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Variable Viscosity And Thermal Conductivity On Heat Transfer In Micro-Polar Fluid Between Two Parallel Disks

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***Abstract*— This paper investigates the effect of viscosity parameters and thermal conductivity parameters on heat transfer rate between two circular parallel disks in continuous squeeze film flow for steady, incompressible flow of micro-polar fluid in porous medium. The flow governing equations are transformed into ordinary differential equations and the resulting boundary value problems are solved numerically by using Runge-Kutta shooting method . The results are represented graphically to illustrate influence of the various physical parameters on the velocity profiles, micro-rotation profile and temperature profile.**

Index terms -MANETs, Variable viscosity and thermal conductivity, micropolar fluid, skin friction, shooting method.

I. INTRODUCTION

Classical Navier-Stokes equations are unable to describe the fluid properties like as micro-rotation, spin-inertia, couple-stress and body-torque which are important in many fluids, for instance, polymeric liquids, liquid crystals, colloidal suspensions, animal bloods and fluids containing small amount of polymeric liquids. Eringen presented the theory of non-Newtonian fluids, in which micro-rotation, spin-inertia, couple-stress and body-torque are important [9] . Such fluids are called micro-polar fluids. During the last few decades, considerable progress has been made in the investigation of micro-polar fluid due to their wide and various applications in engineering , industry and agriculture.

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In general viscosity is a function of temperature. In liquid, usually viscosity decreases with increase of temperature and in the case of gases it increases with increase of temperature In most of fluids thermal conductivity decreases with the increase in temperature, however in some fluids it increases with temperature [8]. To predict the flow accurately, it is necessary to account their variations. Hazarika G, C. has studied heat transfer due to flow of viscous Newtonian fluids between two parallel circular disks of infinite extent with constant viscosity [13] , Borah G. and Hazarika G, C. has studied the effect of variable viscosity and thermal conductivity on heat transfer between two parallel disks [1].

Literature survey reveals that no research regarding to the effect of variable viscosity and thermal conductivity on heat transfer in steady flow of in-compressible micro-polar fluids between two parallel circular disks . This paper aims to investigate to the effect of variable viscosity and thermal conductivity on heat transfer in steady continuous squeeze film flow of incompressible micro-polar fluid between two parallel circular disks where the upper disk is porous and the lower disk is rigid and stationary. Here the disks are assumed to be of infinite extent.

Here the flow governing equations are transformed into ordinary differential equations and the resulting boundary value problems are solved numerically by using Runge-Kutta shooting method [7,13,18].

II. MATHEMATICAL FORMULATIONS

A. Co-axial disk flow

Let us consider the flow between two rigid circular disks at a distant d of infinite extent .The lower disk is stationary with temperature T_1 and the upper disk is moving with angular velocity Ω and has temperature T_1

and let Ω_0 be the micro-rotation of the micro-polar fluids. Considering (u, v, w) as the components of velocity profile and (N_1, N_2, N_3) as the components micro-rotation profile in cylindrical polar co-ordinates, we get flow governing equations in absence of body force and body couple are :-

$$\frac{1}{r}\frac{\partial}{\partial r}(ru)+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\rho[u\frac{\partial u}{\partial r}+w\frac{\partial u}{\partial z}-\frac{v^2}{r}]=-\frac{\partial p}{\partial r}+(\mu+k)[\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}+\frac{\partial^2 u}{\partial r^2}-\frac{u}{r^2}]+2\frac{\partial \mu}{\partial r}\frac{\partial u}{\partial r}+\frac{\partial \mu}{\partial z}(\frac{\partial w}{\partial r}+\frac{\partial u}{\partial z})-k\frac{\partial N_2}{\partial z} \quad (2)$$

$$\rho[u\frac{\partial v}{\partial r}+w\frac{\partial v}{\partial z}+\frac{uv}{r}]=(\mu+k)[\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}+\frac{\partial^2 v}{\partial r^2}-\frac{v}{r^2}]+\frac{\partial \mu}{\partial z}\frac{\partial v}{\partial z} \quad (3)$$

$$\rho[u\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial z}]=-\frac{\partial p}{\partial z}+(\mu+k)[\frac{\partial^2 w}{\partial r^2}+\frac{1}{r}\frac{\partial w}{\partial r}+\frac{\partial^2 w}{\partial z^2}]+2\frac{\partial \mu}{\partial z}\frac{\partial w}{\partial z}+\frac{\partial \mu}{\partial r}(\frac{\partial w}{\partial z}+\frac{\partial w}{\partial r})+k(\frac{\partial N_2}{\partial r}-\frac{N_2}{r}) \quad (4)$$

$$\rho j[u\frac{\partial N_2}{\partial r}+w\frac{\partial N_2}{\partial z}]=\gamma[\frac{\partial^2 N_2}{\partial r^2}+\frac{1}{r}\frac{\partial N_2}{\partial r}+\frac{\partial^2 N_2}{\partial r^2}-\frac{N_2}{r^2}]+(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial r})-2kN_2 \quad (5)$$

$$\rho C_p[u\frac{\partial T}{\partial r}+w\frac{\partial T}{\partial w}]=\lambda[\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}]+\frac{\partial \lambda}{\partial r}\frac{\partial T}{\partial r}+\frac{\partial \lambda}{\partial z}\frac{\partial T}{\partial z}+(\mu+k)[2\{(\frac{\partial u}{\partial r})^2+(\frac{u}{r})^2+(\frac{\partial w}{\partial z})^2\}+(\frac{\partial v}{\partial r}-\frac{v}{r})^2+(\frac{\partial v}{\partial r})^2+(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial r})^2] \quad (6)$$

The boundary conditions are

At z=0, u=0, v=0, w=0, N_2=0, T=T_1 and

At z=d, u=0, v=rΩ, w=0, $N_2 \; -n\left[\frac{\partial v}{\partial z}\right]_{z=d}$, T=$T_0$

Here n is a constant and 0<n<1, [17]. The case n=0 is called strong concentration by Guram and Smith [11], corresponds to the case where the particle density is sufficiently large so that microelements close to the wall are unable to rotate [15]. The case n=0.5 represents a weak representation of the micro-elements and vanishing of anti-symmetric part of the stress tensor [20]. The case n=1 .0 corresponds to the turbulent flow inside the boundary layer [21].Where ρ=density of micro-polar fluids, γ=spin gradient viscosity, μ and k are viscosity coefficient for stress, λ = thermal conductivity, C_p=specific heat at constant pressure, j=micro-inertia density, p=pressure.

Lai and Kulacki have assumed that viscosity and thermal conductivity of fluid to be an inverse linear relation of temperature [16] as

$$\frac{1}{\mu}=\frac{1}{\mu_\infty}[1+\gamma_1(T-T_\infty)] \quad \text{and} \quad \frac{1}{\lambda}=\frac{1}{\lambda_\infty}[1+\gamma_2(T-T_\infty)].$$

Here μ_∞=the viscosity at infinity, λ_∞=the thermal at infinity, T_∞=the fluid temperature at infinity and γ_1 and γ_2 are constant.

To solve the above equations let us assume that

u=rΩf′(η), v=rΩh(η), w=-2dΩf(η) N_2=rΩ_0g(η)

that

$$\frac{T-T_0}{T_1-T_0}=\emptyset_1(\eta)+(\frac{r}{d})^2\emptyset_2(\eta), \quad \mu=-\frac{\mu_0\emptyset_e}{\emptyset_1-\emptyset_e}, \text{ and } \lambda=-\frac{\lambda_0\phi_r}{\phi_1-\phi_r} \quad (7)$$

Where $\eta=\frac{z}{d}$ (dimensionless vertical co-ordinate), μ_0= viscosity of free stream, λ_0= thermal conductivity of free stream and $\phi_e=\frac{T_e-T_0}{T_1-T_0}$ (viscosity parameter), $\phi_r=\frac{T_r-T_0}{T_1-T_0}$ (thermal conductivity parameter)

Using (7) in equations (1-6), eliminating the pressure gradient terms and then simplifying we get

$$[1-\mu_1\frac{\emptyset_1-\emptyset_e}{\emptyset_e}]f^{iv}=2R\,e\frac{\emptyset_1-\emptyset_e}{\emptyset_e}(ff^{|||}+hh^{/})+\frac{1}{\emptyset_1-\emptyset_e}[2\emptyset_1^{/}f^{|||}+\emptyset_i^{||}f^{||}-\frac{2\emptyset_1^{/2}f^{||}}{\emptyset_1-\emptyset_e}]-\frac{\emptyset_1-\emptyset_e}{\emptyset_e}\mu_1 g^{||} \quad (8)$$

$$[1-\mu_1\frac{\emptyset_1-\emptyset_e}{\emptyset_e}]h^{||}+2Re\frac{\emptyset_1-\emptyset_e}{\emptyset_e}[f^{/}h-fh^{/}]=\frac{\emptyset_1^{/}h^{/}}{\emptyset_1-\emptyset_e} \quad (9)$$

$$g^{||}+R_4(f^{||}-2g)-R_3(f^{/}g-2fg^{/})=0 \quad (10)$$

$$\emptyset_1^{||}+4\emptyset_2-\frac{\emptyset_1-\emptyset_r}{\emptyset_r}\Pr[2\,Re\,f\,\emptyset_1^{/}+(\mu_1-\frac{\emptyset_e}{\emptyset_1-\emptyset_e})12\,Ef^{/2}]-\frac{\emptyset_1^{/2}}{\emptyset_1-\emptyset_r}=0 \quad (11)$$

$$\emptyset_2^{||}+[2\,Re\,(f^{/}\emptyset_2-f\emptyset_2^{/})+(\frac{\emptyset_e}{\emptyset_1-\emptyset_e}-\mu_1)E\,(f^{||}+h^{/2})]\Pr\frac{\emptyset_1-\emptyset_r}{\emptyset_r}-\frac{\emptyset_1^{/}\emptyset_2^{/}}{\emptyset_1-\emptyset_r}=0 \quad (12)$$

The functions f, h, g, Φ_1 and Φ_2 areb to be determined with the boundary conditions as follows:-

f(0) = f′(0)= 0, f(1)= f′(1)=0; h(0) = h(1) =1 g(0)=0, g(1)=1

Φ_1(0)=1, Φ_1(1)=0 ; and Φ_2(0)=0, Φ_2(1)=0

Where E=$\frac{V^2}{C_p(T_1-T_0)}$ (Eckert number), Pr = $\frac{C_p\mu_0}{\lambda_0}$ (Prandtl number), Re = $\frac{\rho jVd}{\mu_0}$ (Reynold number), V = Ωd

And the following are dimensionless micro-polar parameters $\mu_1=\frac{k}{\mu_0}$, $R_3=\frac{\rho jVd}{\gamma}$, $R_4=\frac{kd^2}{\gamma}$

Here dashes denote the differentiation w.r. t. "η", the non-dimensional distant function.

The skin friction coefficient C_f and the Nusselt Nu number are given by

$$C_f=\frac{2}{\rho U^2}[(\mu+k)\frac{\partial u}{\partial z}+kN_2]_{z=0}$$

$$=\frac{\xi}{Re}[(\mu_1-\frac{\phi_e}{1-\phi_e})f^{||}(0)] \quad \text{and}$$

$$Nu=\frac{d\lambda\frac{\partial T}{\partial z}}{\lambda_\infty(T_1-T_0)}]_{z=0}$$

$$=-\frac{\emptyset_r}{1-\emptyset_r}[\theta_1^{/}(0)+\xi^2\,\theta_2^{/}(0)]$$

where $\xi=\frac{r}{d}$ (dimensionless distant parameter).

III. METHOD OF SOLUTION

To solve the boundary value problems (8)-(12) the Runge-Kutta shooting method is applied. In this method the BVP are converted to initial value problems by estimating the missing initial values to a desired degree of accuracy by an iterative scheme.

Hazarika [14] showed that through there is no guarantee of convergence of the iterative scheme, if the initial guesses for the missing initial values are on opposite sides of the true values. The convergence is rapid and agrees well with other methods.
Using shooting method, the missing initial values viz $f^{//}(0)$, $f^{///}(0)$, g/(0), $h^{/}(0)$, $\theta_1{}^{/}(0)$, and $\theta_2{}^{/}(0)$ are estimated for various combination of parameters and consequently the problem is solved.

IV. Result And Discussion

Here the system of differential equations governed by the respective boundary conditions are solved numerically by applying an efficient numerical technique based on the common Rung-Kutta shooting method. The whole numerical scheme can be programmed and applied easily. It is experienced that the convergence of the iteration process is quite rapid. The estimated values of the missing initial values are arranged in different tables for various values of the viscosity parameters.

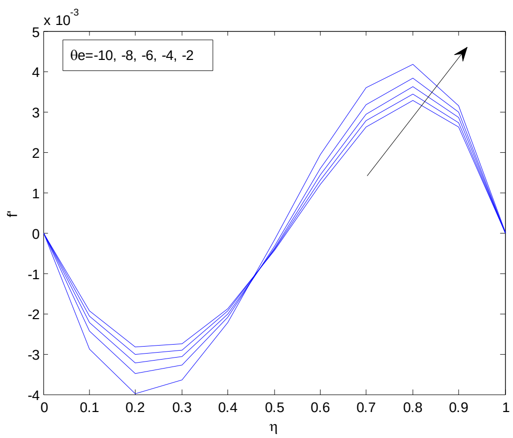

Fig : 1 Velocity Profile against θ_e

Fig. 1 displays the variation velocity profile for different values of viscosity parameters θe. It is observed from the figure that velocity increases for increase of viscosity. Parameters.

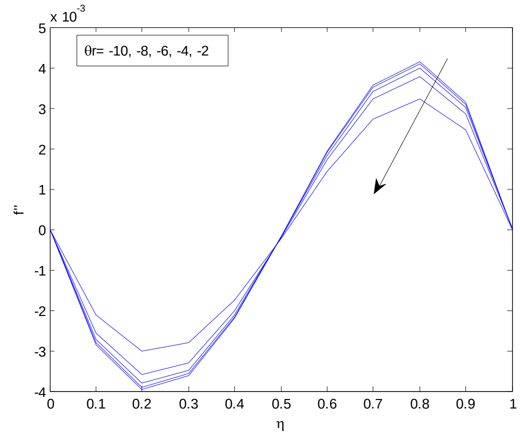

Fig : 2 Velocity Profile against Θ_r

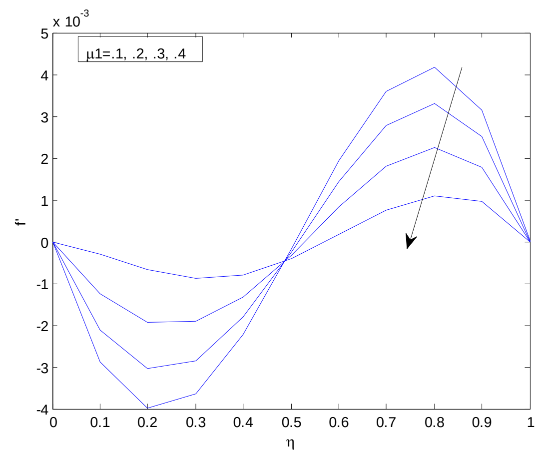

Fig : 3Velocity Profile against μ_1

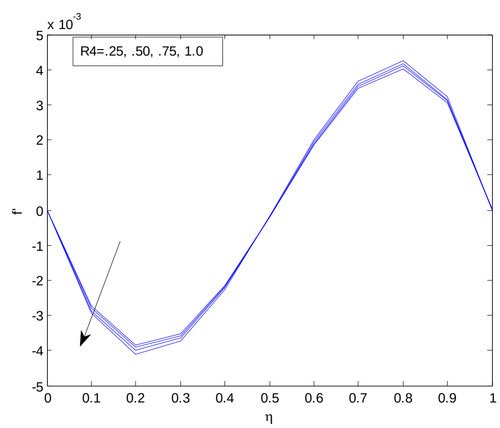

Fig : 4 Velocity Profile against R_4

Fig. 2 to Fig: 4 present the graphs of velocity profile for various values of Θ_r, μ_1, and R_4 respectively. It is clear from these figures that velocity profile decreases for increase of the thermal conductivity parameter Θ_r , micro polar parameters μ_1 and R_4 respectively.

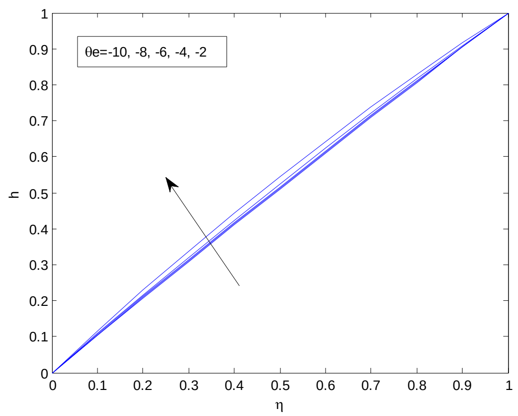

Fig : 5 Angular velocity Profile against $\emptyset_r$

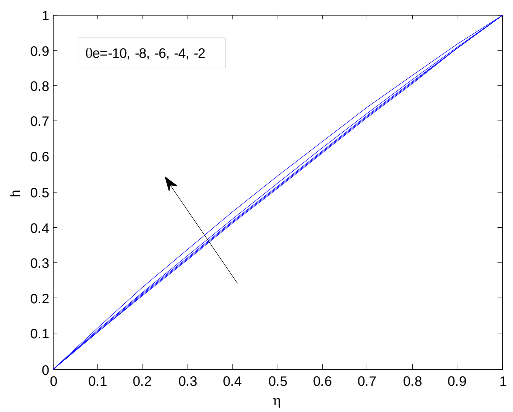

Fig: 6 Angular velocity profile against θ_e

Fig. 5 and Fig.6 represent the graphs of angular velocity profile h(η)for various values of thermal conductivity parameter Θ_r and viscosity parameter Θ_e respectively. It is clear from these figures that angular velocity profile increases for the increasing values of the said two parameters.

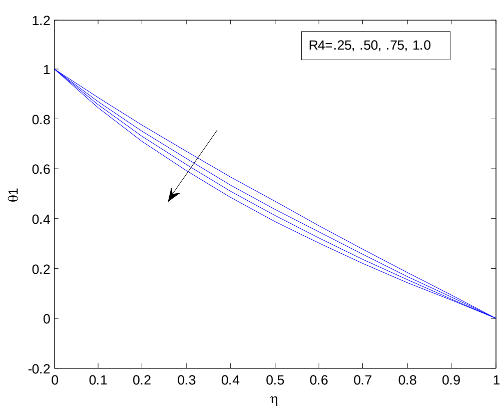

Fig: 7 Temperature Profile against R_4

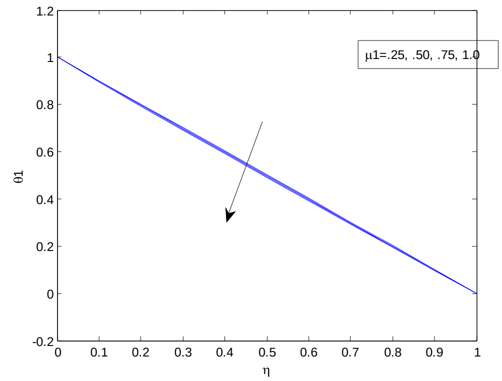

Fig : 8 Temperature Profile against μ_1

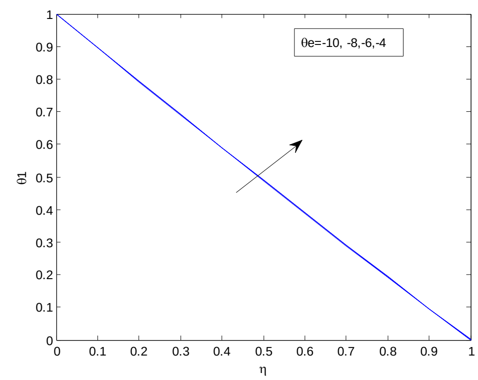

Fig: 9 Temperature Profile against θ_e

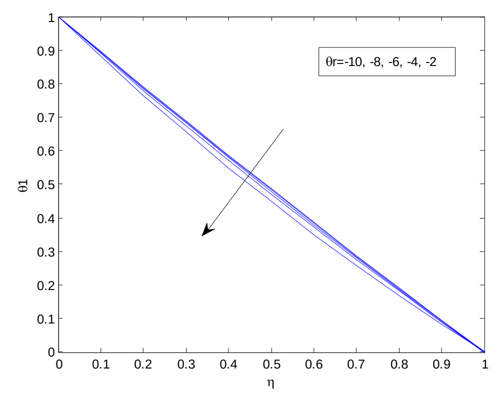

Fig: 10 Temperature Profile against Θ_r

Fig.7 to Fig.10 show the variation of temperature profile for the various values of the micro-polar parameter R_4, and μ_1 , viscosity parameter θ_e the thermal conductivity parameter Θ_r respectively. From the figures we see that temperature profile decreases for the increasing values of the micro-polar parameter μ_1 and R_4 and thermal conductivity parameter but it increases with the increase of viscosity parameter.

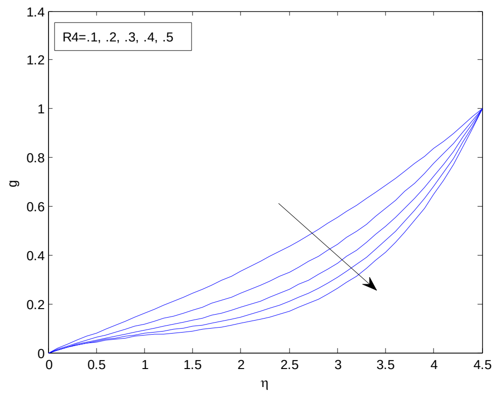

Fig: 11 Micro-rotation Profile against R_4

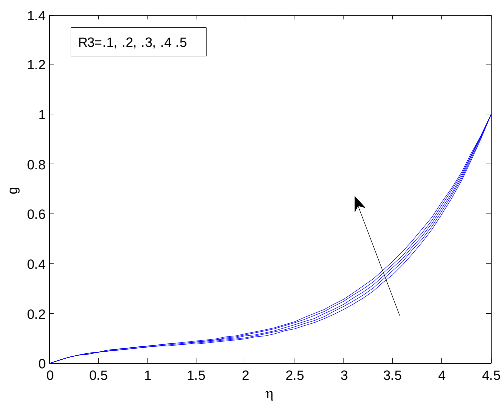

Fig: 12 Micro-rotation Profile against R_3

Fig. 11 and Fig: 12 represent the graphs of micro rotation profile g for micro rotation parameters R_4 and R_3 respectively. It is clear from these figures that micro rotation profile decreases remarkably for increase of micro polar parameters R_4 and it increases with the increases of R_3.

Table -1 to Table – 7 give the missing values $f'''(0)$, f''(o), θ_1'(o), θ_2'(o) and g'(o) for different values of θ_r and θ_e and Pr=0.5, θ_r=-2.0, Ec=0.5, Re=0.5, μ_1=0.1, R3=0.51 and R4=0.51. The results depicted in the tables are self explanatory. The missing values f''(o) gives the wall shear stress where as θ_1'(o), θ_2'(o) give the rate of heat transfer.

Table -1

Missing values of $f''(0)$, $f'''(0)$, $\Theta_1'(0)$, $\Theta_2'(0)$, $g'(0)$, $h'(0)$ For Pr = 0.7, Θ_r = -10, Re = 0.5, μ_1= 0.1 , R_3=0.51 and R_4 =0.51

Θ_e	Ec	$f''(0)$,	$f'''(0)$
-10.0000	0.8000	-0.0245	0.1002
-8.0000	0.8000	-0.0265	0.1123
-6.0000	0.8000	-0.0287	0.1266
-4.0000	0.8000	-0.0317	0.1464
-2.0000	0.8000	-0.0377	0.1868

$\Theta_1'(0)$	$\Theta_2'(0)$	$g'(0)$	$h'(0)$
-1.0382	0.0111	-1.2929	1.043
-1.0393	0.0069	-1.2929	1.0535
-1.0411	0.0001	-1.2929	1.0698
-1.0447	-0.0130	-1.2929	1.1005
-1.0541	-0.0485	-1.2928	1.1789

$\Theta_1'(0)$	$\Theta_2'(0)$	$g'(0)$	$h'(0)$
-1.0382	0.0111	-1.2929	1.043
-1.0393	0.0069	-1.2929	1.0535
-1.0411	0.0001	-1.2929	1.0698
-1.0447	-0.0130	-1.2929	1.1005
-1.0541	-0.0485	-1.2928	1.1789

Table -2

Missing values of $f''(0)$, $f'''(0)$, $\Theta_1'(0)$, $\Theta_2'(0)$, $g'(0)$, $h'(0)$ For Pr = 0.7, Θ_e = -10, Ec= 0.5, Re= 0.5, μ_1=0.1 , and R_3=0.51

ϴr	R4	f//(0),	f///(0)
-10	0.6	-0.0377	0.1862
-8	0.6	-0.037	0.1819
-6	0.6	-0.0359	0.1748
-4	0.6	-0.0336	0.161
-2	0.6	-0.0274	0.1222

ϴ1/(0)	ϴ2/(0),	g/(0),	h/(0)
-1.0495	-0.0061	-1.3407	1.1785
1.0612	-0.0061	-1.3407	1.1793
-1.0802	-0.0061	-1.3407	1.1806
-1.1168	-0.006	-1.3407	1.183
-1.2175	-0.006	-1.3408	1.1896

Table -3

Missing values of $f''(0)$, $f'''(0)$, $\Theta_1'(0)$, $\Theta_2'(0)$, $g'(0)$, $h'(0)$ For Pr=0.7, Θ_e=-10, Re=0.5, μ_1=0.1 , R_3=0.51 and R_4=0.51

ϴr	Ec	f//(0),	f///(0)
-10	0.6	-0.0376	0.1863
-8	0.6	-0.0369	0.182
-6	0.6	-0.0358	0.1749
-4	0.6	-0.0335	0.1611
-2	0.6	-0.0274	0.1223

ϴ1/(0)	ϴ2/(0),	g/(0),	h/(0)
-1.0559	-0.0364	-1.2928	1.179

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-1.0675	-0.0364	-1.2928	1.1798
-1.0865	-0.0363	-1.2928	1.1811
-1.1232	-0.0362	-1.2928	1.1835
-1.2238	-0.0357	-1.2929	1.19

Table -4
Missing values of $f^{//}(0)$, $f^{///}(0)$, $\Theta_1^{/}(0)$, $\Theta_2^{/}(0)$, $g^{/}(0)$, $h^{/}(0)$ For Pr=0.7, Θ_e=-10, Re=0.5, μ_1=0.1, R_3=0.51 and R_4=0.51

Ɵr	Ec	f//(0),	f///(0)
-10	0.4	-0.0378	0.1874
-8	0.4	-0.0371	0.1831
-6	0.4	-0.036	0.176
-4	0.4	-0.0337	0.1622
-2	0.4	-0.0275	0.1234

Ɵ1/(0)	Ɵ2/(0),	g/(0),	h/(0)
-1.0533	-0.0243	-1.2928	1.1788
-1.065	-0.0243	-1.2928	1.1796
-1.084	-0.0242	-1.2928	1.1809
-1.1206	-0.0241	-1.2928	1.1833
-1.2213	-0.0238	-1.2929	1.1898

Table -5
Missing values of $f^{//}(0)$, $f^{///}(0)$, $\Theta_1^{/}(0)$, $\Theta_2^{/}(0)$, $g^{/}(0)$, $h^{/}(0)$

For Pr=0.7, Ec=0.5, Θ_e=-10, Re=0.5, μ_1=0.1, and R_3=0.51

Ɵr	R4	f//(0),	f///(0)
-10	0.8	-0.0369	0.1803
-8	0.8	-0.0362	0.176
-6	0.8	-0.035	0.1689
-4	0.8	-0.0328	0.155
-2	0.8	-0.0266	0.1161

Ɵ1/(0)	Ɵ2/(0),	g/(0),	h/(0)
-1.0495	-0.0061	-1.4436	1.1785
-1.0612	-0.0061	-1.4436	1.1793
-1.0802	-0.0061	-1.4436	1.1806
-1.1169	-0.006	-1.4436	1.1831
-1.2175	-0.006	-1.4436	1.1896

Table -6
Missing values of $f^{//}(0)$, $f^{///}(0)$, $\Theta_1^{/}(0)$, $\Theta_2^{/}(0)$, $g^{/}(0)$, $h^{/}(0)$

For Pr=0.7, Ec=0.5, Θ_e=-10, Re=0.5, μ_1=0.1, and R_4=0.51

R3	f//(0),	f///(0)	Ɵ1/(0)
-10	0.4	-0.0244	0.0997
-8	0.4	-0.0264	0.1119
-6	0.4	-0.0286	0.1263
-4	0.4	-0.0318	0.1467
-2	0.4	-0.0384	0.1906

Ɵ2/(0),	g/(0),	h/(0)	
-1.0433	0.0014	-1.2929	1.0434
-1.0434	0.0009	-1.2929	1.0535
-1.0437	0	-1.2929	1.0699
-1.0441	-0.0016	-1.2929	1.1005
-1.0453	-0.0061	-1.2929	1.1782

Table -7
Missing values of $f^{//}(0)$, $f^{///}(0)$, $\Theta_1^{/}(0)$, $\Theta_2^{/}(0)$, $g^{/}(0)$, $h^{/}(0)$

For Pr=0.7, Ec=0.5, Θ_r=-10, Re=0.5, R_3=0.51, and R_4=0.51

Ɵe	μ1	f//(0),	f///(0)
-10	0.1	-0.0244	0.0998
-8	0.1	-0.0264	0.1119
-6	0	0.1	-0.0286
-4	0.1	-0.0318	0.1467
-2	0.1	-0.0384	0.1906

Ɵ1/(0)	Ɵ2/(0),	g/(0),	h/(0)
-1.0433	0.0014	-1.2929	1.0434
-1.0434	0.0009	-1.2929	1.0535
0.1264	-1.0437	0	-1.2929

-1.0441	-0.0016	-1.2929	1.1005
-1.0453	-0.0061	-1.2928	1.1782

V. Conclusions

The analysis presented above has shown that the micro-polar fluid flow field is influenced by the variation of the thermal conductivity parameter and the viscosity parameters . It is also seen that the heat transfer rate within the boundary layer is influenced by the variation of the said two parameters. Therefore , we can conclude that to predict more accurate results, the variable viscosity and thermal conductivity effects have to be taken into consideration on heat transfer due to non-Newtonian viscous fluid flow between two parallel disks to avoid the spoilt of energy. The result discussed above can be applied to engineering industrial problems for desired final product.

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