EFFECT OF HALL CURRENTS ON CONVECTIVE HEAT AND MASS TRANSFER FLOW OF A VISCOUS ELECTRICALLY CONDUCTING NANO- FLUID

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Abstract

In this paper we investigate the convective study of heat and mass transfer flow of a viscous electrically conducting nano-fluid in a vertical wavy channel under the influence of an inclined magnetic fluid with heat generating sources. The walls of the channels are maintained at constant temperature and concentration. The equations governing the flow heat and concentration are solved by employing perturbation technique with a slope δ of the wavy wall. The velocity, temperature and concentration distributions are investigated for a different values of G, M, m, Sc, N, N_1, α and x. The rate of heat and mass transfer are numerically evaluated for different variations of the governing parameters.

Key words: convective nano-fluid; electrically conducting nano- fluid; heat sources, heat transfer, mass transfer

1. INTRODUCTION

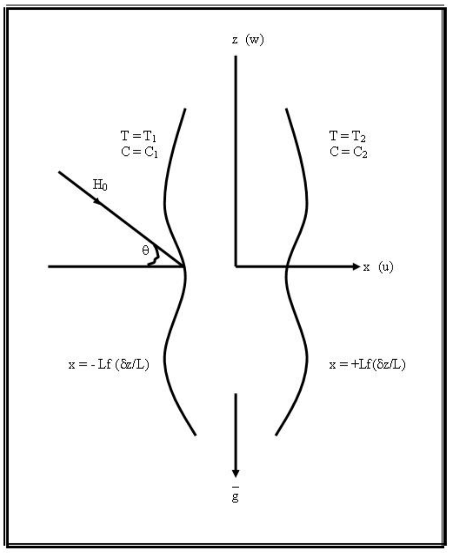
The recent developments in technology require an innovative revolution in heat transfer. The research on nano-fluids has been amplified fast. According to reports nano-fluids are advantageous heat transport fluids for engineering and manufacturing applications. The heat transport development of nano fluids is principally reliant on the heat conductivity of nano particles, particles' volume concentration and mass flow discharges. Under steady particles' volume concentration and flow discharges, the heat transport development only on the heat conductivity of the nano particles. The heat conductivity of nano particles may be revised or transformed by developing hybrid nano-particles. Hybrid nano-particles are nano particles created by two or additional different substantial of nano-meter scale. The flu- ids developed through hybrid nano particles of transformed metals interested in the base fluid are recognized as hybrid nano fluids.

In all the surveys, the Hall and ion slip effects were disregarded. The attention to persistent fascinating terrain, comprising the electromagnetic forces with Hall and ion slip effects, may not be overlooked. For information, Hall effects are the proportions flanked by the cyclotron and electron periodicity and the atom, electron and collision prevalence. The Hall property is note worthy while the magnetic scope is drugged or while the impingement is near the ground While the electromagnetic forces are discernible, the dispersal velocity of the development of ions is insignificant. As long as we believe the dispersal velocity of ions over and above such electrons, ion slips must not be overlooked. Hall and ion slip impacts come across immense solicitations specifically when reviewed in conjunction with heat transport, for instance, refrigerator convolutes, MHD vulcanization accelerators, electrical charge manufacturers, etc. Abo-Eldahab et al.[2] influenced Hall electromotive forces on the pump flow of viscous fluid through a porous medium in an unsymmetrical vertical conduit. Koumy et al. [7] scrutinized identically taking Maxwell fluid toward deliberation. The performances of learning reveal that the average speed dispensation accentuates through elevated ethics of Hall parameterization. Motsa and Shateyi [8] deliberated the results of Hall and ion slip for the flow of MHD micropolar fluid past the flat surface. Sheikholeslami et al. [13] studied the thermal diffusion and heat generation effects on the unsteady MHD flow of radiating and electrically conducting nanofluid past over an oscillating vertical plate through the porous medium Kataria and Mittal [5] discussed the mathematical modeling of flow, heat and mass transfer in the unsteady natural convec- tion MHD flow of electrically conducting nanofluid, past over an oscillating vertical plate. An analytic expression for unsteady hydromagnetic boundary layer flow past an oscillating vertical plate in optically thick nanofluid in the thermal radiation and uniform transverse magnetic field was obtained by Kataria and Mittal [4].

In all these investigations, the effects of Hall currents are not considered. However, in a partially ionized gas, there occurs a Hall current [3] when the strength of the impressed magnetic field is very strong. These Hall effects play a significant role in determining the flow features keeping these applications in view several authors [1,6,9-12,14].

2.FORMULATION OF THE PROBLEM

We consider the steady flow of an incompressible, viscous ,electrically conducting fluid confined in a vertical channel bounded by two wavy walls under the influence of an inclined magnetic field of intensity Ho lying in the plane (y-z).The magnetic field is inclined at an angle α to the axial direction k and hence its components are $(0, H_0 Sin(\alpha), H_0 Cos(\alpha))$.In view of the waviness of the wall the velocity field has components(u,0,w)The magnetic field in the presence of fluid flow induces the current($(J_x, 0, J_z)$.We choose a rectangular cartesian co-ordinate system O(x,y,z) with z-axis in the vertical direction and the walls at $x = \pm f(\frac{\delta z}{L})$.The equations governing the flow, heat and mass transfer in terms of the stokes stream function ψ are



SCHEMATIC DIAGRAM OF THE CONFIGURATION

$$\nabla^4\psi - M_1^2\nabla^2\psi + \frac{G}{R}(\frac{\partial\theta}{\partial x} + N\frac{\partial C}{\partial x}) = R(\frac{\partial\psi}{\partial z}\frac{\partial(\nabla^2\psi)}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial(\nabla^2\psi)}{\partial z}) \quad (2.1)$$

$$PR(\frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial\theta}{\partial x}) = \nabla^2\theta - \alpha\,\theta + \frac{4}{3N_1}\frac{\partial^2\theta}{\partial x^2} \quad (2.2)$$

$$ScR(\frac{\partial\psi}{\partial x}\frac{\partial C}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial C}{\partial x}) = \nabla^2 C \quad (2.3)$$

Where

$G=\frac{\beta g\,\Delta T_e L^3}{\nu^2}$ (Grashof Number), $M^2=\frac{\sigma\mu_e^2 H_o^2 L^2}{\nu^2}$ (Hartman Number)

$M_1^2=\frac{M^2 Sin^2(\alpha)}{1+m^2}$, $R=\frac{qL}{\nu}$ (Reynolds Number), $P=\frac{\mu C_p}{K_f}$ (Prandtl Number)

$\alpha=\frac{QL^2}{\Delta TK_f}$ (Heat Source Parameter), $Sc=\frac{\nu}{D_1}$ (Schmidt Number)

$N=\frac{\beta^*(C_1-C_2)}{\beta(T_1-T_2)}$ (Buoyancy ratio), $N_1=\frac{3\beta_R K_f}{4\sigma^\bullet T_e^3}$ (Radiation parameter)

The boundary conditions are

$$\psi(f)-\psi(-f)=1$$

$$\frac{\partial\psi}{\partial z}=0,\frac{\partial\psi}{\partial x}=0,\theta=1,C=1 \quad at\ \ x=-f(\delta z)$$

$$\frac{\partial\psi}{\partial z}=0,\frac{\partial\psi}{\partial x}=0,\theta=0\ ,C=0 \quad at\ \ x=+f(\delta z)$$

3.Method of Solution

Introduce the transformation such that

$$\bar{x}=\delta\,x,\frac{\partial}{\partial x}=\delta\frac{\partial}{\partial\bar{x}}$$

Then

$$\frac{\partial}{\partial x}\approx O(\delta)\rightarrow\frac{\partial}{\partial\bar{x}}\approx O(1)$$

For small values of δ <<1,the flow develops slowly with axial gradient of order δ and hence we take $\frac{\partial}{\partial \bar{x}} \approx O(1)$.

Using the above transformation the equations (2.23)-(2.25) reduce to

$$F^4\psi - M_1^2 F^2\psi + \frac{G}{R}\left(\frac{\partial\theta}{\partial x} + N\frac{\partial C}{\partial x}\right) = \delta R\left(\frac{\partial\psi}{\partial\bar{z}}\frac{\partial(F^2\psi)}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial(F^2\psi)}{\partial\bar{z}}\right) \tag{3.1}$$

$$\delta P_1 R\left(\frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial\theta}{\partial x}\right) = F^2\theta - \alpha_1\theta \tag{3.2}$$

$$\delta ScR\left(\frac{\partial\psi}{\partial x}\frac{\partial c}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial C}{\partial x}\right) = F^2 C \tag{3.3}$$

where

$$F^2 = \frac{\partial}{\partial x^2} + \delta^2\frac{\partial}{\partial\bar{z}^2}$$

$$P_1 = \frac{3N_1 P}{3N_1 + 4}\ , \alpha_1 = \frac{3N_1\alpha}{3N_1 + 4}$$

Assuming the slope δ of the wavy boundary to be small we take

$$\psi(x,z) = \psi_0(x,y) + \delta\psi_1(x,z) + \delta^2\psi_2(x,z) + \ldots\ldots\ldots\ldots\ldots$$

$$\theta(x,z) = \theta_o(x,z) + \delta\theta_1(x,z) + \delta^2\theta_2(x,z) + \ldots\ldots\ldots\ldots\ldots\ldots \tag{3.4}$$

$$C(x,z) = C_o(x,z) + \delta c_1(x,z) + \delta^2 c_2(x,z) + \ldots\ldots\ldots\ldots\ldots\ldots$$

Let $$\eta = \frac{x}{f(\bar{z})} \tag{3.5}$$

Substituting (3.4) in equations (3.1)-(3.3) and using (3.4) and equating the like powers of δ the equations and the respective boundary conditions to the zeroth order are

$$\frac{\partial^2\theta_0}{\partial\eta^2} - (\alpha_1 f^2)\theta_0 = 0 \tag{3.6}$$

$$\frac{\partial^2 C_0}{\partial\eta^2} = 0 \tag{3.7}$$

$$\frac{\partial^4\psi_0}{\partial\eta^4}-(M_1^2f^2)\frac{\partial^2\psi_0}{\partial\eta^2}=-\frac{Gf^3}{R}(\frac{\partial\theta_0}{\partial\eta}+N\frac{\partial C_0}{\partial\eta}) \quad (3.8)$$

with

$$\psi_0(+1)-\psi_0(-1)=1$$

$$\frac{\partial\psi_0}{\partial\eta}=0,\ \frac{\partial\psi_0}{\partial\overline{z}}=0,\quad \theta_0=1\ ,\ C_0=1\quad at\quad \eta=-1 \quad (3.9)$$
$$\frac{\partial\psi_0}{\partial\eta}=0,\ \frac{\partial\psi_0}{\partial\overline{z}}=0,\quad \theta_0=0\ ,\ C_0=0\quad at\quad \eta=+1$$

and to the first order are

$$\frac{\partial^2\theta_1}{\partial\eta^2}-(\alpha_1f^2)\theta_1=P_1Rf(\frac{\partial\psi_0}{\partial\eta}\frac{\partial\theta_0}{\partial\overline{z}}-\frac{\partial\psi_0}{\partial\overline{z}}\frac{\partial\theta_0}{\partial\eta}) \quad (3.10)$$

$$\frac{\partial^2C_1}{\partial\eta^2}=ScRf(\frac{\partial\psi_0}{\partial\eta}\frac{\partial C_0}{\partial\overline{z}}-\frac{\partial\psi_0}{\partial\overline{z}}\frac{\partial C_0}{\partial\eta}) \quad (3.11)$$

$$\frac{\partial^4\psi_1}{\partial\eta^4}-(M_1^2f^2)\frac{\partial^2\psi_1}{\partial\eta^2}=-\frac{Gf^3}{R}(\frac{\partial\theta_1}{\partial\eta}+N\frac{\partial C_1}{\partial\eta})+ Rf(\frac{\partial\psi_0}{\partial\eta}\frac{\partial^3\psi_0}{\partial z^3}-\frac{\partial\psi_0}{\partial\overline{z}}\frac{\partial^3\psi_0}{\partial x\partial z^2}) \quad (3.12)$$

with

$$\psi_1(+1)-\psi_1(-1)=0$$

$$\frac{\partial\psi_1}{\partial\eta}=0,\ \frac{\partial\psi_1}{\partial\overline{z}}=0,\quad \theta_1=0\,,C_1=0\quad at\quad \eta=-1 \quad (3.13)$$
$$\frac{\partial\psi_1}{\partial\eta}=0,\ \frac{\partial\psi_1}{\partial\overline{z}}=0,\quad \theta_1=0\ .C_1=0\quad at\quad \eta=+1$$

Solving the equations(3.6)-(3.8) subject to the boundary conditions (3.9).we obtain

$$\theta_{0_0}=0.5(\frac{Ch(h\eta)}{Ch(h)}-\frac{Sh(h\eta)}{Sh(h)})\ C_0=0.5(1-\eta)$$

$$\psi_0=a_{11}Cosh(\beta_1\eta)+a_{12}Sinh(\beta_1\eta)+a_{15}\eta+a_{14}+\phi_1(\eta)$$

$$\phi_1(\eta) = a_8\eta^2 - a_9 Sh(h\eta) - a_{10}Ch(h\eta) + 2a_8\eta - a_9 hCh(h\eta) - a_{10}hSh(h\eta)$$

Similarly the solutions to the first order are

$$\theta_1 = a_{34}Ch(h\eta) + a_{35}Sh(h\eta) + \phi_2(\eta)$$

$$\phi_2(\eta) = a_{14} + a_{15}\eta + (a_{16} + a_{18}\eta + a_{25}\eta^2)Ch(h\eta) + (a_{17} + a_{19}\eta +$$

$$+ a_{24}\eta^2)Sh(h\eta) + (a_{20} + a_{22}\eta)Ch(2h\eta) + (a_{21} + a_{23}\eta)Sh(2h\eta)$$

$$+ a_{26}\eta Sh(\beta_2\eta) + a_{27}\eta Sh(\beta_3\eta) + a_{28}\eta Ch(\beta_2\eta) + a_{29}\eta Ch(\beta_3\eta)$$

$$+ a_{30}Ch(\beta_2\eta) + a_{31}Ch(\beta_3\eta) + a_{32}Sh(\beta_2\eta) + a_{33}Sh(\beta_3\eta)$$

$$\begin{aligned} C_1 = {} & a_{36}(\eta^2 - 1) + a_{37}(\eta^3 Sh(\beta_1\eta) - Sh(\beta_1)) + a_{38}\eta(Ch(\beta_1\eta) - Ch(\beta_1)) + \\ & + (a_{39} + a_{53})(\eta Sh(\beta_1\eta) - Sh(\beta_1)) + (a_{40} + a_{52} + a_{50})\eta(Ch(\beta_1\eta) - Ch(\beta_1)) \\ & + (a_{41} + a_{60} + \eta(a_{64} - a_{47}))\eta(Ch(\beta_1\eta) - Ch(\beta_1)) + (a_{62} - a_{41} + \eta(a_{66} + a_{47}))x \\ & x(Ch(\beta_3\eta) - Ch(\beta_3)) + (a_{49} + a_{61})(Sh(\beta_2\eta) - \eta Sh(\beta_2)) + (a_{63} + a_{49})(Sh(\beta_3\eta) \\ & - \eta Sh(\beta_3)) + (a_{42} + a_{56} + \eta(a_{45} + a_{58}))(Ch(2h\eta) - Ch(2h)) + (a_{57} + \eta a_{59})(Sh(2h\eta) \\ & - \eta Sh(2h)) + a_{51}(Sh(h\eta) - \eta Sh(h)) + a_{54}(\eta^2 Ch(h\eta) - Ch(h)) + a_{55}\eta(\eta sh(h\eta) - \\ & - Sh(h)) + (a_{65} + a_{46})(\eta Sh(\beta_2\eta) - Sh(\beta_2)) + (a_{67} + a_{40})((\eta Sh(\beta_3\eta) - Sh(\beta_3)) + \\ & + a_{48}((\eta Sh(2\beta_1\eta) - Sh(2\beta_1)) \end{aligned}$$

$$\psi_1 = b_{49}Cosh(\beta_1\eta) + b_{50}Sinh(\beta_1\eta) + b_{51}\eta + b_{52} + \phi_2(\eta)$$

$$\phi_2(\eta) = b_{21} + b_{22}\eta + b_{23}\eta^2 + b_{24}\eta^3 + b_{25}\eta^4 + b_{26}\eta^5 + b_{27}\eta^6 + b_{28}\eta^7 + (b_{29} + b_{30}\eta +$$

$$+ b_{31}\eta^2 + b_{32}\eta^3 + b_{33}\eta^4 + b_{34}\eta^5 + b_{35}\eta^6)Cosh(\beta_1\eta) + (b_{36} + b_{37}\eta + b_{38}\eta^2 + b_{39}\eta^3$$

$$+ b_{40}\eta^4 + b_{41}\eta^5 + b_{42}\eta^6)Sinh(\beta_1\eta) + b_{43}Cosh(2\beta_1\eta) + b_{44}Sinh(2\beta_1\eta)$$

where $a_1, a_2, \ldots, a_{90}, b_1, b_2, \ldots, b_{51}$ are constants .

5. NUSSELT NUMBER and SHERWOOD NUMBER

The rate of heat transfer (Nusselt Number) on the walls has been calculated using the formula

$$Nu = \frac{1}{f(\theta_m - \theta_w)}(\frac{\partial \theta}{\partial \eta})_{\eta = \pm 1}$$

where

$$\theta_m = 0.5\int_{-1}^{1} \theta \, d\eta$$

$$(Nu)_{\eta=+1} = \frac{1}{f\theta_m}(a_{78} + \delta(a_{76} + a_{77})))$$

$$(Nu)_{\eta=-1} = \frac{1}{f(\theta_m - 1)}(a_{79} + \delta(a_{77} - a_{76})))$$

$$\theta_m = a_{80} + \delta\, a_{81}$$

The rate of mass transfer (Sherwood Number) on the walls has been calculated using the formula

$$Sh = \frac{1}{f(C_m - C_w)}(\frac{\partial C}{\partial \eta})_{\eta = \pm 1}$$

where

$$C_m = 0.5\int_{-1}^{1} C \, d\eta$$

$$(Sh)_{\eta=+1} = \frac{1}{fC_m}(a_{74} + \delta\, a_{70})$$

$$(Sh)_{\eta=-1} = \frac{1}{f(C_m - 1)}(a_{75} + \delta\, a_{71})$$

$$C_m = a_{73} + \delta\, a_{72}$$

5.RESULTS AND DISCUSSION OF THE NUMERICAL RESULTS

Fig (1) represents the variation of u with M, m and α. It is found that higher the Lorentz force lesser the axial velocity in the flow region. An increase in the Hall parameter (m) enhances the axial velocity. An increase in the strength of the heat generating source (α) leads to a depreciation in the axial velocity |u| reduces with M≤4. Also it enhances with Hall parameter (m) and Heat source parameter (α) (Fig (2)).

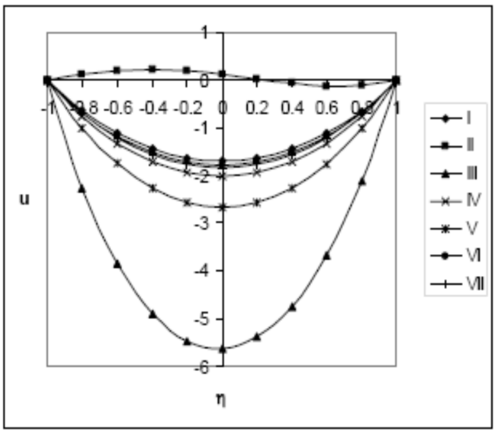


Fig. 1 : Variation of u with M, m, α

	I	II	III	IV	V	VI	VII
M	2	4	6	2	2	2	2
m	0.5	0.5	0.5	1.5	2.5	0.5	0.5
α	2	2	2	2	2	4	6

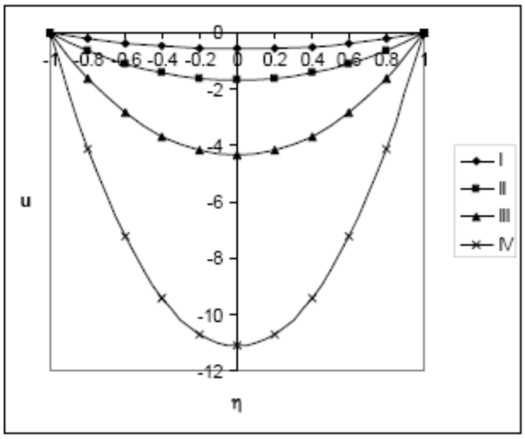


Fig. 2 : Variation of u with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

Fig.3 explains the actual temperature enhances with inclination λ ≤ 0.75 and reduces with higher λ = 1. Also seen that the actual temperature reduces when the Buoyancy forces act in the same direction and for the forces acting in opposite directions the actual temperature enhances in the entire flow region

From fig.4 higher the constriction of the channel walls larger the actual concentration and for higher constriction lesser the actual concentration and for still higher constriction of the channel walls lesser the concentration in the left half and larger in the right half.

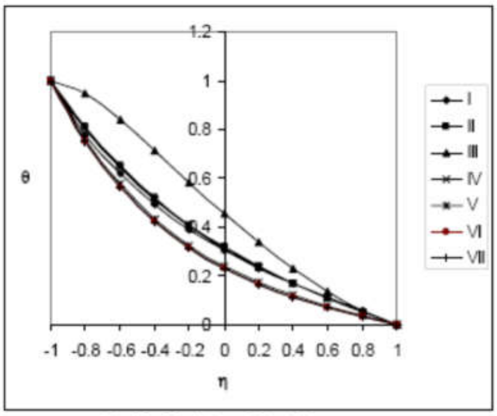


Fig 15 : Variation of θ with λ, x

	I	II	III	IV	V	VI	VII
λ	0.25	0.5	0.75	1	0.5	0.5	0.5
x	π/4	π/4	π/4	π/4	π/2	π	2π

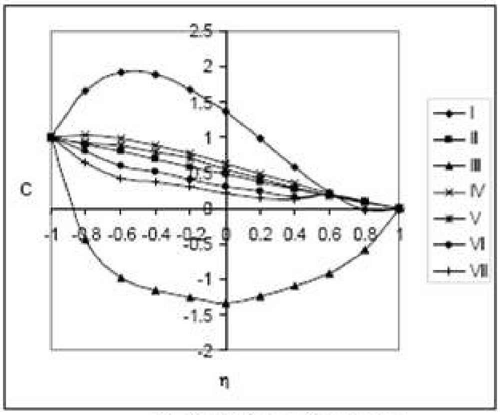


Fig 20 : Variation of C with λ, x

	I	II	III	IV	V	VI	VII
λ	0.25	0.5	0.75	1	0.5	0.5	0.5
x	π/4	π/4	π/4	π/4	π/2	π	2π

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