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EFFECT OF HEAT AND MASS TRANSFER ON MAGNETO-HYDRODYNAMIC FLOW WITH CHEMICAL REACTION AND VISCOUS ENERGY DISSIPATION PAST AN INCLINED POROUS PLATE

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ABSTRACT

In this paper, a mathematical model describing heat and mass transfer of magneto-hydrodynamic flow with chemical reaction and viscous energy dissipation past an inclined porous plate is presented. The governing partial differential equations which describe the phenomenon were non-dimensionalized with the aid of some dimensionless quantities. The dimensionless coupled non-linear partial differential equations were solved using the harmonic solution technique. The results obtained were discussed graphically. Findings from the results obtained reveal that increase in Peclet number; Heat source parameter and Grashof number enhance the velocity profiles. Similarly, an increase in the Peclet energy number, Eckert number, Heat source parameter, angle of inclination, permeability parameter and Stuart number leads to an increase in the temperature profile.

Keywords: Magneto-hydrodynamic, harmonic solution technique, Peclet number, Grashof number, Eckert number

INTRODUCTION

The concept of Magneto-hydrodynamics free convection heat and mass transfer flows through a porous medium has always been an interesting topic due to its applications in many branches of science and technology. Problems of heat transfer arise in many industrial and environmental processes, particularly in energy thermal processing and thermal control. Energy utilization is concerned with energy generation from primary sources such as fossil fuels and solar to end-user energy consumption (i.e. electricity and fuel consumption), through all possible intermediate steps of energy valorization, energy transportation, energy storage, and energy conversion processes. The essence of thermal processing is to create a temperature change in the system that allows or disallows some material transformation e.g. food pasteurization, cooking, steel tempering or annealing (Bejan and John, 1984).

Heat transfer refers to the flow of thermal energy occurring through thermal non-equilibrium commonly measured as a heat flux. The flow of heat transfer of electrically conducting fluids in channels under the effects of an inclined magnetic field occurs in magneto-hydrodynamic (MHD) accelerators, pumps and generators (Stamenkovic *et al.*, 2010)

Radioactive heat transfer is another important factor in thermodynamics of very high temperature system such as electric furnaces, solar collectors, satellites, steel rolling, cryogenic engineering, and so on. The study of such flow under the influence of magnetic field and heat transfer was the interest of many investigators and researchers (Siti *et al.*,2017).

Sharma and Sharma (1997) investigate an unsteady flow and heat transfer between two parallel plates. Sharma and Chaturvedi (2003) considered an unsteady flow and heat transfer of an electrically conducting viscous incompressible fluid between two non-conducting parallel porous plates under a uniform transverse magnetic field.

The experimental and theoretical works on MHD flow with chemical reactions have been done extensively in various areas, i.e. liquid metal cooling of nuclear reactions and electromagnetic casting of metals (Ugwu *et al.*, 2021).

Nowadays, electromagnetic pumps and their modifications are widely used in metallurgy and materials processing to transport and dose (exact batching) melting metal (Ivlev and Baranov 1993). The advantages of MHD pumps over mechanical pumps are the absence of moving and rotating parts (this increases their reliability), noiseless operations (better vibration and noise characteristics), the relative simplicity of control, being completely hermetically sealed. They can be utilized even with chemically aggressive, reactive and very hot fluids in chemical industries (Al-Habahbeh *et al.*, 2016).

Barik *et al*. (2014) studied thermal radiation effects on the unsteady MHD flow past an inclined plate in the presence of chemical reactions and viscous dissipation. The influence of the Soret number on an unsteady magneto-hydrodynamic fluid flow in a semi-infinite vertical plate in the presence of viscous dissipation was discussed by Sheri and Raju (2015). Srinivasa *et al.* (2016) studied both the analytical and numerical results of an unsteady MHD free convective flow past an exponentially moving vertical plate with heat absorption and chemical reaction. Aishah and Mohamed (2017) studied the heat and mass transfer in an unsteady magneto-hydrodynamic free convective flow through a porous medium past a positive vertical plate with uniform surface heat flux. Radiation and chemical reaction effects on an MHD flow along a moving vertical porous plate were studied (Ramana *et al.*, 2016).

Sheri and Rao (2015) studied the heat and mass transfer effect on MHD natural convection flow past a moving vertical plate. The dimensionless non-linear partial differential equations were solved with the aid of finite element method. Similarly, the steady MHD mass transfer flow in presence of heat sink and chemical reactions was also investigated by Ahmed (2017). His governing model equations were solved using the asymptotic series expansion method.

Krishna and Jyothi (2018) considered the unsteady rotating flow of a visco-elastic fluid through a porous medium over an infinite oscillating porous plate with a heat source and chemical reaction. The governing equations were solved by a regular perturbation method for small elastic parameters and also obtained the skin friction, Nusselt number and Sherwood number of the flow. It was also discovered that the velocity of the fluid increases with an increase in the Grashof number and Eckert number. Manga *et al*. (2016) presented the MHD free convective flow past a vertical porous plate in the presence of radiation and heat generation.

Vellanki *et al*. (2021) studied the radiation effect on unsteady free convection oscillatory Couette flow through a porous medium with

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periodic wall temperature and heat generation. They analyzed the reaction effects on heat transfer and magneto-hydrodynamic free convection flow and assumed that free stream velocity oscillates in times about a constant mean. Zubi (2018) analyzed MHD heat and mass transfer of an oscillatory flow over a vertical permeable plate in a porous medium with a chemical reaction. He found out that the fluid velocity increases with an increase in both permeability and chemical reaction parameters, and also increases with decreasing magnetic field parameters.

Sandhya *et al*. (2020) studied heat and mass transfer effects on MHD flow past an inclined porous plate in the presence of a chemical reaction. This research seeks to extend Sandhya *et al*. (2020) by incorporating the viscous dissipation term into the energy equation.

Model Formulation

Consider an unsteady MHD free convective flow of a viscous incompressible and electrically conducting fluid past an infinite inclined porous plate with time-dependent variable plate velocity, heat and mass transfer in a saturated porous medium. The x^* - axis is taken along the leading edge of an inclined plate with an angle of inclination α to a vertical direction. The y^* - axis is taken normal to the plate. Initially, the plate temperature and mass diffusion from the plate into the fluid are increased linearly with reference to time. A uniform magnetic field of strength B_0 is applied transversely to the plate along the y^* - direction. Further, it is considered that the viscous dissipation of energy is not negligible and that the fluid is an optically thin gray radiating but non-scattering medium.

From the work of Sandhya *et al*., (2020) and the above assumptions, the usual Boussinesq approximation, the governing equations considered are as follows:

$$\rho\frac{\partial u^*}{\partial t^*}=\mu\frac{\partial^2 u^*}{\partial y^{*2}}-\sigma B_0^2 u^*-\frac{\mu}{k_p^*}u^*+\rho g\beta\cos\alpha\left(T^*-T_\infty^*\right)+\rho g\beta^*\cos\alpha\left(C^*-C_\infty^*\right) \qquad (1)$$

$$\rho C_p\frac{\partial T^*}{\partial t^*}=k_T\frac{\partial^2 T^*}{\partial y^{*2}}-16a^*\sigma^* T_\infty^{*3}\left(T^*-T_\infty^*\right)+Q^*\left(T^*-T_\infty^*\right)+\mu\left(\frac{\partial u^*}{\partial y^*}\right)^2 \qquad (2)$$

$$\frac{\partial C^*}{\partial t^*}=D_m\frac{\partial^2 C^*}{\partial y^{*2}}+D_T\frac{\partial^2 T^*}{\partial y^{*2}}-k_c^*\left(C^*-C_\infty^*\right) \qquad (3)$$

where,

u^* is the component of velocity along x^* - axis,

υ is the kinematic viscosity,

g is the acceleration due to gravity,

β is the volume expansion coefficient for the heat transfer,

β^* is the volume expansion coefficient for the mass transfer,

k_p^* is the permeability of the porous medium,

q_r is the radiative heat flux,

∞ is the angle of inclination,

σ is the electrical conductivity of the fluid,

T^* is the fluid temperature,

T_∞^* is the far field temperature,

k_T is the thermal conductivity,

k_c^* is the chemical reaction parameter,

Q^* is the heat source parameter,

ρ is the density of the fluid,

C_p is the specific heat at constant pressure,

C^* is the species concentration,

C_∞^* is the far filed concentration,

D_m is the coefficient of molecular diffusivity,

D_T is the coefficient of thermal diffusion.

The initial and boundary conditions are given by,

$$\left.\begin{aligned} & u^*\left(y^*,0\right)=0, \quad u^*\left(0,t\right)=\left(\frac{Ut^*}{l}\right)^2, \quad u^*\left(y^*\to\infty,t\right)\to 0 \\ & T^*\left(y^*,0\right)=T_\infty^*, \quad T^*\left(0,t\right)=T_\infty^*+\left(\frac{T_w^*-T_\infty^*}{l}\right)Ut^*, \quad T^*\left(y^*\to\infty,t\right)\to T_\infty^* \\ & C^*\left(y^*,0\right)=C_\infty^*, \quad C^*\left(0,t\right)=C_\infty^*+\left(\frac{C_w^*-C_\infty^*}{l}\right)Ut^*, \quad C^*\left(y^*\to\infty,t\right)\to C_\infty^* \end{aligned}\right\} \tag{4}$$

Non-dimensionalisation

Equations (1), (2), (3) and (4) using the following dimensionless variables

$$\left. y=\frac{y^*}{l}, \quad t=\frac{Ut^*}{l}, \quad \theta=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*}, \quad \phi=\frac{C^*-C_\infty^*}{C_w^*-C_\infty^*}, \quad u=\frac{u^*}{U}, \right\} \tag{5}$$

After non-dimensionalization, equations (1), (2), (3) and (4) becomes

$$\frac{\partial u}{\partial t}=\frac{1}{R_e}\frac{\partial^2 u}{\partial y^2}-\left(N+\gamma\right)u+G_{r\theta}\cos\alpha\theta+G_{r\phi}\cos\alpha\phi \tag{6}$$

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$$\frac{\partial\theta}{\partial t}=\frac{1}{P_e}\frac{\partial^2\theta}{\partial y^2}-\left(\frac{R}{P_e}-Q\right)\theta+\frac{E_c}{R_e}\left(\frac{\partial u}{\partial y}\right)^2 \qquad (7)$$

$$\frac{\partial\phi}{\partial t}=\frac{1}{S_c}\frac{\partial^2\phi}{\partial y^2}+S_r\frac{\partial^2\theta}{\partial y^2}-k_r\phi \qquad (8)$$

$$\left.\begin{aligned} &u(y,0)=0, \quad u(0,t)=t^2, \quad u(y\to\infty,t)=0,\\ &\theta(y,0)=0, \quad \theta(0,t)=t, \quad \theta(y\to\infty,t)=0,\\ &\phi(y,0)=0, \quad \phi(0,t)=t, \quad \phi(y\to\infty,t)=0, \end{aligned}\right\} \qquad (9)$$

where,

$$\left.\begin{aligned} &\frac{\rho Ul}{\mu}=R_e,\ \frac{\sigma B_0{}^2 l}{\rho U}=N,\ \frac{l\upsilon}{K_p^*U}=\gamma,\ \frac{g\beta l\left(T_w^*-T_\infty^*\right)}{U^2}=G_{r\theta},\ \frac{g\beta*l\left(C_w^*-C_\infty^*\right)}{U^2}=G_{r\phi},\\ &\frac{\rho C_pUl}{k_t}=P_e,\ \frac{16a^*\sigma^*lT_\infty^{*3}}{\rho C_pU}=\frac{16a^*\sigma^*l^3T_\infty^{*3}}{K_T}.\frac{K_T}{\rho C_pUl}=\frac{R}{p_e},\ \frac{Q^*l}{\rho C_pU}=Q,\\ &\frac{\mu U}{\rho C_pl\left(T_w^*-T_\infty^*\right)}=\frac{U^2}{C_p\left(T_w^*-T_\infty^*\right)}.\frac{\mu}{\rho lU}=\frac{E_c}{R_e},\ \frac{U^2}{C_p\left(T_w^*-T_\infty^*\right)}=E_c,\ \frac{\rho lU}{\mu}=R_e,\\ &\frac{Ul}{D_m}=S_c,\ \frac{D_T\left(T_w^*-T_\infty^*\right)}{Ul\left(T_w^*-T_\infty^*\right)}=S_r,\ \frac{k_c^*l}{U}=k_r \end{aligned}\right\} \qquad (10)$$

where,

R_e= Reynold number

N= Stuart number

γ= permeability parameter

$G_{r\theta}$= thermal Grashof number

$G_{r\emptyset}$= Solutal Grashof number

R = Radiation parameter

P_e= Peclet number

Q= heat source parameter

E_c= Eckert number

S_c= Schmidt number

S_r= Soret number

K_r= chemical reaction parameter

MATERIALS AND METHODS

Equations (6), (7) and (8) are coupled and non-linear and are solved by a closed-form method that is, the equation can be reduced to a set of ordinary differential equations which can be solved analytically. In doing so, the velocity, temperature and concentration of the fluid in the neighborhoods of the plate are represented as:

$$u(y,t)=u(y)e^{i\omega t},\quad \theta(y,t)=\theta(y)e^{2i\omega t},\quad \phi(y,t)=\phi(y)e^{i\omega t},\} \tag{11}$$

By substituting equation (11) in equations (6), (7) and (8), the following equations are obtained:

$$\frac{d^2u}{dy^2}-c_1^2u=-G_{r\theta}e^{i\omega t}R_e\cos\alpha\theta-G_{r\phi}R_e\cos\alpha\phi \tag{12}$$

$$\frac{d^2\theta}{dy^2}-c_2^2\theta=-\frac{E_cP_e}{R_e}\left(\frac{du}{dy}\right)^2 \tag{13}$$

$$\frac{d^2\phi}{dy^2}-c_3^2\phi=-S_rS_ce^{i\omega t}\frac{d^2\theta}{dy^2} \tag{14}$$

where

$$c_1=\sqrt{(N+\gamma+i\omega)R_e} \tag{15}$$

$$c_2=\sqrt{\left(\frac{R}{P_e}-Q+2i\omega\right)P_e} \tag{16}$$

$$c_3=\sqrt{(i\omega+k_r)S_c} \tag{17}$$

With the aid of equation (11), the initial and boundary conditions transformed to the following:

$$\left.\begin{aligned}
&u(y)=\frac{u(y,t)}{e^{i\omega t}},\quad u(0)=\frac{t^2}{e^{i\omega t}},\quad u(y\to\infty)=\frac{0}{e^{i\omega t}}=0,\\
&\theta(y)=\frac{\theta(y,t)}{e^{2i\omega t}},\quad \theta(0)=\frac{t}{e^{2i\omega t}},\quad \theta(y\to\infty)=\frac{0}{e^{2i\omega t}}=0,\\
&\phi(y)=\frac{\phi(y,t)}{e^{i\omega t}},\quad \phi(0)=\frac{t}{e^{i\omega t}},\quad \phi(y\to\infty)=\frac{0}{e^{i\omega t}}=0,
\end{aligned}\right\} \tag{18}$$

Equation (12), (13), and (14) becomes

$$\left.\begin{aligned}
&\frac{d^2u}{dy^2}-c_1^2u=-G_{r\theta}e^{i\omega t}R_e\cos\alpha\theta-G_{r\phi}R_e\cos\alpha\phi\\
&u(0)=\frac{t^2}{e^{i\omega t}},\quad u(y\to\infty)=0
\end{aligned}\right\} \tag{19}$$

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$$\left.\begin{aligned}&\frac{d^2\theta}{dy^2}-c_2^2\theta=-\frac{E_cP_e}{R_e}\left(\frac{du}{dy}\right)^2\\&\theta(0)=\frac{t}{e^{2i\omega t}},\quad \theta(y\to\infty)=0\end{aligned}\right\}\tag{20}$$

$$\left.\begin{aligned}&\frac{d^2\phi}{dy^2}-c_3^2\phi=-S_rS_ce^{i\omega t}\,\frac{d^2\theta}{dy^2}\\&\phi(0)=\frac{t}{e^{i\omega t}},\quad \phi(y\to\infty)=0,\end{aligned}\right\}\tag{21}$$

Let,

$0<G_{r\theta}<<1$ and $G_{r\phi}=aG_{r\theta}$ we have,

$$\left.\begin{aligned}&u=u_0+G_{r\theta}u_1+G_{r\theta}^2u_2+...\\&\theta=\theta_0+G_{r\theta}\theta_0+G_{r\theta}^2\theta_0+...\\&\phi=\phi_0+G_{r\theta}\phi_1+G_{r\theta}^2\phi_2+...\end{aligned}\right\}\tag{22}$$

By substituting equations (22) into (19), (20) and (21) and equating corresponding terms on both sides, the following equations are obtained:

For order 0, $G_{r\theta}^0:1,$

$$\left.\begin{aligned}&\frac{d^2u_0}{dy^2}-c_1^2u_0=0\\&u_0(0)=t^2e^{-i\omega t},\quad u_0(y\to\infty)=0\end{aligned}\right\}\tag{23}$$

$$\left.\begin{aligned}&\frac{d^2\theta_0}{dy^2}-c_2^2\theta_0=-\frac{E_cP_e}{R_e}\left(\frac{du_0}{dy}\right)^2\\&\theta_0(0)=te^{-2i\omega t},\quad \theta_0(y\to\infty)=0\end{aligned}\right\}\tag{24}$$

$$\left.\begin{aligned}&\frac{d^2\phi_0}{dy^2}-c_3^2\phi_0=-S_rS_ce^{i\omega t}\,\frac{d^2\theta_0}{dy^2}\\&\phi_0(0)=te^{-i\omega t},\quad \phi_0(y\to\infty)=0\end{aligned}\right\}\tag{25}$$

For order 1, $G_{r\theta}^1:G_{r\theta},$

$$\left.\begin{aligned}&\frac{d^2u_1}{dy^2}-c_1^2u_1=-e^{i\omega t}R_e\cos\alpha\theta_0-aR_e\cos\alpha\phi_0\\&u_1(0)=0,\quad u_1(y\to\infty)=0\end{aligned}\right\}\tag{26}$$

$$\left.\begin{aligned} &\frac{d^2\theta_1}{dy^2} - c_2^2\theta_1 = -\frac{2E_cP_e}{R_e}\left(\frac{du_0}{dy}\right)\left(\frac{du_1}{dy}\right) \\ &\theta_1(0) = 0, \quad \theta_1(y\to\infty) = 0 \end{aligned}\right\} \tag{27}$$

$$\left.\begin{aligned} &\frac{d^2\phi_1}{dy^2} - c_3^2\phi_1 = -S_rS_ce^{i\omega t}\frac{d^2\theta_1}{dy^2} \\ &\phi_1(0) = 0, \quad \phi_1(y\to\infty) = 0 \end{aligned}\right\} \tag{28}$$

The boundary value problems (23) to (28) are solved by the method of undetermined coefficients and obtained the following results:

$$u(y) = B_2e^{-c_1y} + G_{r\theta}\left(B_{11}e^{-c_1y} + B_{12}e^{-c_2y} + B_{13}e^{-2c_1y} + B_{14}e^{-c_3y}\right) \tag{29}$$

$$\theta(y) = B_4e^{-c_2y} + B_5e^{-2c_1y} + G_{r\theta}\begin{pmatrix} B_{17}e^{-c_2y} + B_{18}e^{-2c_1y} + B_{19}e^{-3c_1y} + \\ B_{20}e^{-(c_1+c_3)y} + B_{21}e^{-(c_1+c_2)y} \end{pmatrix} \tag{30}$$

$$\phi(y) = B_7e^{-c_3y} + B_8e^{-c_2y} + B_9e^{-2c_1y} + G_{r\theta}\begin{pmatrix} B_{23}e^{-c_3y} + B_{24}e^{-c_2y} + B_{25}e^{-2c_1y} \\ + B_{26}e^{-3c_1y} + B_{27}e^{-(c_1+c_3)y} + B_{28}e^{-(c_1+c_2)y} \end{pmatrix} \tag{31}$$

The general solution of equations (1), (2) and (3) with the associated boundary and initial conditions (4) is therefore in the form of:

$$\left.\begin{aligned} u(y,t) &= u(y)e^{iwt} \\ \theta(y,t) &= \theta(y)e^{2iwt} \\ \phi(y,t) &= \phi(y)e^{iwt} \end{aligned}\right\} \tag{32}$$

RESULTS

The results obtained in equations (32) which are solutions to the governing equations (1), (2), (3) and (4) are presented in graphs for analysis with the aid of MAPLE software to show the impact of the fluid parameters: Peclet number (P_e), Eckert number (E_c), Soret number (S_r), Reynold number (R_e), Schmidt number (S_c), Radiation parameter (R), angle of inclination (α) and Grashof thermal number $(G_{r\theta})$ on the velocity $u(y,t)$, temperature $\theta(y,t)$ and species concentration of the fluid $\phi(y,t)$ in the flow below:

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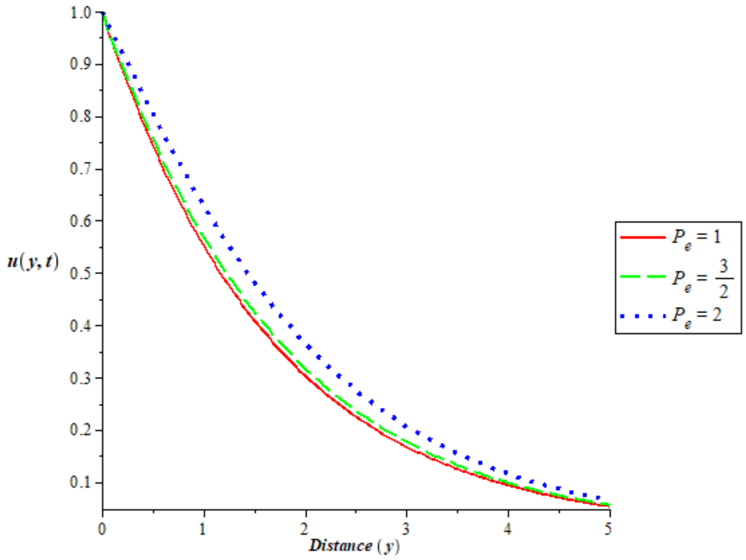

Figure 1: Variation of Velocity of the Fluid $u(y,t)$ against Distance (y) for Different Values of Peclet Number (P_e).

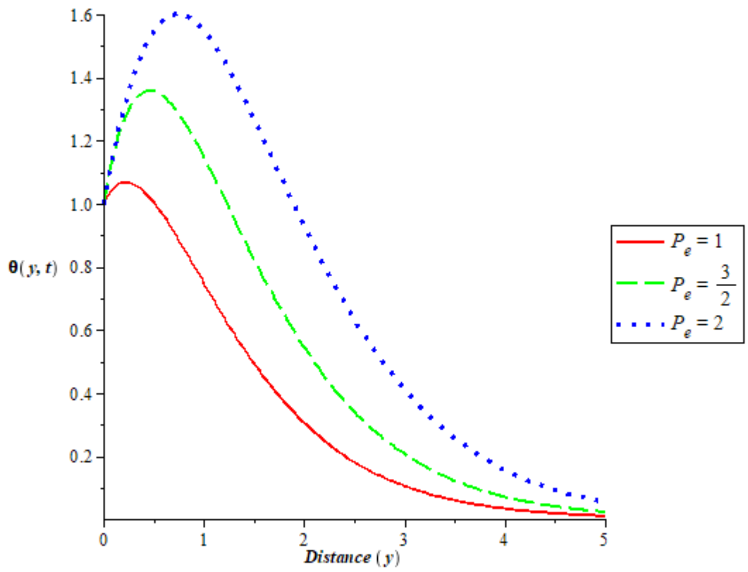

Figure 2: Variation of Temperature of the Fluid $\theta(y,t)$ against Distance (y) for Different Values of Peclet Number (P_e).

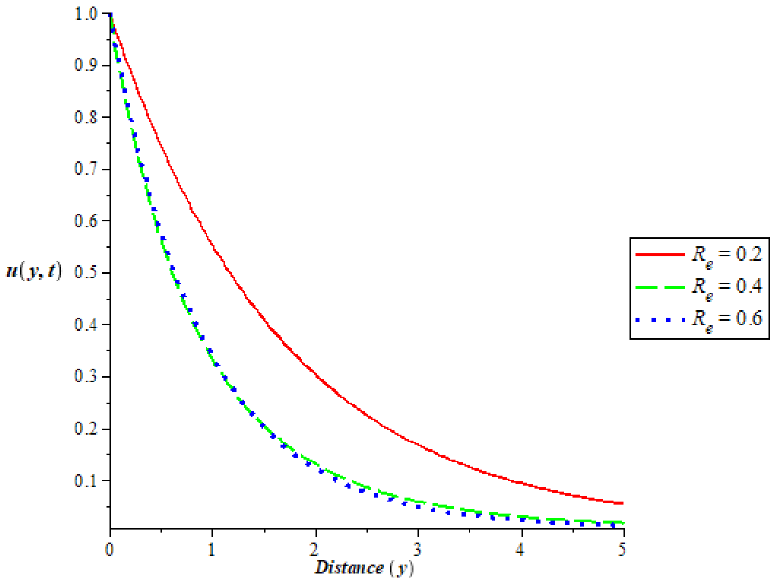

Figure 3: Variation of Velocity of the Fluid $u(y,t)$ against Distance (y) for Different Values of Reynold Number (R_e).

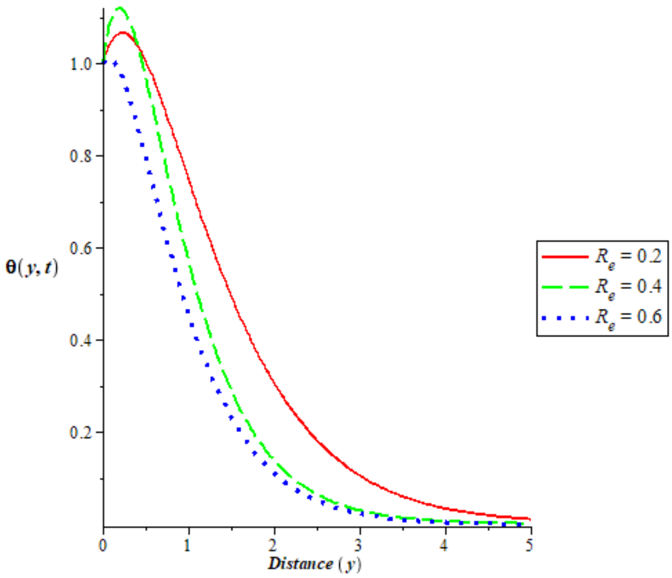

Figure 4: Variation of Temperature of the Fluid $\theta(y,t)$ against Distance (y) for Different Values of Reynold Number (R_e).

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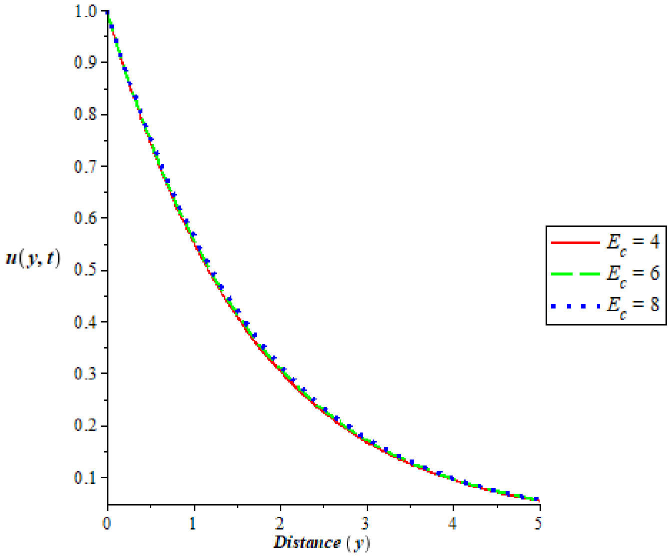

Figure 5: Variation of Velocity of the Fluid $u(y,t)$ against Distance (y) for Different Values of Eckert Number (E_c).

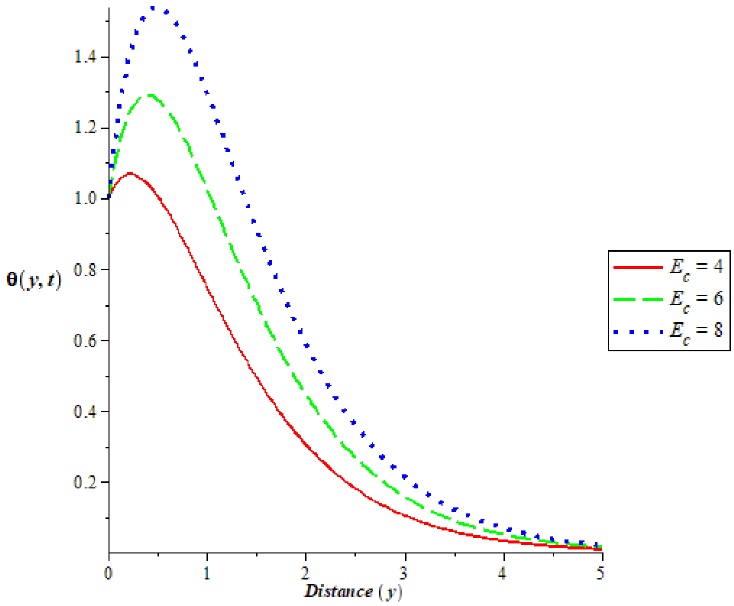

Figure 6: Variation of Temperature of the Fluid $\theta(y,t)$ against Distance (y) for Different Values of Eckert Number (E_c).

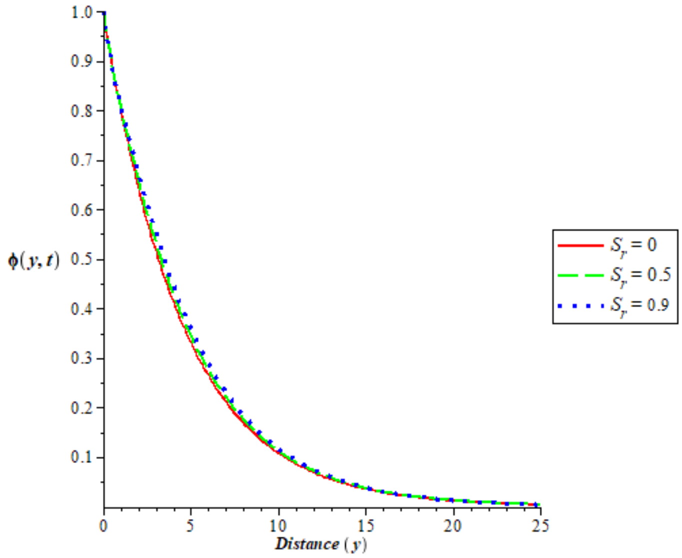

Figure 7: Variation of Species Concentration of the Fluid $\phi(y,t)$ against Distance (y) for Different Values of Soret Number (S_r).

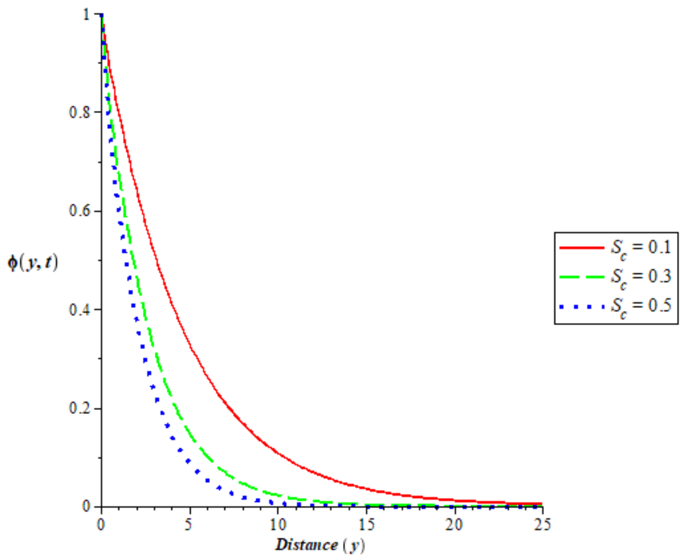

Figure 8: Variation of Species Concentration of the Fluid $\phi(y,t)$ against Distance (y) for Different Values of Schmidt Number (S_c).

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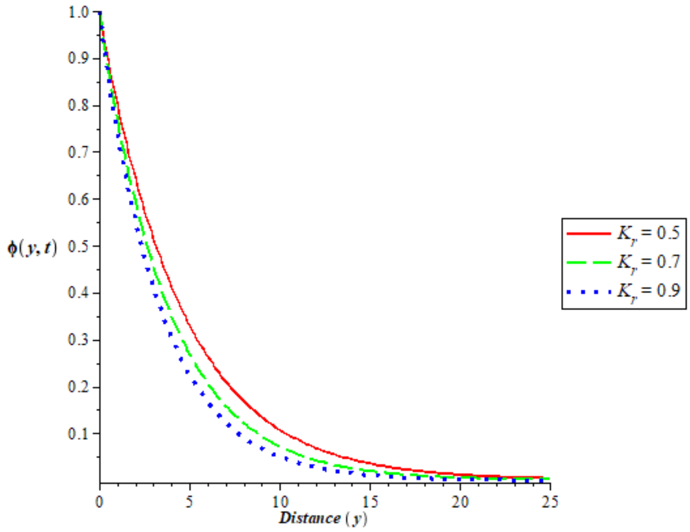

Figure 9: Variation of Species Concentration of the Fluid $\phi(y,t)$ against Distance (y) for Different Values of Chemical Reaction Parameter (K_r).

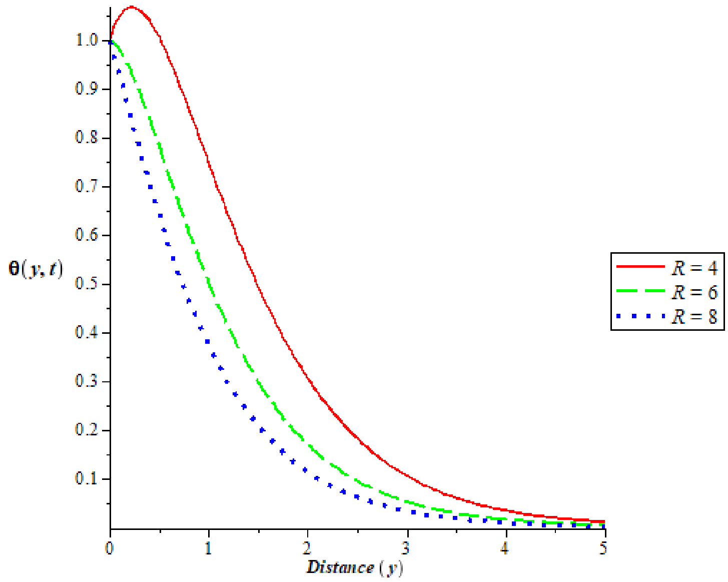

Figure 10: Variation of Temperature of the Fluid $\theta(y,t)$ against Distance (y) for Different Values of Radiation Parameter (R).

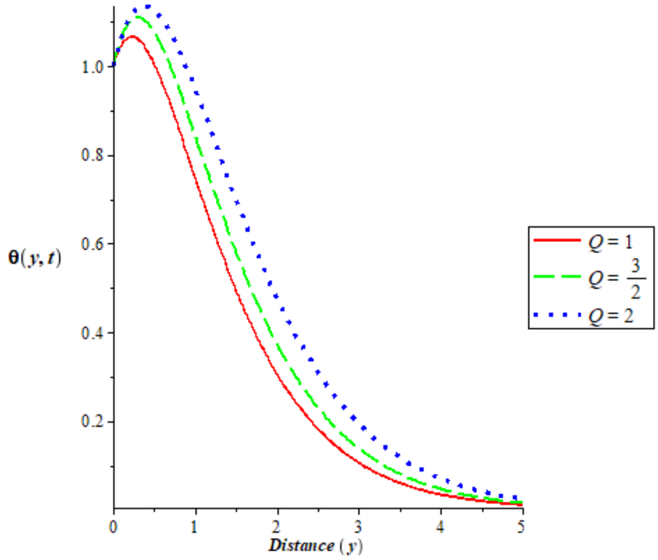

Figure 11: Variation of Temperature of the Fluid $\theta(y,t)$ against Distance (y) for Different Values of Heat Source Parameter (Q).

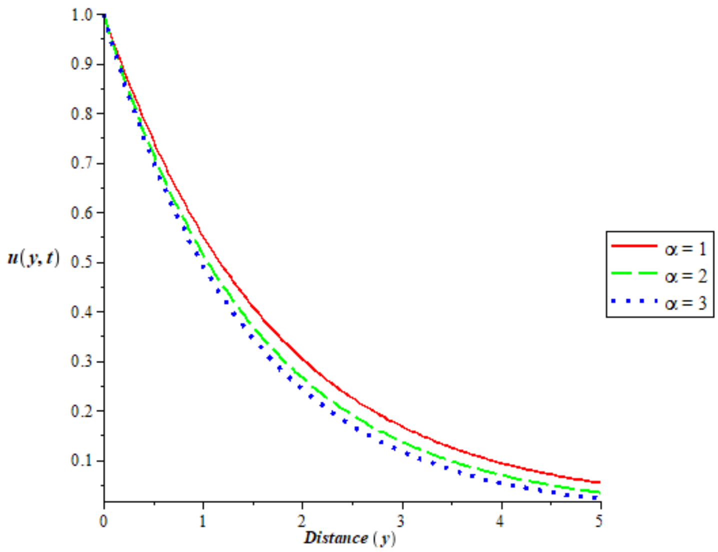

Figure 12: Variation of Velocity of the Fluid $u(y,t)$ against Distance (y) for Different Values of the Angle of Inclination (α).

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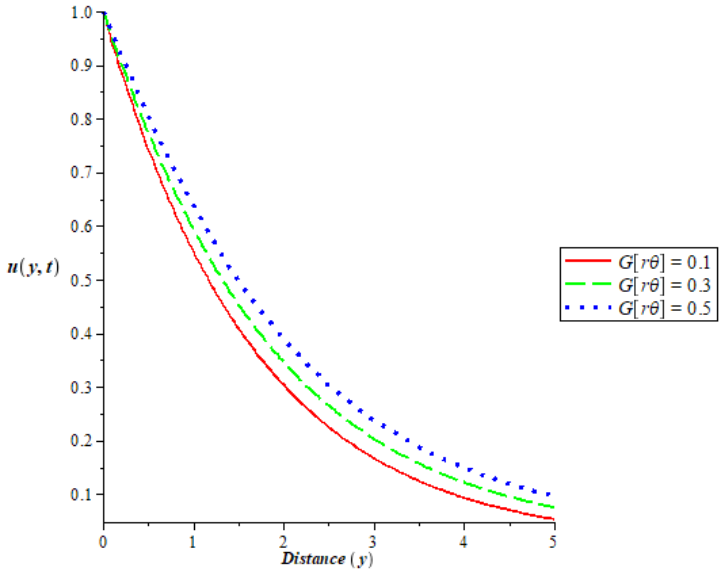

Figure 13: Variation of Velocity of the Fluid $u(y,t)$ against Distance (y) for Different Values of Grashof Thermal Number $(G_{r\theta})$.

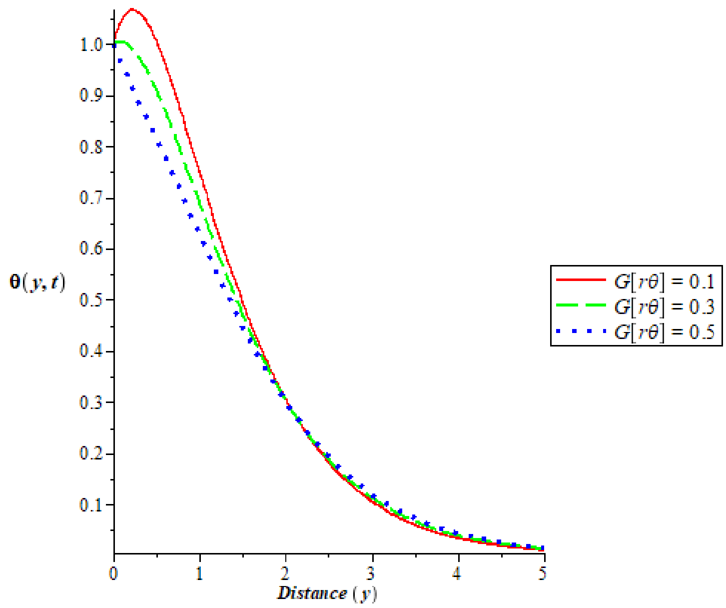

Figure 14: Variation of fluid Temperature $\theta(y,t)$ against Distance (y) for Different Values of Grashof Thermal Number $(G_{r\theta})$.

DISCUSSION

The impact of change in the Peclet number on the velocity and temperature of the fluid are presented in Figures 1 and 2. Figures 1 and 2 show that an increase in the Peclet number stimulates an increase in the velocity and temperature of the fluid along the flow. Figures 3 and 4 show that an increase in the Reynold number depletes the velocity and temperature of the fluid along the distance. The effects of Eckert number on the fluid flow are displayed in Figures 5 and 6. In Figure 5, an increase in the Eckert number E_c declines the velocity of the fluid to the free stream velocity. In Figure 6, an increase in the Eckert number E_c pushes the temperature of the fluid to the relative maximum and then decline to the free stream temperature.

The graph in Figure 7 shows that the fluid Concentration does not change much against distance with an increase in Soret Number (S_r). Figure 8 shows the effect of the increase in Schmidt Number on the fluid Concentration. The graph shows that the species concentration reduces against distance with increase in Schmidt Number (S_c).

The effect of the Chemical Reaction Parameter (K_r)on the fluid is presented in Figure 9. The graph reveals that fluid Concentration reduces against distance with an increase in Chemical Reaction Parameter (R). Figure 10 shows the effect of radiation parameters on the fluid with distance. The graph shows that the fluid Temperature decreases against distance with an increase in Radiation Parameter (R). Figure 11 shows the impact of the heat source parameter on the fluid temperature. The graph reveals that the fluid Temperature increases against distance with increase in Heat Source Parameter(Q).

Figure 12 shows the effect of change in the angle of Inclination on the fluid velocity. The graph shows that the fluid Velocity decreases against distance with an increase in angle of Inclination. The thermal Grashof number $G_{r\theta}$ represents the relative impact of the thermal buoyancy force to the viscous force. Figure 13 shows that there is an increase in the velocity due to an increase in the thermal buoyancy force.

In Figure 14, the temperature of the stream attains a maximum value in the neighborhood of the plate and then decline to approach the free stream value as the thermal Grashof number $G_{r\theta}$ increases.

CONCLUSION

A mathematical analysis has been carried out to study the viscous energy dissipation on heat and mass transfer of magneto-hydrodynamic flow with chemical reaction past an inclined porous plate. The dimensionless governing coupled non-linear partial differential equations for this investigation were solved analytically by using the harmonic solution technique. The impacts of the dimensionless parameters as shown on the graph are summarized below:

(i) Peclet energy number, Heat source parameter and Grashof number increases the velocity of the fluid.
(ii) Reynold number and angle of inclination reduce the velocity of the fluid.
(iii) Peclet energy number, Eckert number, Heat source parameter and angle of inclination enhance the temperature of the fluid.
(iv) Reynold number, Radiation parameter and Grashof number reduce the temperature of the fluid.
(v) Soret number enhances the species concentration of the fluid.
(vi) Schmidt number reduces the species concentration of the fluid.

REFERENCES

Ahmed, N. (2017): Steady MHD mass transfer flow in presence of heat sink and chemical reaction. *International Journal of Fluid Mechanics Research*. 44(1): 15-39.

Aishah, S. Y. & Mohamed A. E. (2017): Heat and mass transfer of unsteady hydromagnetic free convection flow through porous medium past a vertical plate with uniform surface heat flux. *Journal of Theoretical and Applied Mechanics, Sofia*, vol.47, No.3, pp.25-58.

Al-Habahbeh, O.M., Al-Saqqa, M., Safi, M. & Khater, T.A. (2016): Review of magnetohydrodynamic pump applications. *Alexandria engineering journal*. Vol. 55, pp. 1347-1358

Scientia Africana, Vol. 22 (No. 2), August, 2023. Pp 259-276
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Barik R.N. Dash G.C. & Rath P.K. (2014): Thermal radiation effect on an unsteady MHD flow past inclined porous heated plate in the presence of chemical reaction and viscous-dissipation. *Applied Mathematics and Computing,* vol.226,No.1, pp.423-434.

Bejan, A., John, W., (1984). "Convection heat transfer", *Int. journal of energy research* 29: 303-316

Ivlev, V.M.& Baranov, N.N. (1993). Research and development in the field of MHD Devices utilizing Liquid Working Medium for Process Applications: In Metallurgy Technologies, Energy Conversion, and Magnetohydrodynamic Flows. (Progress in Astronautics and Aeronautics). Edited by Herman Branover and Yeshajahu Unger.- Washington DC: *American Institutes of Aeronautics and Astronautics*.148:3-23

Krishna, M.V. & Jyothi, K. (2018): Hall effects on MHD rotating flow of a visco-elastic fluid through a porous medium over an infinite oscillating porous plate with heat source and chemical reaction. *Materials today: Proceedings* 5(1), 367-380

Manga, T. P., Ramana, G.V. & Rami, R. B. (2016): MHD free convective flow past a vertical porous plate in the presence of radiation and heat generation. *International Journal of Chemical Sciences*.

Ramana, G.V., Bhaskar, R. N. & Gorla, R.S. (2016): Radiation and chemical reaction effects on MHD flow along a moving vertical porous plate. *International Journal of Applied Mechanics and Engineering*.

Sandhya, A., Ramana, G.V.R. & Deekshitulu, G.V.S.R. (2020) 'Heat and mass transfer effects on MHD flow past an inclined porous plate in the presence of chemical reaction', *Int.Journal of applied mechanics and engineering, 2020, vol.25, no.3, pp.86- 102*

Sharma, P.R.& Chaturvedi, R. (2003): Unsteady flow and heat transfer of an electrically conducting viscous incompressible fluid between two non-conducting parallel porous plates under uniform transverse magnetic field. − *"Ganita Sandesh" J. Raj. Ganita Parishad, India, vol.17,* pp.9-14.

Sharma, P.R.& Sharma, M.K. (1997): Unsteady flow and heat-transfer between two parallel plates. *Bull. Pure Appl. Science, India, vol.16, pp*.183-198.

Sheri, S.R.& Raju S.R. (2015): Soret effect on unsteady MHD free convective flow past a semi-infinite vertical plate in the presence viscous dissipation. *International Journal of Computational Methods, Engineering, sciences and Mechanics*. vol.16,pp.132-141.

Sheri, S. R. and Rao, J. A. (2015): Heat and mass transfer effect on MHD natural convectionflow past a vertical plate. Journal of Physics. Conf. Ser. 662 012013. Pp 1-7.

Siti, K.S., Anuar, I.& Loan, P. (2017): Unsteady MHD flow and heat transfer over a shrinking sheet with Ohmic heating. *Chinese journal of physics* Vol. 55, pp 1626-1636.

Srinivasa, R. R., Jithender, R. G., Anand, R. J., Rashidi M.M. & Gorla R.S.R. (2016): Analytical and Numerical study of unsteady MHD free convection flow over an exponentially moving vertical plate with heat absorption. *International Journal of Thermal Sciences,* vol.107, 303-315.

Stamenkovic, M.Z., Dragisa, D.N., Bratislav, B.D. & Slobodan, R.S. (2010): MHD flow and heat transfer of two immiscible fluids between moving plates. *Transaction of the Canadian society for mechanical engineering* 34 (3-4), 351-372.

Ugwu U.C., Cole A.T. & Olayiwola R.O. (2021). Analysis of magnetohydrodynamics effects on convective flow of dusty viscous fluid. *Science World Journal Vol*. 16(2), 85-9

Vellanki, N., Rao, Y.S., Reddy, G.R. & Babu, V.S.H. (2021): Radiation effect on unsteady free convection oscillatory couette flow through a porous medium with periodic wall temperature and heat generation. *Journal of Mathematical Control Science and Applications 7(2),* 269-283

Zubi, M.A. (2018): MHD heat and mass transfer of an oscillatory flow over a vertical permeable plate in a porous medium with chemical reaction. *Modern Mechanical Engineering 8 (3),* 179-191