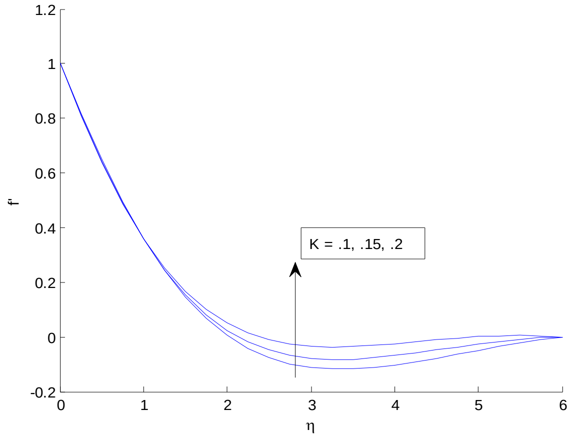

Fig: 1 Velocity profile against K

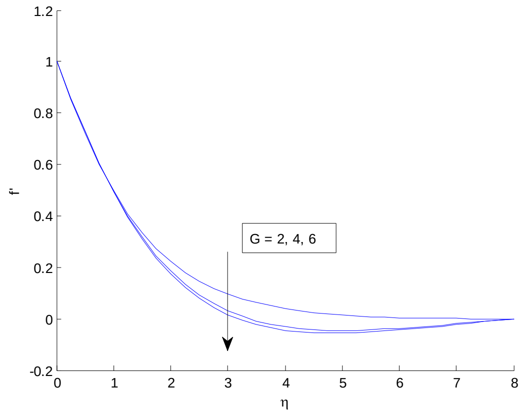

Fig: 2 Velocity profile against G

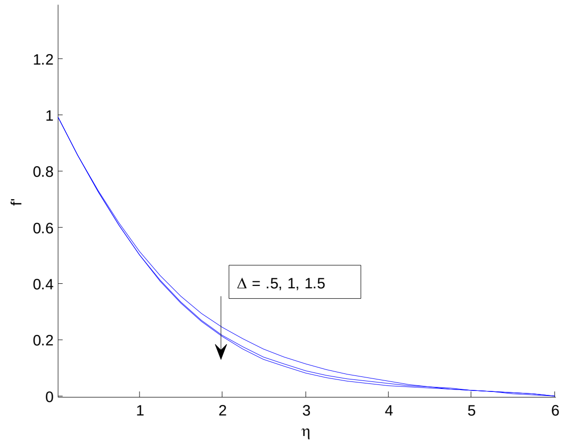

Fig: 3 Velocity profile against Δ

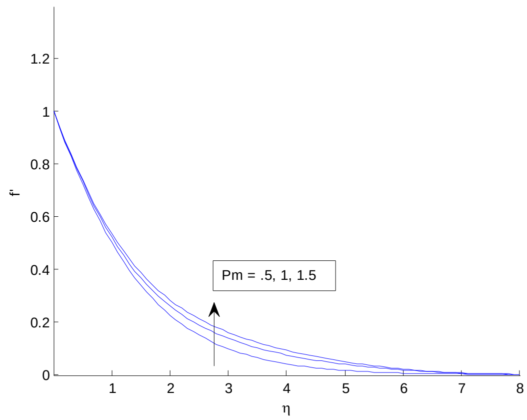

Fig: 4 Velocity profile against Pm

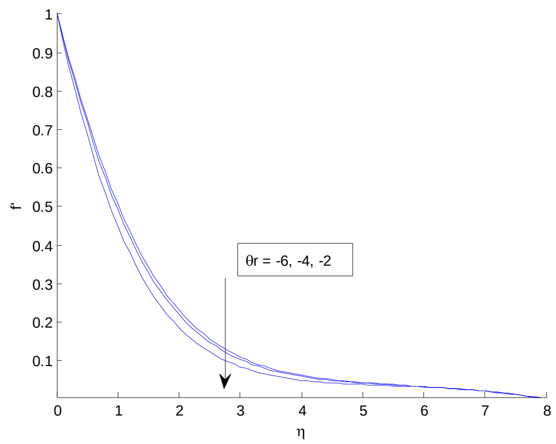

Fig: 5 Velocity profile against θ_r

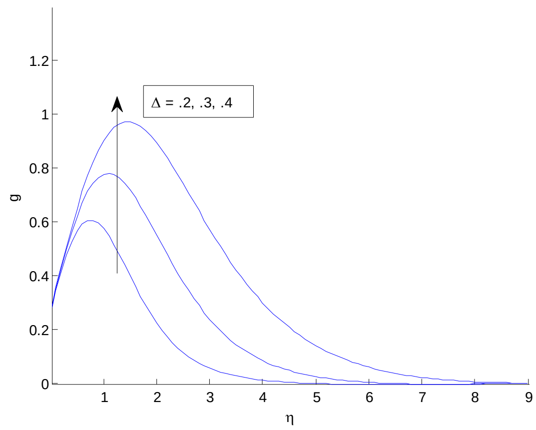

Fig: 6 Micro-rotation profile against Δ

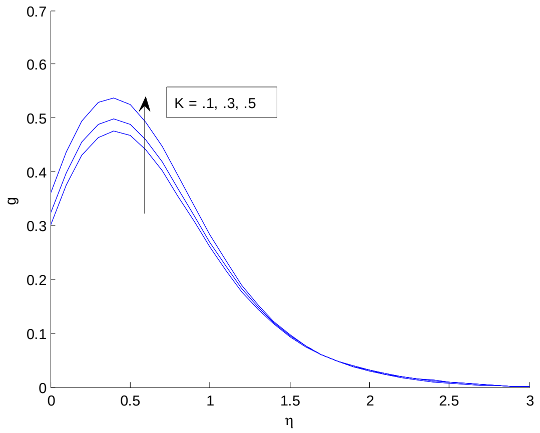

Fig: 7 Micro-rotation profile against K

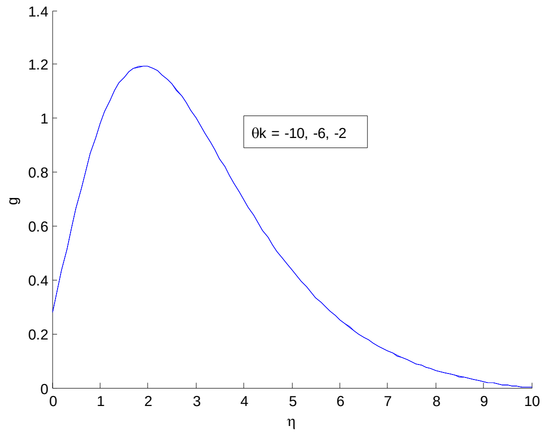

Fig: 8 Micro-rotation profile against θ_k

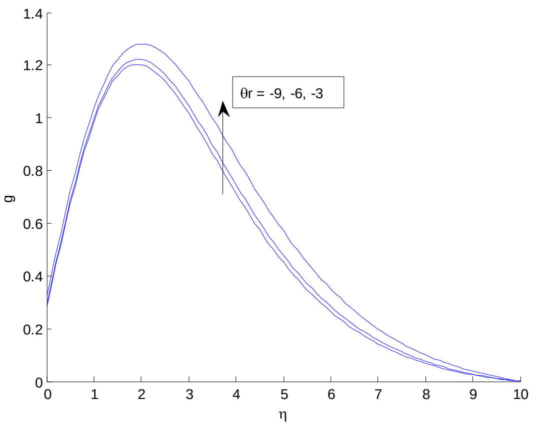

Fig: 9 Micro-rotation profile against θ_r

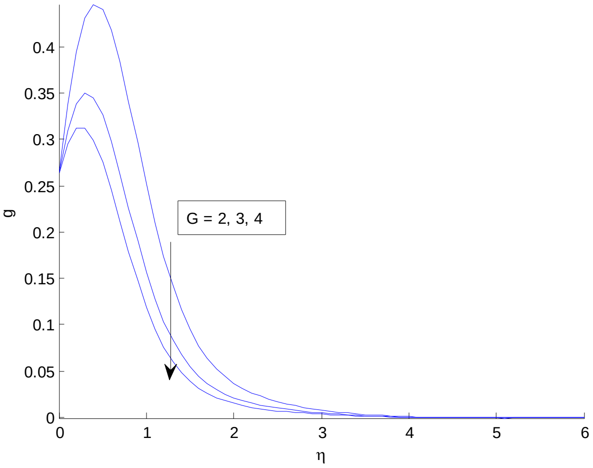

Fig: 10 Micro-rotation profile against G

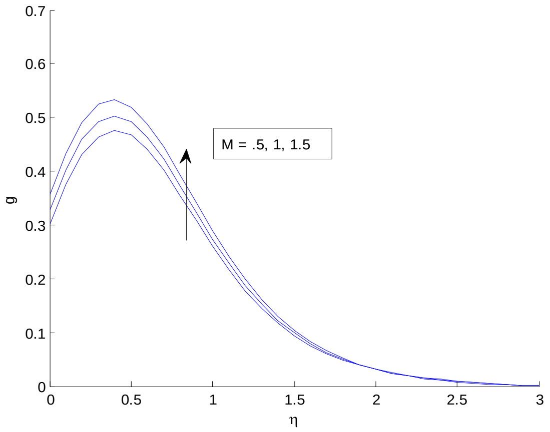

Fig: 11 Micro-rotation profile against M

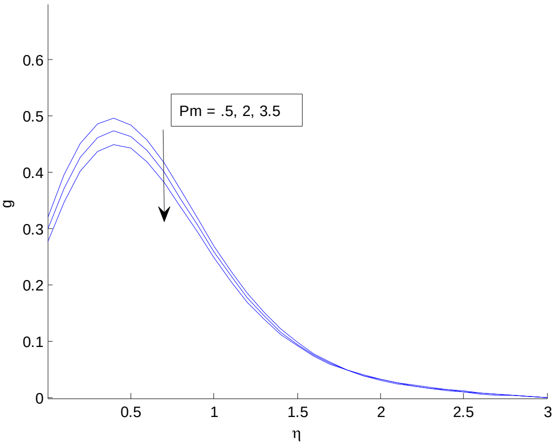

Fig: 12 Micro-rotation profile against Pm

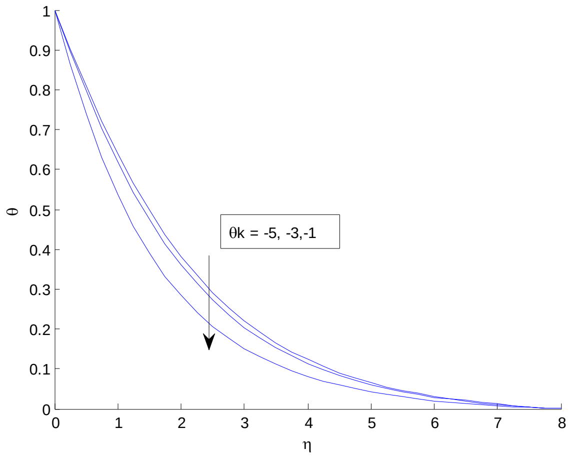

Fig: 13 Temperature profile against θ_k

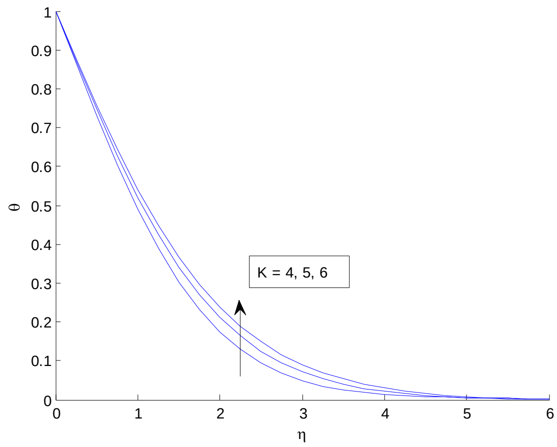

Fig: 14 Temperature profile against K

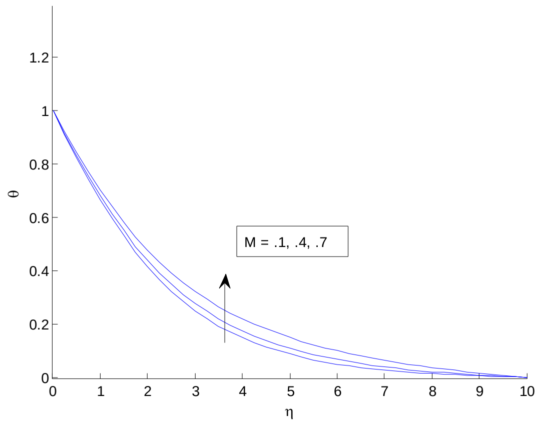

Fig: 15 Temperature profile against M

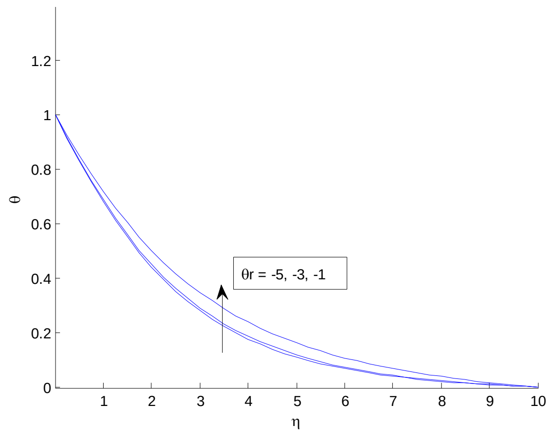

Fig: 16 Temperature profile against θ_r

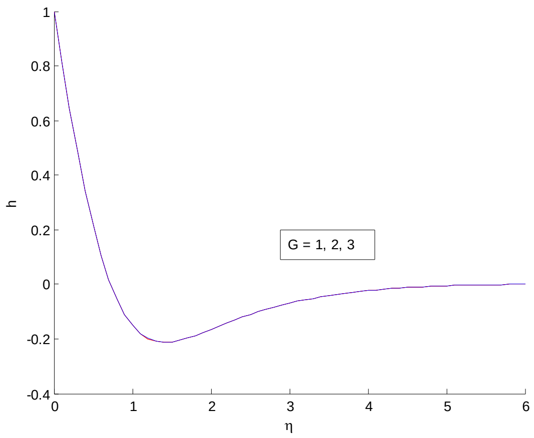

Fig: 17 Magnetic field against G

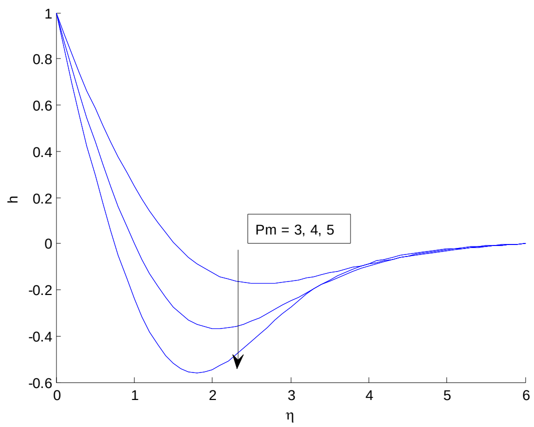

Fig: 18 Magnetic field against Pm

Table 1

K	θ_r	$f''(0)$	$g'(0)$	$\theta'(0)$	cf	Nu
0.1	-10	-0.4407	0.48306	-0.4248	-0.2674	0.12211
	-8	-0.4486	0.48501	-0.4241	-0.2664	0.12191
	-6	-0.4616	0.48819	-0.4229	-0.2649	0.12157
	-4	-0.4873	0.49437	-0.4206	-0.262	0.12092
	-2	-0.5623	0.51149	-0.4142	-0.2549	0.11906
0.3	-10	-0.5426	0.51432	-0.4248	-0.3634	0.12213
	-8	-0.5558	0.51783	-0.424	-0.3652	0.12189
	-6	-0.5782	0.52371	-0.4226	-0.3683	0.12149
	-4	-0.6243	0.53567	-0.4199	-0.3751	0.1207
	-2	-0.7765	0.57382	-0.4116	-0.4011	0.11834
0.5	-10	-0.745	0.5911	-0.4275	-0.5461	0.12289
	-8	-0.7759	0.6013	-0.4265	-0.5589	0.12261
	-6	-0.8317	0.61983	-0.4248	-0.5824	0.12212
	-4	-0.9646	0.66462	-0.4211	-0.6406	0.12107
	-2	-1.7109	0.90785	-0.4064	-0.9919	0.11682

Table 2

G	θ_r	$f''(0)$	$g'(0)$	$\theta'(0)$	cf	Nu
2	-10	-0.4407	0.48306	-0.4248	-0.2674	0.12211
	-8	-0.4486	0.48501	-0.4241	-0.2664	0.12191
	-6	-0.4616	0.48819	-0.4229	-0.2649	0.12157
	-4	-0.4873	0.49437	-0.4206	-0.262	0.12092
	-2	-0.5623	0.51149	-0.4142	-0.2549	0.11906
4	-10	-0.4201	0.29098	-0.4254	-0.2548	0.1223
	-8	-0.4274	0.29226	-0.4247	-0.2538	0.1221
	-6	-0.4394	0.29436	-0.4236	-0.2521	0.12179
	-4	-0.4631	0.29844	-0.4215	-0.249	0.12116
	-2	-0.5318	0.30978	-0.4153	-0.241	0.1194
6	-10	-0.4148	0.19989	-0.4253	-0.2516	0.12227
	-8	-0.4219	0.20077	-0.4247	-0.2505	0.12208
	-6	-0.4337	0.20221	-0.4235	-0.2488	0.12176
	-4	-0.4569	0.20499	-0.4214	-0.2456	0.12114
	-2	-0.5238	0.21269	-0.4153	-0.2374	0.11938

Table 3

G	θ_k	$f''(0)$	$g'(0)$	$\theta'(0)$	cf	Nu
2	-10	-0.4407	0.48306	-0.4248	-0.2674	0.12211
	-8	-0.4408	0.48308	-0.4312	-0.2674	0.1212
	-6	-0.4409	0.48312	-0.4417	-0.2674	0.11973
	-4	-0.4411	0.48319	-0.4624	-0.2676	0.11697
	-2	-0.4416	0.48338	-0.5213	-0.2679	0.1099
4	-10	-0.4201	0.29098	-0.4254	-0.2548	0.1223
	-8	-0.4201	0.29099	-0.4318	-0.2548	0.12139
	-6	-0.4202	0.29101	-0.4424	-0.2549	0.11992
	-4	-0.4204	0.29104	-0.4631	-0.255	0.11716
	-2	-0.4209	0.29114	-0.5222	-0.2553	0.11009
6	-10	-0.4148	0.19989	-0.4253	-0.2516	0.12227
	-8	-0.4148	0.1999	-0.4317	-0.2516	0.12136
	-6	-0.4149	0.19991	-0.4423	-0.2517	0.11989
	-4	-0.4151	0.19993	-0.463	-0.2518	0.11714
	-2	-0.4156	0.2	-0.5221	-0.2521	0.11007

Table 4

K	θ_k	$f''(0)$	$g'(0)$	$\theta'(0)$	cf	Nu
0.1	-10	-0.4407	0.48306	-0.4248	-0.2674	0.12211
	-8	-0.4408	0.48308	-0.4312	-0.2674	0.1212
	-6	-0.4409	0.48312	-0.4417	-0.2674	0.11973
	-4	-0.4411	0.48319	-0.4624	-0.2676	0.11697
	-2	-0.4416	0.48338	-0.5213	-0.2679	0.1099
0.3	-10	-0.5426	0.51432	-0.4248	-0.3634	0.12213
	-8	-0.5427	0.51435	-0.4312	-0.3635	0.12121
	-6	-0.5428	0.5144	-0.4417	-0.3636	0.11972
	-4	-0.543	0.5145	-0.4622	-0.3637	0.11694
	-2	-0.5436	0.51476	-0.5208	-0.3641	0.10979
0.5	-10	-0.745	0.5911	-0.4275	-0.5461	0.12289
	-8	-0.7451	0.59115	-0.4338	-0.5462	0.12194
	-6	-0.7452	0.59122	-0.4442	-0.5463	0.12041
	-4	-0.7455	0.59135	-0.4647	-0.5465	0.11755
	-2	-0.7462	0.59173	-0.5228	-0.547	0.11022

Table 5

M	θ_r	$f''(0)$ (Micropolar)	$\theta'(0)$ (Micropolar)	$f''(0)$ (non-Micropolar)	$\theta'(0)$ (non-Micropolar)
0.2	-10	-0.5313	-0.4085	-0.45819	-0.39473
	-8	-0.5313	-0.4147	-0.46452	-0.39451
	-6	-0.5315	-0.4248	-0.47487	-0.39413
	-4	-0.5317	-0.4447	-0.49487	-0.39339
	-2	-0.5322	-0.5014	-0.55011	-0.39116
0.4	-10	-0.5126	-0.4119	-0.43418	-0.39156
	-8	-0.5126	-0.4181	-0.44037	-0.39133
	-6	-0.5127	-0.4284	-0.4505	-0.39094
	-4	-0.513	-0.4484	-0.47012	-0.39017
	-2	-0.5135	-0.5056	-0.52458	-0.38785
0.6	-10	-0.4915	-0.4157	-0.40639	-0.37829
	-8	-0.4916	-0.422	-0.41237	-0.37807
	-6	-0.4917	-0.4323	-0.42217	-0.3777
	-4	-0.4919	-0.4526	-0.4412	-0.37696
	-2	-0.4924	-0.5103	-0.49428	-0.37473

4. CONCLUSION

From the above study it is clear that the viscosity and thermal conductivity parameter along with the other parameters such as magnetic parameter M, coupling constant parameter K, micro-rotation parameter G, Magnetic Prandtl number Pm etc. have significant effects on velocity, micro-rotation, temperature profile and magnetic field within the boundary layer. We can conclude from this study as:

1. The increasing values of coupling constant parameter (K) enhance the velocity whereas viscosity and micro-rotation parameter (G) reduce the same.
2. Temperature and micro-rotation increase with the increase of coupling constant parameter (K) and viscosity.
3. Micro-rotation parameter (G) reduces the micro-rotation.
4. Hartmann number (M) enhances the temperature and micro-rotation.
5. Increasing values of viscosity and coupling constant parameter (K) retards the skin-friction but micro-rotation parameter (G) enhances the same.
6. The heat transfer rate increases with the increase of micro-rotation parameter (G) but it decreases as the viscosity, thermal conductivity and coupling constant parameter (K) increase.

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