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Effect of Hall Currents on Convective Heat And Mass Transfer Flow of A Viscous Electrically Conducting Fluid In A Non-Uniformly Heated Vertical Channel With Radiation

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ABSTRACT: *In this paper we investigate the convective study of heat and mass transfer flow of a viscous electrically conducting 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 a different variations of the governing parameters.*

Keywords: *convective fluid; electrically conducting fluid; heat sources, heat transfer, mass transfer*

I. INTRODUCTION

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.

In recent years, energy and material saving considerations have prompted an expansion of the efforts at producing efficient heat exchanger equipment through augmentation of heat transfer. It has been established [9] that channels with diverging – converging geometries augment the transportation of heat transfer and momentum. Hence it is advantageous to go for converging-diverging geometries for improving the design of heat transfer equipment. Vajravelu and Nayfeh [22] have investigated the influence of the wall waviness on friction and pressure drop of the generated coquette flow. Vajravelu and Sastry [23] have analyzed the free convection heat transfer in a viscous, incompressible fluid confined between long vertical wavy walls is the presence of constant heat source. Later Vajravelu and Debnath [24] have extended this study to convective flow is a vertical wavy channel in four different geometrical configurations. This problem has been extended to the case of wavy walls by McMicheal and Deutsch [13], Deshikachar et al [7] Rao et. al., [17] and Sree Ramachandra Murthy [21]. Hyan Gook Won et. al., [11] have analyzed that the flow and heat/mass transfer in a wavy duct with various corrugation angles in two dimensional flow regimes. Mahdy et. al., [13a] have studied the mixed convection heat and mass transfer on a vertical wavy plate embedded in a saturated porous media (PST/PSE) Comini et. al.,[13] have analyzed the convective heat and mass transfer in wavy finned-tube exchangers. Jer-Huan Jang et. al.,[11a] have analyzed that the mixed convection heat and mass transfer along a vertical wavy surface.

In all these investigations, the effects of Hall currents are not considered. However, in a partially ionized gas, there occurs a Hall current [4] 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[1,6,12,17-20,25]

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II. 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

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

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

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

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)

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

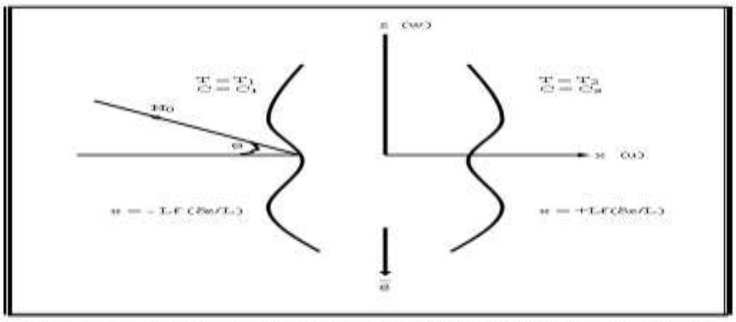
$N = \frac{\beta^*(C_1 - C_2)}{\beta(T_1 - T_2)}$ (Buoyancy ratio), $N_1 = \frac{3\beta_R K_f}{4\sigma^\bullet T_e^3}$ (Radiation parameter)

The boundary conditions are

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

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

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



SCHEMATIC DIAGRAM OF THE CONFIGURATION

III. 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

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

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

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

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

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

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

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

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

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

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

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

with

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

$$\frac{\partial\psi_0}{\partial\eta}=0,\ \frac{\partial\psi_0}{\partial\bar{z}}=0,\quad \theta_0=1\ ,\ C_0=1\quad at\quad \eta=-1 \tag{3.9}$$

$$\frac{\partial\psi_0}{\partial\eta}=0,\ \frac{\partial\psi_0}{\partial\bar{z}}=0,\quad \theta_0=0\ ,\ C_0=0\quad at\quad \eta=+1$$

and to the first order are

$$\frac{\partial^2\theta_1}{\partial\eta^2}-(\alpha_1 f^2)\theta_1=P_1Rf\left(\frac{\partial\psi_0}{\partial\eta}\frac{\partial\theta_0}{\partial\bar{z}}-\frac{\partial\psi_0}{\partial\bar{z}}\frac{\partial\theta_0}{\partial\eta}\right) \tag{3.10}$$

$$\frac{\partial^2 C_1}{\partial\eta^2}=ScRf\left(\frac{\partial\psi_0}{\partial\eta}\frac{\partial C_0}{\partial\bar{z}}-\frac{\partial\psi_0}{\partial\bar{z}}\frac{\partial C_0}{\partial\eta}\right) \tag{3.11}$$

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

with

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

$$\frac{\partial\psi_1}{\partial\eta}=0,\ \frac{\partial\psi_1}{\partial\bar{z}}=0,\quad \theta_1=0\,,C_1=0\quad at\quad \eta=-1 \tag{3.13}$$

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

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

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

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

$$\phi_1(\eta)=a_8\eta^2-a_9Sh(h\eta)-a_{10}Ch(h\eta)+2a_8\eta-a_9hCh(h\eta)-a_{10}hSh(h\eta)$$

Similarly the solutions to the first order are

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

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

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

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

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

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

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

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

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

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

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

IV. NUSSELT NUMBER AND SHERWOOD NUMBER

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

$$Nu = \frac{1}{f(\theta_m - \theta_w)} \left(\frac{\partial\theta}{\partial\eta}\right)_{\eta=\pm1}$$

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

$$Sh = \frac{1}{f(C_m - C_w)} \left(\frac{\partial C}{\partial\eta}\right)_{\eta=\pm1}$$

where

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

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

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

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

V. RESULTS AND DISCUSSION OF THE NUMERICAL RESULTS

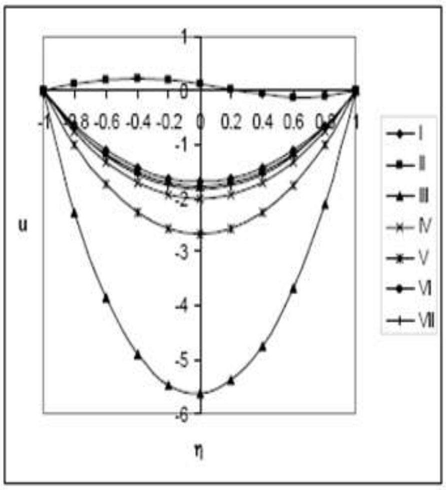


Fig. 1 : Variation of u with M, m, α

	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

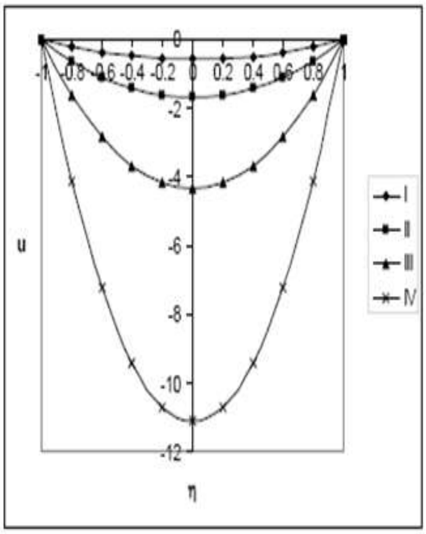


Fig. 2 : Variation of u with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

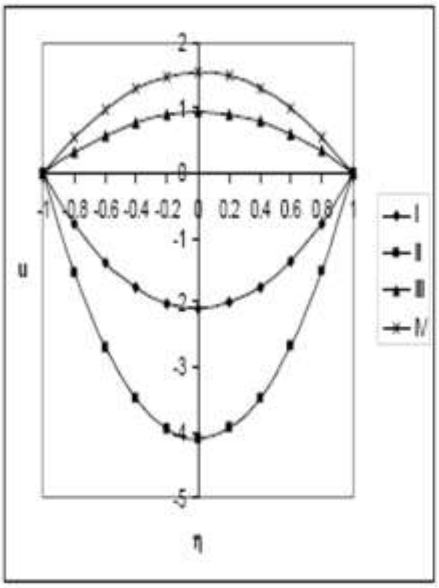


Fig 3 : Variation of u with N

	I	II	III	IV
N	1	2	-0.5	-0.8

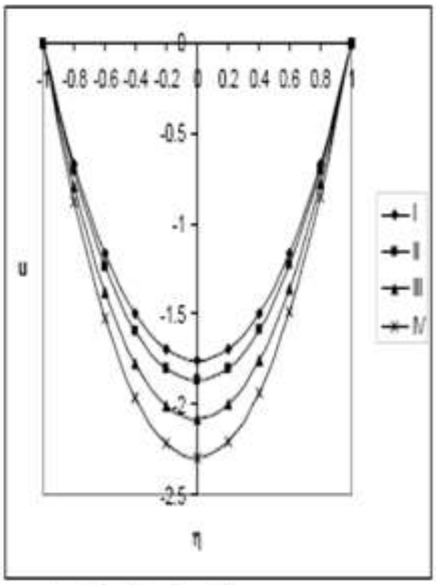


Fig. 4 : Variation of u with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

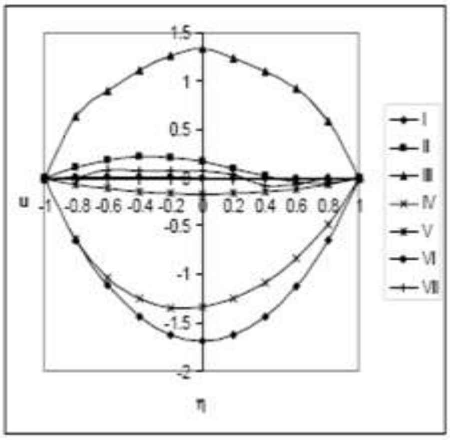


Fig 5 : Variation of u with λ, x

	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

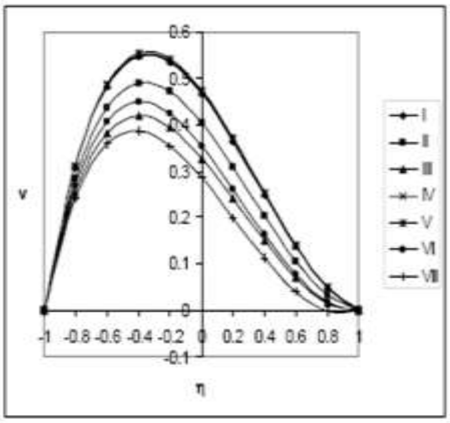


Fig. 6 : Variation of v with M, m, α

	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

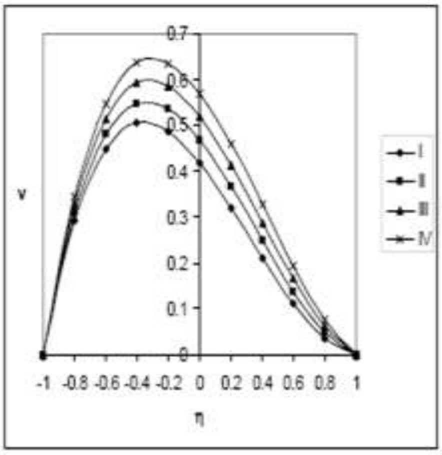


Fig. 7 : Variation of v with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

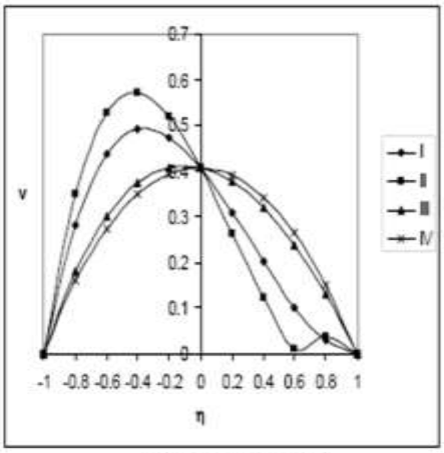


Fig 8 : Variation of v with N

	I	II	III	IV
N	1	2	-0.5	-0.8

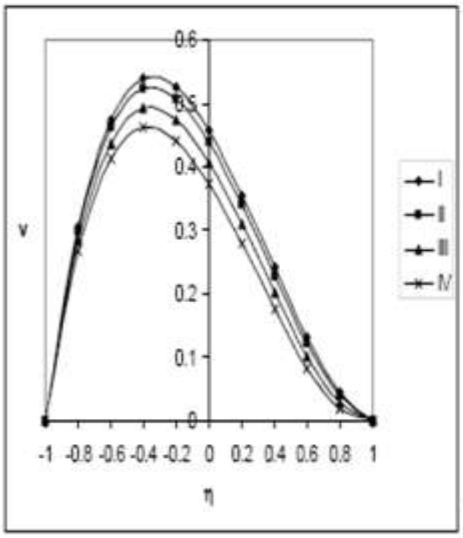


Fig. 9 : Variation of v with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

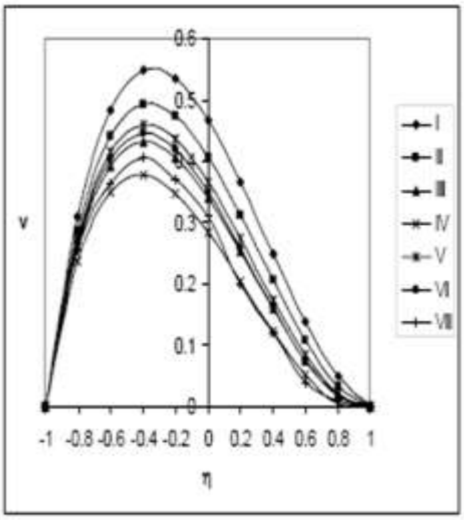


Fig 10 : Variation of v with λ, x

	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

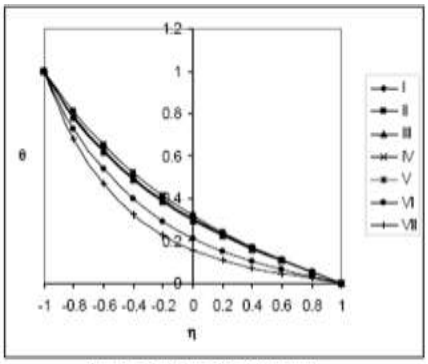


Fig. 11 : Variation of θ with M, m, α

	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

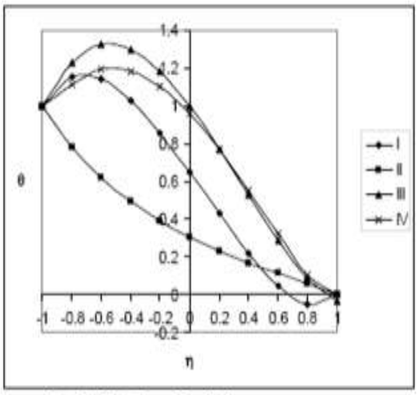


Fig. 12 : Variation of θ with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

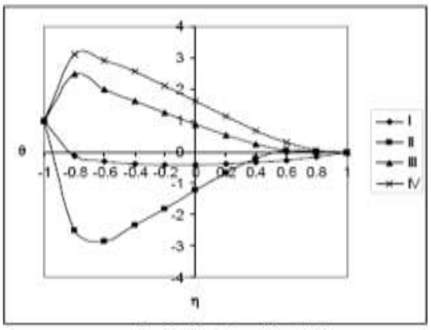


Fig 13 : Variation of θ with N

	I	II	III	IV
N	1	2	-0.5	-0.8

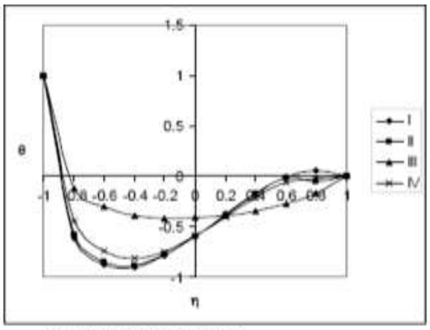


Fig. 14 : Variation of θ with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

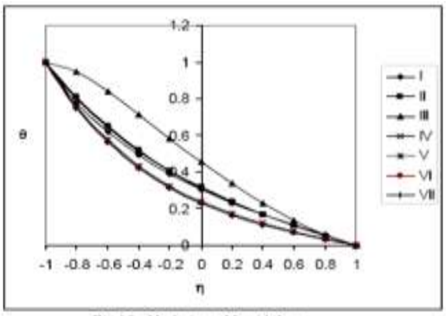


Fig 15 : Variation of θ with λ, x

	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

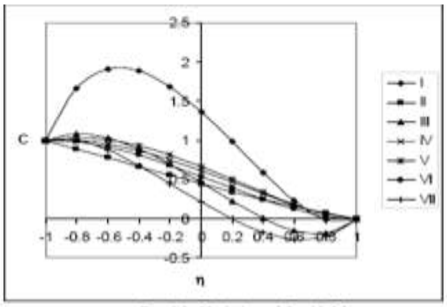


Fig. 16 : Variation of C with M, m, α

	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

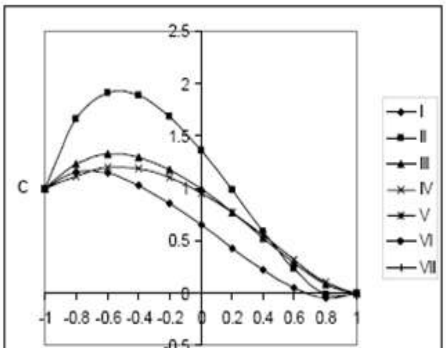


Fig. 17 : Variation of C with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

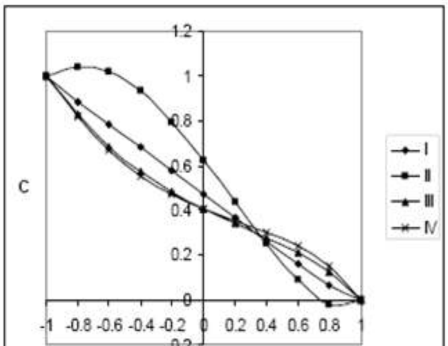


Fig 18 : Variation of C with N

	I	II	III	IV
N	1	2	-0.5	-0.8

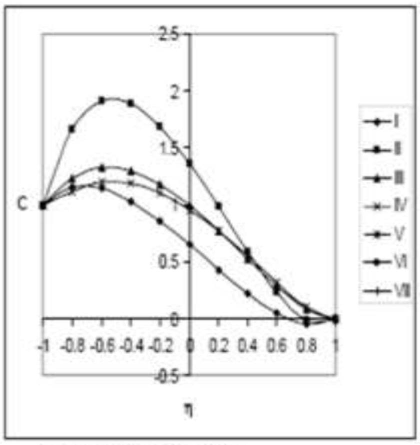


Fig. 17 : Variation of C with β

	I	II	III	IV
β	-0.3	-0.5	-0.7	-0.9

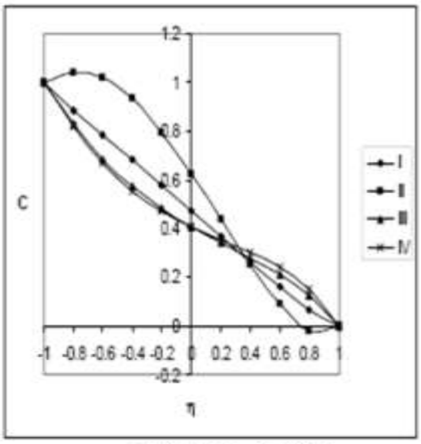


Fig 18 : Variation of C with N

	I	II	III	IV
N	1	2	-0.5	-0.8

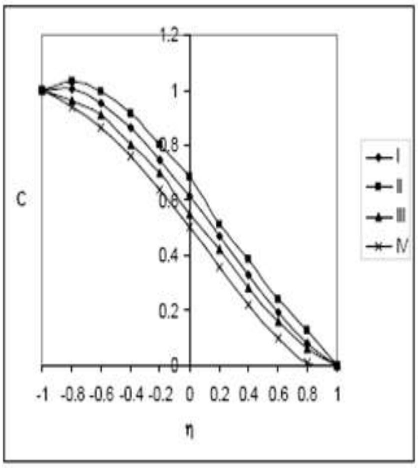


Fig. 19 : Variation of C with Sc

	I	II	III	IV
Sc	0.24	0.6	1.3	2.01

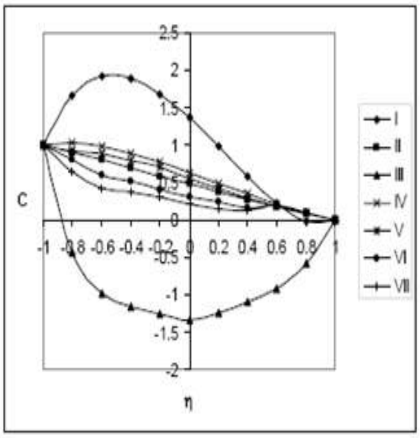


Fig 20 : Variation of C with λ, x

	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

The conclusions are

1. 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.
2. It is found that higher the constriction of the channel walls larger |v| in the flow region.
3. When the molecular Buoyancy force dominates over the thermal Buoyancy force. The axial velocity enhances in the left region and reduces in the right region when the Buoyancy forces act in the same direction and for the forces acting in opposite direction, the velocity depreciates in left region and enhances in the right region (fig (10)).
4. The variation of v Schmidt number (Sc) shows that lesser the molecular diffusivity smaller v in the flow region (fig (11)).
5. From fig (12) we find that an increase in the inclination of the magnetic field results in the depreciation in v.
6. |u| reduces with M≤4. Also it enhances with Hall parameter (m) and Heat source parameter (α) (Fig (2)).
7. higher the constriction of the channel walls larger |u| in the flow region (fig (3)).
8. When the molecular Buoyancy force dominates over the thermal Buoyancy force, the secondary velocity enhances in magnitude irrespective of the directions of the Buoyancy forces (fig (4)).
9. lesser the molecular diffusivity larger |u| in the flow region (fig (5)).
10. An increase in the inclination of the magnetic field λ ≤ 0.5, |u| depreciates and for higher λ = 0.75, it enhances and for still higher value of λ = 1 it depreciates in magnitude.

11. higher the Lorentz force larger the actual temperature and for further higher Lorentz force lesser the actual temperature. The actual temperature enhances with increase in the Hall parameter $m \leq 1.5$ and reduces with higher values of $m \geq 2.5$. An increase in the heat source parameter α leads to a depreciation in the actual temperature (fig (14)).

12. higher the constriction of the channel walls lesser the actual temperature except in narrow region adjacent to $\eta = 1$ and for further higher constriction larger the actual temperature and for still higher constriction lesser the actual temperature except in the region $0.4 \leq \eta \leq 0.8$.

13. 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.

14. lesser the molecular diffusivity larger the actual temperature in the left half and lesser in the right half and for further lowering of the molecular diffusivity lesser the actual temperature in the let half and larger in the right half. (fig (17)).

15. The the actual temperature enhances with inclination $\lambda \leq 0.75$ and reduces with higher $\lambda = 1$.

16. the actual concentration reduces with $M \leq 4$ and for higher $M \geq 6$, the actual concentration enhances in the left half and reduces in the right half. An increase in the Hall parameter $m \leq 1.5$ results in a depreciation in the actual concentration and for higher $m \geq 2.5$ we notice an enhancement in the actual concentration. An increase in $\alpha \leq 4$ depreciates the concentration and for higher $\alpha \geq 6$ it depreciates except in the vicinity of $\eta = -1$.

17. 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 (21)).

18. the actual concentration enhances in the flow region except in the region $0.4 \leq \eta \leq 0.8$ where it depreciates when the Buoyancy forces act in the same direction and for the forces acting in opposite direction the actual concentration depreciates in the left half and enhances in the right half (fig (22)).

19. lesser the molecular diffusivity smaller the actual concentration in the flow field (fig (23)).

20. An Increase in $\lambda \leq 0.75$ leads to a depreciation in the actual concentration and for higher $\lambda \leq 1$, we notice an enhancement in C.

Table 1

Nusselt Number (Nu) at $\eta = 1$

G	I	II	III	IV	V	VI	VII
10^3	-11.98829	-42.793	-0.50763	-1.88259	-2.05014	-2.44022	-21.17508
$3X10^3$	-2.14927	8.02139	-0.4443	-2.23234	-2.3966	-13.00948	-99.75994
-10^3	-17.1206	-0.27554	-0.3272	-13.55019	-7.73351	8.84851	9.47034
$-3X10^3$	-4.72538	0.51007	-0.35795	-4.4215	-4.14614	22.58604	15.3519
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

Table 2

Nusselt Number (Nu) at $\eta = 1$

G	I	II	III	IV	V	VI
10^3	-6.3484	-11.98829	-4.22639	-1.80165	-5.78081	-2.21439
$3X10^3$	-2.61933	-2.84927	-1.40821	-0.73513	-2.2412	-2.13254
-10^3	1.76734	-17.1206	-1.95859	-0.6937	-20.51178	-9.31945
$-3X10^3$	9.59863	-10.72538	-1.6939	-0.70968	-4.39197	-3.79054
β	-0.3	-0.5	-0.7	-0.9	-0.5	-0.5
R	35	35	35	35	70	140

Table 3

Nusselt Number (Nu) at $\eta = 1$

G	I	II	III	IV	V	VI	VII
10^3	-11.9882	0.5053	0.4699	0.9917	-0.9949	-0.9456	-0.9982
$3X10^3$	-2.1493	0.8067	0.6015	7.1883	-2.5462	-1.1459	-1.1649
-10^3	-17.1206	-0.1996	0.06167	-0.6341	0.3756	-0.2681	-0.6188
$-3X10^3$	-4.7254	0.6361	0.06114	-0.8956	1.7449	-0.3662	-0.3677
λ	0.25	0.5	0.75	1.	0.25	0.25	0.25
X	$\pi/4$	$\pi/4$	$\pi/4$	$\pi/4$	$\pi/2$	π	2π

Table 4

Nusselt Number (Nu) at η = 1

G	I	II	III	IV	V	VI	VII
10^3	-1.2224	-1.1746	-1.7313	-1.7012	-1.6972	4.7913	-9.7376
$3X10^3$	-1.6751	-1.4406	-2.0569	-1.9226	-1.8645	-4.5539	-5.1542
-10^3	-1.3531	-5.9749	-6.9413	1.5329	-3.0464	-1.3324	-1.4712
$-3X10^3$	-0.4321	-2.4587	-4.3874	0.6015	-2.4531	-1.5762	-1.6995
Sc	1.3	2.01	0.24	0.6	1.3	1.3	1.3
N	1	1	1	1	2	-0.5	-0.8

Table 5

Nusselt Number (Nu) at η = -1

G	I	II	III	IV	V	VI	VII
10^3	-5.0163	-0.928646	3.530498	-9.47244	-7.895881	19.16804	10.36107
$3X10^3$	-7.529252	-1.649825	3.300662	-7.038785	-6.234847	56.98809	22.9403
-10^3	-3.187133	-7.560344	2.723109	-3.272533	-3.290047	-11.43055	-21.4962
$-3X10^3$	-4.18854	-4.399603	2.899336	-4.12201	-4.048025	-21.49378	-83.29836
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

Table6

Nusselt Number (Nu) at η = -1

G	I	II	III	IV	V	VI
10^3	19.05358	-5.0163	-4.228974	-2.21112	-64.65746	-13.07395
$3X10^3$	-69.06149	-7.529252	-3.269913	-1.356228	-7.719963	-8.129309
-10^3	-2.398982	-3.187133	-2.219865	-1.027081	-3.089025	-2.908075
$-3X10^3$	-4.5444	-2.18854	-2.539345	-1.134496	-4.115279	-3.975556
β	-0.3	-0.5	-0.7	-0.9	-0.5	-0.5
R	35	35	35	35	70	140

Table 7

Nusselt Number (Nu) at η = -1

G	I	II	III	IV	V	VI	VII
10^3	-16.1298	-1.1345	-0.4504	13.8105	3.8443	1.4082	1.3931
$3X10^3$	-7.5292	-0.0281	-0.4695	13.4541	7.3836	1.2263	1.2197
-10^3	-3.1872	-1.5282	-0.4868	12.1384	-0.3369	1.6519	1.6528
$-3X10^3$	-4.1885	-2.0777	0.4757	12.6205	-2.0477	1.7508	1.7526
λ	0.25	0.5	0.75	1.	0.25	0.25	0.25
x	π/4	π/4	π/4	π/4	π/2	π	2π

Table 8

Nusselt Number (Nu) at η = -1

G	I	II	III	IV	V	VI	VII
10^3	1.4803	-8.4233	-10.3159	-8.9816	-6.5373	-2.2998	-2.9753
$3X10^3$	-6.6358	-7.2255	-7.3483	-7.0912	-5.7028	-3.3995	-3.8068
-10^3	-1.8095	-3.6264	-4.1138	-2.5523	-4.3964	-7.7243	-6.6504
$-3X10^3$	-2.1215	-4.6424	-5.1298	-3.2595	-5.1295	-8.1249	-7.2509
Sc	1.3	2.01	0.24	0.6	1.3	1.3	1.3
N	1	1	1	1	2	-0.5	-0.8

Table 9

Sherwood number (Sh) at η = 1

G	I	II	III	IV	V	VI	VII
10^3	-1.04422	-14.17238	-20.50905	-0.23277	-0.12739	-0.36263	-1.23054
$3X10^3$	-1.67511	-26.67278	-20.5356	-1.16585	-0.63459	-1.28821	-2.80625
-10^3	0.1291	-14.26308	-15.80429	0.09063	0.04856	0.08326	0.93316
$-3X10^3$	1.14436	-24.01008	-18.07686	0.82719	0.47362	1.09847	3.19485
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

Table 10

Sherwood number (Sh) at η = 1

G	I	II	III	IV	V	VI
10^3	-22.64324	-1.04422	-0.08541	-0.01474	-0.15159	-0.47703
$3X10^3$	-10.35031	-1.67511	-0.41006	-0.09851	-0.50364	-0.16276
-10^3	0.38005	0.1291	0..02957	0.00042	-0.00423	-0.03286
$-3X10^3$	3.51584	1.14436	0.34735	0.08644	0.21816	-0.30646
β	-0.3	-0.5	-0.7	-0.9	-0.5	-0.5
R	35	35	35	35	70	140

Table 11

Sherwood number (Sh) at η = 1

G	I	II	III	IV	V	VI	VII
10^3	-1.0447	34.8689	-3.6787	2.6987	1.9024	2.2523	1.2614
$3X10^3$	-1.6788	-21.8316	-5.5578	3.9904	1.2959	18.9527	18.9414
-10^3	0.1287	-20.7239	-3.8064	0.9058	0.8438	0.9309	0.9301
$-3X10^3$	1.1448	-30.2709	-5.6257	3.0247	10.1019	17.8433	17.8379
λ	0.25	0.5	0.75	1.	0.25	0.25	0.25
x	π/4	π/4	π/4	π/4	π/2	π	2π

Table 12

Sherwood number (Sh) at η = 1

G	I	II	III	IV	V	VI	VII
10^3	-0.2482	-0.2364	-1.9853	-1.0816	-0.2234	0.2125	0.0903
$3X10^3$	-1.6703	-1.0749	-3.1652	-3.9247	-0.9535	3.0791	1.7714
-10^3	0.1406	0.0908	0.8059	0.3181	0.0861	-0.5733	-0.2436
$-3X10^3$	1.1518	0.7803	5.2142	2.0245	0.6505	-3.2814	-1.7468
Sc	1.3	2.01	0.24	0.6	1.3	1.3	1.3
N	1	1	1	1	2	-0.5	-0.8

Table 13

Sherwood number (Sh) at η = - 1

G	I	II	III	IV	V	VI	VII
10^3	-2.294783	4.774063	9.085408	-0.08165	-0.031178	-0.115872	-0.431864
$3X10^3$	3.078805	18.98452	9.809118	0.711211	0.342909	-0.378887	-0.499336
-10^3	0.068704	- 3.966851	7.669532	0.068309	0.061456	0.33736	0.375243
$-3X10^3$	-0.712843	11.85803	9.052016	-0.482359	-0.23703	0.818546	0.91194
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

Table 14

Sherwod number (Sh) at η = - 1

G	I	II	III	IV	V	VI
10^3	-14.24577	-2.294783	-0.143922	-0.021857-	-0.638146	-0.602033
$3X10^3$	7.6109111	1.078805	0.248394	0.059321	0.159005	-0.08895
-10^3	0.0188	0.008704	0.041318	0.018524	0.086838	0.063949
$-3X10^3$	-2.565435	-0.712843	-0.198233	-0.046828	-0.022447	0.08898
β	-0.3	-0.5	-0.7	-0.9	-0.5	-0.5
R	35	35	35	35	70	140

Table 15

Sherwood number (Sh) at η = - 1

G	I	II	III	IV	V	VI	VII
10^3	-2.2947	15.1985	1.9234	-0.7189	-1.4391	-1.1559	-1.2615
$3X10^3$	1.0788	22.4488	3.7801	-2.6257	-0.546894	-19.1098	-19.0966
-10^3	0.0687	-12.6629	1.9597	-0.3551	-0.3205	-0.9236	-0.9041
$-3X10^3$	-0.7128	19.1734	3.8023	-2.3054	0.15062	-17.9767	-17.9691
λ	0.25	0.5	0.75	1.	0.25	0.25	0.25
x	π/4	π/4	π/4	π/4	π/2	π	2π

Table 16

Sherwood number (Sh) at η = - 1

G	I	II	III	IV	V	VI	VII
10^3	0.02482	0.0189	-0.1728	-0.0598	-0.0132	-0.4494	-0.3328
$3X10^3$	1.1296	0.7499	8.4591	2.5755	0.4063	-3.6973	-2.3608
-10^3	0.0302	0.0056	0.1419	-0.1321	0.1142	1.1626	0.6344
$-3X10^3$	-0.7854	-0.5004	-3.3683	-1.6736	-0.2439	3.9973	2.3435
Sc	1.3	2.01	0.24	0.6	1.3	1.3	1.3
N	1	1	1	1	2	-0.5	-0.8

1. at η = +1, the rate of heat transfer enhances with m for G>0 and depreciates for G<0. At η = -1, |Nu| enhances with m ≤ 1.5 and depreciates with higher m ≥ 2.5.
2. higher the constriction of the channel walls larger |Nu| and for higher constriction (|β| ≥ 0.7), we notice a depreciation at η = +1 and at η=-1, larger |Nu| for G.
3. the rate of heat transfer at η = +1 depreciates with increase in λ ≤ 0.75 and enhances with λ ≥ 1, while at η = -1, |Nu| depreciates with λ ≤ 0.5 and enhances with higher λ ≥ 0.75.
4. higher the constriction of the channel walls lesser |Sh|
5. An increase in the inclination λ of the magnetic field (λ ≤ 0.5). The rate of mass transfer enhances and depreciates with higher λ ≥ 0.75, at both the walls.

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