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Radiation Effect on MHD Flow of a Micropolar Fluid with Heat Generation or Absorption

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ABSTRACT. This work analyzes radiation effect on heat and mass transfer of steady, laminar, MHD micropolar fluid along a stretched semi-infinite vertical plate in the presence of temperature-dependent heat generation or absorption. A magnetic field applied normal to the plate. The governing partial differential equations were transformed into ordinary differential equations using the similarity variables. The obtained self-similar equations are solved numerically using the Galerkin finite element method. The obtained results are validated against previously published work for special cases of the problem in order to access the accuracy of the numerical method and found to be in excellent agreement. The effect of various physical parameters on velocity, microrotation and temperature is conducted.
Keywords: MHD, micropolar fluid, stretched surface, heat generationor absorption, radiation.

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I. INTRODUCTION

The study of convective flow, heat transfer has been an active field of research as it plays a crucial role in diverse applications, such as thermal insulation, extraction of crude oil etc. Although considerable work has been reported on flow of heat studies have been become important. All the above-mentioned work has been based on the Newtonian i.e. Navier-Stokes fluid model, but the fluids used in most of the metallurgical and chemical engineering flows, exhibit strong non-Newtonian behaviour. To overcome the inadequacy of the Navier-Stokes equations to explain certain phenomena exhibited by fluids with suspended particles like colloidal suspension, exotic lubricants, animal blood etc, Eringen [1] developed the theory of micropolar fluids which take into account the local rotary inertia and couple stresses.

Over the years, the dynamics of micropolar fluids has been popular area of research anda significant amount of research papers dealing with micropolar fluid flow over a flat Plate was reported. For instance, Srinivasacharya and Upendar [2] analyzed the effect of double stratification on MHD micropolar fluid with mixedconvection. Gorla [3] studied the forced convective heat transfer to a micropolar fluid flow over a flat plate. The boundary layer flow of a micropolar fluid past a semi-infinite plate studied by Peddieson and McNitt [4]. Rees and Bassom [5] analyzed Blasius boundary-layer flow of a micropolar fluid over a flat plate. Hady [6] dealt with heat transfer to micropolar fluid from a non-isothermal stretching sheet with injection. Kelson and Desseaux [7] studied the effect of surface conditions on the flow of a micropolar fluid driven by a porous stretching surface. The boundary layer flow of micropolar fluids past a semi-infinite plate was studied by Ahmadi [8] taking into account the gyration vector normal to the xy-plane and the micro-inertia effects. Perdikis and Raptis [9] studied the heat transfer of a micropolar fluid in the presence of radiation. Raptis [10] considered the flow of a micropolar fluid past a continuously moving plate in the presence of radiation. El-Arabawy [11] analyzed the problem of the effect of suction/injection on the flow of a micropolar fluid past a continuously moving plate in the presence of radiation. Abo-Eldahab and El Aziz [12] analyzed flow and heat transfer in a micropolar fluid past a stretching surface embedded in a non-Darcian porous medium with uniform free stream. Odda and Farhan [13] studied the effects of variable viscosity and variable thermal conductivity on heat transfer to a micro-polar fluid from a non-isothermal stretching sheet with suction and blowing. Mahmoud [14] considered thermal radiation effects on MHD flow of a micropolar fluid over a stretching surface with variable thermal conductivity. Aouadi [15] reported a numerical study for micropolar flow over a stretching sheet.

Recently, considerable attention has also been focused on new applications of magneto-ydrodynamics (MHD) and heat transfer in for e.g. metallurgical processing. Melt refining involves magnetic field application to control excessive heat transfer rates. Other applications of MHD heat transfer include MHD generators, plasma propulsion in astronautics, nuclear reactor thermal dynamics and ionized-geothermal energy systems etc. Srinivasacharya and Upendar[16] studied the effect of cross diffusion on MHD mixed convection in a micropolar fluid. Patil and Kulkarni [17] studied the effects of chemical reaction on free convective flow of a micropolarfluid through a porous medium in the presence of internal heat generation. Representative studies dealing with heat generation or absorption effects have been reported previously by such authors as Acharya and Goldstein [18], Vajravelu and Nayfeh [19] and Chamkha [20].
The objective of this paper is to consider MHD flow of a micropolar fluid along a stretched vertical plate in the presence of wall suction or injection effects and heat generation or absorption effects.

II. PROBLEM FORMULATION

Consider steady, laminar, MHD boundary-layer flow of a micro polar fluid past a permeable
uniformly stretched semi-infinite vertical plate in the presence of heat generation or absorption, thermal radiation and viscous dissipation effects. The fluid is assumed to be viscous and has constant properties. The applied magnetic field is assumed to be constant and the magnetic Reynolds number is assumed to be small so that the induced magnetic field is neglected. No electric field is assumed to exist and the Hall Effect of magnetohydrodynamics is neglected.

The governing boundary-layer equations may be written as follows:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu+K^*}{\rho}\frac{\partial^2 u}{\partial y^2}+\frac{K^*}{\rho}\frac{\partial N}{\partial y}-\frac{\sigma B^2(x)}{\rho}u \qquad (2)$$

$$\frac{\gamma}{K^*}\frac{\partial^2 N}{\partial y^2}-2N-\frac{\partial u}{\partial y}=0 \qquad (3)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2+\frac{Q(x)}{\rho c_p}(T-T_\infty)-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y} \qquad (4)$$

where u, v are the velocity components along the x-axis and y-axis, N is the microrotation, T is the temperature. P is the fluid density,, ν ($\nu = (\mu + K)/\rho$) is the apparent kinematic viscosity, μ is the fluid dynamic viscosity, Cp is the specific heat at constant pressure and α is the thermal diffusivity. γ and K^* are the spin gradient viscosity and the vortex viscosity, respectively. σ, B(x), Q(x) and qr are the electrical conductivity, magnetic induction, heat generation (> 0) or absorption (< 0) coefficient and the radiative heat flux, respectively.

The boundary conditions for this problem are given by

$$u=U_0,\quad v=V_w,\quad N=0,\quad T=T_w \quad \text{at} \quad y=0 \qquad (5)$$

$$u\to 0,\quad N\to 0 \quad T\to T_\infty \quad \text{as} \quad y\to\infty \qquad (6)$$

Where U_0, V_w and T_w are the streatching velocity, suction($V_w < 0$) or injection ($V_w > 0$) velocity and wall temperature, respectively.
By using Rosseland approximation

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial(T^4)}{\partial y}$$

where σ^* is the Stefan-Boltzmann constant and k^* is the mean absorption coefficient. Assuming that the temperature differences within the flow are sufficiently small so that T^4 can be expended in Taylor series about the free stream temperature T_∞ to yield

$$T^4 = 4TT_\infty^3 - 3T_\infty^4$$

Where the higher-order terms of the expansion are neglected.
Substituting the Eqs.(7) and (8) into the Eq.(4), we obtain

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2+\frac{Q(x)}{\rho c_p}(T-T_\infty)-\frac{16\sigma^* T_\infty^3}{3\rho c_p k_1}\frac{\partial^2 T}{\partial y^2} \qquad (9)$$

Introduce the stream function ψ in the usual way such that $u=\frac{\partial\psi}{\partial y}$, $v=-\frac{\partial\psi}{\partial x}$ and using the following dimensionless variables(EI-Arbawy,[11]):

$$\eta = y\sqrt{\frac{U_0}{2\nu x}} \qquad \psi = \sqrt{2\nu U_0 x f(\eta)}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \qquad N = \sqrt{\frac{U_0^3}{2\nu x}}\,\omega(\eta),$$

$$u = U_0 f'(\eta), \qquad v = -\sqrt{\frac{\nu U_0}{2x}}\left[t(\eta) - f'(\eta)\right] \tag{10}$$

We obtain the following non-dimensional equations

$$f''' + ff'' - Ha^2 f' + \Delta\omega' = 0 \tag{11}$$

$$\lambda\omega'' - 4\omega - 2f'' = 0 \tag{12}$$

$$(3N_r + 4)\theta'' + 3N_r P_r \phi\theta + 3N_r P_r E_c (f'')^2 = 0 \tag{13}$$

Where

$$Ha = \sqrt{\frac{2\sigma x B^2(x)}{\rho U_0}}, \quad Pr = \frac{\rho\nu c_p}{k}, \quad \lambda = \frac{\gamma U_0}{K^*\nu x}, \quad \Delta = \frac{K^*}{\rho\nu},$$

$$Ec = \frac{U_0^2}{C_p(T_w - T_\infty)}, \quad \emptyset = \frac{2xQ(x)}{\rho c_p U_0}, \quad N_r = \frac{kk^*}{4\sigma^* T_\infty^3} \tag{14}$$

are the Hartmann number, Prandtl number, microrotation parameter, coupling constant parameter, Eckert number, dimensionless internal heat generation or absorption parameter and the radiation parameter, respectively

The wall shear stress and the wall couple stress

$$\tau_w = \left((\eta + k)\frac{\partial u}{\partial y} + kN\right)_{y=0}, \qquad m_w = \gamma\left[\frac{\partial N}{\partial y}\right]_{y=0} \tag{15}$$

The dimensionless wall shear stress and the couple stress:

$$C_f = \frac{2\tau_w}{\rho U_0^2}, \qquad M_w = \frac{m_w}{L\rho U_0^2} \tag{16}$$

Are given by

$$C_f = -2Re^{-1/2} f''(0), \qquad M_w = Re^{-1/2}\omega'(0)$$

Where $Re = \frac{U_\infty x}{\nu}$ is the local Reynolds number

The heat transfer from the plate is given by

$$q_w = -k\left(\frac{\partial T}{\partial y}\right)_{y=0} - \frac{4\sigma^*}{3k_1}\left(\frac{\partial T^4}{\partial y}\right)_{y=0}$$

III. NUMERICAL METHOD

The transformed two-point boundary value problem defined by equations (11 - 13) is solved using the finite element method. Details of the method are given in Reddy [21]. The whole domain is subdivided into two noded elements. In a nutshell, the Finite element equation are written for all elements and then on assembly of all the element equations we obtain a matrix of order 328×328. After applying the given boundary conditions a system of 320 equations remains for numerical solution, a process which is successfully discharged utilizing the Gauss-Seidel method maintaining an accuracy of 0.0005.

The accuracy of the aforementioned numerical method was validated by direct comparisons with the numerical results reported earlier by El-Arabawy [11]. Table 1 present comparison for the wall slopes of velocity, microrotation values for various conditions. These comparisons show excellent agreement between the results.

Table 1. Comparision of $-f''(0)$ and $\omega'(0)$ with EI-Arabawy [11] for $Ha = 0, \Delta = 0.2$

f_0	$-f_0''$ El-Arabawy[11]	w_0' El-Arabawy[11]	$-f_0''$ Prasent work	w_0' Prasent work
-0.7	0.278827	0.236917	0.278939	0.237101
-0.4	0.404227	0.286997	0.404381	0.287120
-0.2	0.504059	0.321165	0.504192	0.321321
0	0.616542	0.355330	0.616844	0.355563
0.2	0.741521	0.389278	0.741691	0.389410
0.4	0.877517	0.422223	0.877682	0.422393
0.7	1.099430	0.468923	1.103311	0.469098

IV. RESULTS AND DISCUSSION

The effect of magnetic parameter (Ha) on velocity, microrotation and temperature is shown in Figs. 1 - 3. From Fig 1., it is clear that the velocity is decreasing as Ha is increasing. The presence of a magnetic field has the tendency to produce a drag-like force called the Lorentz force which acts in the opposite direction of the fluid's motion. This causes the fluid velocity decrease. Fig.2.explains that the microrotation is decreases as Ha increases. From Fig.3, it is evident that the temperature increases as Ha increases. As the fluid velocity decreases as a effect of Ha, the heat transfer rate decreases, hence, the temperature increases.

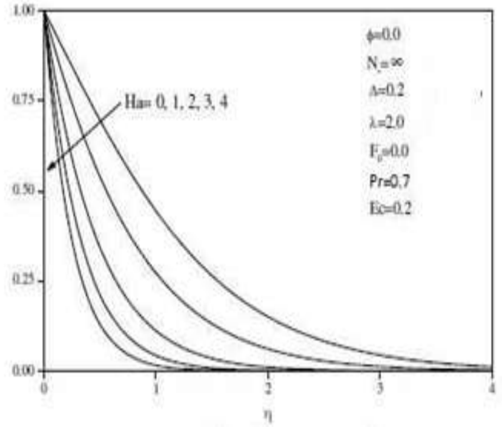
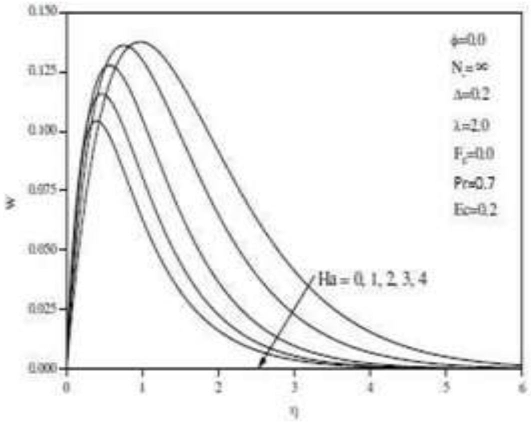


FIG. 1, Effect of Magnetic parameter on velocity profile



FG. 2, Effect of Magnetic parameter on microrotation profile

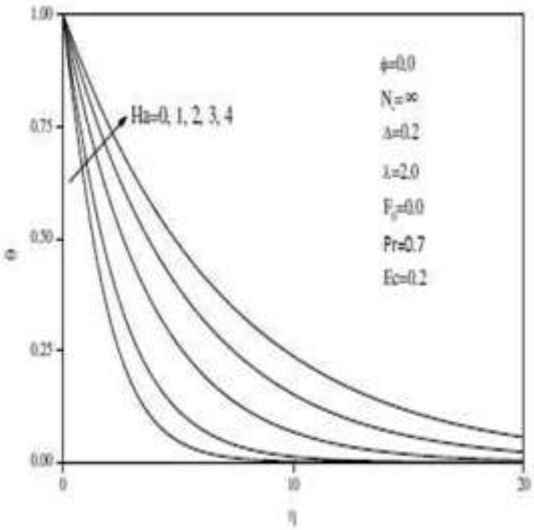


FIG. 3, Effect of Magnetic parameter on temperature profile

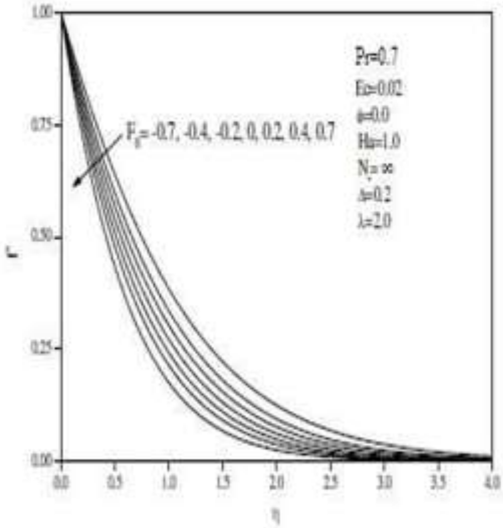


FIG. 4, Effect of F_0 on velocity profile

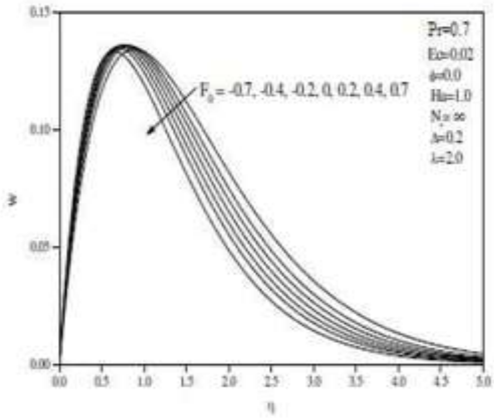


FIG. 5, Effect of F_0 on microrotation profile

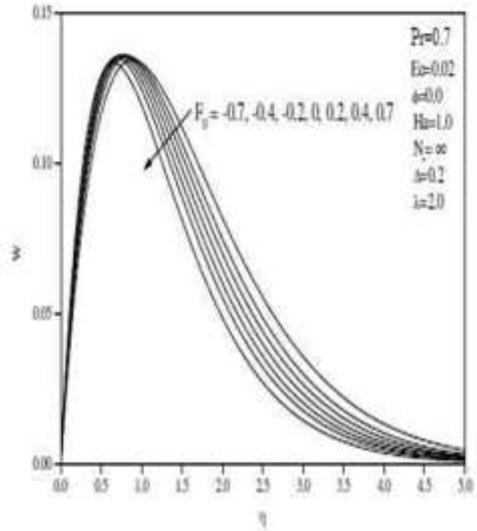


FIG. 6, Effect of F_0 on microrotation profile

Figs. 4 - 6 show the effect of suction/injection parameter (F_0) on velocity, microrotation and temperature profiles. The fluid wall suction ($F_0 > 0$) tends to decrease all of the fluid velocity, microrotation, and temperature as well as their boundary-layer thicknesses. On the other hand, injection or blowing of fluid at the plate surface ($F_0 < 0$) produces the exact opposite effect namely increases in the fluid velocity, microrotation and temperature and their boundary-layer thicknesses.

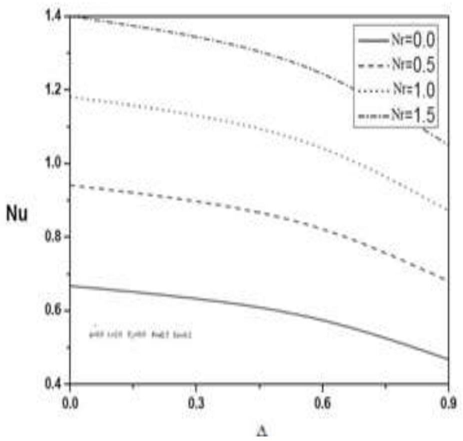


Fig. 7. Radiation effect on Hear transfer rate

It is noticed from these figures that both the Effect of radiation parameter on Nusselt number is given in Fig. 7. It is noticed that Nusselt number increases with the increase in the radiation parameter. Higher values of radiation parameter imply higher values of wall temperature. Consequently, the temperature gradient and hence the Nusselt number increases.

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