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Effect of Thermal Radiation and Hall Effect on Mixed Convective Heat and Mass Transfer Flow of a Viscous Electrically Conducting Fluid in Vertical Wavy Channel

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Abstract— In this paper, we investigate the convective heat and mass transfer flow of a viscous electrically conducting fluid in a vertical wavy channel under the influence of an inclined magnetic field with walls maintained at constant temperature and concentration. The governing equations of the flow heat and mass transfer are solved using perturbation technique with the slope 'δ' of the wavy wall. The graphs are drawn for the velocity, temperature and concentration. The rate of heat and mass transfer are calculated and analyzed for different variations of the governing parameters.

Index Terms— Hall Effect, Thermal radiation, Heat and Mass transfer, Vertical wavy channel.

1 Introduction

The flow of heat and mass from a wall embedded in a porous media is a subject of great interest in the research activity due to its practical applications in geothermal processes, the petroleum industry, the spreading of pollutants, cavity wall insulation systems, flat-plate solar collectors, flat-plate condensers in refrigerators, grain storage containers, nuclear waste management. Coupled heat and mass transfer by natural convection in a fluid-saturated porous medium has attracted considerable attention in recent years due to many important engineering and geophysical applications such as cooling of nuclear fuel in shipping flasks and water filled storage bags, insulation of high temperature gas-cooled reactor vessels, drums containing heat generating chemicals in the earth, thermal energy storage tanks, regeneration heat exchanges containing catalytic reaction.

Siva Prasad *et. al.,* [1] have studied Hall effects on unsteady MHD free and forced convection flow in a porous rotating channel. Alam *et. al.,*[2] have studied unsteady free convective heat and mass transfer flow in a rotating system with Hall currents, viscous dissipation and Joule heating. Jer-Huan Jang *et. al.,*[3] have analyzed that the mixed convection heat and mass transfer along a vertical wavy surface. Recently Seth *et. al.,* [4] have investigated the effects of Hall currents on heat transfer in a rotating MHD channel flow in arbitrary conducting walls. Sarkar *et. al.,* [5] have analyzed the effects of mass transfer and rotation and flow past a porous plate in a porous medium with variable suction in slip flow region. Anwar Beg et al(6) have discussed unsteady Hartmann- Couette flow and heat transfer in a channel with Hall current, ionslip, Viscous and Joule heating effects . Shanti [7] has investigated effect of Hall current on mixed convective heat and mass transfer flow in a vertical wavy channel with heat sources. Ahmed [8] has discussed the Hall effects on transient flow past an impulsively started infinite horizontal porous plate in a rotating system. Leela kumari [9] has studied the effect of Hall currents on the convective heat and mass transfer flow in a horizontal wavy channel under inclined magnetic field.

In this paper we investigate the convective heat and mass transfer flow of a viscous electrically conducting

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fluid in a vertical wavy channel under the influence of an inclined magnetic field 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 different values of G,R,M,m, Sc, N, N_1, β,α, λ and x. The rate of heat and mass transfer are numerically evaluated for different variation of the governing parameters.

2 Formulation and Solution 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 plane (x-z).The magnetic field is inclined at an angle α_1 to the axial direction and hence its components are $(0, H_0Sin(\alpha_1), H_0Cos(\alpha_1))$ .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

$$j_x - m H_0 J_z Sin(\alpha_1) = -\sigma\mu_e H_0 w Sin(\alpha_1) \quad (2)$$

$$J_z + m H_0 J_x Sin(\alpha_1) = \sigma\mu_e H_0 u\, Sin(\alpha_1) \quad (3)$$

where m= $\omega_e\tau_e$ is the Hall parameter.

On solving equations (2)&(3) we obtain

$$j_x = \frac{\sigma\mu_e H_0 Sin(\alpha_1)}{1+m^2H_0^2Sin^2(\alpha_1)}(mH_0Sin(\alpha_1) - w) \quad (4)$$

$$j_z = \frac{\sigma\mu_e H_0 Sin(\alpha_1)}{1+m^2\,H_0^2Sin^2(\alpha_1)}(u + mH_0 w\,Sin(\alpha_1)) \quad (5)$$

where u, w are the velocity components along x

choose a rectangular Cartesian co-ordinate system O(x,y,z) with z-axis in the vertical direction and the walls at $x = \pm f(\frac{\delta z}{L})$.

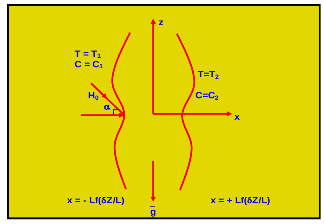

Fig.1 configuration of the problem

When the strength of the magnetic field is very large we include the Hall current so that the generalized Ohm's law is modified to

$$\bar{J} + \omega_e\tau_e \bar{J}x\bar{H} = \sigma(\bar{E} + \mu_e \bar{q}x\bar{H}) \quad (1)$$

where q is the velocity vector, H is the magnetic field intensity vector, E is the electric field, J is the current density vector, ω_e is the cyclotron frequency, τ_e is the electron collision time, σ is the fluid conductivity and μ_e is the magnetic permeability. Neglecting the electron pressure gradient, ion-slip and thermo-electric effects and assuming the electric field E=0, equation (1) reduces

and z directions respectively,

The Momentum equations are

$$u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} = -\frac{\partial p}{\partial x} + \mu(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}) + \mu_e(-H_0J_zSin(\alpha)) \quad (6)$$

$$u\frac{\partial W}{\partial x} + w\frac{\partial W}{\partial z} = -\frac{\partial p}{\partial z} + \mu(\frac{\partial^2 W}{\partial x^2} + \frac{\partial^2 W}{\partial z^2}) + \mu_e(H_0J_xSin(\alpha_1)) \quad (7)$$

Substituting J_x and J_z from equations (4)&(5) in equations (6)&(7) we obtain

$$u\frac{\partial u}{\partial x} + w\frac{\partial u}{\partial z} = -\frac{\partial p}{\partial x} + \mu(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}) - \frac{\sigma\mu_e H_{0\,0}^{2}Sin^2(\alpha_1)}{1+m^2H_0^2Sin^2(\alpha_1)}(u + mH_0wSin(\alpha_1)) \quad (8)$$

$$u\frac{\partial W}{\partial x} + w\frac{\partial W}{\partial z} = -\frac{\partial p}{\partial z} + \mu(\frac{\partial^2 W}{\partial x^2} + \frac{\partial^2 W}{\partial z^2}) - \frac{\sigma\mu_e H_0^2 Sin^2(\alpha_1)}{1+m^2H_0^2Sin^2(\alpha_1)}(w - mH_0uSin(\alpha_1)) - \rho g$$

(9)

The energy equation is

$$\rho C_p(u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}=k_f(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2})+Q(T_e-T)-\frac{\partial(q_r)}{\partial x}$$

(10)

The diffusion equation is

$$u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial z}=D_1(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial z^2})$$

(11)

The equation of state is

$$\rho-\rho_0=-\beta(T-T_o)-\beta^{\bullet}(C-C_o)$$

(12)

Where T,C are the temperature and concentration in the fluid. k_f is the thermal conductivity, Cp is the specific heat at constant pressure, D_1 is molecular diffusivity, β is the coefficient of thermal expansion, $\beta^{\bullet}$ is the coefficient of volume expansion ,Q is the strength of the heat source and q_r is the radiative heat flux.

By Rosseland approximation (Brewester [3a]) the radiative heat fluxis given by

$$q_r=-\frac{4\sigma^{\bullet}}{3\beta_r}\frac{\partial(T'^4)}{\partial y}$$

(13)

Expanding T'^4 about Te by Taylor expansion and neglecting the higher order terms we get

$$T'^4\cong 4TT_e^3-3T_e^4$$

(14)

Where $\sigma^{\bullet}$ is the Stefan-Boltzman constant and β_r is the mean absorption coefficient.

Substituting (13)&(14) in (10) we obtain

$$\rho C_p(u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}=k_f(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2})+Q(T_e-T)-\frac{16\sigma^* T_e^3}{3\beta_R}\frac{\partial^2 T}{\partial x^2}$$

(15)

The flow is maintained by a constant volume flux for which a characteristic velocity is defined as

$$q=\frac{1}{L}\int_{-Lf}^{Lf}wdx$$

(16)

The boundary conditions are

u= 0 ,w=0 T=T_1 ,C=C_1 on $x=-f(\frac{\delta z}{L})$

(17a)

u=0, w=0, T=T_2 ,C=C_2 on $x=f(\frac{\delta z}{L})$

(17b)

Eliminating the pressure from equations (8)&(9) and introducing the Stream function ψ as

$$u=-\frac{\partial\psi}{\partial z}\quad,\ w=\frac{\partial\psi}{\partial x}$$

(18)

the equations (8)&(9) ,(15)&(11) in terms of ψ is

$$\frac{\partial\psi}{\partial z}\frac{\partial(\nabla^2\psi)}{\partial x}-\frac{\partial\psi}{\partial x}\frac{\partial(\nabla^2\psi)}{\partial z}=\mu\nabla^4\psi+\beta g\frac{\partial(T-T_e)}{\partial x}+\beta^{\bullet}g\frac{\partial(C-C_e)}{\partial x}-(\frac{\sigma\mu_e^2H_0^2Sin^2(\alpha_1)}{1+m^2H_0^2\,Sin^2(\alpha_1)})\nabla^2\psi$$

(19)

$$\rho C_p(\frac{\partial\psi}{\partial x}\frac{\partial T}{\partial z}-\frac{\partial\psi}{\partial z}\frac{\partial T}{\partial x}=k_f(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial z^2})+Q(T_e-T)+\frac{16\sigma^{\bullet}T_e^3}{3\beta_R}\frac{\partial^2 T}{\partial x^2}$$

(20)

$$\frac{\partial\psi}{\partial x}\frac{\partial C}{\partial z}-\frac{\partial\psi}{\partial z}\frac{\partial C}{\partial x}=D_1(\frac{\partial^2 C}{\partial x^2}+\frac{\partial^2 C}{\partial z^2})$$

(21)

On introducing the following non-dimensional variables

$$(x',z')=(x,z)/L\,,$$

$$\psi'=\frac{\psi}{qL},\ \theta=\frac{T-T_2}{T_1-T_2},C'=\frac{C-C_2}{C_1-C_2}$$

(22)

the equations of momentum and energy in the non-dimensional form are

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

(23)

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

(24)

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

(25)

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

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$$M_1^2 = \frac{M^2\lambda^2}{\lambda^2(1+m^2)},\ \lambda = Sin(\alpha_1)$$

$m = \omega_e \tau_e$ (Hall Parameter)

$R = \frac{qL}{\nu}$ (Reynolds Number)

$P = \frac{\mu C_p}{K_f}$ (Prandtl Number)

$\alpha = \frac{QL^2}{K_f C_p}$ (Heat Source Parameter)

The corresponding boundary conditions are

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

$$\frac{\partial\psi}{\partial z} = 0, \frac{\partial\psi}{\partial x} = 0, \theta = 1, C = 1 \quad at\ x = -f(\delta z) \tag{26}$$

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

3 ANALISIS OF FLOW

Introduce the transformation such that

$$\bar{z} = \delta z, \frac{\partial}{\partial z} = \delta\frac{\partial}{\partial \bar{z}} \quad \text{then}$$

$$\frac{\partial}{\partial z} \approx O(\delta) \to \frac{\partial}{\partial \bar{z}} \approx O(1)$$

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

Using the above transformation the equations (23)-(25) reduce to

$$F^4\psi - M_1^2F^2\psi + \frac{G}{R}(\frac{\partial\theta}{\partial x} + N\frac{\partial C}{\partial x}) = \delta R(\frac{\partial\psi}{\partial\bar{z}}\frac{\partial(F^2\psi)}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial(F^2\psi)}{\partial\bar{z}}) \tag{27}$$

$$\delta P_1 R(\frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial\theta}{\partial x}) = F^2\theta - \alpha_2\theta \tag{28}$$

$$\delta ScR(\frac{\partial\psi}{\partial x}\frac{\partial c}{\partial z} - \frac{\partial\psi}{\partial z}\frac{\partial C}{\partial x}) = F^2 C \tag{29}$$

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

$P_1 = \frac{3N_1 P}{3N_1 + 4}$, $\alpha_2 = \frac{3N_1\alpha}{3N_1 + 4}$

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

$Sc = \frac{\nu}{D_1}$ (Schmidt Number)

$N = \frac{\beta^*(C_1 - C_2)}{\beta(T_1 - T_2)}$ (Buoyancy ratio) ,

$N_1 = \frac{3\beta_R K_f}{4\sigma^\bullet T_e^3}$, $N_2 = \frac{3N_1}{3N_1+4}, P_1 = PN_2, \alpha_1 = \alpha N_2$ (Radiation parameter)

$$\psi(x,z) = \psi_0(x,z) + \delta\psi_1(x,z) + \delta^2\psi_2(x,z) + ...$$
$$\theta(x,z) = \theta_o(x,z) + \delta\theta_1(x,z) + \delta^2\theta_2(x,z) + ...$$
$$C(x,z) = C_o(x,z) + \delta c_1(x,z) + \delta^2 c_2(x,z) + ... \tag{30}$$

Let $\eta = \frac{x}{f(\bar{z})}$ (31)

Substituting (30) in equations (27) - (29) and using (31) and equating the like powers of δ the equations and the respective boundary conditions to the zeroth order are

$$\frac{\partial^2\theta_0}{\partial\eta^2} - (\alpha_2 f^2)\theta_0 = 0 \tag{32}$$

$$\frac{\partial^2 C_0}{\partial\eta^2} = 0 \tag{33}$$

$$\frac{\partial^4\psi_0}{\partial\eta^4} - (M_1^2 f^2)\frac{\partial^2\psi_0}{\partial\eta^2} = -\frac{Gf^3}{R}(\frac{\partial\theta_0}{\partial\eta} + N\frac{\partial C_0}{\partial\eta}) \tag{34}$$

with

$$\psi_0(+1) - \psi_0(-1) = 1$$
$$\frac{\partial\psi_0}{\partial\eta} = 0,\ \frac{\partial\psi_0}{\partial\bar{z}} = 0,\quad \theta_0 = 1\ , C_0 = 1 \quad at \quad \eta = -1$$
$$\frac{\partial\psi_0}{\partial\eta} = 0,\ \frac{\partial\psi_0}{\partial\bar{z}} = 0,\quad \theta_0 = 0\ , C_0 = 0 \quad at \quad \eta = +1 \tag{35}$$

and to the first order are

$$\frac{\partial^2\theta_1}{\partial\eta^2} - (\alpha_2 f^2)\theta_1 = P_1 Rf(\frac{\partial\psi_0}{\partial\eta}\frac{\partial\theta_0}{\partial\bar{z}} - \frac{\partial\psi_0}{\partial\bar{z}}\frac{\partial\theta_0}{\partial\eta}) \tag{36}$$

$$\frac{\partial^2 C_1}{\partial\eta^2} = ScRf(\frac{\partial\psi_0}{\partial\eta}\frac{\partial C_0}{\partial\bar{z}} - \frac{\partial\psi_0}{\partial\bar{z}}\frac{\partial C_0}{\partial\eta}) \tag{37}$$

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

(38)

with

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

$$\frac{\partial \psi_1}{\partial \eta} = 0, \ \frac{\partial \psi_1}{\partial \bar{z}} = 0, \quad \theta_1 = 0, C_1 = 0 \quad at \quad \eta = -1$$

$$\frac{\partial \psi_1}{\partial \eta} = 0, \ \frac{\partial \psi_1}{\partial \bar{z}} = 0, \quad \theta_1 = 0 .C_1 = 0 \quad at \quad \eta = +1$$

(39)

4 SOLUTIONS OF THE PROBLEM

Solving the equations (3.5)&(3.6) subject to the boundary conditions (3.7).we obtain

$$\theta_0 = 0.5\left(\frac{Ch(h\eta)}{Ch(h)} - \frac{Sh(h\eta)}{Sh(h)}\right)$$

$$C_0 = 0.5(1-\eta) + \frac{a_1}{h^2}(Sh(h\eta) - \eta Sh(h)) - \frac{a_2}{h^2}(Ch(h\eta) - Ch(h))$$

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

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

Similarly the solutions to the first order are

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

$$\begin{aligned}\phi_2(\eta) = {} & a_{14} + a_{15}\eta + (a_{16} + a_{18}\eta + a_{25}\eta^2)Ch(h\eta) + (a_{17} + a_{19}\eta + \\ & + a_{24}\eta^2)Sh(h\eta) + (a_{20} + a_{22}\eta)Ch(2h\eta) + (a_{21} + a_{23}\eta)Sh(2h\eta) \\ & + a_{26}\eta Sh(\beta_2\eta) + a_{27}\eta Sh(\beta_3\eta) + a_{28}\eta Ch(\beta_2\eta) + a_{29}\eta Ch(\beta_3\eta) \\ & + a_{30}Ch(\beta_2\eta) + a_{31}Ch(\beta_3\eta) + a_{32}Sh(\beta_2\eta) + a_{33}Sh(\beta_3\eta)\end{aligned}$$

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

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

$$\begin{aligned}\phi_2(\eta) = {} & b_{21} + b_{22}\eta + b_{23}\eta^2 + b_{24}\eta^3 + b_{25}\eta^4 + b_{26}\eta^5 + b_{27}\eta^6 + b_{28}\eta^7 + (b_{29} + b_{30}\eta + \\ & + b_{31}\eta^2 + b_{32}\eta^3 + b_{33}\eta^4 + b_{34}\eta^5 + b_{35}\eta^6)Cosh(\beta_1\eta) + (b_{36} + b_{37}\eta + b_{38}\eta^2 + b_{39}\eta^3 \\ & + b_{40}\eta^4 + b_{41}\eta^5 + b_{42}\eta^6)Sinh(\beta_1\eta) + b_{43}Cosh(2\beta_1\eta) + b_{44}Sinh(2\beta_1\eta)\end{aligned}$$

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

4.1 Nusselt Number and Sherwood Number

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

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

Where

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

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

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

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

5 DISCUSSION OF THE NUMERCAL RESULTS

In this analysis, we investigate the effect of thermal radiation and Hall effects on convective heat and mass transfer flow of a viscous electrically conducting fluid in vertical wavy channel under the influence of inclined magnetic field with walls maintained at constant temperature and concentration. The non-linear coupled equations governing the flow heat and mass transfer have been solved by applying the perturbation technique with the slope 'δ' of wavy wall as a perturbation parameter.

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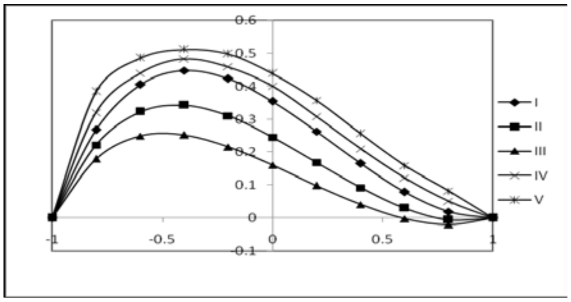

Fig. 1a : Variation of 'w' with M and m

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

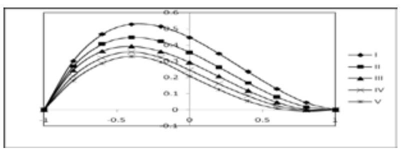

Fig. 2 : Variation of 'w' with N_1

	I	II	III	IV
N_1	0.5	1.5	5	10

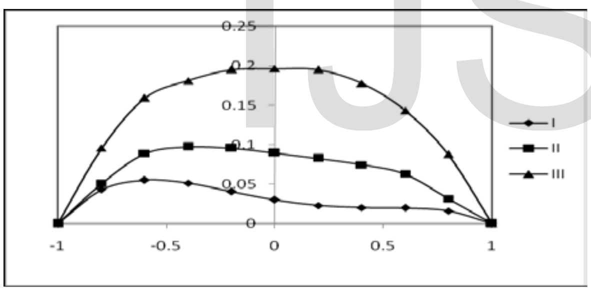

Fig. 3 : Variation of u with m

	I	II	III
m	0.5	1.5	2.5

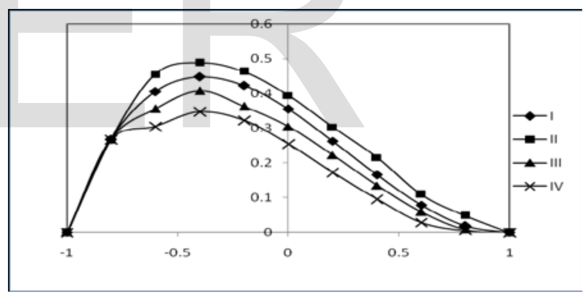

Fig. 4 : Variation of u with N

	I	II	III	IV
N	1	2	-0.5	-0.8

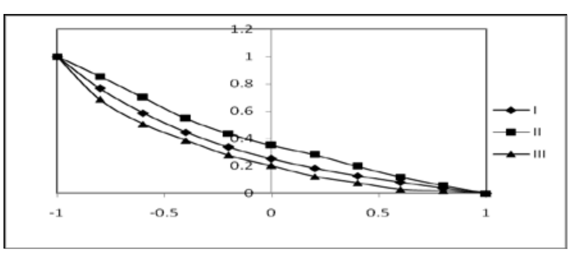

Fig. 5 : Variation of θ with M

	I	II	III
M	2	4	6

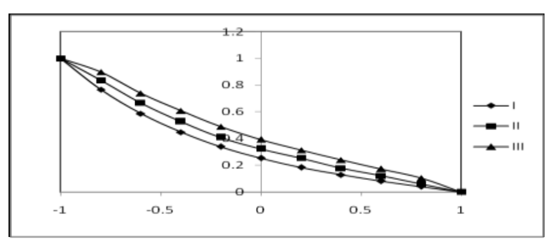

Fig. 6 : Variation of θ with m

	I	II	III
m	0.5	1.5	2.5

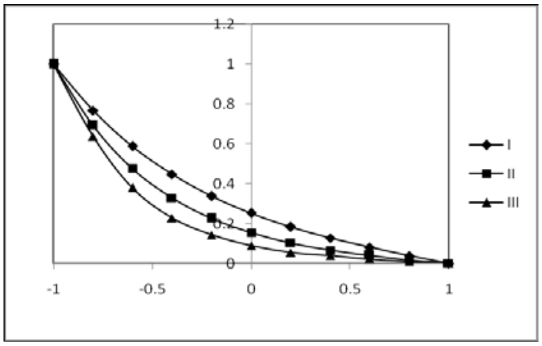

Fig. 7 : Variation of θ with α

	I	II	III
α	2	4	6

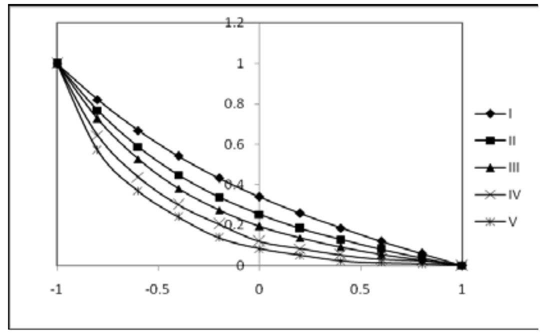

Fig. 8 : Variation of θ with N_1

	I	II	III	IV	V
N_1	0.5	1.5	5	10	100

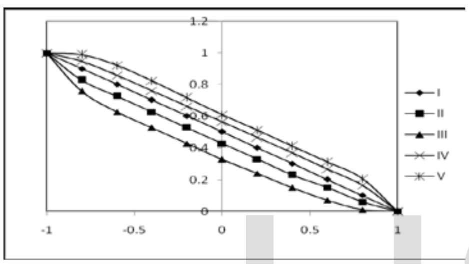

Fig. 9 : Variation of C with N_1

	I	II	III	IV	V
N_1	0.5	1.5	5	10	100

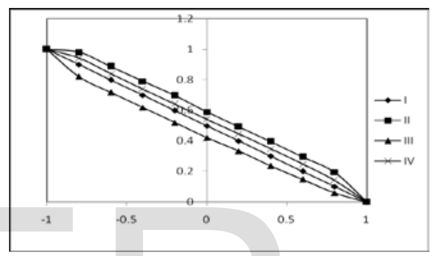

Fig. 10 : Variation of C with λ

	I	II	III	IV
λ	0.25	0.5	0.75	1

Fig (1a) represents 'w' with Hartmann number 'M' and Hall parameter 'm'. It is found that the axial velocity experiences retardation with increase in 'M'. An increase in Hall parameter 'm' enhances '$|w|$' in entire flow region. Fig (2) represents 'w' with radiation parameter N_1. We notice that higher the radiative heat flux smaller the axial velocity. Fig (3) represents 'u' with Hall parameter 'm'. It is noticed from the profiles that higher the hall current effects larger the secondary velocity 'u'. Fig (4) represents 'u' with buoyancy ratio 'N'. It is found that the secondary velocity enhances with increase in N>0 when the buoyancy forces are in the same direction and for the forces acting in opposite direction '$|u|$'depreciates in the flow region. Fig (5) represents 'θ' with 'M'. It can be seen from the profile that the actual temperature increases with increase in $M \leq 5$ and depreciates with higher $M \geq 10$. Fig (6) represents 'θ' with Hall parameter 'm' higher the hall current effects larger the actual temperature. An increase in the strength of the heat sources 'α' results in depreciation in the actual temperature Fig (7). Fig (8) represents 'θ' with radiation parameter 'N_1'. It is found that higher the radiative heat flux smaller the actual temperature. From fig (9), we find that the concentration depreciates with $N_1 \leq 5$ and enhances with higher $N_1 \geq 10$. From Fig (10), we notice that the concentration enhances with inclination $\lambda \leq 0.5$, depreciates at λ=0.75 and again enhances with higher value $\lambda \geq 1$.

6 CONCLUSIONS

1. It is found that the rate of heat transfer enhances with increase in '$|G|$'and R at both the walls. When the molecular buoyancy force dominates over the thermal buoyancy force the rate of heat transfer enhances at $\eta = \pm 1$, when the buoyancy forces acting in the same direction and for the forces acting in opposite direction it reduces at $\eta = \pm 1$. The variations of Nu with radiation parameter N_1 an increase in $N_1 \leq 1.5$ enhances $|Nu|$ at η=+1 and reduces at η=-1 and for larger $N_1 \geq 5$ it enhances at η =-1and η =+1. It reduces in

the heating case and enhances in the cooling case for N_1=10.

2. With respect to magnetic parameter 'M' it is found that the rate of mass transfer $|Sh|$ enhances with increases $M \leq 4$ and reduces with higher $M \geq 6$. An increase in the Hall parameter m, leads to a depreciation in $|Sh|$ at both the walls. with reference to heat source parameter 'α' it is observed that $|Sh|$' reduces at $\eta = \pm 1$ with increase in $\alpha \leq 4$ and for higher $\alpha \geq 6$, it enhances at η =+1 and reduces at η =-1 for all $|G|$ also it reduces with increases in 'Sc' thus lesser the molecular diffusivity smaller $|Sh|$ at $\eta = \pm 1$.

Higher the dilation of channel walls β=-0.7 larger $|Sh|$ at $\eta = \pm 1$ and smaller for further higher dilation ($\beta \geq 0.9$). An increase in the inclination of the magnetic field $\lambda \leq 0.5$ enhances $|Sh|$ at $\eta = \pm 1$ while for higher $\lambda \geq 0.75$ reduces at both the walls. Moving along axial direction of channel walls, the rate of mass transfer $|Sh|$, reduces with $x \leq \pi/2$ and for higher $x \geq \pi$, it enhances for G>0 and reduces for G<0 at both the walls.

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