EFFECTS OF AN INCLINED CENTRED CONDUCTOR ON MHD NATURAL AND FORCED CONVECTION WITHIN A HEATED WAVY CHAMBER.

Abstract: The study of the effect of hall and ion slip on an inclined conductor on MHD natural and forced convection in a heated wavy chamber with a constant transversal magnetic field applied. The governing momentum and energy equation were solved by applying finite central scheme approximation and the resulting partial difference equations were solved by MATLAB software. The study showed that an increase heat absorption coefficient lowers the surface heat transfer thus lowering flow rate. An increase in Rayleigh number increases the flow rate while an increase in the angle of inclination of the conductor increases the buoyancy force component thereby increasing the flow rate. The results further showed that flow rate became higher at an inclination angle of 90º. In addition, the results also showed that an increase in Hartmann increases the flow rate. The Hartmann number, Rayleigh number and Absorption coefficient are analytically discussed and represented in tables and graphical profiles with respect to flow velocity and temperature profile due to engineering demand. This current study a direct application in the development of MHD propelled vessels in the marine and space-craft department.

Nomenclature

ω Angle of inclination.

B_0 Magnetic field strength

g Gravitational field strength.

u, v Velocity components in x and y direction respectively (m/s).

U,V Dimensionless velocity components along x and y axis.

T Thermodynamic temperature (Kelvin)

x, y Coordinates.

Pr Prandtl number

Ra_T Thermal Rayleigh number

Gr Grashof number

ƒ Density (kg/m^3)

Re Reynolds number

P Static pressure (N/m^2)

Nu Nusselt number

T Thermodynamic temperature**.**

Ha Hartmann Number

N_c Buoyancy ratio

INTRODUCTION

Magneto hydrodynamic flow, which is the mass transfer of electrically conductive fluids within a magnetic field, is of vital importance both internationally and locally in the marine and aircraft depart among other sectors of engineering where it's gained massive application. In the department of Marine and Aircraft, many researchers have tried to solve the problem of developing vessels which are not mechanically propelled by other forms of energy such as fuels, among others. The MHD convective flow knowledge can be tapped into and the knowledge is used to develop bodies which are very fast, easy to manoeuvre, economical, and environmentally friendly to operate. Therefore, how to increase the induced force during MHD flow has been the basis of most of studies.

Nasrin (2011) studied the effects of a conducting obstacle centred on MHD combined convection in a wavy chamber.. The result showed that Richardson number (Ri) and the diameter (D) of the conducting obstacle strongly affect the flow phenomenon.

Khantun *et al.* (2018), numerically investigated the magneto hydrodynamic free convection fluid flow

over an upright permeable plate with induced magnetic field. The results obtained showed that the velocity profile decreases with an increase in Prandtl number, magnetic parameter (m) and Schmidt number (S_c). Roizaini *et al.* (2020), investigated magnetic field effects on mixed convection heat transfer in a lid – driven rectangular cavity. The result of the study showed that Hartmann number has a significant effect on the convective current. Arash Karimipour *et al.* (2020), investigated the magnetic field influence on combined convection heat transfer in a lid-driven rectangular enclosure. The results of the study showed that Hartmann number significantly affects the fluid flow structure and temperature field. Absana *et al.* (2021) investigated a two-dimensional unsteady MHD free convection flow over a vertical plate in the presence of radiation. The results of their study showed that the velocity profile of the flow decreases with an increase in radiative parameter while the velocity profiles reduced with an increase in Prandtl number. Despite all these studies, the problem of effects of an inclined conductor on MHD natural and forced convection within a heated wavy chamber has not received any attention, hence the aim of this study.

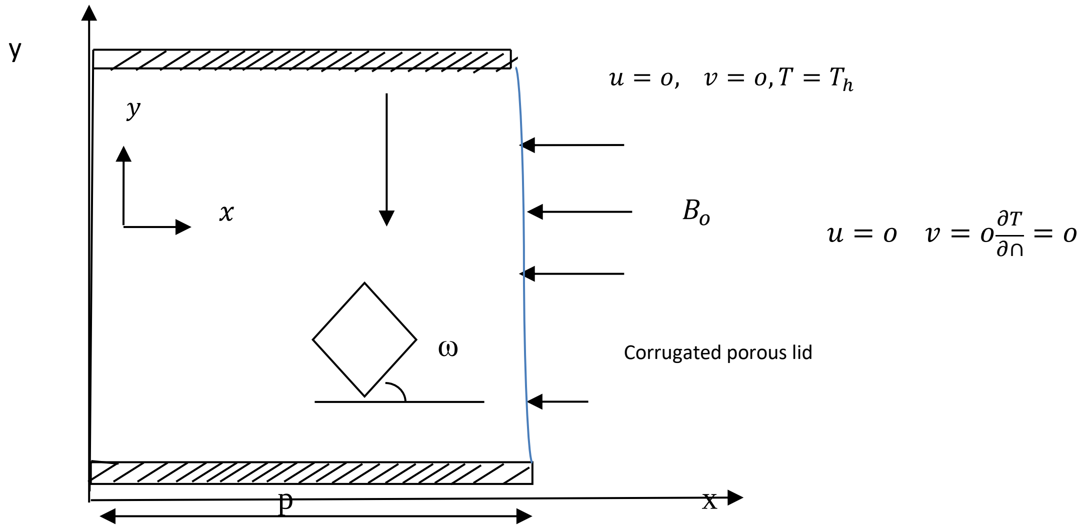
The specific objectives of the study are:

i. To formulate a mathematical model for the effects of an inclined conductor on MHD natural and forced convection in a heated wavy chamber.
ii. To determine the effect of the angle of inclination on temperature distribution.
iii. To determine the influence of magnetic field on temperature distribution profile.
iv. To determine the effects of flow parameter on temperature and velocity profile distribution.

Model Specification.

The set-up below consists of a two-dimensional lid-driven rectangular chamber of length P. The upper and lower parts of the cavity are insulated, the left lid is at a uniform velocity and the temperature T_i (20˚C), while the right wall with a temperature T_h(100˚C).The conductor is tilted through an angle (ω) for (30˚≤ ω≤90˚) along the horizontal axis within a conductive fluid taken as air of (Pr = 0.71).A constant magnetic field of strength B_o is applied in the horizontal direction to the sidewalls of the chamber.

Figure 1: The flow model



T is the temperature, and B_0 is the external magnetic field strength.

Assumptions.

In order to solve and analyse this occurrence, the following assumptions are made:

i. The flow is steady, laminar, 2-D and incompressible.
ii. The earth's magnetic effect s are negligible
iii. There is no radiation effect.
iv. Magnetic effect is only experienced in the horizontal direction.
v. The magnetic field meets the centred conductor perpendicularly.
vi. There is no magnetic dissipation since the external magnetic field is a mono- pole with no other magnetic field interaction.

Mathematical formulation

The flow is assumed to be laminar, steady and incompressible and that magnetic effect only acts horizontally.

Natural Convection

The specific momentum equation for this case will be obtained by considering Newton's second law. The external forces acting on the fluid under this case are the buoyancy and magnetic force.

Equation along x – axis

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right]+\sin\omega g\beta_T\left[T-T_C\right] \quad (1)$$

Equation along y-axis

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\left[\frac{\partial^2 v}{\partial x^2}+v\frac{\partial^2 v}{\partial y^2}\right]+\cos\omega g\beta_T\left[T-T_C\right]-\frac{k\sigma\beta_0{}^2 v}{\rho} \quad (2)$$

Enegy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right]+\frac{Q_0}{\rho C_p}\left(T-T_c\right) \quad (3)$$

Forced Convection.

In this type of convection, there is a mass movement or fluid movement due to an external forcing condition.

Momentum along x-axis

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial x^2}+\sin\omega \quad (4)$$

Momentum along y-axis.

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=v\frac{\partial^2 v}{\partial y^2}+\cos\omega-\frac{k\sigma\beta_0{}^2 v}{\rho} \quad (5)$$

Energy equation.

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right]+\frac{Q_0}{\rho C_P}\left(T-T_C\right) \tag{6}$$

Introducinginitial boundary conditions.

With initial boundary conditions:

$u = 0, v = v_o, T = T_i$ vertical walls

At horizontal wall: $u = 0, v = 0, \frac{\partial T}{\partial n} = 0$

At the wavy surface:$u = 0, v = 0, T = T_n$

At the solid-fluid interface$\left[\frac{\delta T}{\delta n}\right]_{fluid} = \frac{K_S}{K}\left(\frac{\delta T}{\delta n}\right)_{solid}$

The rate of heat transfer on the wavy wall is expressed in terms of Nusselt number

$$\overline{Nu} = \frac{Convective\ heat\ transfer}{Conductive\ heat\ transfer} = \frac{h}{K/L} = \frac{hl}{K} = \frac{\partial T}{\partial n}L$$

Introducing non-dimensional numbers:

$$X = \frac{x}{L}, Y = \frac{y}{L}, U = \frac{UL}{\alpha}, V = \frac{vL}{\alpha}, P = \frac{pL^2}{\rho\alpha^2}$$

$$\theta = \frac{T - T_c}{T_h - T_c}, Pr = \frac{v}{\alpha}, \alpha = \frac{K}{\rho C_p}, \sigma = \frac{\rho L^2}{L^2}$$

$$Ha^2 = \frac{\sigma {B_o}^2 L^2}{\mu}. \quad Ra = \frac{g\beta L^3 (T_n - T_c)Pr}{V^2}, \sigma = \frac{\rho^2 \alpha}{L^2}, \alpha = \frac{K}{\rho C_p}$$

Momentum along x-axis

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\Pr\left[\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right]+\sin\omega\left(Ra_T\Pr\left[\theta-N_C\right]\right) \tag{7}$$

Equation along y - axis

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\Pr\left[\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right]+\cos\omega\left[Ra_T\Pr\left(\theta-N_c\right)-Ha^2\Pr V\right] \tag{8}$$

Energy Equation.

The specific energy equation is obtained from the first law of Thermodynamics where Φ is the heat absorption coefficient.

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\left[\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right]+\Phi\theta \tag{9}$$

FORCED CONVECTION

The dimensionless equation for this case becomes:

Equation along x -axis

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=\Pr\left[\frac{\partial^2 U}{\partial X^2}\right]+\sin\omega \tag{10}$$

Equation along y -axis

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=\Pr\left[\frac{\partial^2 V}{\partial Y^2}\right]+\cos\omega-Ha^2\Pr V \tag{11}$$

Method of solution

The problem under investigation generates partial differential equations whose solutions are to be determined using the finite difference approach. In this technique, the derivatives occurring in generated differential equations are solved using Finite Difference (central scheme) method. MATLAB simulation software to develop results.

Discretization of Momentum Equation a long x axis

We consider Momentum Equation a long x axis (7) and use it to investigate the fluid velocity profiles. For the central scheme (CDS), the values, U_x, U_y, U_{xx} and U_{yy} are replaced by the central difference approximation.

$$u\left(\frac{U_{i+1,j}-U_{i-1,j}}{2\Delta x}\right)+v\left(\frac{U_{i,j+1}-U_{i,j-1}}{2\Delta y}\right)=\left(\frac{U_{i+1,j}-2U_{i,j}+U_{i-1,j}}{(\Delta x)^2}+\frac{U_{i+1,j+1}-2U_{i,j+1}+U_{i-1,j+1}}{(\Delta y)^2}\right)+\sin\omega\left(Ra_T\Pr\left(\theta-N_c\right)\right) \qquad (12)$$

Take $u = v = N_C = \theta = 1$, multiply both sides by $2(\Delta x)$ and let Pr = 0.71 and take $\Delta x = \Delta y = 0.1$ on a square mesh into equation (12) we get the scheme;

$$0.86U_{i+1,j} + 8U_{i,j} - 1.14U_{i-1,j} = -0.86U_{i,j+1} + 1.14U_{i,j-1} + \sin\omega\left(Ra_T\Pr\left(\theta-N_c\right)\right) \qquad (13)$$

Taking i = 1,2,3……5 and j = 1 we form the following systems of linear algebraic equation,

And with initial and boundary conditions $U_{i,0} = U_{0,j} = 1$ and $U_{i,2} = 0$ respectively, the above algebraic equations (13) can be written in matrix form as;

$$\begin{bmatrix} 8 & 0.86 & 0 & 0 & 0 \\ -1.4 & 8 & 0.86 & 0 & 0 \\ 0 & -1.4 & 8 & 0.86 & 0 \\ 0 & 0 & -1.4 & 8 & 0.86 \\ 0 & 0 & 0 & -1.4 & 8 \end{bmatrix}\begin{bmatrix} U_{1,1} \\ U_{2,1} \\ U_{3,1} \\ U_{4,1} \\ U_{5,1} \end{bmatrix} = \begin{bmatrix} 0.14+0.7\sin\omega Ra_T \\ 0.07+0.7\sin\omega Ra_T \\ 0.07+0.7\sin\omega Ra_T \\ 0.07+0.7\sin\omega Ra_T \\ 0.07+0.7\sin\omega Ra_T \end{bmatrix} \qquad (14)$$

We use equation (14) to investigate the effects of ω and Ra_T on the horizontal fluid velocity profile.

Discretization of Momentum Equation a long y axis

We consider Momentum Equation a long y axis (8) and use it to investigate the fluid velocity profiles. For the central scheme (CDS), the values, V_x, V_y, V_{xx} and V_{yy} are replaced by the central difference approximation. On substituting these values into Equation (8), it gives;

$$u\left(\frac{V_{i+1,j}-V_{i-1,j}}{2\Delta x}\right)+v\left(\frac{V_{i,j+1}-V_{i,j-1}}{2\Delta y}\right)=\left(\frac{V_{i+1,j}-2V_{i,j}+V_{i-1,j}}{(\Delta x)^2}+\frac{V_{i+1,j+1}-2V_{i,j+1}+V_{i-1,j+1}}{(\Delta y)^2}\right)+\cos\omega\left(Ra_T\Pr\left(\theta-N_c\right)\right)-0.7Ha^2V_{i,j} \qquad (15)$$

Take $u = v = N_C = \theta = 1$, multiply both sides by $2(\Delta x)$ and let Pr = 0.71 and take $\Delta x = \Delta y = 0.1$ on a square mesh into equation (15) we get the scheme;

$$0.86V_{i+1,j}+\left(8+Ha^2\right)V_{i,j}-1.14V_{i-1,j}=-0.86V_{i,j+1}+1.14V_{i,j-1}+\cos\omega\left(Ra_T\Pr\left(\theta-N_c\right)\right) \qquad (16)$$

Taking and i = 1,2,3…….5 and j = 1 we form the following systems of linear algebraic equations and with initial and boundary conditions $V_{i,0} = V_{0,j} = 1$ and $V_{i,2} = 0$ respectively, the above equation in its matrix form comes to:

$$\begin{bmatrix}(8+Ha^2) & 0.86 & 0 & 0 & 0\\ -1.4 & (8+Ha^2) & 0.86 & 0 & 0\\ 0 & -1.4 & (8+Ha^2) & 0.86 & 0\\ 0 & 0 & -1.4 & (8+Ha^2) & 0.86\\ 0 & 0 & 0 & -1.4 & (8+Ha^2)\end{bmatrix}\begin{bmatrix}V_{1,1}\\ V_{2,1}\\ V_{3,1}\\ V_{4,1}\\ V_{5,1}\end{bmatrix}=\begin{bmatrix}0.14+0.7\cos\omega Ra_T\\ 0.07+0.7\cos\omega Ra_T\\ 0.07+0.7\cos\omega Ra_T\\ 0.07+0.7\cos\omega Ra_T\\ 0.07+0.7\cos\omega Ra_T\end{bmatrix} \qquad (17)$$

We use equation (17) to investigate the effects of Ha^2, ω and Ra_T on the vertical fluid velocity profile.

Discretization of Energy Equation

We consider Energy Equation (9) and use it to investigate the fluid temperature distribution. For the central scheme (CDS), the values, $\theta_x, \theta_x, \theta_{xx}$ and θ_{yy} are replaced by central difference approximation. When these values are substituted into Equation (9), we get;

$$u\left(\frac{\theta_{i+1,j}-\theta_{i-1,j}}{2\Delta x}\right)+v\left(\frac{\theta_{i,j+1}-\theta_{i,j-1}}{2\Delta y}\right)=\left(\frac{\theta_{i+1,j}-2\theta_{i,j}+\theta_{i-1,j}}{(\Delta x)^2}+\frac{\theta_{i+1,j+1}-2\theta_{i,j+1}+\theta_{i-1,j+1}}{(\Delta y)^2}\right)+\Phi\theta_{i,j} \qquad (18)$$

Take $u = v = N_C = \theta = 1$, multiply both sides by $2(\Delta x)$ and let Pr = 0.71 and take $\Delta x = \Delta y = 0.1$ on a square mesh into equation (18) we get the scheme;

$$-19\theta_{i+1,j} + (80 - 0.2\phi)\theta_{i,j} - 21\theta_{i-1,j} = 19\theta_{i,j+1} + 21\theta_{i,j-1} \tag{19}$$

Taking and i = 1,2,3…….5 and j = 1 we form the following systems of linear algebraic equations and with initial boundary conditions and with initial and boundary conditions $\Theta_{i,0}=\Theta_{0,j}=1$ and $\Theta_{i,2} = 0$ respectively ,the above algebraic equation in its matrix form becomes:

$$\begin{bmatrix} (8-0.2\Phi) & 0.86 & 0 & 0 & 0 \\ -1.4 & (8-0.2\Phi) & 0.86 & 0 & 0 \\ 0 & -1.4 & (8-0.2\Phi) & 0.86 & 0 \\ 0 & 0 & -1.4 & (8-0.2\Phi) & 0.86 \\ 0 & 0 & 0 & -1.4 & (8-0.2\Phi) \end{bmatrix} \begin{bmatrix} \theta_{1,1} \\ \theta_{2,1} \\ \theta_{3,1} \\ \theta_{4,1} \\ \theta_{5,1} \end{bmatrix} = \begin{bmatrix} 420 \\ 210 \\ 210 \\ 210 \\ 210 \end{bmatrix} \tag{20}$$

We use equation (20) to investigate the effects of Φ, on the temperature distribution.

The next chapter details the results obtained for the effects of ω, Φ and Ra_T on the horizontal, vertical fluid velocity profiles and temperature distribution. The results are presented in tables and discussed graphically.

RESULTS AND DISCUSSION

Effect of angle of inclination on horizontal fluid velocity profile

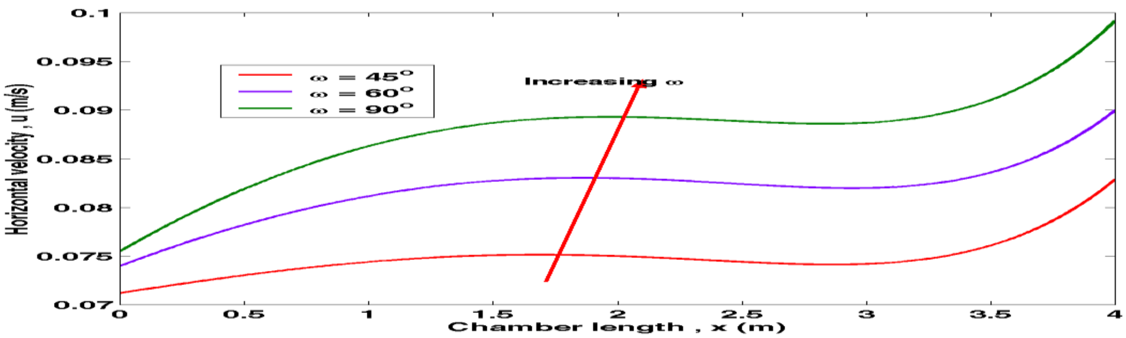
We hold constant the values of Ra_T= 1000, and solve equation (14) for values of varying values of ω.Table 1 shows horizontal fluid velocity with varying angle of inclination.

Table 1: Effect of angle of inclination on horizontal fluid velocity profile.

Angle of inclination	**Chamber length, x(m)**				
	0	**1**	**2**	**3**	**4**
$\omega = 45^0$	0.0712 35	0.0744 864	0.0750 436	0.0742555	0.0829442
$\omega = 60^0$	0.0740769	0.0811685	0.0830 311	0.0820422	0.0907568
$\omega = 90^0$	0.0755 57	0.0863766	0.0893757	0.0887995	0.0992755

Figure 2 gives the influence of angle of inclination on the horizontal velocity profiles. It is observed that the velocity is increased by increasing the angle of inclination. The fluid velocity is higher at the vertical surface than at the inclined surface.

Figure 2:Effect of angle of inclinition on the horizontal velocity.



2. Effect of Rayleigh number on horizontal fluid velocity profile

We hold constant the values of $\omega = 45^0$ and solve equation (14) for values of varying values of

Ra_T = 1000, 2000 and 3000 in equation (8)**,** we obtain the solutions of Ra_T as presented in the table 2.

Table 2 shows horizontal fluid velocity with varying Rayleigh number.

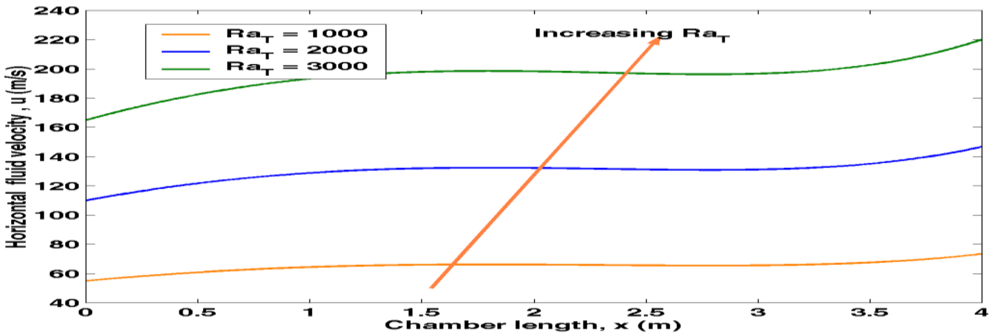
Table 2: Effect of Rayleigh number on horizontal fluid velocity profile.

Rayleigh number	**Chamber length, x**				
	0	**1**	**2**	**3**	**4**
$Ra_T = 1000$	54.969867	64.39719864	66.10490750	65.56742555	73.35829483
$Ra_T = 2000$	109.9240769	128.786 853	132.200311	131.1230422	146.7075683
$Ra_T = 3000$	164.8767 57	193.1704766	198.293755	196.6797998	220.0527557

The results in table 2 are represented graphically as shown graphically in figure 3

The effect of Rayleigh number on horizontal fluid velocity can be observed from figure 3. An increase in Rayleigh number leads to an increases in the horizontal fluid velocity. The result also shows a conducting dominating regime is at low Rayleigh number with vertical velocity profiles and a convective dominating regime is at high Rayleigh number with horizontal velocity profiles.

Figure 3: Effects of Rayleigh number on horizontal velocity.



3. Effect of Rayleigh number on vertical fluid velocity profile: We hold constant the values of $\omega = 45^0$ and solve equation (17) for values of varying values of Ra_T = 1000, 2000 and 3000 in equation (17)**,** we obtain the solutions of Ra_T as presented in the table 3

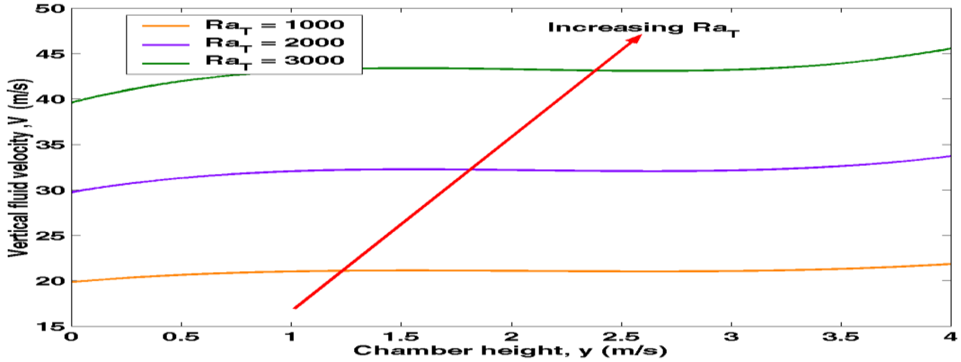
Table 3.Effect of Rayleigh number on vertical fluid velocity profile.

Rayleigh number	**Chamber height, y(m)**				
	0	**1**	**2**	**3**	**4**
$Ra_T = 1000$	19.87721432	21.031356494	21.099543722	21.077565	21.8573449
$Ra_T = 2000$	29.74487769	32.0595853	32.19609 311	32.1480422	33.711568
$Ra_T = 3000$	39.62095 57	43.08773766	43.29263757	43.220557995	45.5657758

From figure 4 below, it can be concluded that the strength of these vertical velocity profiles increases as the Rayleigh number (Ra) increases. The result also shows a conducting dominating regime at low Rayleigh number with vertical velocity profiles and convective dominating regime at high Rayleigh number.

The results in Table 3 are represented graphically as shown graphically in figure 4

Figure 4: Effects of Rayleigh number on vertical velocity.



4. Effects of Hartmann number on vertical velocity profile

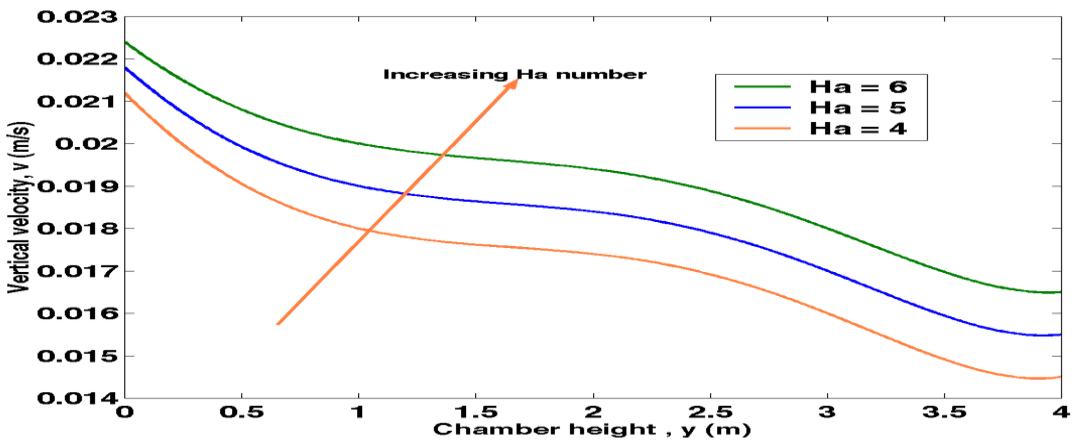
We hold constant the values of Ra_T = 1000, $\omega = 45^0$ and solve equation (17) for values of varying values of Ha = 4, 5 and 6 in equation (17)**,** for varying values of Ha, we obtain solutions as presented in the table 4 below.

Table 4.Vertical fluid velocity with varying Hartmann number

Hartman number	**Chamber height, y(m)**				
	0	**1**	**2**	**3**	**4**
$Ha = 4$	0.02242373	0.02008426	0.01942971	0.018014275	0.01652252
$Ha = 5$	0.02183564	0.01907728	0.01840992	0.017035289	0.01552758
$Ha = 6$	0.0212922	0.01806648	0.017411235	0.01605638	0.01456488

The results in table 4 are represented graphically as in figure 5 below;

Figure 5. Vertical velocity against chamber length with varying the Hartman number.



From the above, it can be concluded that the velocity is influenced by Hartmann number. This is due to the formation of a narrower boundary zone, which shows a general trend to induce an electromotive force to the free stream flow of MHD, hence the velocity increase as shown above.

5. Effect of dimensionless absorption coefficient on temperature distribution

We varying $\Phi = 10$, 15, and 20 in equation (20). Solving equation (20) for varying values of Φ **,** we obtain solutions for varying Φ as presented in the table 5 below.

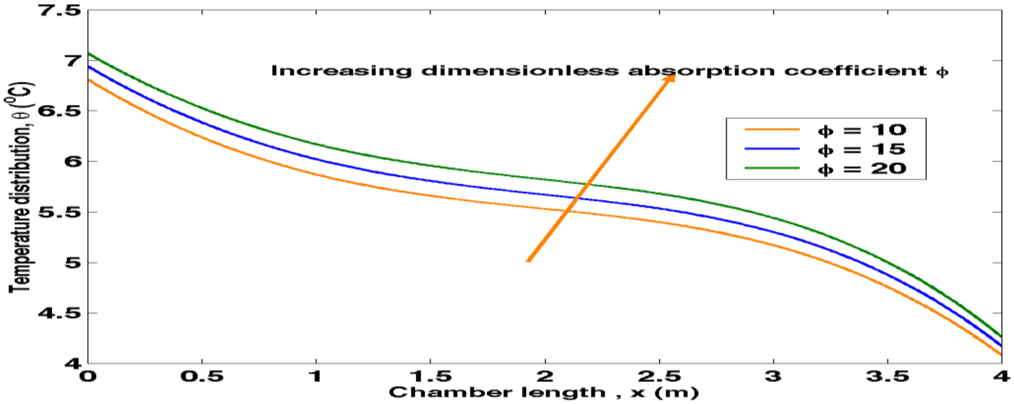
Table 5. Fluid temperature distribution for varying dimensionless absorption coefficient.

Dimensionless absorption coefficient	**Chamber length, x**				
	0	**1**	**2**	**3**	**4**
$\Phi = 10$	6.813856	5.872194	5.5395637	5.1702643	4.0835628
$\Phi = 15$	6.941472	6.021216	5.6722278	5.3011632	4.172579
$\Phi = 20$	7.069552	6.170012	5.82 3442	5.4426483	4.263325

The results in Table 5 are represented graphically as shown in figure.6 below.

The figure below shows that for certain values of dimensionless absorption coefficient, the surface heat flow tends to decrease by increasing in Φ. Additionally, slightly away from the point of temperature dispersion is considerable and subsequently as we move far away from the plate, the outcome is found to be reducing.

Figure 6 .Temperature against chamber length with varying dimensionless absorption coefficient:



CONCLUSION

A numerical study performed to analyze the influence of the effects; Rayleigh number, Hartmann number, angle of inclination, and absorption coefficient on fluid velocity profiles and temperature distribution. The following outcomes can be deduced from the study:

- An increase in Rayleigh and Hartmann numbers increases the flow velocity.
- . An increase in absorption coefficient lowers the surface heat flow. Thereby lowering the fluid flow rate.
- The angle of inclination of a conductor directly affects the buoyancy force component, thereby affecting the rate of fluid flow. The buoyancy force increases with an increase in angle of inclination.

Data availability.

Simulated data are from the above literatures and graphically plotted on MATLAB.

Greek symbols.

α Thermal diffusivity (m^2/s)

σ Electrical conductivity (Ohm-metre)

k Thermal conductivity (W/M/K)

ϕ Absorption coefficient (1/cm)

β Fluid thermal expansion coefficient (1/K)

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