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Micropolar Fluid Flow in Porous Medium Sandwiched between Black Isothermal Plate and Solid Plate

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Abstract

This study employs a comprehensive analytical approach to investigate the flow of micropolar fluid within a porous medium, confined between two plates: a black isothermal plate at the lower region and a solid plate at the upper region. The plates are maintained at distinct constant temperatures, while radiative heat effects on the pressure gradient are neglected.The Brinkman equation is utilized to describe the behavior of the micropolar fluid in the porous domain. The governing equations are transformed into a system of differential equations and solved analytically using the Linear Differential Equation (LDE) method. Closed-form expressions for fluid velocity, micro-rotation, and temperature are derived, highlighting the influence of radiation in the absence of scattering, where the medium itself emits and absorbs radiation. Associated parameters such as viscosity, permeability, Prandtl number, Eckert number, and thermal radiation, are examined in detail, with their impacts visualized graphically using MATHEMATICA (10.3). The findings have significant practical implications for applications such as heat exchangers, cooling systems, and thermal energy storage solutions.

Keywords: Micropolar fluid, thermal radiation, radiation parameter, linear differential equation, isothermal plate, porous region,

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1. Introduction

With the progress of research, the study of non-Newtonian fluids has attracted considerable attention from scientists and researchers due to its growing utility and practical application in many fields, such as biological processes, industries, and engineering. A micropolar fluid is classified as a liquid with asymmetrical stress and a non-Newtonian complicated fluid with microstructure. Blood flows, Ferrofluids,liquid with crystaline structure, bubbling liquids etc. are examples of physical phenomena. Flow via a sponge, wire mesh, skin, rye bread, plant's branches, extraction and filtering of unpurified oils from the earth's surface, etc., needs the understanding of fluid flow in the porous medium [1, 2]. Micropolar fluid in porous regions has various engineering applications, such as heat exchangers, cooling systems, thermal energy storage, and some biomedical devices and treatments. Modeling of micropolar fluid in the existence of black isothermal plates presents additional challenges as compared to classical fluid flow due to the need to account for microstructural effect and their interaction with thermal radiation from the black surface. The problem presented and solved in this study is an application of the fluid flow through the porous medium.

Brinkman [3] made significant contributions to the study of fluid flow in regions with high permeability porous media by extending Darcy's law [4] through the inclusion of a viscous term. Erigen [1] was the first person who introduced the theory of the micropolar fluid, which involves the impact of the existence of microstructure and their movement on fluid flow. Comprehensive analysis of the practical application and theory can be obtained in the article by Ariman [5] and Lukaszewicz [2]. Shenoy [6] extensively analyzed the literature on heat transfer in non-Newtonian fluids in which Darcy and non-Darcy circumstances in confined flow and boundary layer with a fluid-saturated porous medium. Siegel [7] explained the fundamentals of radiative transfer, energy, and radiative transfer equation. Single-phase flow and entry conditions of the porous region were examined by Hamdan [8]. Rajak et al. [9] studied the propagation of waves in a fluid-saturated porous region to inspect the effect of heterogeneity with different variations in material properties.

Kaviany [10] examined the impact of Nusselt no., temperature profile, and excess pressure drop in the laminar flow of fluid through a porous matrix bounded by two parallel plates. Ishak

[11] discussed the thermal boundary layer in the stretching sheet and found that under the effect of radiation, the heat rate transmission at the surface reduces. Hassanien et al.[12] inspected heat transfer to micropolar fluid from a non-isothermal stretching sheet and obtained that the power law constant for the wall temperature and the surface mass transfer rate significantly impact on heat transfer. Reddy [13] examined micropolar fluid flow in stretching sheet with radiation effect using fourth-order Runge-Kutta along with the shooting method. Keimanesh et al. [14] explained the intensity of radiation and magnetic field on micropolar fluid over a stretching sheet and observed that the thickness of the thermal boundary layer decreased by reduction of radiation parameters and magnetic field effect. Mahmoud [15] described the radiation effect and variable thermal conductivity in micropolar fluid through a stretching sheet and found that the thermal boundary thickness decreased as the radiation parameter decreased while it increased as the thermal conductivity parameter increased. Hsiao [16] studied the heat and mass transfer with radiation effect in boundary layer flow in non-linear stretching sheet using the Runge–Kutta and Newton–Raphson method and Finite-difference method.

Bhattacharyya et al. [17] discussed the radiation effect in micropolar fluid in a shrinking sheet, governing equation solved with the help of the shooting method and shows that the wall mass suction must be raised to maintain a steady flow of micropolar fluid. Rashidi et al. [18] investigated the effect of radiation in micro-polar fluid by applying DTM and DTM Padé Approximation techniques and compared the obtained results from both techniques with Numerical Results. Alazmi et al. [19] used interfacial conditions in the flow and heat transfer of fluid through the porous region and applied slip and no-slip conditions at the interface. The impact of chemical reaction, radiation, and partial slip in MHD micropolar fluid over an inclined plate was examined by Das [20] and discussed the slip effect on mass and heat transfer in the presence of various physical parameters associated with that model. Raptis [21, 22] studied the radiation effect on the steady flow over a black isothermal plate in which an optically thin gray micropolar fluid was used. He used an optically thin gray micropolar fluid instead of thick gray micropolar fluid, and for thermal radiation, Rosseland Approximation was applied.

The model discussed about earlier, often used to study fluid flow and heat transfer through radiation with or without a permeable medium, inspired to explore the present problem. The main

goal of the present study is to discuss the radiation effect and flow behavior of micro-polar fluid in the porous region bounded by a black isothermal plate and solid plate. Kaviany [10] used viscous fluid flow through a porous matrix bounded by parallel plates in which equal temperature is considered. The boundary effect becomes less significant in the fluid flow because it depends on the porous shape, while in our study we used micropolar fluid instead of viscous fluid, and the porous region is bounded by black isothermal plate with the different constant temperatures at the boundary wall. Rashidi et al. [18] used porous region past in semi-infinite horizontal plate through which micropolar fluid flows. Using the Differential Transform Method (DTM), the authors derived an analytical solution and demonstrating that if the series approximation converges then the solution is considered to be exact. In contrast, the Linear Differential Equation (LDE) approach directly yields exact solutions, consistent with the principles of mathematical theory. Exact solutions are characterized by complete accuracy and precision, reflecting the true value without error or deviation. Meanwhile, the DTM produces an approximate solution expressed as a series expansion. Raptis [21, 22] studied radiation effect in micropolar fluid in clear fluid region. This study is very limited and unable to deal with the behavior of fluid flow and heat transfer rate, while in current problem we deal with heat transfer rate and define the behavior of fluid flow velocity and micro-rotation in the presence of various associated parameters.

To the author's knowledge, micropolar fluid in a porous region sandwiched between a black isothermal plate and a solid plate has not been inspected. Linear differential equation is applied to obtain an analytical solution. The effect of radiation parameter on heat transfer at the top and bottom of the region is defined in tabular format. The impact of all relevant parameters associated with our model on the velocity profile and temperature are represented graphically and described in detail.

2. Formualtion of the Problem

2.1. Explanation of the Governing Equation

The basic system of equation [2] for the micro-polar fluid are described below:

Equation of continuity

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \mathbf{v}) = 0 \tag{1}$$

Equation of linear momentum

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p + (\lambda + \mu - \mu_r)\nabla div\mathbf{v} + (\mu + \mu_r)\Delta \mathbf{v} + 2\mu_r \nabla \times \omega + \rho f \tag{2}$$

Equation of angular momentum

$$\rho I \frac{D\omega}{Dt} = 2\mu_r(\nabla \times v - 2\omega) + (c_0 + c_d - c_a)\nabla div\omega + (c_a + c_d)\Delta\omega + \rho g \tag{3}$$

Equation of energy

$$\frac{DT}{dt} + \nabla.(\mathbf{v}T) = \alpha \nabla^2(T) + \rho g \mathbf{v} \tag{4}$$

The fluid dynamics are characterized by various coefficients and variables, each representing specific physical properties. The general viscosity coefficients are denoted as λ and μ, while ρ indicates the density of fluid. The microrotational dynamic viscosity, describing resistance to angular motion within the fluid, is represented by μ_r. The angular viscosity coefficients, which account for rotational effects in the fluid, are expressed as c_0, c_a, and c_d.

The variable ω represents the micro-rotational velocity of the fluid, while v denotes the linear (or translational) velocity. The temperature field is indicated by T. Additionally, the microinertia coefficient, which quantifies the resistance to angular acceleration, is symbolized by I. External forces acting linearly on the fluid are denoted by f, and couple forces (torques) are represented by g.

The thermal diffusivity parameter, α, is defined as $\alpha = \frac{\tilde{\kappa}}{\rho C_p}$, where $\tilde{\kappa}$ is the effective thermal conductivity, and C_p is the specific heat capacity of the fluid. This parameter encapsulates the fluid's ability to conduct heat relative to its ability to store heat.

2.2. *Mathematical Model*

The physical configuration (Figure 1) explains that the porous medium exists between black isothermal plate and solid plate in which laminar incompressible micropolar fluid flows and plates expand in $x-$ axis and $y-$ axis. In the given region, h is the width of the porous region in which fluid flows under constant pressure gradient $P = \frac{\partial p}{\partial x}$. T_1 and T_2 are distinct constant temperatures imposed at the boundary of the wall and radiative heat do not affect the pressure gradient. Certain

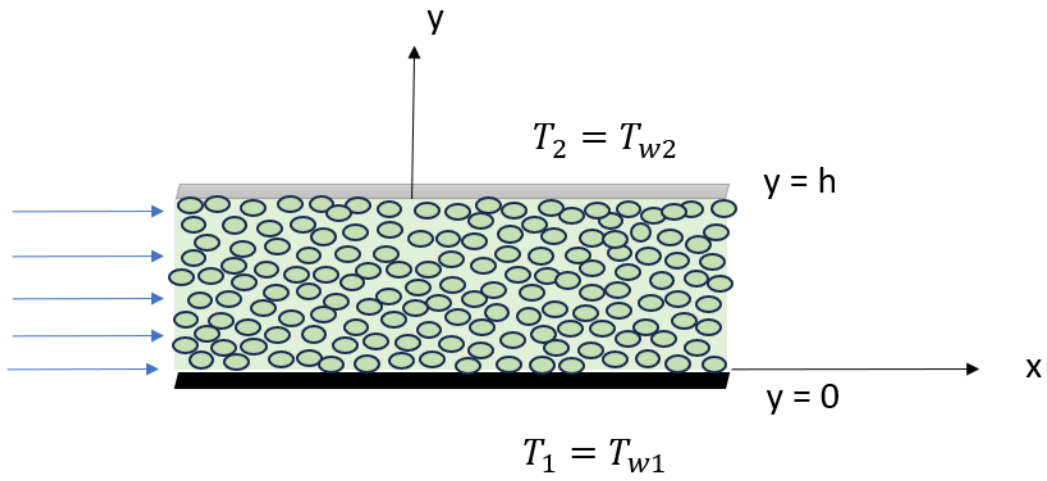


Figure 1: Geometry of the problem

assumptions are taken into consideration by authors based on thermal properties and flow of fluid, and they are characterized as

- The flow is considered incompressible, fully developed and steady.
- The flow is fully developed laminar, unidirectional, and along y-axis.
- Porous region is homogeneous and it is assumed that the radiative heat flux along the x-direction is negligible.
- The transport properties of micropolar fluid are supposed to be constant.

Based on these assumptions, the governing equation of motion, micro-rotational and temperature under the absence of external body force and body couple are as follows

$$(\mu + \kappa)\frac{d^2u}{dy^2} + \kappa\frac{d\omega}{dy} - \frac{\mu}{k^*}u = \frac{dp}{dx} \tag{5}$$

$$\gamma\frac{d^2\omega}{dy^2} - \kappa(2\omega + \frac{du}{dy}) = 0 \tag{6}$$

$$k^{**}\frac{d^2T}{dy^2} + \mu(\frac{du}{dy})^2 - \frac{1}{\rho C_p}\frac{dq_r}{dy} = 0 \tag{7}$$

where k^{**} is thermal conductivity, and $\frac{dq_r}{dy}$ is thermal radiative heat flux at the y-axis. μ, κ, and γ are are the viscosity coefficients of micropolar fluid.The component form of linear and micro-rotational velocities is v = (u, 0, 0) and $\omega = (0, 0, \omega)$, respectively. It is important to note that the y-component of velocity becomes constant because of the fully developed flow and continuity equation for incompressible flow; and this component vanishes when we apply the no-slip boundary condition at the parallel plates. And x- component of velocity of the fluid will be function of y only. As a result,v = (u,0,0), u = u(y) can be used to represent the flow velocity of micropolar fluid for our considered problem.The mathematical expression for γ is used by Ahmadi et al.[23] is as follows:
$\gamma = (\mu + \frac{\kappa}{2})j_d$, j_d defines microinertia density.

3. Solution of the problem

The following physical parameters are used to simplify the governing Eqs. (5)-(7)

$$\tilde{u} = \frac{u}{U}, \quad \tilde{y} = \frac{y}{h}, \quad \tilde{x} = \frac{x}{h}, \quad \tilde{p} = \frac{p}{\mu U/h}, \quad \tilde{\omega} = \frac{\omega}{U/h}, \quad \overset{*}{K} = \frac{k^*}{h^2}, \quad S^* = \frac{16a\sigma^*\mu T_r^3}{k^{**}}, \tag{8}$$

$$m = \frac{1}{\mu}, \quad j_d = h^2, \quad K = \frac{\kappa}{\mu}, \quad P_r = \frac{C_p\mu}{k^{**}}, \quad E_c = \frac{u^2}{C_p(T_{w1} - T_{w2})}, \quad \theta_i = \frac{T_i - T_{w2}}{T_{w1} - T_{w2}} \tag{9}$$

where U is the characteristic velocity of the fluid, h is the layer's width, and $\overset{*}{K}$ is the non dimensional permeability of the porous medium. S^*, E_c, and P_r are radiation parameter, Eckert no., and Prandtl no. respectively. With the help of parameters (dropping ~ symbol), the dimensionless form of governing Eqs.(5)-(6) can be define as:

$$(1 + K)\frac{d^2u}{dy^2} + K\frac{d\omega}{dy} - \frac{u}{\overset{*}{K}} = mP \tag{10}$$

$$(1 + \frac{K}{2})\frac{d^2\omega}{dy^2} - K(2\omega + \frac{du}{dy}) = 0 \tag{11}$$

at the region $0 \leq y \leq 1$, where m is the viscosity ratio and the material parameter of the micropolar fluid is represented by K. The range value of the micro-polar fluid parameter is K[0,∞) described in[1]. Let $\lambda = \frac{1}{\sqrt{K}^*}$ and Eq.(10) and Eq.(11) can be solved by simultaneous linear differential equation.

$$u(y) = c_1 e^{\xi y} + c_2 e^{-\xi y} + c_3 e^{\phi y} + c_4 e^{-\phi y} - \frac{2mP}{\lambda^2} \tag{12}$$

$$\omega(y) = S c_1 e^{\xi y} - S c_2 e^{-\xi y} + T c_3 e^{\phi y} - T c_4 e^{-\phi y} \tag{13}$$

where $\xi = \sqrt{\frac{f'^2 + \sqrt{f'^4 - 4g'^2}}{2}}$, $\phi = \sqrt{\frac{f'^2 - \sqrt{f'^4 - 4g'^2}}{2}}$, $f'^2 = \frac{\lambda^2 + 2K}{1+K}$ $g'^2 = \frac{4K\lambda^2}{(1+K)(2+K)}$,

S = $\frac{\lambda^2 - (1+K)\xi^2}{K\xi}$, T = $\frac{\lambda^2 - (1+K)\phi^2}{K\phi}$

and c_1, c_2, c_3 and c_4 are arbitrary constants.

For temperature analysis:

When considering micropolar fluid, the local radiation across a black isothermal plate can be described as follows: [7]

$$-\frac{dq_r}{dy} = 2a\sigma^*(T_1^4 + T_2^4 - 2T^4) \tag{14}$$

where absorption coefficient is denoted by a and the Stefan-Boltzman constant is denoted by σ^*. T denotes fluid temperature, T_1 is the fluid temperature at the isothermal plate and T_2 is the fluid temperature at solid plate.

We put

$$2T_r^4 = T_1^4 + T_2^4 \tag{15}$$

where $T_2 < T_r < T_1$

By using Eqs. (14)-(15), Eq. (7) gives

$$\frac{\kappa^{**}}{\rho C_p}\frac{d^2T}{dy^2} + \mu(\frac{du}{dy})^2 + \frac{4a\sigma^*}{\rho C_p}(T_r^4 - T^4) = 0 \tag{16}$$

According to our presumption, the temperature variance within the flow is such that T^4 can be written as a linear function of T. This is accomplished by neglecting higher-order terms and expansion in a Taylor series about Tr thus

$$T^4 \cong 4T_r^3 T - 3T_r^4 \tag{17}$$

using (17) in equation (16) gives

$$\frac{\kappa^{**}}{\rho C_p}\frac{d^2T}{dy^2} + \frac{16a\sigma^* T_r^3}{\rho C_p}(T_r - T) + \mu(\frac{du}{dy})^2 = 0 \tag{18}$$

With the help of parameters Eqs. (8)-(9), the non-dimensional form of governing eq. (7) can be defined as:

$$\frac{d^2\theta}{dy^2} - S^*\theta = E_c P_r(\frac{du}{dy})^2 \tag{19}$$

Using the classical method of linear differential technique to get the solution of Eq.(19).

$$\theta(y) = l_1 e^{\sqrt{S^*}y} + l_2 e^{-\sqrt{S^*}y} + r_1 e^{2\xi y} + r_2 e^{-2\xi y} + r_3 + r_4 e^{2\phi y} + r_5 e^{-2\phi y} + r_6 + r_7 e^{(\xi+\phi)y} - r_8 e^{-(\xi-\phi)y} - r_9 e^{(\xi-\phi)y} + r_{10} e^{-(\xi+\phi)y} \tag{20}$$

where l_1 and l_2 are arbitrary constants and the values of r_1-r_{10} are given in the appendix section.

4. Boundary Condition

The dimensionless boundary conditions on the temperature and velocity are as follows

No slip boundary condition

$$u = 0 \;\; at \;\; y = 0 \;\; and \;\; y = 1 \tag{21}$$

No spin condition

$$\omega = 0 \;\; at \;\; y = 0 \;\; and \;\; y = 1 \tag{22}$$

For temperature effect

$$\theta = 0 \;\; at \;\; y = 1 \tag{23}$$

$$\theta = 1 \;\; at \;\; y = 0 \tag{24}$$

By using LinearSolve in MATHEMATICA (10.3) software, boundary conditions (21)-(24) applied in Eqs. (12)-(13) and (20), the authors are able to determine the values of arbitrary constants, which are mentioned below in the appendix section.

4.1. ***Heat transfer rate***

The rate of heat transfer through the black isothermal plate to the fluid in the dimensionless form is given by

$H_T = (\frac{d\theta}{dy})_{y=1}$ and $H_B = (\frac{d\theta}{dy})_{y=0}$ where H_T and H_B are heat transfer rate at the top and bottom respectively.

5. Result and discussion

The present problem deals with the flow of micro-polar fluid in a porous medium sandwiched between a black isothermal plate and a solid plate. The influence of various fluid flow controlling parameters are discussed below, and data has been taken from [11, 17, 21, 24] .

5.1. Fluid velocity under the impact of physical parameters

Figures 2–4 vividly depict the non-dimensional velocity profile of the fluid, showcasing its intricate variation with respect to the permeability, K, and the viscosity parameter. Fig. 2 explores the influence of varying viscosity under constant pressure gradient, material parameter, and permeability. The results indicate that increasing the viscosity parameter reduces the fluid's velocity. This outcome reflects the expected behavior, as higher viscosity represents greater internal resistance, leading to a reduction in fluid motion. Fig. 3 define the effect of permeability parameter on velocity profile. In this case, the focus shifts to the impact of permeability while maintaining material parameter (K) , viscosity, and fixed pressure gradient. The velocity profile demonstrates a positive correlation with permeability; as the permeability parameter increases, the fluid velocity rises. This behavior can be attributed to reduced resistance to flow in more permeable media, enabling the fluid to move more freely. Fig.4 explain the role of the material parameter K, using a range of values referenced from [24]. It is observed that as K increases, the fluid velocity decreases. This suggests that the microstructural effects represented by K impose additional constraints on the fluid's motion, reducing its velocity. The observed trends align with previous findings in the literature, particularly those reported in [24], further validating the results. These relationships emphasize the complex interplay of viscosity, permeability, and K on the velocity profile of micropolar fluids.

5.2. Micro-rotation velocity under the influence of taken parameters

The description explains the findings presented in Figs. 5-6, which focus on the behavior of micro-rotational velocity, a characteristic feature of micropolar fluids. These fluids exhibit unique properties due to their ability to sustain micro-rotational motion, influenced by factors like viscosity and the material parameter K. Fig. 5 examines how changes in the viscosity parameter affect

the micro-rotational velocity while keeping other factors such as pressure gradient, permeability, and material parameter constant. The results show that as the viscosity parameter increases, the micro-rotational velocity decreases. This behavior suggests that higher viscosity dampens the rotational motion of the fluid particles, reducing their ability to rotate freely under the same conditions.Figure 6 depict the effect of material parameter on mmicro-rotational velocity. An increase in K also results in a reduction in the micro-rotational velocity. This indicates that larger values of K, potentially representing stiffer or more resistant microstructural components, suppress the micro-rotational dynamics of the fluid. The described trends align with findings in prior studies [16, 24], reinforcing the consistency of these observations across different contexts.

5.3. Effect of physical parameters on temperature

Fig.7-11 describe the impact of all parameters like viscosity, Prandtl no. Eckert no., radiation parameter, etc., on the temperature profile. Fig. 7 defines the impact of viscosity in the existence of thermal radiation, Prandtl no., Eckert no., constant pressure gradient, etc., on temperature. Raising the viscosity reduces temperature because viscosity is reciprocal to temperature, while material parameter showing in Fig. 8 explains its impression on the temperature profile. The range of material parameter (K) adopted as the same of [24]; raising the range of K found to be directly proportional to an increment in the fluid's temperature. Fig. 9 explains the effect of the radiation parameter on temperature variation. Raising the value of the radiation parameter leads to a reduction in temperature. The variation of the current study found to be similar with [16].

Fig. 10-11 illustrate the dynamic relationship between non-dimensional parameters Prandtl number and Eckert number and their impact on thermal profiles under unchanging pressure gradients, thermal radiation, and viscosity effects. Fig. 10 reveals that as the Prandtl number increases, the temperature also rises, emphasizing the parameter's influence on thermal conductivity and diffusivity balance. Similarly,Fig. 11 demonstrates how the Eckert number influence the temperature profile, with higher values driving an increase in temperature due to enhanced viscous dissipation effects. These observed trends align closely with the findings reported in previous studies [16, 24], further validating the results presented.

Fig. 12 and Fig. 13 explain the 3D visualization of variation in velocity and temperature under

the influence of viscosity parameters. Table indicate the variation in heat transfer rate under the influence of radiation parameter. When we raise the range of radiation parameter then heat transfer rate get effected and decrease.

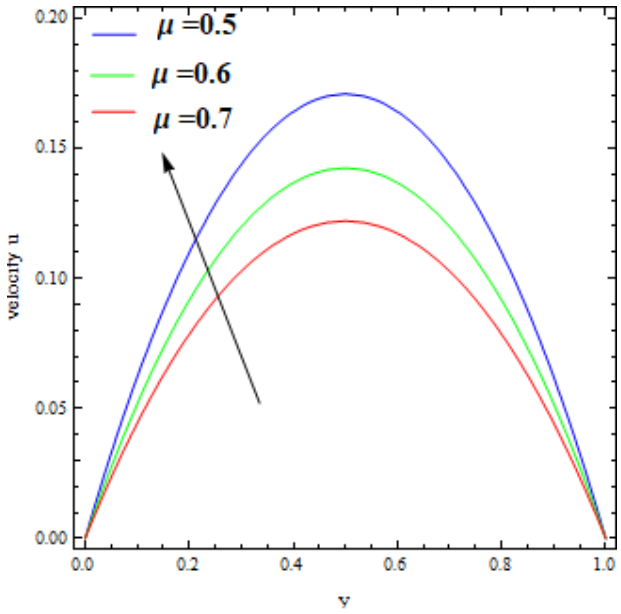


Figure 2: changement in velocity profile for different value of μ when P = -0.7,K = 1 and κ=0.5

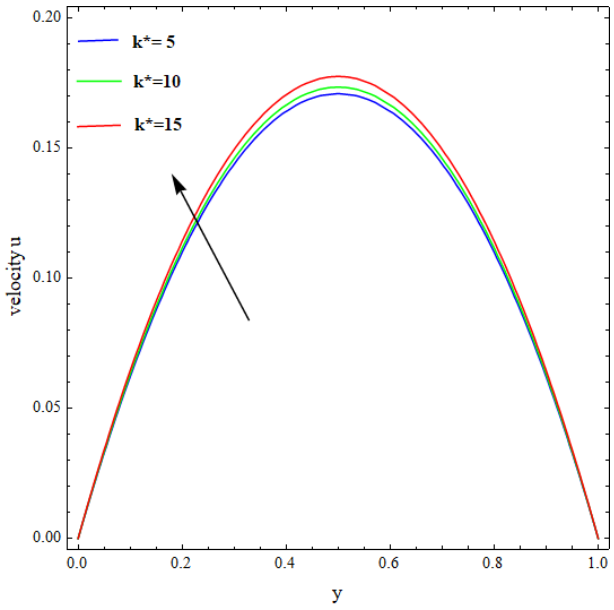


Figure 3: variation in velocity for different value k^* when μ = 0.5, P = -0.7, K = 1 and κ=0.5

Table : Impact of radiation parameter on Heat transfer rate

P=-0.7, κ=0.5, μ=0.5, h=1 and k^*=5 showing changes in the top and bottom for heat transfer rate					
S^*	K	E_c	P_r	H_T	H_B
6	1	0.5	0.5	-0.84626680797	0.84626680797
7	1	0.5	0.5	-0.57738041431	0.57738041431
8	1	0.5	0.5	-0.44307304089	0.44307304089
9	1	0.5	0.5	-0.36108785693	0.36108785693

6. Conclusion

In this work, the author presented a mathematical model for the flow of fluid in a porous region sandwiched between a black isothermal plate and a solid plate. The mathematical model

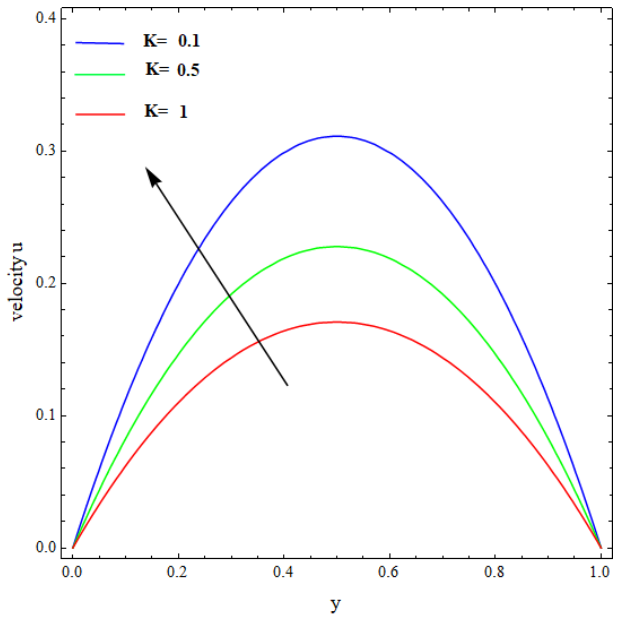


Figure 4: variation in velocity for different value of K when μ = 0.5, P = -0.7 and κ=0.5

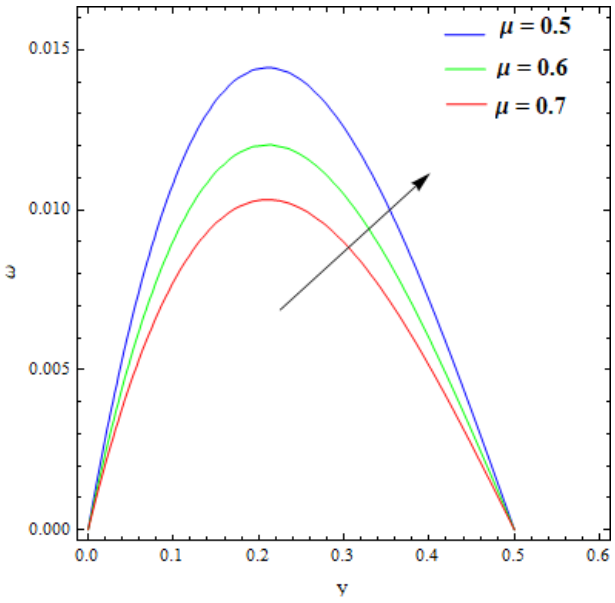


Figure 5: variation in microrotation velocity with respect to viscosity when P =-0.7, K = 1 and κ=0.5

associated with the problem is resolved through analytical methods, incorporating appropriate boundary conditions. The variation of velocity, micro-rotation, and temperature, as well as the influence of all physical parameters, are represented graphically by MATHEMATICA. From this study, the authors made the following conclusions.

- This study reveals that raising the viscosity parameter will reduce the fluid linear, micro-rotation velocity and temperature profile.
- Increasing the value of Prandtl no., Eckert no. and material parameter increase the temperature while the opposite result appears in case of temperature with respect to radaition parameter.
- Increasing the material parameter enhances the fluid's resistance to motion, leading to a reduction in both linear and micro-rotation velocities. This reflects the influence of material properties on fluid dynamics..
- Enhancing the range value of permeability defines that there is an increment in fluid velocity.

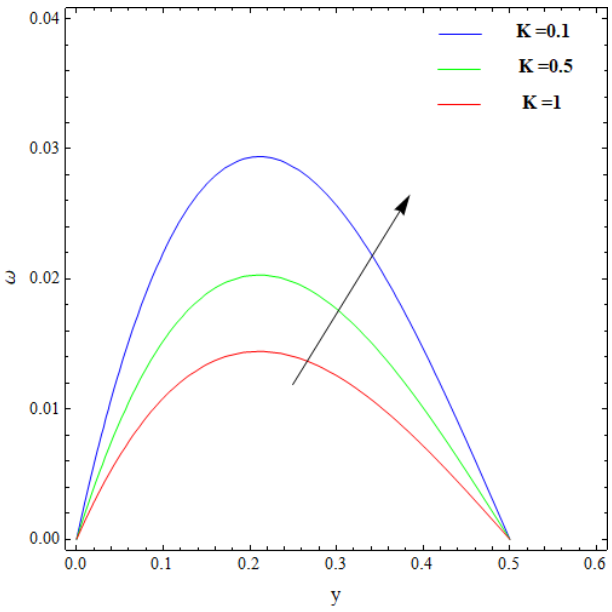


Figure 6: variation in microrotation velocity with respect to material parameter when μ =0.5,P = -0.7, K = 1and κ=0.5

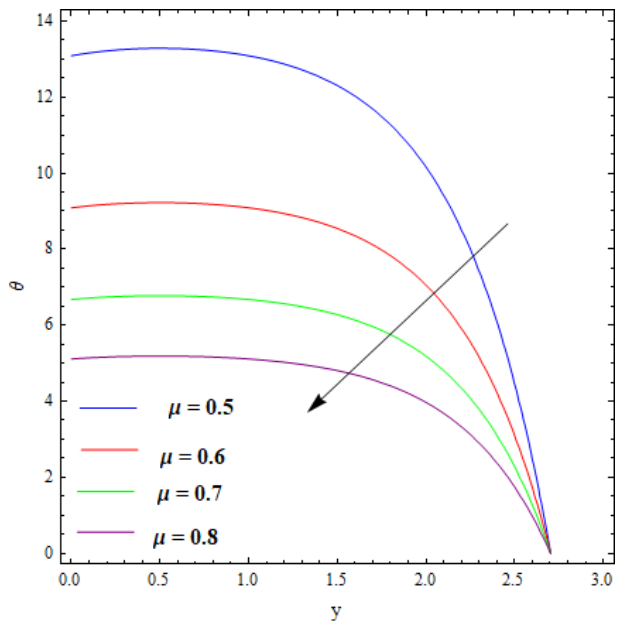


Figure 7: Temperature profile with respect to viscosity when P = -0.7, K = 1, P_r=1, E_c=1, S^*=6 κ=0.5

Author contribution The work have been equally accomplished by each authors.

Data availability The data that support the finding of this study are available.

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Declaration

Conflict of interest Regarding the research, writing, and publication of this paper, the authors stated that there are no conflicts of interest.

References

[1] A. C. Eringen, Theory of micropolar fluids, Journal of mathematics and Mechanics (1966) 1–18.

[2] G. Lukaszewicz, Micropolar fluids: theory and applications, Springer Science & Business Media, 1999.

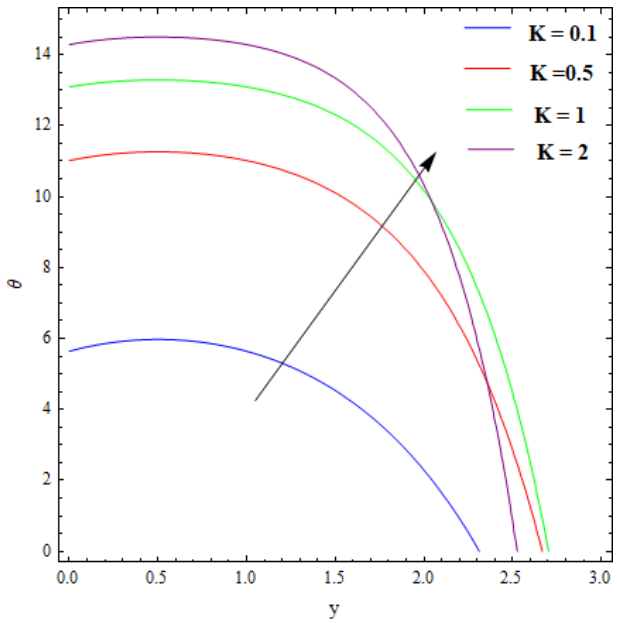


Figure 8: variation in temperature with respect to material parameter when P = -0.7, μ= 0.5, P_r=1, E_c=1, S^*=6, κ=0.5

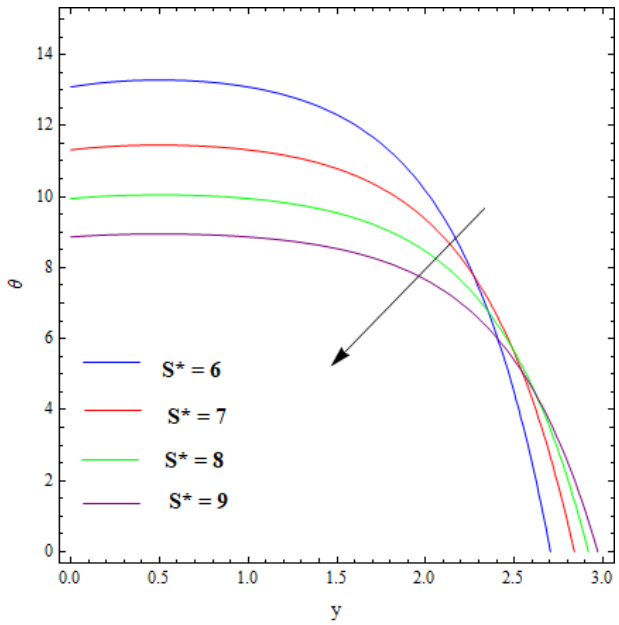


Figure 9: variation in temperature with respect to radaition parameterwhen P = -0.7, μ= 0.5, P_r=1, E_c=1,κ=0.5 and K =1

[3] H. C. Brinkman, A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles, Flow, Turbulence and Combustion 1 (1949) 27–34.

[4] H. Darcy, Les fontaines publiques de la ville de Dijon: exposition et application des principes à suivre et des formules à employer dans les questions de distribution d'eau... un appendice relatif aux fournitures d'eau de plusieurs villes au filtrage des eaux, Vol. 1, Victor Dalmont, éditeur, 1856.

[5] T. Ariman, Micropolar and dipolar fluids, International Journal of Engineering Science 6 (1) (1968) 1–8.

[6] A. Shenoy, Non-newtonian fluid heat transfer in porous media, in: Advances in Heat transfer, Vol. 24, Elsevier, 1994, pp. 101–190.

[7] R. Siegel, Thermal radiation heat transfer, CRC press, 2001.

[8] M. Hamdan, Single-phase flow through porous channels a review of flow models and channel entry conditions, Applied Mathematics and Computation 62 (2-3) (1994) 203–222.

[9] B. P. Rajak, S. Kundu, S. Gupta, D. Kumar, Love wave propagation characteristics in a fluid-saturated cracked double porous layered structure, Mechanics of Advanced Materials and Structures (2022) 1–13.

[10] M. Kaviany, Laminar flow through a porous channel bounded by isothermal parallel plates, International Journal of Heat and Mass Transfer 28 (4) (1985) 851–858.

[11] A. Ishak, Thermal boundary layer flow over a stretching sheet in a micropolar fluid with radiation effect, Meccanica 45 (2010) 367–373.

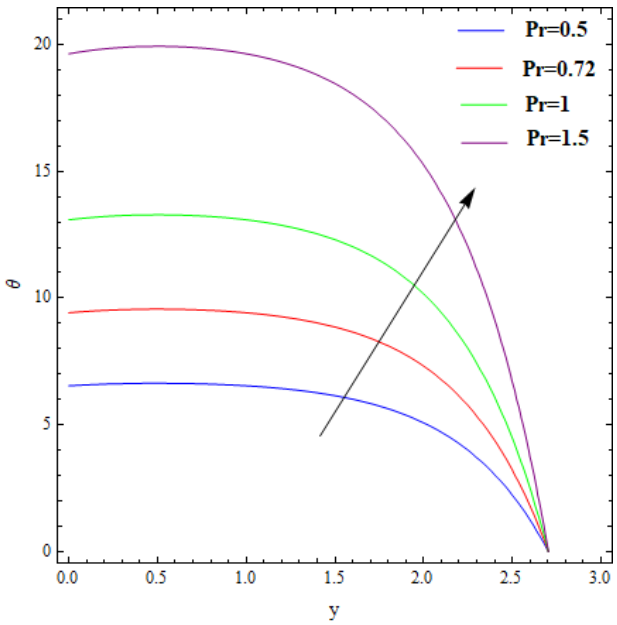


Figure 10: effect in temperature with respect to Prandtl no. when P = -0.7, μ= 0.5, E_c=1, S^*=6, κ=0.5 and K=1

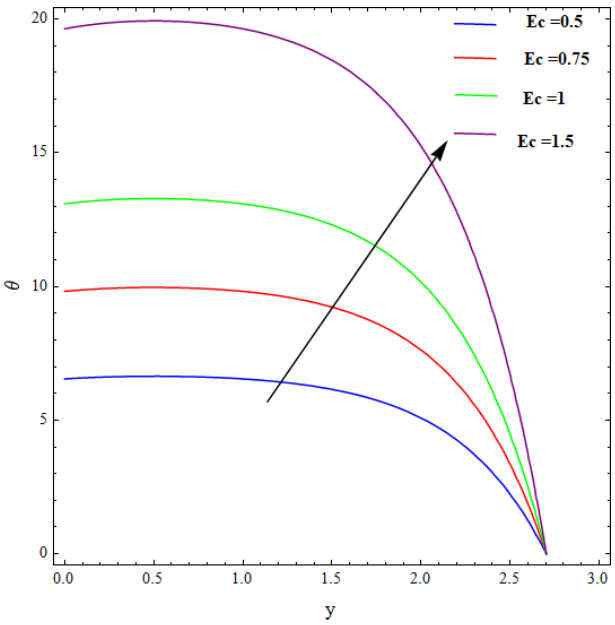


Figure 11: variation in temperature with respect to Eckert no. when P = -0.7, μ= 0.5, P_r=1,S^*=6, κ=0.5 and K=1

[12] I. Hassanien, R. Gorla, Heat transfer to a micropolar fluid from a non-isothermal stretching sheet with suction and blowing, Acta Mechanica 84 (1990) 191–199.

[13] M. G. Reddy, Heat generation and thermal radiation effects over a stretching sheet in a micropolar fluid, International Scholarly Research Notices 2012 (2012).

[14] R. Keimanesh, C. Aghanajafi, The effect of temperature dependent viscosity and thermal conductivity on micropolar fluid over a stretching sheet, Tehn. vjesn 24 (2017) 371–378.

[15] M. A. Mahmoud, Thermal radiation effects on mhd flow of a micropolar fluid over a stretching surface with variable thermal conductivity, Physica A: Statistical Mechanics and its Applications 375 (2) (2007) 401–410.

[16] K.-L. Hsiao, Heat and mass transfer for micropolar flow with radiation effect past a nonlinearly stretching sheet, Heat and mass transfer 46 (2010) 413–419.

[17] K. Bhattacharyya, S. Mukhopadhyay, G. Layek, I. Pop, Effects of thermal radiation on micropolar fluid flow and heat transfer over a porous shrinking sheet, International Journal of Heat and Mass Transfer 55 (11-12) (2012) 2945–2952.

[18] M. Rashidi, S. Mohimanian Pour, A novel analytical solution of heat transfer of a micropolar fluid through a porous medium with radiation by dtm-padé, Heat Transfer—Asian Research 39 (8) (2010) 575–589.

[19] B. Alazmi, K. Vafai, Analysis of fluid flow and heat transfer interfacial conditions between a porous medium and a fluid layer, International Journal of Heat and Mass Transfer 44 (9) (2001) 1735–1749.

[20] K. Das, Slip effects on heat and mass transfer in mhd micropolar fluid flow over an inclined plate with thermal

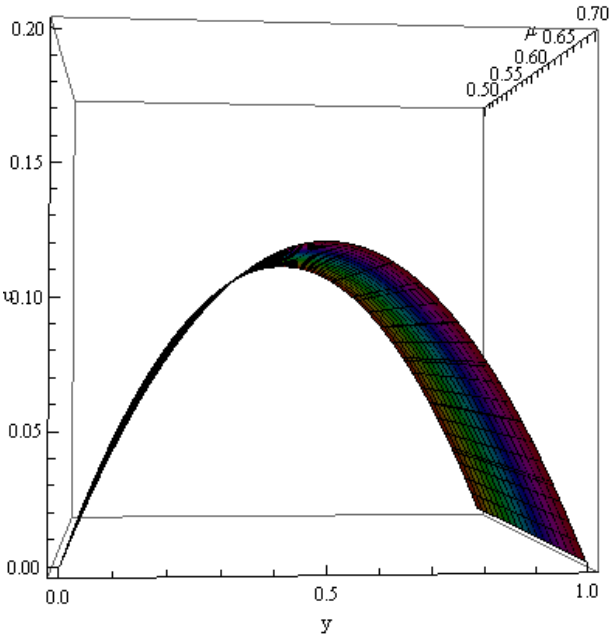


Figure 12: velocity profile for different range of viscosity when P = -0.7,K = 1 and κ=0.5

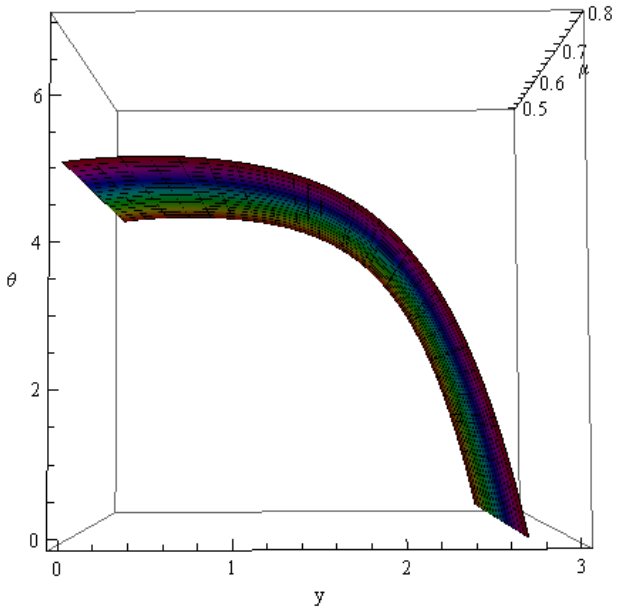


Figure 13: Temperature profile with respect to viscosity when P = -0.7, K = 1, P_r=1, E_c=1, S^*=6 κ=0.5

radiation and chemical reaction, International Journal for Numerical Methods in Fluids 70 (1) (2012) 96–113.

[21] A. Raptis, Micropolar flow over a black isothermal plate in the presence thermal radiation, International Journal of Applied Mechanics and Engineering 26 (2) (2021) 235–241.

[22] A. Raptis, Thermal radiation and magnetohydrodynamics flow over a black isothermal plate, Thermal Science 26 (1 Part B) (2022) 753–758.

[23] G. Ahmadi, Self-similar solution of imcompressible micropolar boundary layer flow over a semi-infinite plate, International Journal of Engineering Science 14 (7) (1976) 639–646.

[24] J. Umavathi, A. J. Chamkha, M. Shekar, Flow and heat transfer of two micropolar fluids separated by a viscous fluid layer, International Journal of Microscale and Nanoscale Thermal and Fluid Transport Phenomena 5 (1) (2014) 23.

Appendix

$$r_1 = \frac{E_c \mathrm{P}_r \xi^2 {c_1}^2}{4\xi^2 - S^*}, \quad r_2 = \frac{E_c \mathrm{P}_r \xi^2 c_2^2}{4\xi^2 - S^*}, \quad r_3 = \frac{2E_c \mathrm{P}_r c_1 c_2}{S^*}, \quad r_4 = \frac{E_c \mathrm{P}_r \phi^2 c_3^2}{4\phi^2 - S^*}$$

$$r_5 = \frac{E_c \mathrm{P}_r \phi^2 c_4^2}{4\phi^2 - S^*}, \quad r_6 = \frac{2E_c \mathrm{P}_r c_3 c_4}{S^*}, \quad r_7 = \frac{2E_c \mathrm{P}_r \xi\phi c_1 c_3}{(\phi+\xi)^2 - S^*}, \quad r_8 = \frac{2E_c \mathrm{P}_r \xi\phi c_2 c_3}{(\xi-\phi)^2 - S^*}$$

$$r_9 = \frac{2E_c \mathrm{P}_r \xi\phi c_1 c_4}{(\xi-\phi)^2 - S^*}, \quad r_{10} = \frac{2E_c \mathrm{P}_r \xi\phi c_2 c_4}{(\xi+\phi)^2 - S^*}, \quad l_1 = \frac{\mathrm{e}^{\sqrt{S^*}}}{-1 + \mathrm{e}^{2\sqrt{S^*}}}, \quad l_2 = \frac{-\mathrm{e}^{\sqrt{S^*}}}{-1 + \mathrm{e}^{2\sqrt{S^*}}}$$

$$c_1 = \frac{2\left(-1+\mathrm{e}^{\phi}\right)mPT}{\left(S-\mathrm{e}^{\xi}S+\mathrm{e}^{\phi}S-\mathrm{e}^{\xi+\phi}S-T-\mathrm{e}^{\xi}T+\mathrm{e}^{\phi}T+\mathrm{e}^{\xi+\phi}T\right)\lambda^2},$$

$$c_2 = \frac{2\mathrm{e}^{\xi}\left(-1+\mathrm{e}^{\phi}\right)mPT}{\left(S-\mathrm{e}^{\xi}S+\mathrm{e}^{\phi}S-\mathrm{e}^{\xi+\phi}S-T-\mathrm{e}^{\xi}T+\mathrm{e}^{\phi}T+\mathrm{e}^{\xi+\phi}T\right)\lambda^2},$$

$$c_3 = \frac{2\left(-1+\mathrm{e}^{\xi}\right)mPS}{\left(-S+\mathrm{e}^{\xi}S-\mathrm{e}^{\phi}S+\mathrm{e}^{\xi+\phi}S+T+\mathrm{e}^{\xi}T-\mathrm{e}^{\phi}T-\mathrm{e}^{\xi+\phi}T\right)\lambda^2},$$

$$c_4 = \frac{2\mathrm{e}^{\phi}\left(-1+\mathrm{e}^{\xi}\right)mPS}{\left(-S+\mathrm{e}^{\xi}S-\mathrm{e}^{\phi}S+\mathrm{e}^{\xi+\phi}S+T+\mathrm{e}^{\xi}T-\mathrm{e}^{\phi}T-\mathrm{e}^{\xi+\phi}T\right)\lambda^2}$$