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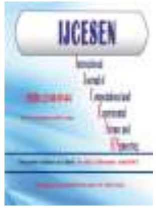

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**Research Article**

# Unsteady MHD Free Convection Flow in a Porous Channel with Radiative Heat and Mass Transfer Effects

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**Abstract:**

The present investigation explores the unsteady magnetohydrodynamic (MHD) free convective oscillating flow of an optically thin incompressible viscous fluid embedded in two parallel porous walls under the influence of an externally applied transverse magnetic field with a chemical reaction. The radiative heat flux and heat absorption effects are considered. The governing equations are solved for the velocity, temperature, and concentration distributions making by making use of the Laplace transformation methodology. The impacts of a combined of relevant flow parameters on concentration, temperature, and velocity distribution are discussed with pertinent non-dimensional parameters. The analytical solutions for the governing equations are found by utilization of Laplace transformation methodology. The velocity, temperature and concentration profiles are analyzed. The expression for the velocity, the concentration, the shear stress and the rate of heat and mass transfer are derived and are analysed for different variations of the governing parameters.

## 1. Introduction

Magnetohydrodynamic (MHD) is a subdivision of fluid dynamics, and this studied the association of the electrically conducting fluids in the magnetic field. Many investigative efforts in the MHD have been proceeding extensively for the duration of the preceding little decades after the established work of Hartmann [1] in fluid metalized ducts flow under external magnetic field. There are most applications for the parabolic movement, for instance solar cookers, solar concentrators and parabolic through stellar collectors. The parabolic concentrator model solar cookers have a wide range of applications, for example baking, roast as well as distillations. Solar concentrator model had those applications into growing rates of evaporations in dissipate stream, in food dispensations, for producing consumption of water from salt water as well as seawater. Murthy et al. [2] discussed by the evaluations of thermal performances of temperature exchangers units for parabolic.

Recently, the authors [3] explored the diffusion-thermos effect, radiating-absorptions, Hall as well as ion slip impacts on the MHD liberated convection gyratory flows of the nanofluids past the semi-infinite permeable inspiring plate with unchanging temperature sources. The impacts of radiating as well as Hall currents on the unsteady MHD liberated central heating flows into the perpendicular channel/duct packed by the absorbent media has been explored by Krishna et al [4]. The temperature generating/absorption as well as thermo-diffusions on the unsteady complimentary convection MHD flows of radiation as well as the chemical reactive second grade liquid past an unbounded perpendicular plate during the absorbent media as well as considering the Hall current into accounts had been considered in [5].

The investigation of heat and mass transport problems with chemical reaction is of immense sensible importance to engineers and scientists since of those approximately worldwide incidence in numerous regions of science along with engineering streams. A small number of delegates of fields of interest in mixed heat and mass transportation with chemically reacting play an important role in the chemical processing industry, they are, food dispensation as well as polymer productions. Many researchers, like Mahapatra et al. [6] explored the impacts of chemical reacting on free convective flows during an absorbent medium delimited past an infinite perpendicular surface. The authors of [7] discussed the impacts of chemical reacting on a moving isothermal vertical surface with effect of suction. The authors in [8] explore the cooling of the electronic system, chemical catalytic reactor, ceramic processes, grains storage device fibers as well as granular insulations, petrol reservoirs, coal combustor, ground water pollution in addition to filtrations process. The partial differential equations recurrently appear in a lot of areas of natural and physical discipline. They described dissimilar physical organisms, ranges from gravitational to fluid dynamics and had been utilized to solve the problem by the physical and chemical sciences, mathematical biosciences, solid mechanical engineering knowledge, etc. Soundalgekar and Takhar [9] initially, deliberated the consequence of radiation for the natural convective flow of the gases over a semi infinite plate with numerical modeling. Takhar et al. [10] explored the impact of radiation on MHD free convective flow past semi-infinite vertical plate. Currently, Hossain et al. [11] explored influences of the chemical reacting on a transient magnetohydrodynamic free convective flow past a moving perpendicular porous plate. Convective heat transportation in a permeable medium has been a subject of immense interest for the preceding small number of decades. heat flux, and heat absorption has not been discussed yet. Therefore, the present problem inspects the problem of the unsteady MHD free convective oscillating flow of an optically thin incompressible viscous fluid embedded in two parallel porous walls under the influence of an external applied transverse magnetic field with chemical reaction, radiative heat flux, and heat absorption." Keeping the above-mentioned facts, the unsteady MHD free convective oscillating flow of an optically thin incompressible viscous fluid embedded in two parallel porous walls under the influence of an external applied transverse magnetic field with chemical reaction, radiative heat flux, and heat absorption."

## 2. Formation of Problem

We consider the effect of chemical reaction on the unsteady motion of viscous, fluid through a porous medium in a vertical channel bounded by wavy walls. The thermal buoyancy in the flow field is created by an oscillatory flux in the fluid region. The walls are maintained at constant temperature and concentration. The Bossiness approximation is used so that the density variation will be considered only in the buoyancy force. The viscous and Darcy dissipations are neglected in comparison with heat by conduction and convection in the energy equation. Also, the Kinematic viscosity ν,the thermal conducting k are treated as constants. We choose a rectangular Cartesian system 0 (x,y) with x-axis in the vertical direction and y-axis normal to the walls. The walls of the channel are at $q(1+k\,e^{i\omega t}) = \frac{1}{L}\int_{-L\,f}^{L\,f} u\,dy$.

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

$$q(1+k\,e^{i\omega t}) = \frac{1}{L}\int_{-L\,f}^{L\,f} u\,dy \quad . \tag{1}$$

The boundary conditions for the velocity and temperature fields are

$$u = 0\ ,\ v = 0\ ,T=T_1\ ,C=C_1 \qquad \text{on} \qquad y = -Lf\left(\frac{\delta x}{L}\right)$$

$$u=0,\ v=0, T=T_2 \qquad C=C_2 \qquad \text{on} \qquad y = +Lf\left(\frac{\delta x}{L}\right) \tag{2}$$

In view of the continuity equation we define the stream function ψ as

$$u = -\psi_y,\ v = \psi_x \tag{3}$$

The equations governing the flow, heat and mass transfer in terms of the Stokes steam function ψ are

$$[(\nabla^2\psi)_t + \psi_x(\nabla^2\psi)_y - \psi_y(\nabla^2\psi)_x] = \nu\nabla^4\psi - \beta g(T-T_0)_y - \beta^* g(C-C_0)_y - (\frac{\mu}{k})\nabla^2\psi \tag{4}$$

$$\rho_e C_p(\frac{\partial T}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial T}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial T}{\partial y}) = k_f\nabla^2 T - Q(T-T_o) + Q_1'(C-C_e) \tag{5}$$

$$(\frac{\partial C}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}) = D_1\nabla^2 C - k_1(C-C_o) \tag{6}$$

Introducing the non-dimensional variables in (4 )-(6) as

$$x' = x/L, \quad y' = y/L, t' = t\omega, \Psi' = \Psi/\nu, \quad \theta = \frac{T-T_2}{T_1-T_2}, C' = \frac{C-C_2}{C_1-c_2} \tag{7}$$

the governing equations in the non-dimensional form (after dropping the dashes) are

$$R(\gamma^2(\nabla^2\psi)_t + \frac{\partial(\psi,\nabla^2\psi)}{\partial(x,y)}) = \nabla^4\psi + (\frac{G}{R})(\theta_y + NC_y) - D^{-1}\nabla^2\psi \tag{8}$$

$$P(\gamma^2\frac{\partial\theta}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}) = \nabla^2\theta - \alpha\theta + Q_1 C \tag{9}$$

$$Sc(\gamma^2\frac{\partial C}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial C}{\partial y}) = \nabla^2 C - KC \tag{10}$$

Reynolds number, $R = \frac{UL}{\nu}$

Grashof number, $G = \frac{\beta g\Delta T_e L^3}{\nu^2}$

Prandtl number, $\mathrm{P} = \frac{\mu c_p}{k_f}$

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

Heat source parameter $\alpha = \frac{QL^2}{k_f C_p}$

Chemical reaction parameter, $\gamma_1 = \frac{K_1 L^2}{D_1}$

Wormsely Number $\gamma^2 = \frac{\omega L^2}{\nu}$

Darcy parameter $D^{-1} = \frac{L^2}{k}$

Radiation absorption parameter, the corresponding conditions are given bellow.

$$Q_1 = \frac{Q_1'(C_1-C_2)L^2}{k_f(T_1-T_2)}$$

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

$$\frac{\partial\psi}{\partial x} = 0, \quad \frac{\partial\psi}{\partial y} = 0 \quad at\,\eta = \pm 1 \tag{11}$$

$$\theta(x,y) = 1, C = 1 \quad on \quad \eta = -1$$

$$\theta(x,y) = 0, C = 0 \quad on \quad \eta = 1$$

$$\frac{\partial\theta}{\partial y} = 0, \frac{\partial C}{\partial y} = 0 \quad at \quad \eta = 0 \tag{12}$$

The value of ψ on the boundary assumes the constant volumetric flow consistently with the hypothesis (1). Also, the wall temperature varies in the axial direction in accordance with the prescribed arbitrary function t.

## 3. Solution of Problem

The main aim of the analysis is to discuss the perturbations created over a combined free and forced convection flow due to traveling thermal wave imposed on the boundaries. The perturbation analysis is carried out by assuming that the aspect ratio $\delta$ to be small.

Introduce the transformation such that

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

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

For small values of δ <<1, the flow develops slowly with axial gradient of order δ.

And hence we take $\frac{\partial}{\partial \bar{x}} \approx O$

Using the above transformation the equations (8 - 10) reduces to (13).

$$\delta R(\gamma^2 (\nabla_1^2 \psi)_t + \frac{\partial(\psi, \nabla_1^2 \psi)}{\partial(x,y)}) = \nabla_1^4 \psi + (\frac{G}{R})(\theta_y + NC_y) - D^{-1}\nabla^2 \psi \quad (13)$$

$$\delta P_1(\gamma^2 \frac{\partial \theta}{\partial t} + \frac{\partial \psi}{\partial y}\frac{\partial \theta}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial \theta}{\partial y}) = (\frac{\partial^2 \theta}{\partial y^2} + \delta^2 N_2 \frac{\partial^2 \theta}{\partial x^2}) - \alpha\theta + Q_1 C \quad (14)$$

$$\delta Sc(\gamma^2 \frac{\partial C}{\partial t} + \frac{\partial \psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial C}{\partial y}) = \nabla_1^2 C - KC \quad (15)$$

$$\nabla_1^2 = \delta^2 \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$$

Introducing the transformation $\eta = \frac{y}{f(\bar{x})}$ the equations (13-15) reduce to

$$\delta R f(\gamma^2 (F^2 \psi)_t + \frac{\partial(\psi, F^2 \psi)}{\partial(\bar{x},\eta)}) = F^4 \psi + (\frac{Gf^3}{R})(\theta_\eta + NC_\eta) - (D^{-1} f^2) F^2 \psi$$
(16)

$$\delta P(\gamma^2 \frac{\partial \theta}{\partial t} + f(\frac{\partial \psi}{\partial \eta}\frac{\partial \theta}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial \theta}{\partial \eta}) = F^2\theta - \alpha\theta + Q_1 C \quad (17)$$

$$\delta Sc(\gamma^2 \frac{\partial C}{\partial t} + f(\frac{\partial \psi}{\partial \eta}\frac{\partial C}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial C}{\partial \eta}) = F^2 C - KC$$
(18)

In (18), $F^2 = \delta^2 \frac{\partial^2}{\partial \bar{x}^2} + \frac{\partial^2}{\partial \eta^2}$

We adopt the perturbation scheme and write

$$\begin{aligned} \psi(x,\eta,t) &= \psi_0(x,\eta,t) + ke^{it}\overline{\psi}_0(x,\eta,t) + \delta(\psi_1(x,\eta,t) + ke^{it}.\overline{\psi}_1(x,\eta,t)) + ............. \\ \theta(x,\eta,t) &= \theta_0(x,\eta,t) + ke^{it}\overline{\theta}_0(x,\eta,t) + \delta(\theta_1(x,\eta,t) + ke^{it}.\overline{\theta}_1(x,\eta,t)) + ............. \\ C(x,\eta,t) &= C_0(x,\eta,t) + ke^{it}C\overline{\phi}_0(x,\eta,t) + \delta(C_1(x,\eta,t) + ke^{it}.\overline{C}_1(x,\eta,t)) + ............. \end{aligned} \quad (19)$$

On substituting (19) in (16) - (18) and separating the like powers of δ the equations and respective conditions to the zeroth order are given as follows.

$$\psi_{0,\eta\eta\eta\eta} - (M_1^2 f^2)\psi_{0,\eta\eta y} = -(\frac{Gf^3}{R})(\theta_{0,\eta} + NC_{0,\eta}) \quad (20)$$

$$\theta_{o,\eta\eta} - (\alpha f^2)\theta_0 = -Q_1 C_0 \quad (21)$$

$$C_{o,\eta\eta} - (KScf^2)C_0 = 0 \quad (22)$$

with

$\psi_0(+1) - \Psi_0(-1) = 1$,
$\psi_{0,\eta} = 0$, $\psi_{0,x} = 0$
at $\eta = \pm 1$ (23)

$$\theta_o = 1, \quad C_0 = 1 \quad on \quad \eta = -1$$
$$\theta_o = 0, \quad C_0 = 0 \quad on \quad \eta = 1$$
(24)

$$\overline{\theta}_{0,\mu\eta} - (iP\gamma^2 f^2)\overline{\theta}_0 = -Q_1\overline{C}_0 \quad (25)$$

$$\overline{C}_{0,\eta\eta} - (KSc\gamma^2 f^2)\overline{C}_o = 0 \quad (26)$$

$$\overline{\psi}_{0,\eta\eta\eta\eta} - ((M_1^2 + i\gamma^2) f^2)\overline{\psi}_{0,\eta\eta} = -(\frac{Gf^3}{R})(\overline{\theta}_{0,\eta} + N\overline{C}_{0.\eta})$$
(27)

$$\overline{\theta}_o(\pm 1) = 0 \qquad \overline{C}_o(\pm 1) = 0$$
$$\overline{\psi}_o(+1) - \overline{\psi}_o(-1) = 1 \quad \overline{\psi}_{o,\eta}(\pm 1) = 0, \overline{\psi}_{o,x}(\pm 1) = 0$$
(28)

The first order equations are as follows.

$$\psi_{1,\eta\eta\eta\eta} - (M_1^2 f^2)\psi_{1,\eta\eta} = -(\frac{Gf^3}{R})(\theta_{1,\eta} + N\,C_{1,\eta}) + (Rf)(\psi_{0,\eta}\,\psi_{0,x\eta\eta} - \psi_{0,x}\,\psi_{0,\eta\eta\eta}) \quad (29)$$

$$\theta_{1,\eta\eta} - (\alpha\, f^2)\,\theta_1 = (PRf)\,(\psi_{0,x}\theta_{o,\eta} - \psi_{0,\eta}\theta_{ox}) - Q_1 C_1 \quad (30)$$

$$C_{1,\eta\eta y} - (KScf^2)\,C_1 = (Scf)\,(\psi_{0,x}C_{o,\eta} - \psi_{0,\eta}C_{ox}) \quad (31)$$

$$\overline{\psi}_{1,\eta\eta\eta\eta} - ((M_1^2 + i\gamma^2)\,f^2)\overline{\psi}_{1,\eta\eta} = -(\frac{Gf^3}{R})(\overline{\theta}_{1,\eta} + N\,\overline{C}_{1,\eta}) + (Rf)(\overline{\psi}_{0,\eta}\,\psi_{0,x\eta\eta} + \psi_{0,\eta}\,\overline{\psi}_{0,x\eta\eta} - \psi_{0,x}\,\overline{\psi}_{0,\eta\eta\eta} - \overline{\psi}_{0,x}\,\overline{\psi}_{0,\eta\eta\eta}) \quad (32)$$

$$\overline{\theta}_{1,\eta\eta} - ((iP\gamma^2 + \alpha)\,f^2)\,\overline{\theta}_1 = (PRf)\,(\psi_{0,\eta}\overline{\theta}_{o,x} + \overline{\psi}_{0,\eta}\theta_{ox} - \overline{\psi}_{0,x}\theta_{o,\eta} - \psi_{0,x}\overline{\theta}_{o\eta}) - Q_1\overline{C}_1 \quad (33)$$

$$\overline{C}_{1,\eta\eta} - ((K + i\gamma^2)Scf^2)\,\overline{C}_1 = (Scf)\,(\psi_{0,\eta}\overline{C}_{o,x} + \overline{\psi}_{0,\eta}C_{ox} - \overline{\psi}_{0,x}C_{o,\eta} - \psi_{0,x}\overline{C}_{o\eta}) \quad (34)$$

with

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

$\psi_{1,\eta} = 0$ , $\psi_{1,x} = 0$ at $\eta = \pm 1$ (35)

$\theta_1(\pm 1) = 0$ $\quad C_1(\pm 1) = 0$

$\overline{\theta}_1(\pm 1) = 0$ $\quad \overline{C}_1(\pm 1) = 0$

$\overline{\psi}_1(+1) - \overline{\psi}_1(-1) = 1 \quad \overline{\psi}_{1,\eta}(\pm 1) = 0, \overline{\psi}_{1,x}(\pm 1) = 0$ (36)

The equations (20)- (22), (25)-(27) & (29)-(34) are solved analytically subject to the relevant boundary conditions. For brevity we are not presenting the solutions.

$$C_{o,\eta\eta} - (KScf^2)C_0 = 0 \quad (22)$$

with

$\psi_0(+1) - \Psi_0(-1) = 1$ ,

$\psi_{0,\eta} = 0$ , $\psi_{0,x} = 0$ at $\eta = \pm 1$ (23)

$\theta_o = 1$ , $C_0 = 1$ *on* $\eta = -1$

$\theta_o = 0$ , $C_0 = 0$ *on* $\eta = 1$ (24)

$$\overline{\theta}_{0,\mu\eta} - (iP\gamma^2 f^2)\overline{\theta}_0 = -Q_1\overline{C}_0 \quad (25)$$

$$\overline{C}_{0,\eta\eta} - (KSc\gamma^2 f^2)\overline{C}_o = 0 \quad (26)$$

$$\overline{\psi}_{0,\eta\eta\eta\eta} - ((M_1^2 + i\gamma^2)\,f^2)\overline{\psi}_{0,\eta\eta} = -(\frac{Gf^3}{R})(\overline{\theta}_{0,\eta} + N\overline{C}_{0.\eta}) \quad (27)$$

$\overline{\theta}_o(\pm 1) = 0 \quad \overline{C}_o(\pm 1) = 0$

$\overline{\psi}_o(+1) - \overline{\psi}_o(-1) = 1 \quad \overline{\psi}_{o,\eta}(\pm 1) = 0, \overline{\psi}_{o,x}(\pm 1) = 0$ (28)

The first order equations are given below.

$$\psi_{1,\eta\eta\eta\eta} - (M_1^2 f^2)\psi_{1,\eta\eta} = -(\frac{Gf^3}{R})(\theta_{1,\eta} + N\,C_{1,\eta}) + (Rf)(\psi_{0,\eta}\,\psi_{0,x\eta\eta} - \psi_{0,x}\,\psi_{0,\eta\eta\eta}) \quad (29)$$

$$\theta_{1,\eta\eta} - (\alpha\, f^2)\,\theta_1 = (PRf)\,(\psi_{0,x}\theta_{o,\eta} - \psi_{0,\eta}\theta_{ox}) - Q_1 C_1 \quad (30)$$

$$C_{1,\eta\eta y} - (KScf^2)\,C_1 = (Scf)\,(\psi_{0,x}C_{o,\eta} - \psi_{0,\eta}C_{ox}) \quad (31)$$

$$\overline{\psi}_{1,\eta\eta\eta\eta} - ((M_1^2 + i\gamma^2)\,f^2)\overline{\psi}_{1,\eta\eta} = -(\frac{Gf^3}{R})(\overline{\theta}_{1,\eta} + N\,\overline{C}_{1,\eta}) + (Rf)(\overline{\psi}_{0,\eta}\,\psi_{0,x\eta\eta} + \psi_{0,\eta}\,\overline{\psi}_{0,x\eta\eta} - \psi_{0,x}\,\overline{\psi}_{0,\eta\eta\eta} - \overline{\psi}_{0,x}\,\overline{\psi}_{0,\eta\eta\eta}) \quad (32)$$

$$\overline{\theta}_{1,\eta\eta} - ((iP\gamma^2 + \alpha)\,f^2)\,\overline{\theta}_1 = (PRf)\,(\psi_{0,\eta}\overline{\theta}_{o,x} + \overline{\psi}_{0,\eta}\theta_{ox} - \overline{\psi}_{0,x}\theta_{o,\eta} - \psi_{0,x}\overline{\theta}_{o\eta}) - Q_1\overline{C}_1 \quad (33)$$

$$\overline{C}_{1,\eta\eta} - ((K + i\gamma^2)Scf^2)\,\overline{C}_1 = (Scf)\,(\psi_{0,\eta}\overline{C}_{o,x} + \overline{\psi}_{0,\eta}C_{ox} - \overline{\psi}_{0,x}C_{o,\eta} - \psi_{0,x}\overline{C}_{o\eta}) \quad (34)$$

with

$\psi_{1(+1)} - \psi_{1(-1)} = 0$

$\psi_{1,\eta} = 0$ , $\psi_{1,x} = 0$ at $\eta = \pm 1$ (35)

$\theta_1(\pm 1) = 0$ $C_1(\pm 1) = 0$

$\overline{\theta}_1(\pm 1) = 0$ $\overline{C}_1(\pm 1) = 0$

## 4. Nusselt number and Sherwood number

$$(\tau)_{y=-1} = d_6 + Ecd_7 + \delta d_8 + O(\delta^2)$$

The local rate of heat transfer coefficient Nusselt number (Nu) on the walls has been calculated using the formula.

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

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

and the corresponding expressions are

$$(Nu)_{\eta=+1} = \frac{(d_9 + \delta d_{11})}{(\theta_m - Sin(x+\gamma t))},$$

$$(Nu)_{\eta=-1} = \frac{(d_8 + \delta d_{10})}{(\theta_m - 1)}$$

where $\theta_m = d_{14} + \delta d_{15}$

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

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

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

and the corresponding expressions are

$$(Sh)_{\eta=+1} = \frac{(d_4 + \delta d_6)}{(C_m)}$$

$$(Sh)_{\eta=-1} = \frac{(d_5 + \delta d_7)}{(C_m - 1)}$$

## 5. Results and Discussions

The effects of thermo-diffusion and heat generation on the unstable free convection MHD gy- rating flow of radiation and chemical reactive second order fluid through an unbounded perpendicular

$$\overline{\psi}_1(+1) - \overline{\psi}_1(-1) = 1 \quad \overline{\psi}_{1,\eta}(\pm 1) = 0, \overline{\psi}_{1,x}(\pm 1) = 0 \qquad (36)$$

The equations (20)- (22), (25)-(27) and (29)-(34) are solved analytically subject to the relevant boundary conditions. For brevity we are not presenting the solutions.

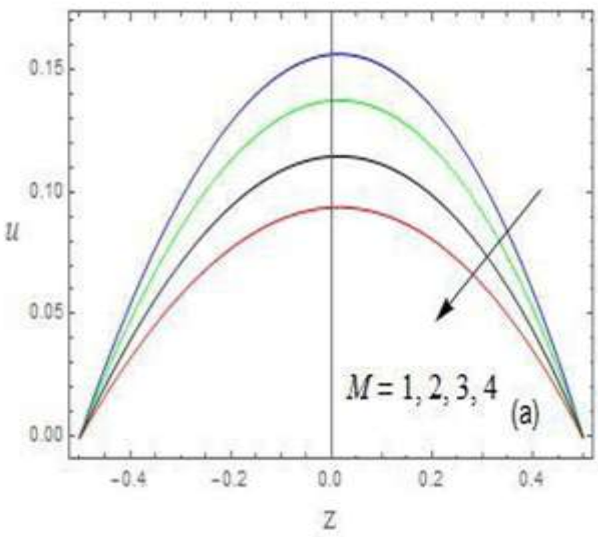
plate during absorbent medium have been explored in the current inquiry. The Laplace transformation process is used to get analytical solutions for the governing equations.

It is explored tentatively the unsteady MHD free convective oscillating flow of an optically thin incompressible heat absorption. The investigative analytical solutions of the governing equations have been unwavering by making use of the Laplace transformation methodology. The velocity, temperature and concentration are found systematically and then are exhibited diagrammatically.

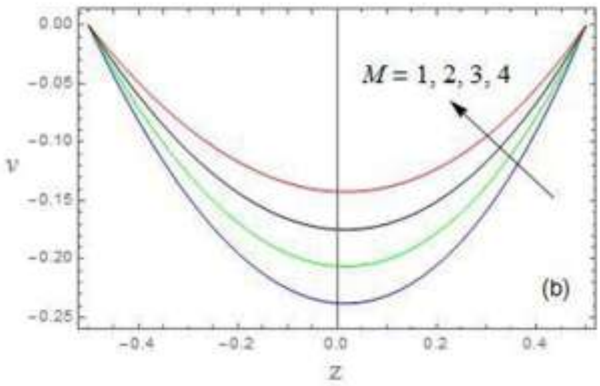
Figures (2–9) represent the profiles of velocity components, temperature, and concentration distributions. The frictional force, Nusselt number and Sherwood number under the influence of an external applied transverse magnetic field with chemical reaction, radiative heat flux and viscous fluid embedded in two parallel porous walls reduces and get to vanishes setting few parameters, M = 2, K = 0.5, λ = 2, Q = 1, Pr = 0.71, Gr = 3, Gm = 5, N = 2, ω = 5, Kc = 1,Sc = 0.22, and t = 0.2, while it is drawn the profiles of every variable speckled to the domain concurrently. For computational intention Figures 1(a-b) displayed the consequences of the magnetic field parameters on the initial velocity component u and secondary component velocity v. In the sense that the u and v are the proximal fractions of the lessening into the plate are of the similar environment in the complete fluid medium. This is since Lorentz strength, it emerged due toward the submissions with the magnetic field immediately ahead of an electrically performing fluid and provide to the resisting nature of forces. Appropriate to the strength of the magnetic domain, the flow of fluid into the impetus boundary layered thickness reached to slow down. It is also found that the resultant velocity and boundary layered thickness are also retarded with increasing Hartmann number.

Figures 2(a-b) depict that, the constituents of the velocity u and v are escalating by amplify in permeability constraint K in entire fluid constituency. It is noticeable that, the largest quantity of K, improves the resulting velocity as and subsequently enlarges the impetus boundary layer thickness. Lower the permeability sources the lesser fluid velocity is scrutinized into the flow domain preoccupied with the fluid. The resultant velocity and momentum boundary layer thickness are also boosted with a growing into the permeability parameter.

Figures 3(a-b)–4(a-b) portrayed the effects of heat and concentration buoyancy strengths on the most important and fluid secondary velocity constituent in the flow region. This is alleged that, mutually the velocity modules u along with v augmented on a mounting in thermal Grashofs number Gr and in mass Grashofs number Gm. Thermal Grashofs number embodies the relative strengths of thermal buoyancy force to viscous force and, mass Grashofs number symbolizes the virtual strength of concentration buoyancy strength to viscous forces. Therefore, thermal Grashofs quantity Gr and mass Grashofs quantity Gm enhance on an increasing in the thermal and the concentration buoyancy strengths respectively. Therefore, natural convective flows are influencing owing to the heat and to concentration buoyancy strengths, therefore, heat and concentrations buoyancy strengths tendency to pace up the primary and secondary fluid velocity constituents with the boundary layered thicknesses It is shown from Figs. 5(a-b) that, the most significant velocity component u retards on growing in suction parameter λ while the secondary velocity component v
enhances on rising in suction parameter λ all the way through the fluid medium. The resulting velocity over and above momentum boundary layered thicknesses also decreases with increasing suction parameters.

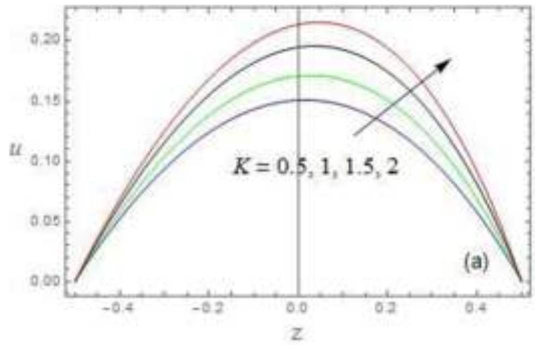



*(a)*

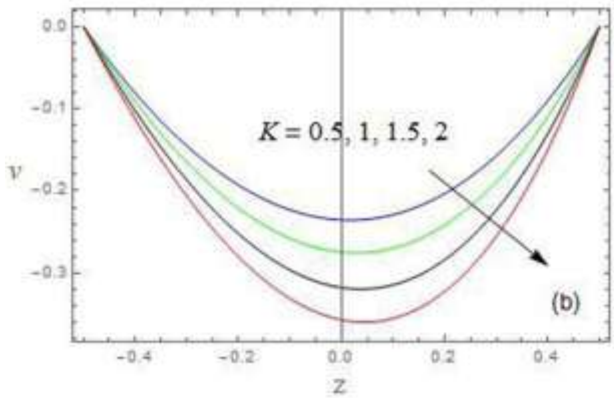



***(b)***

***Figure 1 (a-b).*** *The velocity profiles against M.*

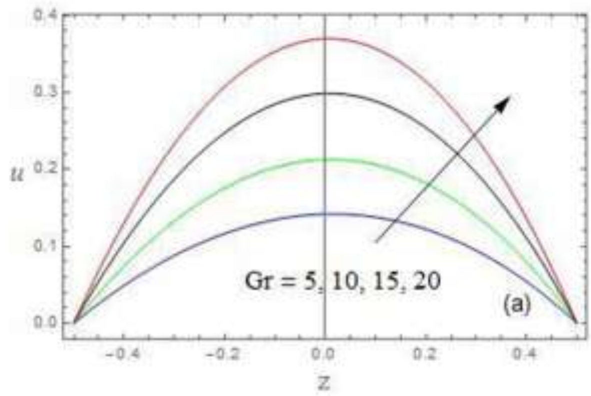



***(a)***

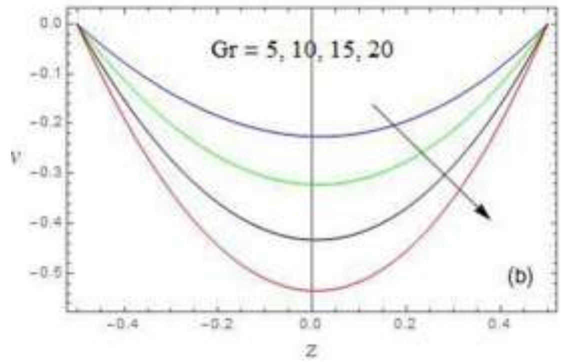



***(b)***

***Figure 2. (a-b).*** The velocity profiles against *K*.

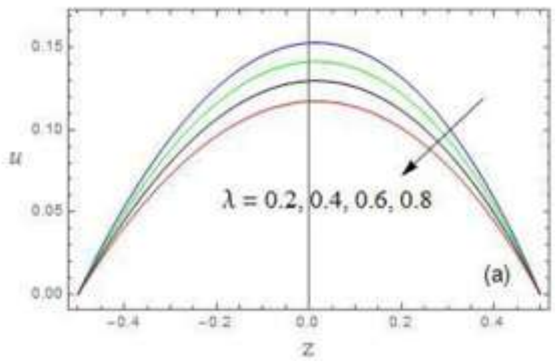



***(a)***

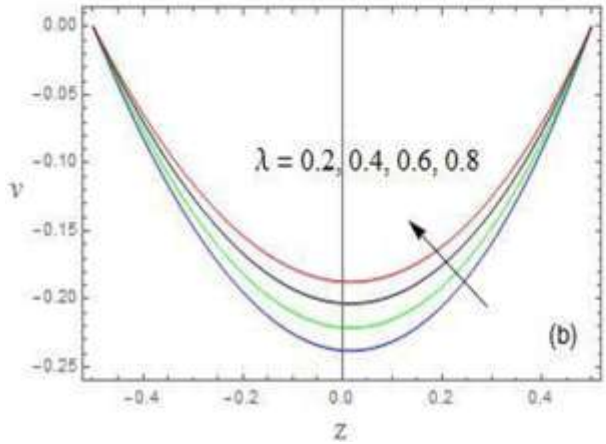



*(b)*

***Figure 3. (a-b).*** The velocity profiles against Gr.

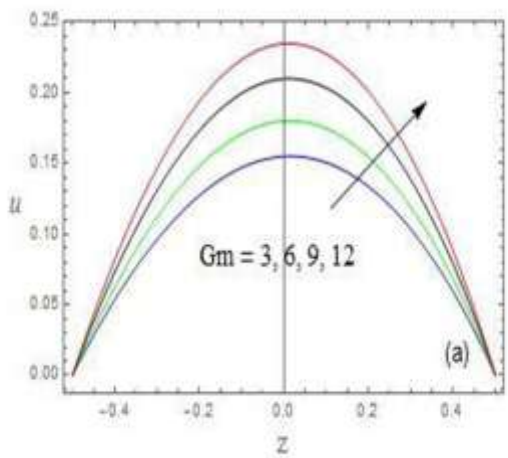



*(a)*

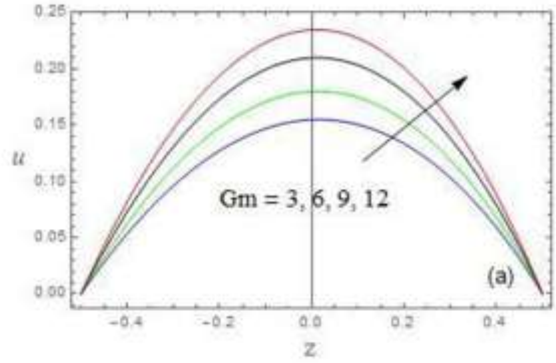



*(b)*

***Figure 4. (a-b).*** The Velocity profiles against λ.




*(a)*




*(b)*

***Figure 5. (a-b).*** The velocity profiles against $G_m$

Table 1 is describing the enormity of skin friction with respect to the governing parameters. An improvement of Hartmann number move forwarded to increase into the Skin friction. Because of the Lorentz forces on viscous fluid increases the friction drag. Similar feature is found with an augmentation in suction parameter as well as heat absorption parameter. Also, an increment in permeability parameter K move downward to tolerate and lesser the skin friction near the boundary of the plate, while the similar characters are found and indistinguishable when an increment in thermal Grashofs number as well as mass Grashofs number at the boundary of the plate.

***Table 1.*** *Shear stresses.*

| M | | r | Gm | λ | Q | $T_L$ | $T_U$ |
|---|---|---|---|---|---|---|---|
| 1 | | | 3 | 0.2 | 1 | 0.810547974 | 0.9897749 |
| 2 | | | | | | 0.9119882 | 1.0938742 |
| 3 | | | | | | 1.010598749 | 1.6338578 |
| | .5 | | | | | 0.775112548 | 0.8938497 |
| | | | | | | 0.7535548 | 0.7897789 |
| | | 0 | | | | 0.76996659 | 0.7938555 |
| | | 5 | | | | 0.227001452 | 0.5938795 |
| | | | 6 | | | 0.782855497 | 0.9048855 |
| | | | 9 | | | 0.74826658 | 0.8245745 |
| | | | | 0.4 | | 0.873850013 | 1.0371456 |
| | | | | 0.6 | | 0.927251001 | 1.1450218 |
| | | | | | 2 | 1.091585997 | 1.0828555 |
| | | | | | 3 | 1.350468523 | 1.4878897 |

## 6. Conclusion

This study analytically examined the unsteady MHD free convective oscillatory flow of a radiative and chemically reactive second-order fluid in a porous channel under the influence of an externally applied transverse magnetic field. The governing equations were solved using the Laplace transformation method, and the effects of various parameters on velocity, temperature, and concentration distributions were analyzed.

Key findings include:

- The presence of a magnetic field introduces a resistive Lorentz force, reducing the fluid velocity and momentum boundary layer thickness as the Hartmann number increases.
- Higher permeability enhances the velocity components and momentum boundary layer thickness, whereas lower permeability restricts fluid motion.
- Thermal and concentration buoyancy forces accelerate fluid motion, increasing both velocity components and expanding the boundary layers.

These findings provide insights into applications in industrial heat transfer, energy systems, and fluid transport in porous environments. Further research can extend this work by considering non-linear effects and numerical approaches for broader parameter variations [12-16].

## Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

## References

[1]. Hartmann, J. (1937). Hg-dynamics I: Theory of the laminar flow of an electrically conductive liquid in a homogeneous magnetic field. *Det Kongelige Danske Videnskabernes Selskab Mathematisk-fysiske Meddelser*, *15*, 1–27.

[2]. Murty, V. V. S., Gupta, A., Mandloi, N., & Shukla, A. (2007). Evaluation of thermal performance of heat exchanger unit for parabolic solar cooker for off-place cooking. *Indian Journal of Pure and Applied Physics, 45*, 745–748.

[3]. Krishna, M. V., & Chamkha, A. J. (2019). Hall and ion slip effects on MHD rotating boundary layer flow of nanofluid past an infinite vertical plate embedded in a porous medium. *Results in Physics, 15*, 102652. https://doi.org/10.1016/j.rinp.2019.102652

[4]. Krishna, M. V., Reddy, G. S., & Chamkha, A. J. (2018). Hall effects on unsteady MHD oscillatory free convective flow of second grade fluid through porous medium between two vertical plates. *Physics of Fluids*, *30*, 023106. https://doi.org/10.1063/1.5010863

[5]. Krishna, M. V., & Chamkha, M. V. (2018). Hall effects on unsteady MHD flow of second grade fluid through porous medium with ramped wall temperature and ramped surface concentration. *Physics of Fluids*, *30*, 053101. https://doi.org/10.1063/1.5025542

[6]. Mahapatra, N., Dash, G. C., Panda, S., & others. (2010). Effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface. *Journal of Engineering Physics and Thermophysics, 83*, 130–140.

[7]. Muthucumaraswamy, R. (2002). Effects of a chemical reaction on a moving isothermal vertical surface with suction. *Acta Mechanica*, *155*, 65–70.

[8]. Al-Odat, M. Q., & Al-Azab, T. A. (2007). Influence of chemical reaction on a transient MHD free convection flow over a moving vertical plate. *The Journal of Engineering Research*, *12*, 15–21.

[9]. Soundalgekar, V. M., & Takhar, H. S. (1992). Radiative convective flow past a semi-infinite vertical plate. *Modelling, Measurement, and Control*, *51*, 31–40.

[10]. Takhar, H. S., Gorla, S. R., & Soundalgekar, V. M. (1996). Radiation effects on MHD free convection flow of a gas past a semi-infinite vertical plate. *International Journal of Numerical Methods for Heat & Fluid Flow*, *6*, 77–83.

[11]. Hossain, A. M., Alim, M. A., & Rees, D. A. S. (1999). The effect of radiation on free convection from a porous vertical plate. *International Journal of Heat and Mass Transfer*, *42*, 181–191

[12]. Namala, K. K., & Krishna, V. B. M. (2021). A Short Review and Investigate Study on Performance of Magneto-Hydrodynamic Using High Reynolds Numbers. *Latest Trends in Renewable Energy Technologies: Select Proceedings of NCRESE 2020*, 377-386, https://doi.org/10.1007/978-981-16-1186-5_31

[13]. G. V. Mrudul, Rohit. G, Harshavardhan. G, Dhanush. K, & Anudeep. B. (2024). Efficient Energy Management: Practical Tips for Household Electricity Conservation. *Journal of Modern Technology*, *1*(1), 1~8,

[14]. Rao, P. V. L. N., V. Lavanya, D. Manasa, Boggavarapu, S., & Soni, B. P. (2024). Battery Models and Estimation Techniques for Energy

Storage Systems in Residential Buildings. *Journal of Modern Technology*, *1*(1),

[15]. K. Neelashetty, Sonali Goel, Farooqhusain Inamdar, Yeswanth Dintakurthy, L. N. Sastry Varanasi, & V. B. Murali Krishna. (2025). Optimal Energy Management in Microgrids: A Demand Response Approach with Monte Carlo Scenario Synthesis and K-Means Clustering. *International Journal of Computational and Experimental Science and Engineering*, *11*(1). https://doi.org/10.22399/ijcesen.1023

[16]. K. Neelashetty, V. Praveena Kumara, P.V. V. Raghava Sharma, Pramod, & V. B. Murali Krishna. (2025). Two-Stage Stochastic Optimization for Cost-Effective Energy Management in Grid-tied Microgrids. *International Journal of Computational and Experimental Science and Engineering*, *11*(1). https://doi.org/10.22399/ijcesen.1022