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MHD Flow Over A Rotating Vertical Porous Plate with Exponentially Accelerating Velocity, Temperature, and Mass in the Presence of Hall Current and Heat Source

Dr D. Lakshmikaanth[1], M. Krishnakumari[2]

[1]Department of Mathematics, College of Fish Nutrition & Food Technology (CFNFT), Tamilnadu Dr. J. Jayalalithaa Fisheries University (TNJFU), Chennai-600051, India

[2] Department of Mathematics, Mahalashmi Women's College of Arts and Science , No.!,Mahalashmi nagar ,Paruthipattu., Avadi, Chennai, Tamilnadu

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ABSTRACT:

This study analyzes exponentially accelerating fluid through vertically porous plate with a heat source. The effects of rotation, porosity, and Thermal Radiation on velocity (Speed), temperature (Warmth), and concentration(accumulation) profiles are investigated. Results indicate that velocity rises with heat source increase but decreases with radiation and rotation. Temperature increases with heat generation raises while concentration drops with higher Schmidt numbers. Also, Skin friction, Nusselt & Sherwood values tabulated.

Keywords: Exponential, Sherwood, Generation, Plate, Concentration.

INTRODUCTION

Heat sources are used a lot in the processing of chemicals and polymers, like film coating, extrusion, and drying, because they speed up reaction and production rates. In the food industry, heat sources are used in processes like pasteurisation, and film coating. Controlled heating speeds up reactions, improves texture, and makes products more stable. [1] Kota et al. studied transient MHD flow across a vertically speeding permeable plate with viscous heating and warmth generation. [2] A. Selvaraj and E. Jothi looked into how the temperature of the plate rises in a straight line over time, with the highest values happening close to the surface of the plate. [3]-[4] Nath and Deka compared the behaviour of nanofluids with two stratifications to that without any stratification without and with Chemical reaction. [5] Rakesh Rabha and Rudra K. Deka analyzed the flow with and without stratification, observing that steady state(independent of time) is reached faster in the presence of stratification. [6] K.Balu and his collegue examines MHD across rapidly sloped plate and concentrating on the region adjacent to the plate. [7] Pratibha P. Ubale Patil et al. found that axial skin friction goes down as water permeability goes up, changes in an irregular way in air, and oscillates in both fluids when a heat source is present.[8]-[11] D. Lakshmikanth and his team looked into how a heat source with and without rotation, as well as the Dufour effect, affected a vertically accelerated isothermal plate that was undergoing chemical reaction and radiation.[12] R. Muthukumaraswamy and a coworker used MATLAB to make graphs of skin friction, temperature, concentration, and velocity profiles for different thermophysical parameters. [13]-[14] Hetnarski introduces an algorithm for the formulas of inverse Laplace transforms.

Mathematical Formulation

We are looking at a non-conductive vertical plate at $z = 0$, with a viscous incompressible conducting fluid flowing past it. The plate is vertical and the z axis is normal to it. The velocity, temperature and concentration all are e^{at} at t=0. The velocity components make the flow characteristics when there is constant pressure across flow and continuity is met. Taking these assumptions into account, the governing equations for the transient flow are written like this:

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$$\frac{\partial \tilde{u}}{\partial \tilde{t}} - 2\Omega\tilde{u} = \vartheta \frac{\partial^2 \tilde{u}}{\partial \tilde{z}^2} + g\beta\left(\tilde{T} - \tilde{T}_\infty\right) + g\beta\left(\tilde{C} - \tilde{C}_\infty\right) - \frac{\sigma B_0^2 \mu^2 (\tilde{u} + m_1 \tilde{v})}{\rho\left(1 + m_1^2\right)} - \frac{\vartheta \tilde{u}}{K_1} \qquad (1)$$

$$\frac{\partial \tilde{v}}{\partial \tilde{t}} + 2\Omega\tilde{v} = \vartheta \frac{\partial^2 \tilde{v}}{\partial \tilde{z}^2} - \frac{\sigma B_0^2 \mu^2 (m_1 \tilde{u} - \tilde{v})}{\rho\left(1 + m_1^2\right)} - \frac{\vartheta \tilde{v}}{K_1} \qquad (2)$$

$$\frac{\partial \tilde{\theta}}{\partial \tilde{t}} = \frac{1}{Pr} \frac{\partial^2 \tilde{\theta}}{\partial \tilde{z}^2} - R\tilde{\theta} + Q\tilde{\theta} \qquad (3)$$

$$\frac{\partial \tilde{C}}{\partial \tilde{t}} = \frac{1}{Sc} \frac{\partial^2 \tilde{C}}{\partial \tilde{z}^2} \qquad (4)$$

The conditions are

$$\begin{aligned} &\tilde{t} \le 0: \tilde{u} = \tilde{v} = 0, \tilde{T} = \tilde{T}_\infty, \tilde{C} = \tilde{C}_\infty, \forall\, \tilde{z} \le 0, \\ &\tilde{t} > 0: \tilde{u} = \tilde{u}_0\left(e^{a\tilde{t}}\right), \tilde{v} = 0, \tilde{T} - \tilde{T}_\infty = \tilde{C} - \tilde{C}_\infty = 0\ \forall\, z = 0, \\ &\tilde{t} > 0: \tilde{u} \to 0, \tilde{v} \to 0, \tilde{T} \to \tilde{T}_\infty, \tilde{C} \to \tilde{C}_\infty \text{ as } z \to \infty, \end{aligned} \qquad (5)$$

The consequent dimensionless aggregate is

$$\begin{aligned} &Z = \frac{\tilde{z} u_0}{\vartheta},\ t = \frac{\tilde{t} u_0^2}{\vartheta}, U = \frac{\tilde{u}}{u_o}, \theta = \frac{\tilde{T} - \tilde{T}_\infty}{\tilde{T}_w - \tilde{T}_\infty}, C = \theta = \frac{\tilde{C} - \tilde{C}_\infty}{\tilde{C}_w - \tilde{C}_\infty} \\ &Gr = \frac{g\beta\vartheta\left(\tilde{T}_w - \tilde{T}_\infty\right)}{u_o^3}, Gc = \frac{g\beta\vartheta\left(\tilde{C}_w - \tilde{C}_\infty\right)}{u_o^3}, M^2 = \frac{\sigma B_o^2}{\rho}\left(\frac{\vartheta}{u_o^2}\right)^{1/3} \\ &Pr = \frac{\mu Cp}{k}, K = K_1\left(\frac{\vartheta}{u_o^2}\right)^{1/3}, Sc = \frac{\vartheta}{D} \end{aligned} \qquad (6)$$

(1)+ i×(2) and putting velocity $q = u+iv$ we get ,

$$\frac{\partial q}{\partial t} = G_r\theta + G_c C + \frac{\partial^2 q}{\partial z^2} - mq - \frac{q}{K_1} \quad \text{where } m = \frac{M^2}{(1 + hi)} + 2\Omega i$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2} - R\theta + Q\theta$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2}$$

With conditions

$q = 0,\ \theta = C = 0$ for all $z, t \le 0$

$q = e^{at},\ \theta = e^{at},\ C = e^{at}$ for all $z, t = 0$

$q \to 0,\ \theta \to 0,\ C \to 0$ as $z \to \infty$.

RESULTS & DISCUSSION

Solving Using Inverse technique of Laplace we have

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$$C=\frac{e^{at}}{2}\left[e^{-2\eta\sqrt{atSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}-\sqrt{at}\right)+e^{z\sqrt{atSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}+\sqrt{at}\right)\right]$$

$$\theta=\frac{e^{at}}{2}\left[e^{-\sqrt{4\eta^2P_r}\sqrt{at+Rt-Qt}}\operatorname{erfc}\left(\sqrt{\eta^2P_r}-\sqrt{at+Rt-Qt}\right)+e^{\sqrt{4\eta^2P_r}\sqrt{(a+R-Q)t}}\operatorname{erfc}\left(\sqrt{\eta^2P_r}+\sqrt{at+Rt-Qt}\right)\right]$$

$$\begin{aligned}
q=&\frac{e^{at}}{2}\left[e^{-\sqrt{\left(m+\frac{1}{k_1}+a\right)4\eta^2t}}\operatorname{erfc}\left(\eta-\sqrt{mt+\frac{t}{k_1}+at}\right)+e^{\sqrt{\left(m+\frac{1}{k_1}+a\right)4\eta^2t}}\operatorname{erfc}\left(\eta+\sqrt{mt+\frac{t}{k_1}+at}\right)\right]\\
&+\frac{G_r}{(P_r-1)}\frac{1}{(a-b)}\left\{\begin{array}{l}
\frac{e^{at}}{2}\left[\begin{array}{l}e^{-\sqrt{\left(mt+\frac{t}{k_1}+at\right)4\eta^2}}\operatorname{erfc}\left(\eta-\sqrt{mt+\frac{t}{k_1}+at}\right)\\
+e^{\sqrt{\left(mt+\frac{t}{k_1}+at\right)4\eta^2}}\operatorname{erfc}\left(\eta+\sqrt{mt+\frac{t}{k_1}+at}\right)\end{array}\right]\\
-\frac{e^{bt}}{2}\left[\begin{array}{l}e^{-\sqrt{\left(mt+\frac{t}{k_1}+bt\right)4\eta^2}}\operatorname{erfc}\left(\eta-\sqrt{\left(mt+\frac{t}{k_1}+bt\right)}\right)\\
+e^{\sqrt{\left(mt+\frac{t}{k_1}+bt\right)4\eta^2t}}\operatorname{erfc}\left(\eta+\sqrt{\left(mt+\frac{t}{k_1}+bt\right)}\right)\end{array}\right]
\end{array}\right\}\\
&+\frac{G_c}{(S_c-1)}\frac{1}{(a-c)}\left\{\begin{array}{l}
\frac{e^{at}}{2}\left[\begin{array}{l}e^{-\sqrt{\left(mt+\frac{t}{k_1}+at\right)4\eta^2}}\operatorname{erfc}\left(\eta-\sqrt{\left(mt+\frac{t}{k_1}+at\right)}\right)\\
+e^{\sqrt{\left(mt+\frac{t}{k_1}+at\right)4\eta^2}}\operatorname{erfc}\left(\eta+\sqrt{\left(mt+\frac{t}{k_1}+at\right)}\right)\end{array}\right]\\
-\frac{e^{ct}}{2}\left[\begin{array}{l}e^{-\sqrt{\left(mt+\frac{t}{k_1}+ct\right)4\eta^2}}\operatorname{erfc}\left(\eta-\sqrt{\left(mt+\frac{t}{k_1}+ct\right)}\right)\\
+e^{\sqrt{\left(mt+\frac{t}{k_1}+at\right)4\eta^2}}\operatorname{erfc}\left(\eta+\sqrt{\left(mt+\frac{t}{k_1}+ct\right)}\right)\end{array}\right]
\end{array}\right\}\\
&-\frac{G_r}{(P_r-1)}\frac{1}{(a-b)}\left\{\begin{array}{l}
\frac{e^{at}}{2}\left[\begin{array}{l}e^{-\sqrt{(R-Q+a)4t\eta^2\,Pr}}\operatorname{erfc}\left(\sqrt{\eta^2\,Pr}-\sqrt{Rt-Qt+at}\right)\\
+e^{\sqrt{(R-Q+a)4t\eta^2\,Pr}}\operatorname{erfc}\left(\sqrt{\eta^2\,Pr}+\sqrt{Rt-Qt+at}\right)\end{array}\right]\\
-\frac{e^{bt}}{2}\left[\begin{array}{l}e^{-\sqrt{(R-Q+b)4t\eta^2\,Pr}}\operatorname{erfc}\left(\sqrt{\eta^2\,Pr}-\sqrt{Rt-Qt+bt}\right)\\
+e^{\sqrt{(R-Q+b)4t\eta^2\,Pr}}\operatorname{erfc}\left(\sqrt{\eta^2\,Pr}+\sqrt{Rt-Qt+bt}\right)\end{array}\right]
\end{array}\right\}\\
&-\frac{G_c}{(S_c-1)}\frac{1}{(a-c)}\left\{\begin{array}{l}
\frac{e^{at}}{2}\left[e^{-2\eta\sqrt{atSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}-\sqrt{at}\right)+e^{2\eta\sqrt{atSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}+\sqrt{at}\right)\right]\\
-\frac{e^{ct}}{2}\left[e^{-2\eta\sqrt{ctSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}-\sqrt{ct}\right)+e^{2\eta\sqrt{ctSc}}\operatorname{erfc}\left(\eta\sqrt{Sc}+\sqrt{ct}\right)\right]
\end{array}\right\}
\end{aligned}$$

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where $\eta = \frac{z}{2\sqrt{t}}$, $b = \frac{m + \frac{1}{k_1} - (R - Q)\Pr}{\Pr - 1}$, $c = \frac{m + \frac{1}{k_1}}{Sc - 1}$

Skin Friction (Sk)

$$\left(\frac{\partial q}{\partial z}\right)_{z=0} = e^{at}\left[\left(\frac{-1}{\sqrt{\pi t}}\right)e^{-\left(mt + t\frac{1}{k_1} + at\right)} - \left[1 - \operatorname{erfc}\left(\sqrt{mt + t\frac{1}{k_1} + at}\right)\right]\left(\sqrt{m + \left(\frac{1}{k_1}\right) + a}\right)\right]$$

$$+ \frac{G_r}{(P_r - 1)(a - b)}\left[\begin{array}{l} e^{at}\left[-\left(\frac{1}{\sqrt{\pi t}}\right)e^{-\left(mt + t\frac{1}{k_1} + at\right)} - \left[1 - \operatorname{erfc}\left(\sqrt{mt + t\frac{1}{k_1} + at}\right)\right]\left(\sqrt{m + \left(\frac{1}{k_1}\right) + a}\right)\right] \\ -e^{bt}\left[-\left(\frac{1}{\sqrt{\pi t}}\right)e^{-\left(mt + t\frac{1}{k_1} + bt\right)} - \left[1 - \operatorname{erfc}\left(\sqrt{mt + t\frac{1}{k_1} + bt}\right)\right]\left(\sqrt{m + \left(\frac{1}{k_1}\right) + b}\right)\right] \end{array}\right]$$

$$+ \frac{G_c}{(Sc - 1)(a - c)}\left[\begin{array}{l} e^{at}\left[\left(-\left(\frac{1}{\sqrt{\pi t}}\right)\right)e^{-\left(mt + t\frac{1}{k_1} + at\right)} - \left[1 - \operatorname{erfc}\left(\sqrt{mt + t\frac{1}{k_1} + bt}\right)\right]\left(\sqrt{m + \left(\frac{1}{k_1}\right) + a}\right)\right] \\ -e^{bt}\left[-\left(\frac{1}{\sqrt{\pi t}}\right)e^{-\left(mt + t\frac{1}{k_1} + ct\right)} - \left[1 - \operatorname{erfc}\left(\sqrt{mt + t\frac{1}{k_1} + bt}\right)\right]\left(\sqrt{m + \left(\frac{1}{k_1}\right) + c}\right)\right] \end{array}\right]$$

$$- \frac{G_r}{(P_r - 1)(a - b)}\left[\begin{array}{l} e^{at}\left[-\left(\frac{\Pr}{\sqrt{\pi t}}\right)e^{-(Rt - Qt + at)} - \left[1 - \operatorname{erfc}\left(\sqrt{Rt - Qt + at}\right)\right]\left(\sqrt{(R - Q + a)\Pr}\right)\right] \\ -e^{bt}\left[-\left(\frac{\sqrt{\Pr}}{\sqrt{\pi t}}\right)e^{-(Rt - Qt + bt)} - \left[1 - \operatorname{erfc}\left(\sqrt{Rt - Qt + bt}\right)\right]\left(\sqrt{(R - Q + b)\Pr}\right)\right] \end{array}\right]$$

$$- \frac{G_c}{(Sc - 1)(a - c)}\left[e^{at}\left[\left(\frac{-\sqrt{Sc}}{\sqrt{\pi t}}\right)e^{-at} - \left[1 - \operatorname{erfc}\left(\sqrt{at}\right)\right]\left(\sqrt{aSc}\right)\right] - e^{bt}\left[\left(\frac{-\sqrt{Sc}}{\sqrt{\pi t}}\right)e^{-bt} - \left[1 - \operatorname{erfc}\left(\sqrt{bt}\right)\right]\left(\sqrt{bSc}\right)\right]\right]$$

Nusselt Number (Nu) $\left(\frac{\partial \theta}{\partial z}\right)_{z=0} = e^{at}\left[\left(\frac{-\sqrt{\Pr}}{\sqrt{\pi t}}\right)e^{-(Rt - Qt + at)} - \left[1 - \operatorname{erfc}\left(\sqrt{Rt - Qt + at}\right)\right]\left(\sqrt{(R\Pr - Q\Pr + a\Pr)}\right)\right]$

Sherwood Number (Sh)

$$\left(\frac{\partial C}{\partial z}\right)_{z=0} = e^{at}\left[\left(\frac{-\sqrt{Sc}}{\sqrt{\pi t}}\right)e^{-at} - \left[1 - \operatorname{erfc}\left(\sqrt{at}\right)\right]\left(\sqrt{aSc}\right)\right]$$

Nusselt Number (Nu)

R	**Q**	**Pr**	**t**	**Nu**	
3.0	2.0	7.0	0.4	-3.4646	
5.0	2.0	7.0	0.4	-5.0003	**R**
7.0	2.0	7.0	0.4	-6.2683	

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5.0	**0.5**	7.0	0.4	-5.9710	
5.0	**2.0**	7.0	0.4	-5.0003	**Q**
5.0	**4.0**	7.0	0.4	-3.4646	
5.0	2.0	**0.71**	0.4	-1.5925	**Pr**
5.0	2.0	**7.0**	0.4	-5.0003	
5.0	2.0	7.0	**0.1**	-6.1739	
5.0	2.0	7.0	**0.2**	-5.3226	**T**
5.0	2.0	7.0	**0.4**	-5.0003	

Sherwood Number (Sh)

Sc	**t**	**Sh**	
0.3	0.4	-0.5287	
0.6	0.4	-0.7478	**Sc**
2.01	0.4	-1.3686	
2.01	**0.1**	-2.5804	
2.01	**0.2**	-1.8611	**t**
2.01	**0.4**	-1.3686	

Skin Friction (τ)

Gr	**Gc**	**R**	**Q**	**k1**	**M**	**hc**	**w**	***τ***	
10.0	25.0	5.0	2.0	1.0	1.5	3.0	2.0	0.7275	**Gr**
18.0	25.0	5.0	2.0	1.0	1.5	3.0	2.0	1.7715	
25.0	25.0	5.0	2.0	1.0	1.5	3.0	2.0	2.6849	
25.0	**10.0**	5.0	2.0	1.0	1.5	3.0	2.0	1.5370	
25.0	**18.0**	5.0	2.0	1.0	1.5	3.0	2.0	2.1493	**Gc**
25.0	**25.0**	5.0	2.0	1.0	1.5	3.0	2.0	2.6849	
25.0	25.0	**2.0**	2.0	1.0	1.5	3.0	2.0	3.4668	**R**
25.0	25.0	**3.0**	2.0	1.0	1.5	3.0	2.0	3.1615	
25.0	25.0	**5.0**	2.0	1.0	1.5	3.0	2.0	2.6849	
25.0	25.0	5.0	**0.5**	1.0	1.5	3.0	2.0	2.4134	**Q**

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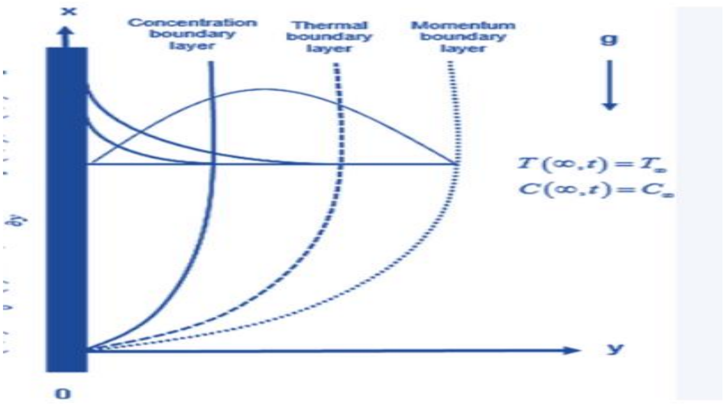
25.0	25.0	5.0	**2.0**	1.0	1.5	3.0	2.0	2.6849	
25.0	25.0	5.0	**4.0**	1.0	1.5	3.0	2.0	3.1615	
25.0	25.0	5.0	2.0	**0.5**	1.5	3.0	2.0	-1.7834	**k1**
25.0	25.0	5.0	2.0	**1.0**	1.5	3.0	2.0	2.6849	
25.0	25.0	5.0	2.0	**4.0**	1.5	3.0	2.0	6.1627	
25.0	25.0	5.0	2.0	1.0	**1.5**	3.0	2.0	2.6849	**M**
25.0	25.0	5.0	2.0	1.0	**2.5**	3.0	2.0	1.3032	
25.0	25.0	5.0	2.0	1.0	**3.0**	3.0	2.0	0.2148	
25.0	25.0	5.0	2.0	1.0	1.5	**0.25**	2.0	0.9419	**Hc**
25.0	25.0	5.0	2.0	1.0	1.5	**1.0**	2.0	1.9332	
25.0	25.0	5.0	2.0	1.0	1.5	**3.0**	2.0	2.6849	
25.0	25.0	5.0	2.0	1.0	1.5	3.0	**2.0**	2.6849	**Ω**
25.0	25.0	5.0	2.0	1.0	1.5	3.0	**3.0**	-0.3271	
25.0	25.0	5.0	2.0	1.0	1.5	3.0	**4.0**	-4.7847	



Geometrical Representation

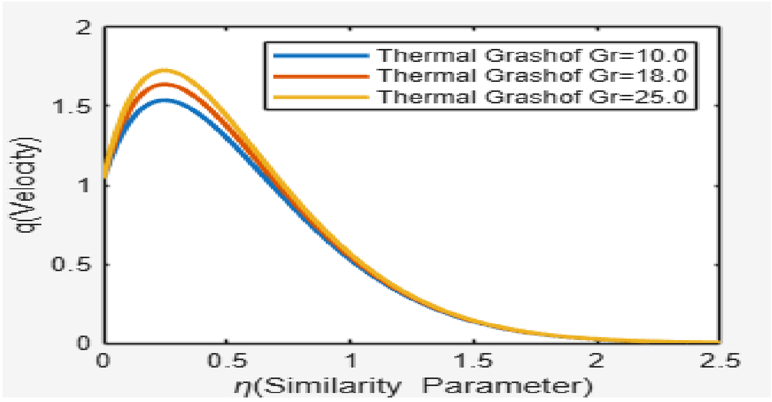


Figure 1

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Fig 1 :The buoyancy force induced by the difference in temperature stronger as the thermal Grashof number (Gr) goes up. This higher buoyancy makes the fluid move faster, which speeds up the flow.

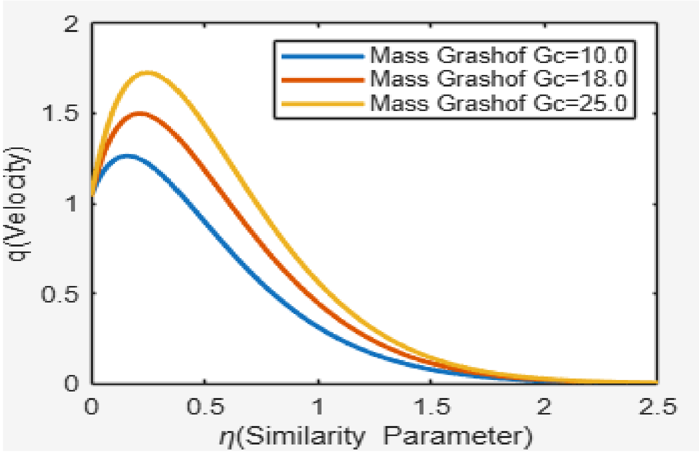

Figure 2

Fig 2 It shows that when the Mass Grashof number (Gc) goes up the velocity (speed) goes up also. This is because a bigger mass-concentration differential makes buoyancy forces greater, which pushes the fluid faster and raises the flow speed.

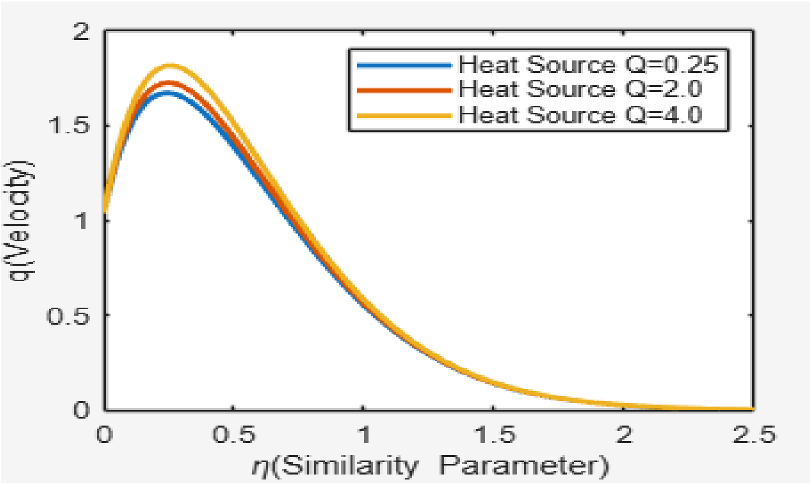

Figure 3

Fig 3: It discovers that the speed of the fluid rises as the heat source (Q) gets greater. This is because more heating increases the buoyancy force, which pushes the fluid faster.

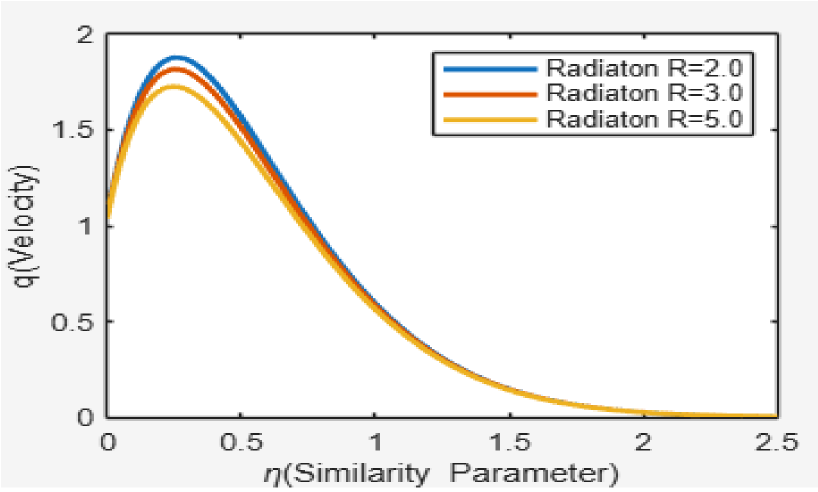

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Figure 4 In Fig 4 As radiation(R) rises, the velocity (speed) drops because more radiation takes heat out from the fluid, which lowers the buoyancy force and slows down the flow.

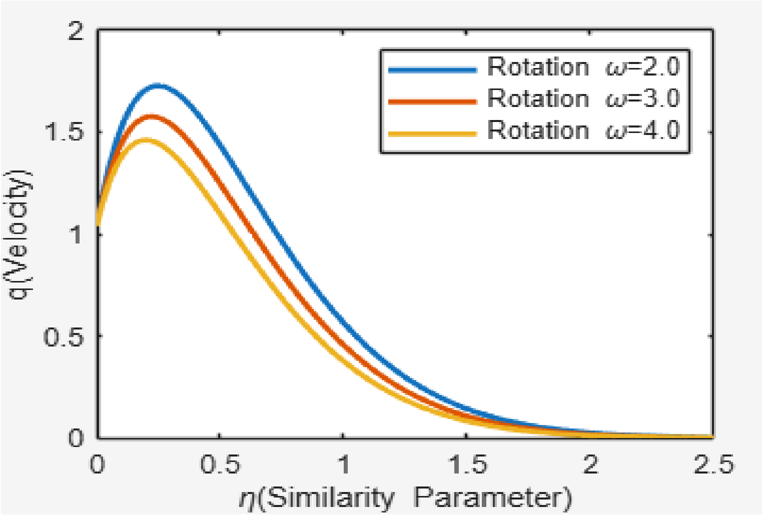

Figure 5 In Fig 5 As the rotation (w) speeds up, the velocity (speed) down. This is because higher rotational effects create Coriolis and centrifugal forces, which slow down the flow by resisting the fluid motion.

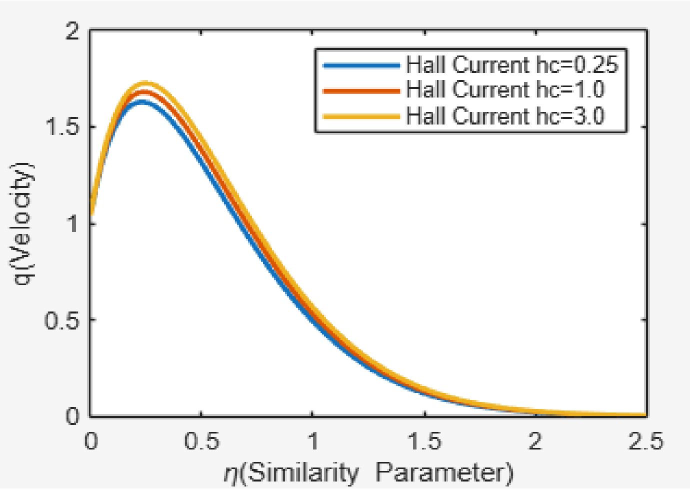

Figure 6 In Fig 6 As the Hall current (hc)goes up, the speed (velocity) goes up also. This is because the Hall effect makes the electromagnetic force stronger in the fluid, which speeds up the motion and raises the flow speed.

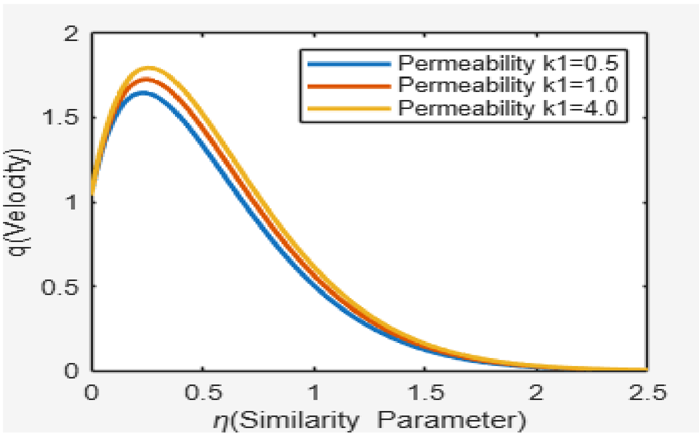

Figure 7In Fig 7 The speed (velocity) goes up when permeability(k1) goes up. This is because increased permeability makes it easier for the fluid to move through the medium, which lowers resistance and speeds up flow.

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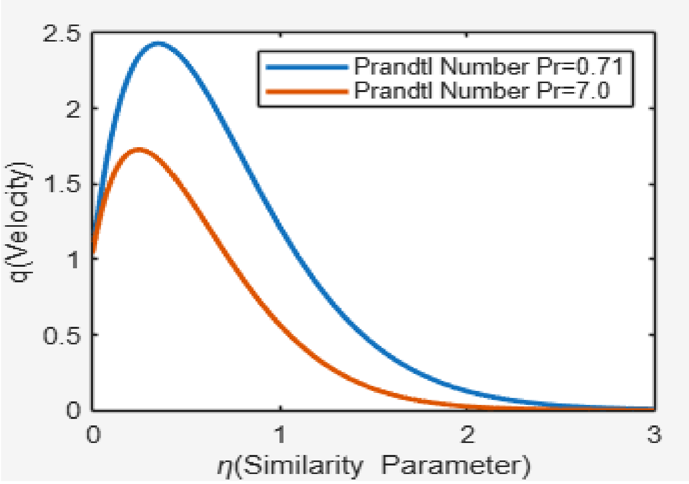

Figure 8 In Fig 8 As the Prandtl number (Pr) goes up, the velocity (speed) goes down. This is because a higher Prandtl number indicates that momentum spreads out quicker than heat, which slows down the fluid motion and stops the thermal boundary layer from growing.

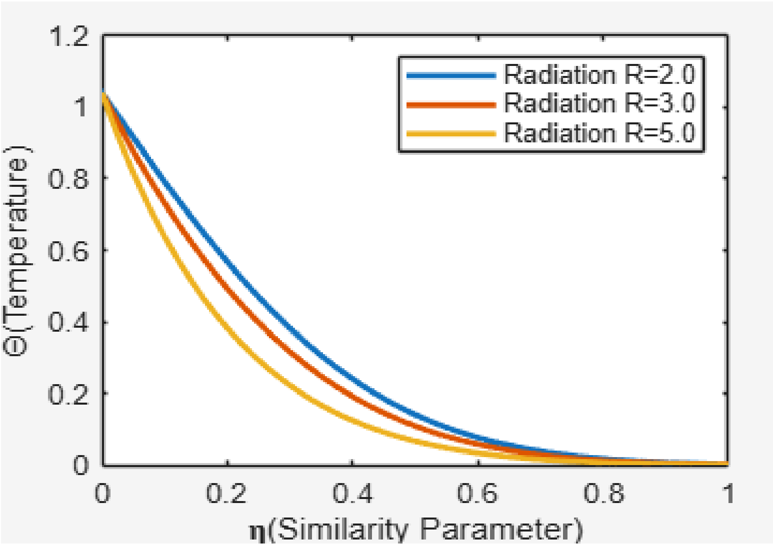

Figure 9 In Fig 9 As radiation (R) rises, the temperature drops. This is because increased radiation takes heat out from the fluid, lowering its thermal energy and lowering the temperature.

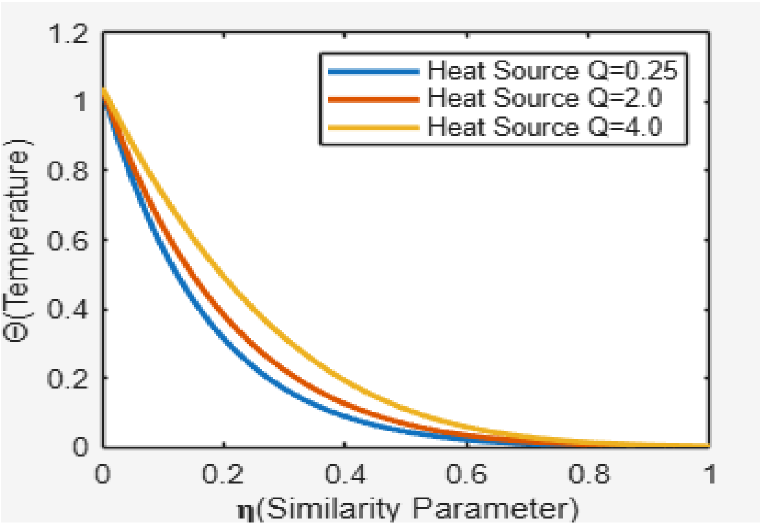

Figure 10 In Fig. 10, the temperature goes up because greater Heat source (Q) contributes more thermal energy to the fluid, which makes it hotter.

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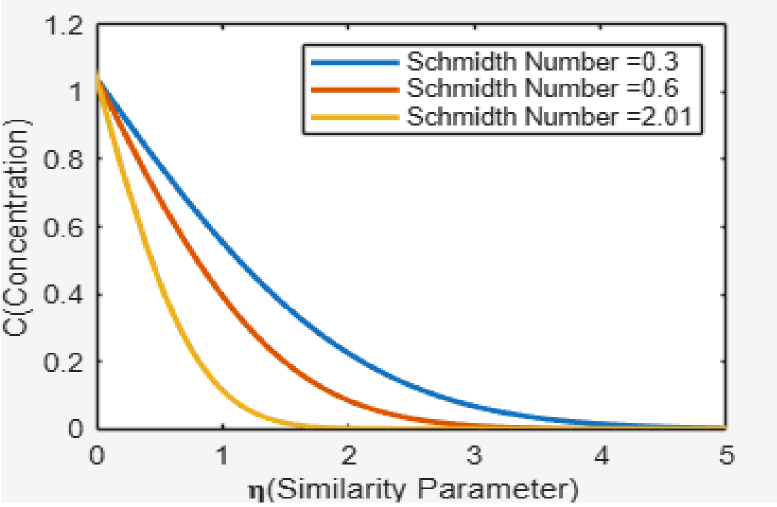

Figure 11 In Fig 11 The Schmidt number (Sc) goes up, which means that mass diffusion is slower than momentum. This slows down the flow and diminishes the fluid motion.

CONCLUSION

The fast isothermal flow over a inclined vertical plate is the focus of this easy-to-use and interesting framework for computer research. This has to do with HMT. These computations allow for the deduction of several crucial relationships:

(i) Velocity increases when the Heat Source increases, whereas velocity decreases with raise in permeability and Hall Current

(ii)Temperature drops as radiation levels rise whereas the Heat Source raises, the temperature raises.

(iii)The concentration of the species involved tends to decline as the rate of the schmidth raises.

(iv)The Skin friction decreases as Prandtl, Hartmaann, Permeability, Radiation and Hall Current Values increases whereas skin friction increases when Rotation, Heat Source, Thermal Grashof and Mass Grashof values increases.

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