Frontiers in Heat and Mass Transfer (FHMT), 19, 27 (2022)
DOI: 10.5098/hmt.19.27

Global Digital Central
ISSN: 2151-8629

Frontiers in Heat and Mass Transfer
Available at www.ThermalFluidsCentral.org

THERMOPHORESIS IMPACT ON A MICROPOLAR FLUID UNDER CHANGEABLE HEAT FLUX IN CONDUCTING FIELD

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ABSTRACT

This examination carried out on thermophoresis impact on a micropolar fluid under heat flux which is not changeable in conducting field. The flow past a vertical porous plate is taken with the influence of thermal radiation and diffusion simultaneously. The flow governed non linear partial differential equations in this model are distorted to a structure of non-linear ordinary ones through fitting corresponding transformations and later solved by Runge–Kutta Fourth order with shooting technique method. The effects of selected corporal parameters on the dimensionless velocity, microrotation and temperature profiles are examined and handled graphically. Lastly, numerical table values of the extended quantities, such as the local skin friction, the couple stress coefficient and the local Nusselt numeral are framed and analyzed.

Keywords: Thermal Radiation, Thermophoresis, MHD, Micro-polar fluid, Heat flux.

1. INTRODUCTION

Thermophoresis is an admirable physical phenomenon by which temperature decay is possible when mini-sized elements floating in an unisothermal gas. The created velocity is named as thermopharetic velocity and the force skilled by the hovering particles is known as thermopharetic force. The analyses on these models are popular in many chemical and petroleum industries. Because of its substantial applications in engineering, aerodynamics, geophysics, and aeronautics, MHD fluids with a range of geometries have gained great impetus on engineering scientists and applied mathematics. Solar concentrators are used to accelerate the disappearance of waste water, as well as in food distribution and the generation of drinking water from brackish and salt water. These flows past the plates defining the angles of inclination have recently gained attention due to their usefulness in liquid purification and underground water operations.

Many articles was published which are related to shared effects of thermophoresis and thermal energy on stable MHD liberated convection flow of micropolar fluids. Chen (2008) establishes the influences of convected heat transport on non-Newtonian and power-law fluids past an expanded piece in conducting field. Reddy (2013) explained heat creative and radiative impacts on MHD natural flow of micro-polar liquid past an affecting shell. Talbot et al. (2013) reported thermophoresis of particles in a heated boundary layer. Noor et al. (2015) considered and analyzed slip conditions effects on stagnation flow of a natural convective micro-polar nanofluid along a vertically surface. The influence of nano fluid through inclined widen surface under slip condition and convective border effect is portrayed by Rashad et al. (2017). Rehman et al. (2018) projected that an inclined cylinder surface will create and cause joule heating on thermally stratified mixed convective powel fluid stagnation point flow of in conducting field. The influence of Eyring-Powell fluid over dual stratified mixed convection flow with inclined stretched cylinder was studied by Khalil et al. (2016). Under the existence of Hall current, Rajput and Kumar (2016) considered and investigated the reaction influence on unsteady mode of MHD flow past an impetuously started inclined plate. Chandra Reddy et al. (2015, 2018) carried out the analyzation on thermal as well as solutal optimism impacts on MHD flow nature under unreliable suction with variety of parameters. Hall and rotational effects were induced on MHD flow via an accelerated permeable plate with a cross diffusion effect by Paul et al. (2022). Chandra Reddy et al. (2016, 2018) examined radiation and Dufour effects on free convective magneto-nanofluid flow past a moving vertical plate. Further we have gone through the articles (2021) published in recent years related to this work. More recently Hari Babu et al. (2021, 2022) analyzed the flows of non-Newtonian fluids with different geometries.

Most of previous works are not studied heat transfer MHD free convective flow of micropolar fluid through a porous medium with heat flux in the presence of the thermophoresis. In view of these published results, we have acted upon a numerical inquiry on the shared effects of thermal thermophoresis and radiation on balanced magnetohydrodynamic free of charge convected heat transfer on micropolar fluid flows pasta perpendicular leaky plate under heat flux border line conditions.

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2. MATHEMATICAL ANALYSIS

Let us consider a steady to-dimensional MHD free convective flow of viscous incompressible electrically conducting fluid past a semi-infinite permeable inclined flat plate, while a magnetic field of uniform strength B_0 is applied in the y-direction which is normal to the flow direction as shown in Figure 1. Fluid suction is imposed at the plate surface and the suction size is taken to be constant. The temperature of the surface is held uniform at T_W which is higher than the ambient temperature T_∞. The Rosseland approximation is used to describe the radioactive heat flux in the x-direction which is considered negligible in comparison to the y-direction. The effects of thermophoresis are being taken into account to help in the understanding of the mass deposition variation on the surface. Radiation absorption is not considered as the thermophoresis impact is in existing and also the computations with coupled equations become complicated. Joule heating is not considered because thermophoresis effect is given importance in this analysis. Under the above assumptions, the governing equations for this problem can be written as:

(i) Continuity:

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

(ii) Momentum:

$$v\frac{\partial u}{\partial y}+u\frac{\partial u}{\partial x}=\nu_a\frac{\partial^2 u}{\partial y^2}+\frac{S}{\rho}\frac{\partial N}{\partial y}+\beta_T 2\left(T-T_\infty\right)g$$
$$+\beta_C\left(C-C_\infty\right)g-\frac{\sigma B_0^2 u}{\rho}-\frac{\nu_a}{K'}(u-U_\infty)-\frac{b}{K'}(u-U_\infty)^2 \tag{2}$$

(iii) Angular momentum:

$$u\frac{\partial N}{\partial x}+v\frac{\partial N}{\partial y}=\frac{\nu_s}{\rho j}\frac{\partial^2 N}{\partial y^2}-\frac{S}{\rho j}\left(2N+\frac{\partial u}{\partial y}\right)=0 \tag{3}$$

(vi) Energy:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \tag{4}$$

where u, v represents velocity directions in the x, y axes, $\nu_a=(\mu+s)/\rho$ is the apparent viscosity, g denotes acceleration due to gravity, T is the temperature, β_T and β_C are the coefficients of thermal and volumetric expansions respectively, $\nu_s=(\mu+s/2)j$ is the micro rotation viscosity or spin-gradient viscosity, j is the micro-inertia density, T_∞ is the temperature far-off to the plate, U_∞ is the velocity of the fluid far-off to the plate, σ is the electrical conductivity, B_0 is the magnetic induction, k is the fluid thermal conductivity, ρ is the fluid density, C_p is the specific heat at constant pressure, q_r is the radiative heat flux in the y-direction, μ is the dynamic viscosity and V_T is the thermophoretic velocity.

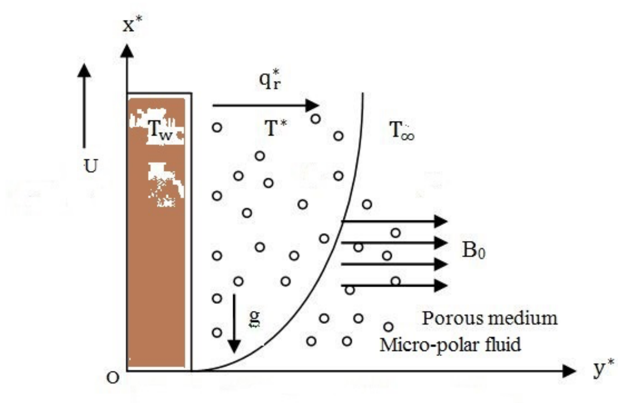

Figure 1: Physical Geometry of the problem

The boundary conditions for the model are as follows

$$u=0,\ v=\pm v_w(x),\ N=-n\frac{\partial u}{\partial y},\ \frac{\partial T}{\partial y}=-\frac{q_m}{k}\quad at\ y=0$$
$$u\to U_\infty,\ N\to 0,\ T\to T_\infty\quad \text{as } y\to\infty \tag{5}$$

where U_0 is the regular platter velocity and $v_w(x)$ denotes fluid suction/dissection over the leaky surface. Rosseland guess is used to state the radiative heat flux in the y' direction as

$$q_r=-\frac{4\sigma_1}{3k_1}\frac{\partial T^4}{\partial Y} \tag{6}$$

where σ_1 & k_1 gives Stefan-Boltzmann & mean absorption coefficient.

Assuming that the temperature diversities inside the flow being adequately small and so T^4 is expanded in Taylor series in view of free watercourse temperature T_∞ to gain as follows. $T^4\cong 4T_\infty^3 T-3T_\infty^4$ (7)

In which the higher power terms are mistreated.

By means of (6) and (7) the equation (4) reduces to

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_e}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\frac{16\sigma_1 T_\infty^3}{3\rho c_p k_1}\frac{\partial^2 T}{\partial y^2} \tag{8}$$

Now the thermophoretic velocity V_T, can also be stated as

$$V_T=-kv\frac{\nabla T}{T_{ref}}=\frac{-kv}{T_{ref}}\frac{\partial T}{\partial y} \tag{9}$$

where T_{ref} denotes the reference and k is the termophoretic coefficient of temperature from 0.2 to 1.

$$k=\frac{\left[1+\left(C_1+C_2e^{-C_3/K_n}\right)\times K_n\right]2Cs\left(C_tK_n+\lambda_g/\lambda_p\right)}{\left(1+3C_mK_n\right)\left(2C_tK_n+1+2\lambda_g/\lambda_p\right)} \tag{10}$$

Where C_1, C_2, C_3, C_m, C_s, C_t are constants, λ_g and λ_p are the thermal conductivities of the fluid and diffused particles respectively and K_n is the Knudsen number.

A thermophoretic parameter τ can be defined as

$$\tau=\frac{k\left(T_\infty-T_w\right)}{T_r} \tag{11}$$

3. SIMILARITY TRANSFORMATIONS

The non-dimensional values help in gaining the solutions which are as follows:

$$\eta=\left(\frac{U_\infty}{2\nu_a x}\right)^{1/2}y,\ u=U_0f'(\eta),\ \theta(\eta)=\frac{T-T_\infty}{Q/k}\sqrt{\frac{U_\infty}{2\nu_a x}},$$
$$\psi=\left(2\nu_a U_\infty x\right)^{1/2}f(\eta),\ N=\left(\frac{U_\infty^3}{2\nu_a x}\right)^{1/2}g(\eta) \tag{12}$$
$$v=-\sqrt{\frac{2\nu_a U_\infty}{x}}\left[f(\eta)-\eta f'(\eta)\right],$$

If the dimensional stream function $\psi(x,y)$ then $u=\frac{\partial\psi}{\partial y}$.

The simplified form of continuity and energy equation which satisfies the Eqs. (2), (3), (5) and (8) are as follows:

$$f'''+ff''+Kg'+Gr\,\theta-Mf'-2\lambda\left(f'-1\right)-Fs\left(f'-1\right)^2=0 \tag{13}$$
$$G_2g''-2G_1(2g+f'')+f'g+fg'=0 \tag{14}$$
$$(3R+4)\theta''+3R\Pr f\theta'+3R\Pr f'\theta=0 \tag{15}$$

Frontiers in Heat and Mass Transfer (FHMT), 19, 27 (2022) Global Digital Central
DOI: 10.5098/hmt.19.27 ISSN: 2151-8629

The primes mean differentiation with respect to η,

$M = \dfrac{\sigma B_0^2 2x}{\rho U_\infty}$ is the magnetiec field parameter,

$Gr = g\beta_T \sqrt{\dfrac{\nu_a (2x)^3}{U_\infty^5}} \dfrac{Q}{k}$ local thermal Grashof number,

$K = \dfrac{s}{\rho \nu_a}$ is the couplling parameter,

$\lambda = \dfrac{1}{Da}$ is the Darcy parameter,

Da = modified Darcy number,

$Fs = \dfrac{bx}{K'}$ modified Forchheimer number,

$G_1 = \dfrac{sx}{\rho j U_\infty}$ vortex parameter for viscosity,

$G_2 = \dfrac{\nu_s}{\rho j \nu_a}$ whirl grade viscosity parameter,

$G = \dfrac{G_1 U_0}{2\nu x}$ micro-rotation parameter,

$\Pr = \dfrac{\rho \nu c_p}{k}$ Prandtl number,

$R = \dfrac{k k_e}{4\sigma_s T_\infty^3}$ thermal radiation parameter,

The changed periphery condition (6) is given by

$$f(0) = \pm f_w,\ g(0) = 0,\ \theta(0) = -1,\ f'(0) = 0,$$
$$f(\infty) = 0,\ g(\infty) = 0,\ \theta(\infty) = 0, \tag{16}$$

Where $f_w = -v_w(x)\sqrt{\dfrac{2x}{\vartheta U_0}}$ indicates positive and negative permeability of the leaky surface for suction and injection respectively.

The physical quantities of interest are the local skin friction coefficient and the local Nusselt number which are defined as respectively where the skin friction C_f and the heat transfer $q_w(x)$ are given by

$$C_f \operatorname{Re}_x^{-1/2} = \frac{\tau_w}{(1/2)\rho U_o^2} = 2f''(0),\ \tau_w = \mu\left(\frac{du}{dy}\right)_{y=0}$$

From the temperature field, the rate of heat transfer which is given by

$$Nu_x \operatorname{Re}_x^{-1/2}\left(\frac{3R}{3R+4}\right) = \frac{q_w(x)}{\lambda(T_w - T_\infty)} = -\frac{1}{2}\theta'(0);$$
$$q_w(x) = -k\left(\frac{\partial T}{\partial y}\right)_{y=0} - \frac{4\sigma_1}{3k_1}\left(\frac{\partial T^4}{\partial y}\right)_{y=0}$$

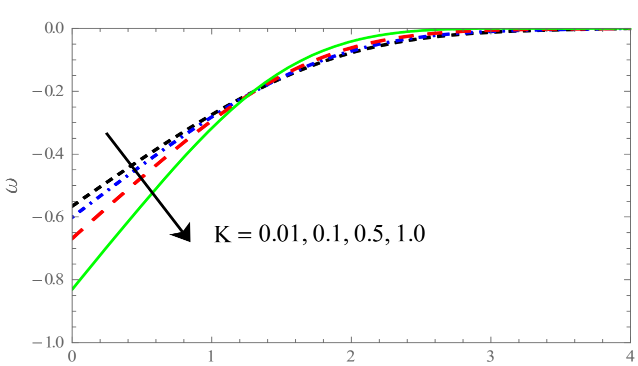

Figure 2. Effects of K on micro rotation distribution $\omega(\eta)$

4. METHOD OF SOLUTION

The system of ordinary differential equations (13 – (15) subject to the boundary conditions (16) are coupled and so the solution by general analytical methods is complicated and hence they are solved numerically using Runge – Kutta fourth-order with shooting iteration technique. Initially some guess values are taken for three variables and then the remaining variables are computed by shooting nearest values. All the computations and graphs are drawn by using MATLab program. A step size of $\Delta\eta = 0.01$ was selected to be satisfactory for a convergence criterion of 10^{-6} in all cases. The results are presented graphically and conclusions are drawn for flow field and other physical quantities of interest that have significant effects.

5. RESULTS AND DISCUSSION:

The physical behavior of the fluid flow is shown with the help of figures and tables. Figure 1 shows that the micro-rotation dwindle in the vicinity of the spongy plate and opposite trends is noticed far gone to the platter as couple constant raise. Effect due to magnetic stricture M on the velocity and micro-rotation profiles is shown in Figures 3, 4 respectively. It is clearly seen from Fig. 3 that the velocity sketch drop off with escalating values of magnetic parameter M. This happens due to the retarding force created by magnetic field which resists the velocity of the fluid. It is also seen Fig.4 that the microrotation increases near the porous plate and then decreases far gone to the platter as magnetic parameter M increases. The micro-rotation and also temperature profiles are designed in Figures 5, 6 under the influence of R clearly. The results show that both the microrotation and temperature on the vertical plate increases near the porous plate and opposite trends far gone to the platter as increasing radiation parameter. The natural phenomena of thermal radiation enhance the heat of the plate and hence the microrotation as well as temperature increases.

Numerical values of the skin-friction coefficient and local Nusselt number are tabulated in Table 1 for special values of magnetic parameter M and coupling constant K, local Darcy parameter λ and modified Forchheimer number Fs. Table 1 shows that magnetic parameter, modified Forchheimer number increase the values of the skin-friction coefficient, where as reversible trends are seen by rising the values of K, λ Further, it is clear that the local Nusselt number increases with increase M and Fs whereas reverse trend is seen by increasing values of K and λ.

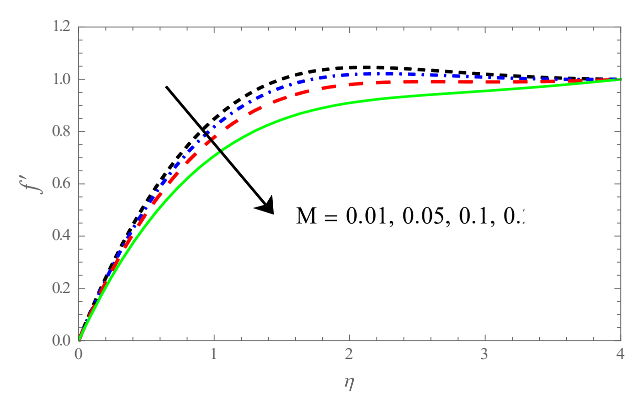

Figure 3. Effects of M on velocity distribution $f'(\eta)$

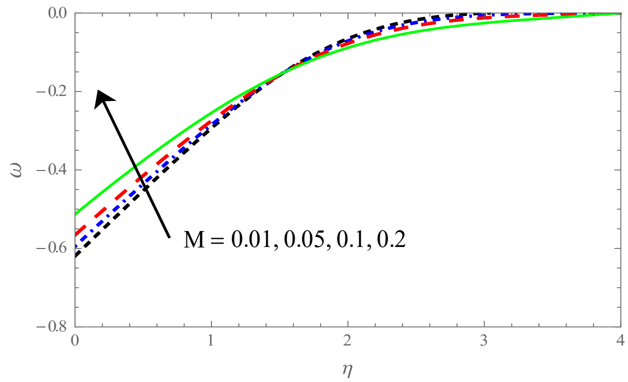

Figure 4. Effect of M on micro rotation distribution $\omega(\eta)$

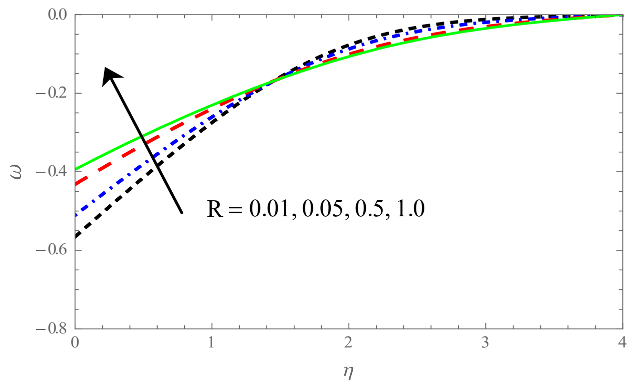

Figure 5. Effects of R on micro-rotation distribution $\omega(\eta)$

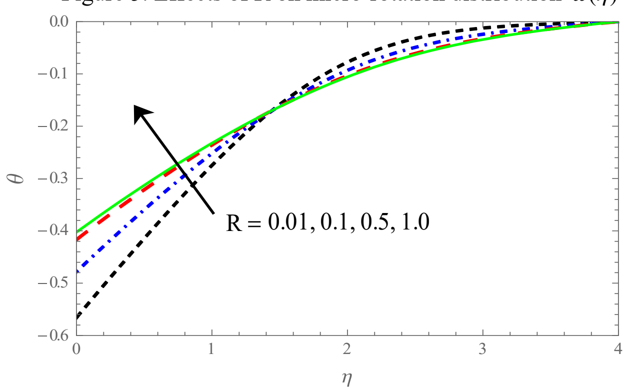

Figure 6. Effects of R on temperature distribution $\theta(\eta)$

Table. Variations in local Nusselt number and skin-friction coefficient

M	K	λ	Fs	C_f	Nu_x
0.15	0.10	0.25	0.30	-1.266454	0.924684
0.25	0.10	0.25	0.30	-1.243888	0.92867
0.50	0.10	0.25	0.30	-1.223899	0.923744
0.15	0.10	0.25	0.30	-1.425566	0.776655
0.15	0.50	0.25	0.30	-1.466055	0.754233
0.15	1.00	0.25	0.30	-1.531977	0.736422
0.15	0.10	0.25	0.30	-1.122422	0.984644
0.15	0.10	0.55	0.30	-1.128255	0.984044
0.15	0.10	1.05	0.30	-1.134133	0.983455
0.15	0.10	0.25	0.30	-1.415833	0.781266
0.15	0.10	0.25	0.50	-1.407444	0.787499
0.15	0.10	0.25	1.50	-1.393658	0.797411

CONCLUSION

The main outcomes of this study can be outlined as:

- Fluid speed falls down when M values increases.
- The microrotation increase near the surface and then decrease far away from the surface with raise in magnetic parameter M, radiation parameter R and reverse trends observed for the coupling constant K
- The Temperature increases nearthe surface and then decreases way from the surface with increase in radiation parameter R.
- The Skin friction coefficient raise with an increase in M and Fs, and decreases for rising values of K and λ.
- Rate of heating dispersion decreases with increase in K and λ, but increases with in the case of M and Fs.

NOMENCLATURE:

Cp	Specific heat at constant pressure
Gr	Thermal Grashof number
G	micro-rotation parameter
g	Acceleration due to gravity
k_T	Thermal conductivity
B_o	Magnetic field parameter
Pr	Prandtl number
K	porosity parameter
Q	heat generation parameter
R	radiation parameter
Da	modified Darcy number
M	magnetic parameter
G_1	vortex parameter for viscosity
G_2	whirl grade viscosity parameter
Nu	Nusselt number
u	Velocity of the plate [m.s^{-1}]
t	Time [s]
θ	Temperature [K]
f_w	permeability of the leaky surface
F_s	modified Forchheimer number
y	Coordinate axis [m]
D_1	thermal diffusivity
V_T	thermophoretic velocity
	Greek symbols
β	Thermal volumetric coefficient
μ	Coefficient of viscosity
ν	Kinematic viscosity
ρ	Density of the fluid
τ	skin friction
σ	Electrical conductivity

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