Impact Of Magnetic Field On Natural Convective Flow Of A Micropolar Fluid Between Two Porous Vertical Walls

Y. V. Seshagiri Rao[1], G. Bal Reddy[2], Dr. A. Srinivas[3]

[1]Department of Basic Sciences & Humanities, Vignan Institute of Technology and Science,
Deshmukhi (V), Pochampally (M), Yadadri-Bhuvanagiri (Dist), TS-508284, India
Email: yangalav@gmail.com

[2]Department of Mathematics & Humanities, Mahatma Gandhi Institute of Technology,
Kokapet (V), Gandipet, Hyderabad, TS-500075, India
Email: gbalu1729@gmail.com

[3]Department of Mathematics, Balaji Institute of Technology and Science (Autonomous)
Narsampet, Warangal, TS -506331, India
E-mail: anumandlasrinivas8845@gmail.com

ABSTRACT

Mathematical analysis of an unsteady boundary layer flow of an incompressible micro-polar fluid under uniform magnetic field and motion takes place due to the buoyancy force between porous vertical walls along heat source has been carried out. The governing unsteady boundary layer momentum, angular momentum and energy equations of micro-polar fluid are nondimensionilzed and solved numerically by using finite difference method. The effect of magnetic parameter, porous permeability, vortex viscosity parameter, Prandtl number and material parameter on velocity, micro-rotation and temperature profiles is discussed numerically.

Keywords: Magnetic field, Micro-polar fluid, Vertical walls, Porous medium

1. INTRODUCTION

Convection flow arises in many physical situations such as in the cooling of nuclear reactors and environmental heat transfer processes amongst others. It is of three types namely free, mixed and force. Amongst them, the problems of magneto hydrodynamic free convective flow in a porous medium have drawn considerable attentions of several researchers in various scientific and technological applications such as pumps, plasma jet engines, generators, accelerators, flow meters, and magnetic control of molten iron flow in steel industry and industrial processes in metallurgy and material processing, in chemical industry, industrial power engineering and nuclear engineering. In view of above many authors explained their motivated ideas, some of them studied [1-10].

The concept of micropolar fluid deals with a class of fluids that exhibit certain microscopic effects arising from the micromotions of the fluid elements. These fluids contain dilute suspension of rigid macromolecules with individual motions that support stress and body moments and are influenced by spin inertia. Micropolar fluids are those which contain micro-constituents that can undergo rotation, the presence of which can affect the hydrodynamics of the flow so that it can be distinctly non-Newtonian. It has many practical applications, for example, analyzing the behaviour of exotic lubricants, the flow of colloidal suspensions or polymeric fluids, liquid crystal, additive suspensions, human and animal blood, turbulent shear flow and so forth. Above consideration studied by [11-20].

Many natural fluids accumulate small TC (thermal conductivity) for heat transfer, which is regarded as a significant barrier in the development of the thermal flow system. The manufacturing of numerous devices and components used in industrial and technological applications has advanced significantly in the modern world. For example, in the industry, several gadgets due to the resistance of electricity begin to increase their temperature with time. Because of the electric resistance, the heat-carrying capability of such gadgets was reduced, resulting in a technical fault. Heat intemperance from various devices and components is required to reduce the risk of a technical fault. As a result, industrialists utilize fluids like water, air, and lubricants to manage proper heat transport. However, at the industrial level, such natural fluids do not meet the requirements. To accomplish these objectives, investigators have investigated various ways to keep fluid flow and transmission of heat within the design limit. One of these ways is to add nanoparticles (NPs) to various natural fluids because of their lower TC. Furthermore, the properties of nanofluids can be designed for a particular application if required [21-30].

In these studies, the importance of hydromagnetic flows has been overlooked in spite of their large-scale industrial and engineering applications—mainly in the pharmaceutical products, curative drugs, metallurgy, paper production, fabrication of glass, MHD flow meters and pumps, etc.

2. FORMULATION OF THE PROBLEM

Made an attempt on unsteady free convective flow of an incompressible micro-polar fluid between two insulated porous vertical walls separated by a distance L apart subjected to a uniform transverse magnetic field along with heat source. The coordinate system is chosen such that x' measures the distance along the walls and y' measures the distance normal to it. Initially, the temperatures of walls the fluid are same says T_j'. When time $t'>0$, the temperature of the walls at $y'=0$ and $y'=L$ is instantaneously raised and lowered to T_h' and T_c' respectively such that $T_h'>T_c'$ which is the after maintained constant. A constant uniformly distributed transverse magnetic field strength B_0 is applied in the y' direction. Physically model and coordinate system are shown below figure (1).

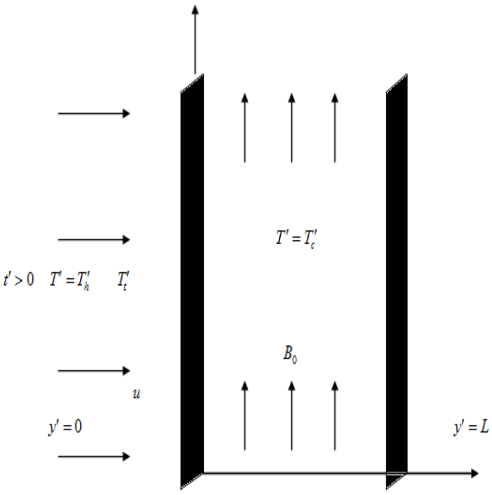

Figure (1): Flow geometry

The transversely applied magnetic field and magnetic Reynolds number are very small and hence the induce magnetic field is negligible. No electrical field is assumed to exist and both viscous and magnetic dissipation are neglected. The Hall effects, the viscous dissipation and the joule heating terms are also neglected. Under these assumption and taking into account the Boussinesq and boundary layer approximations, momentum, angular momentum and energy equation of micropolar fluid can be expressed as follows.

$$\rho\frac{\partial u'}{\partial t'} = (\mu+k)\frac{\partial^2 u'}{\partial y'^2} + k\frac{\partial \omega'}{\partial y'} + \rho g\,\beta\left(T' - T_m'\right) - B_0^2\sigma u' - \nu u' \tag{1}$$

$$\rho j\frac{\partial \omega}{\partial t'} = (\mu + 0.5k)\frac{\partial^2 \omega'}{\partial y'^2} - k\left(2\omega' + \frac{\partial u'}{\partial y'}\right) \tag{2}$$

$$\frac{\partial T'}{\partial t'} = \alpha\frac{\partial^2 T'}{\partial y'^2} - \frac{Q'}{\rho c_p}\left(T' - T_m'\right) \tag{3}$$

The initial and boundary conditions are:

$$\begin{aligned} &t \le 0: u' = \omega' = 0,\ T' = T_j' && 0 \le y' \le 1 \\ &t > 0: u' = \omega' = 0,\ T' = T_h' && y' = 0 \\ &\qquad\quad u' = \omega' = 0,\ \ T' = T_j' && y' = L \end{aligned} \tag{4}$$

Introducing the following similarity transformations in to equations (1) – (3)

$$\begin{gathered} y = \frac{y'}{L}, u = \frac{\nu u'}{\beta g L^2}, t = \frac{\nu t'}{L^2},\ \theta = \frac{(T' - T_m')}{(T_h' - T_m')}, \omega = \frac{\nu\omega'}{\beta g L(T_h' - T_m')}, b = \frac{L^2}{j} \\ \Pr = \frac{\mu}{\alpha},\ m = \frac{T_c' - T_m{}'}{T_h' - T_m{}'},\ R = \frac{k}{\mu},\ M = \frac{\sigma B_0{}^2 L^2}{\mu},\ \ K = \frac{k\ L^2}{\mu},\ \ Q = \frac{Q' L^2}{\nu\rho c_p} \end{gathered} \tag{5}$$

We get the following linear system of differential equations

$$\frac{\partial u}{\partial t} = (1+R)\frac{\partial^2 u}{\partial y^2} + \theta + R\frac{\partial \omega}{\partial y} - \left(M^2 + K\right)u \tag{6}$$

$$\frac{\partial \omega}{\partial t} = (1 + 0.5R)\frac{\partial^2 \omega}{\partial y^2} - Rb\left(\frac{\partial u}{\partial y} + 2\omega\right) \tag{7}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - Q\theta \tag{8}$$

The corresponding initial boundary conditions (4) to the considered model are reduced as follows:

$$\begin{aligned} &t \le 0 : u = \omega = 0, \quad \theta = 0 \qquad && 0 \le y \le 1 \\ &t > 0 : u = \omega = 0, \quad \theta = 1 && y = 0 \\ &\qquad\; u = \omega = 0, \quad \theta = m && y = L \end{aligned} \tag{9}$$

The physical quantities used in the above equations are defined as: b is material parameter, g acceleration due to gravity, L is distance between two vertical walls, m is temperature ratio, M is magnetic parameter, K is Porous permeability, $\Pr$ is Prandtl number, R is vertex viscosity parameter, t is time non-dimensional form time, t' time, T_c' temperature of the wall at $y' = L$, T_h' temperature of the wall at $y' = 0$, T_m' initial temperature of the fluid, u fluid velocity in non-dimensional form, u' velocity of fluid, y dimensionless co-ordinate perpendicular to the walls, y' co-ordinate perpendicular of the wall, ω dimensionless angular velocity, j micro-inertial density, κ is vertex viscosity, μ is dynamic viscosity, θ is temperature of the fluid in non-dimensional form, ν is kinematic viscosity of the fluid.

3. NUMERICAL SOLUTION

The governing linear parabolic partial differential equations (6) - (8) with initial and boundary conditions are solved numerically by using MatLab software (finite difference method). We have taken increment step along t as 0.05 and y-direction as 0.0323 in entire numerical computations. In present problem, the cost and the accuracy of the solution depend strongly on length of the vector y. This attentive problem requests the solution on mesh produced by speed points from the space interval [0, 1] and 40 values of t from the time interval [0, 2].

In Table (1), we have compared numerical and analytical solutions of steady-state velocity, micro rotation and Temperature profiles for different values of the magnetic parameter *M*, vortex viscosity *R*, material parameter *b* and Prandtl number *Pr* for both the cases asymmetric and symmetric. We can see that the numerical and analytic results agree very well. Table (2), Table (3)) verify that our solution is independent of step size for asymmetric and symmetric cases respectively.

Table (1): Numerical values of steady state velocity profiles, Micro rotation, Temperature profiles

M	Pr	Q	m	R	b	K	y	Numerical solution for velocity	Numerical solution for micro-rotation	Numerical solution for temperature
0.1	0.72	0	0	0.5	0.1	0.5	0.2	0.0320	-0.0000881	0.8000
							0.6	0.0410	0.0001165	0.4000
5	0.72	0	0	0.5	0.1	0.5	0.2	0.0144	-0.0000152	0.8000
							0.6	0.0130	0.00006214	0.4000
0.1	0.72	1	1	0.5	0.1	0.5	0.2	0.0533	-0.0002132	1
							0.6	0.8000	0.0001064	1
5	0.72	1	1	0.5	0.1	0.5	0.2	0.0211	-0.0000717	1
							0.6	0.0320	0.0000337	1
5	0.72	0	0	0.5	0.1	0.5	0.2	0.0144	-0.000016	0.8000
							0.6	0.0130	0.000062	0.4000
5	0.72	0	0	0.5	0.1	0.5	0.2	0.0142	-0.0000152	0.7888
							0.6	0.0128	0.00006188	0.3984
5	0.72	1	1	0.5	0.1	0.5	0.2	0.0211	-0.00007176	1
							0.6	0.0289	0.00003376	1
5	0.72	1	1	0.5	0.1	0.5	0.2	0.0211	-0.00007172	0.9999
							0.6	0.0310	0.00003377	0.9999
5	0.72	0	0	0.5	0.5	0.5	0.2	0.0144	-0.0000782	0.8000
							0.6	0.0127	0.0003024	0.4000
5	0.72	0	0	0.5	1.5	0.5	0.2	0.0144	-0.0002581	0.8000
							0.6	0.0127	0.0008588	0.4000
5	0.72	1	1	0.5	0.1	0.5	0.2	0.0211	-0.0003563	1
							0.6	0.0290	0.0001675	1
5	0.72	1	1	0.5	0.1	0.5	0.2	0.0212	-0.001100	1

							0.6	0.0290	0.000500	1
5	0.72	0	0	0.4	0.1	0.5	0.2	0.0146	-0.00001227	0.8000
							0.6	0.0127	0.00005371	0.4000
5	0.72	0	0	1.2	0.1	0.5	0.2	0.0131	-0.000002277	0.8000
							0.6	0.0120	0.00007908	0.4000
5	0.72	1	1	0.4	0.1	0.5	0.2	0.0221	-0.00006092	1
							0.6	0.0325	0.00002857	1
5	0.72	1	1	1.2	0.1	0.5	0.2	0.0186	-0.0001178	1
							0.6	0.0250	0.0000565	1

Table (2): Velocity, micro-rotation and temperature profiles for different step size at $M=1.0, R=1.0, b=0.2, \Pr=0.71, K=1.0, m=0, t=0.2, Q=1.0$

y	Velocity profiles on [0, 1]			Micro-rotation profiles on [0, 1]			Temperature profile on [0, 1]		
	Different step size			Different step size			Different step size		
	31	21	11	31	21	11	31	21	11
0.2	0.0317	0.0317	0.0317	-0.077	-0.014	-0.001	0.845	0.845	0.845
0.4	0.0420	0.0420	0.0420	0.0114	0.028	0.0014	0.543	0.5453	0.5453
0.6	0.0317	0.0317	0.0317	0.0115	0.031	0.0023	0.426	0.426	0.426
0.8	0.0210	0.0210	0.0210	0.0134	0.054	0.0036	0.222	0.2242	0.2242

Table (3): Velocity, micro-rotation and temperature profiles for different step size at $M=0.1, R=0.5, b=0.1, \Pr=1, K=0.5, m=1, t=0.5$

y	Velocity profiles for step size on [0, 1]	Micro-rotation profiles for step size on [0, 1]	Temperature profiles for step size on [0, 1]

	Different step size			Different step size			Different step size		
	31	21	11	31	21	11	31	21	11
0.2	0.052	0.0524	0.0524	-0.003	-0.00030	-0.00030	0.9922	0.9922	0.9922
0.4	0.081	0.0814	0.0814	0.0013	0.000103	0.000103	0.1423	0.1423	0.1423
0.6	0.156	0.1562	0.1562	0.0013	0.000103	0.000103	0.1423	0.1423	0.1423
0.8	0.052	0.0524	0.0524	0.0213	0.000213	0.000213	0.9922	0.9922	0.9922

Conclusion

The following conclusions are found out:

- Velocity and temperature profiles of the fluid decreases with increasing Prandtl number
- The amplitude of the velocity as well as the boundary layer thickness decreases when magnetic parameter is increases.
- Velocity and temperature profiles are an increasing function to time (t).
- Magnitude of the micro-rotation has increasing tendency with the material parameter (M), material parameter (b) and vertex viscosity (R) while decreases with increases in Prandtl number.
- The steady state time of fluid velocity as well as micro-rotation is more for symmetric cases compared to asymmetric cases.
- The velocity and micro-rotation profiles of fluid decreases at any point of fluid regime with magnetic parameter.

REFERENCES

[1] K. Ramesh Babu, D. Chenna Kesavaiah, B. Devika, Dr. Nookala Venu (2022): effect on MHD free convective heat absorbing Newtonian fluid with variable temperature, NeuroQuantology, Vol. 20 (20), 1591-1599

[2] D. Chenna Kesavaiah, Mohd Ahmed, K. Venugopal Reddy, Dr. Nookala Venu (2022): Heat and mass transfer effects over isothermal infinite vertical plate of Newtonian fluid with chemical reaction, NeuroQuantology, Vol. 20 (20), pp. 957-967

[3] G. Bal Reddy, D. Chenna Kesavaiah, G. Bhaskar Reddy, Dr. Nookala Venu (2022): A note on heat transfer of MHD Jeffrey fluid over a stretching vertical surface through porous plate, NEUROQUANTOLOGY, Vol. 20 (15), pp. 3472-3486

[4] D. Chenna Kesavaiah, P. Govinda Chowdary, G. Rami Reddy, Dr. Nookala Venu (2022): Radiation, radiation absorption, chemical reaction and Hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source, *NEUROQUANTOLOGY*, Vol. 20 (11), pp. 800-815

[5] M. Rajaiah and A. Sudhakaraiah (2015): Unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, International Journal of Science and Research, Vol. 4 (2), pp. 1503-1510

[6] D. Chenna Kesavaiah, M. Karuna Prasad, G. Bhaskar Reddy, Dr. Nookala Venu (2022): Chemical reaction, heat and mass transfer effects on MHD peristaltic transport in a vertical channel through space porosity and wall properties, *NEUROQUANTOLOGY*, Vol. 20 (11), pp. 781-794

[7] Y. Haranth and A. Sudhakaraiah (2015): Viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, International Journal of Science and Research, Vol. 4 (2), pp. 2650-2654

[8] D. Chenna Kesavaiah, G. Bhaskar Reddy, Anindhya Kiran, Dr. Nookala Venu (2022): MHD effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface, *NEUROQUANTOLOGY*, Vol. 20 (8), pp. 9442-9452

[9] M. Rajaiah, A. Sudhakaraih, S. V. K. Varma and P. Venkatalakshmi (2015): Chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium. *i-manager's Journal on Mathematics*, Vol. 4(1), pp. 32-39

[10] D. Chenna Kesavaiah, P. Govinda Chowdary, M. Chitra, Dr. Nookala Venu (2022): Chemical reaction and MHD effects on free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with radiative heat transfer, *NEUROQUANTOLOGY*, Vol. 20 (8), pp. 9425-9434

[12] S. Karunakar Reddy, D Chenna Kesavaiah and M N Raja Shekar (2013): MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, *International Journal of Innovative Research in Science, Engineering and Technology*, *Vol. 2 (4)*, pp.973- 981

[13] Chenna Kesavaiah DAMALA, Venkateswarlu BHUMARAPU, Oluwole Daniel MAKINDE (2021): Radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, *Engineering Transactions*, Vol. 69(4), pp. 373–401

[14] M. Rajaiah, Dr.A.Sudhakaraiah, Dr.P.Venkatalakshmi and M. Sivaiah (2014): Unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating In the presence of suction or injection, International Journal of Mathematics and Computer Research, Vol. 2 (5), pp. 428-453

[15] D. Chenna Kesavaiah, T. Ramakrishna Goud, Nookala Venu, Y V Seshagiri Rao (2021): MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, *Journal of Mathematical Control Science and Applications*, Vol. 7 (2), pp. 393-404

[16] G. Rami Reddy , D Chenna Kesavaiah, Venkata Ramana Musala and G Bhaskara Reddy (2021): Hall Effect on MHD Flow of a Visco-Elastic Fluid through Porous Medium Over an Infinite Vertical Porous Plate with Heat Source, *Indian Journal of Natural Sciences*, Vol. 12 (68), pp. 34975-34987

[17] D. Chenna Kesavaiah and B Venkateswarlu (2020): Chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, *International Journal of Fluid Mechanics Research, Vol. 47 (2), pp. 153-169*

[18] M. Rajaiah and A. Sudhakaraiah (2015): Radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, International Journal of Science and Research, Vol. 4 (2), pp. 1608-1613

[19] D. Chenna Kesavaiah, T. Ramakrishna Goud, Y. V. Seshagiri Rao, Nookala Venu (2019): Radiation effect to MHD oscillatory flow in a channel filled through a porous medium with heat generation, *Journal of Mathematical Control Science and Applications*, Vol. 5 (2), pp. 71-80

[20] B. Mallikarjuna Reddy, D Chenna Kesavaiah and G V Ramana Reddy (2018): Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, *ARPN Journal of Engineering and Applied Sciences*, Vol. 13 (22), pp. 8863-8872

[21] D. Chenna Kesavaiah, T Ramakrishna Goud, Nookala Venu, Y V Seshagiri Rao (2017): Analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation, *Journal of Mathematical Control Science and Applications*, Vol. 3 (2), pp. 113-126

[22] Damala Ch Kesavaiah, P V Satyanarayana (2014): Radiation Absorption and Dufour effects to MHD flow in vertical surface, *Global Journal of Engineering, Design & Technology, Vol. 3 (2), pp. 51-57*

[23] D. Chenna Kesavaiah, P V Satyanarayana (2013): MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, *Indian Journal of Applied Research, Vol. 3 (7), pp. 310-314*

[24] D. Ch Kesavaiah, P V Satyanarayana, J Gireesh Kumar and S Venkataramana (2012): Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous Dissipation, *International Journal of Mathematical Archive, Vol. 3 (8)*, pp. 3028-3035

[25] D. Ch Kesavaiah, P V Satyanarayana and S Venkataramana (2011): Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, *Int. J. of Appl. Math and Mech.* Vol. 7 (1), pp. 52-69

[26] H. Yeddala, A. Sudhakaraiah, P. Venkatalakshmi and M. Sivaiah (2016): Finite difference solution for an MHD free convective rotating flow past an accelerated vertical plate. *i-manager's Journal on Mathematics*, Vol. 5 (2), pp. 34-44

[27] D. Ch Kesavaiah, P V Satyanarayana, J Gireesh Kumar and S Venkataramana (2012): Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous Dissipation, *International Journal of Mathematical Archive, Vol. 3 (8)*, pp. 3028-3035

[28] Srinathuni Lavanya and D Chenna Kesavaiah (2017): Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, *International Journal of Pure and Applied Researches, Vol. 3 (1), pp. 43 - 56*

[29] D. Chenna Kesavaiah, P V Satyanarayana (2013): MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, *Indian Journal of Applied Research, Vol. 3 (7), pp. 310-314*

[30] Damala Ch Kesavaiah, P V Satyanarayana (2014): Radiation Absorption and Dufour effects to MHD flow in vertical surface, *Global Journal of Engineering, Design & Technology, Vol. 3 (2), pp. 51-57*