

Heat And Mass Transfer Analysis on Magnetohydrodynamics (Mhd) Unsteady Free Convection Flow in the Presence Of Viscous Dissipation in A Vertical Channel

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Received on: August, 2025

Revised and Accepted on: September, 2025

Published on: October, 2025

ABSTRACT

This study investigates the effectiveness of treating biogas with 20% calcium hydroxide solution to improve its This research numerically investigated the impact of heat and mass transfer analysis in an unsteady free convection flow with viscous dissipation in a vertical channel affected by constant suction/injection factors. The nonlinear partial differential equation regulating flow formation is solved with the implicit finite difference method. Several physical parameters were studied, including skin friction, Nusselt number, thermal Grashof number, solutal Grashof number, magnetic field, and porous parameters, which lead to an increase in fluid velocity. However, in the case of viscous dissipation, the parameter increases the fluid velocity as it increases, and also significantly improves the energy of the temperature profile with its increase. In all the conditions described, thermal management may be accomplished by understanding the influence of each flow parameter and adjusting it accordingly.

Keywords: Heat and Mass Transfer, Viscous Dissipation, MHD, Unsteady Convection Flow, Variable thermal conductivity.

1.0 INTRODUCTION

Magneto-hydrodynamics (MHD) is the study of electrically conducting liquids, namely, salty water, electrolytes, plasma, and liquid metals. This kind of fluid has a variety of scientific and technological significance, namely, in the production of crystals, reactor cooling, magnetic drug targeting, and MHD sensors. The empirical analysis of contemporary MHD flow in a laboratory was first done by Hartmann and Lazarus (1937). This investigation established the basic ideas for the creation of several MHD equipment, such as MHD pumps, MHD generators, brakes, flow meters, and so on. Buoyancy-induced flow along a magnetized oscillating system with heat transfer across different geometrical settings has been a topic of growing interest among many researchers today, owing to its vast applications in geophysics, solid mechanics, hydrology, oil recovery, and in the field of engineering, to cite a few (Chitra and Suhasini, 2018). To this end, Omokhuale *et al.* (2024) performed the analysis of viscous dissipation on a thermally and chemically controlled nanofluid through a boundary layer region in an oscillating system, while Usman *et al.* (2024) examined the impact of thermophoresis on a magnetized oscillatory system of a buoyancy-induced flow with nanoparticles along a boundary layer regime. The function of magnetized natural convective slip flow of a chemically reacting fluid affected by convective heating was reported by Hamza *et al.* (2021). Taid and Ahmed (2022) deliberated on the

actions of thermal diffusion, viscous dissipation, and chemical reaction on steady two-dimensional MHD natural flow across an inclined porous plate coated with porous media using the perturbation series scheme. Using the Laplace transformation procedure, Osman *et al.* (2022) described the impact of buoyancy-induced magnetized flow across an infinite inclined plate. A thorough response to the MHD impact on a heat transfer evaluation of electroosmotic flow in a rotating microfluidic channel was described by Siva *et al.* (2021). Amar *et al.* (2023) looked at the effects of thermal radiation and viscous dissipation on the MHD heat transfer flow of Casson fluid along a shifting wedge with a convective boundary condition when internal heat production and intake are present. Sharma *et al.* (2022) discussed the numerical study of MHD oscillatory flow of viscous dissipative fluid along an upstanding channel entrenched with porous medium due to heat source and thermal radiation impacts. Falade *et al.* (2017) deliberated on suction/injection effects in a magnetized oscillatory slip flow along a vertical plate with unequal wall temperature confined to an applied magnetic field. Hamza *et al.* (2011) considered the influence of chemical reaction and slip condition on a transient MHD heat and mass transfer flow via a vertical plate filled with porous medium in an oscillating system.

Viscous dissipation is the process by which a fluid's work on adjacent layers is converted to heat due to shear forces.

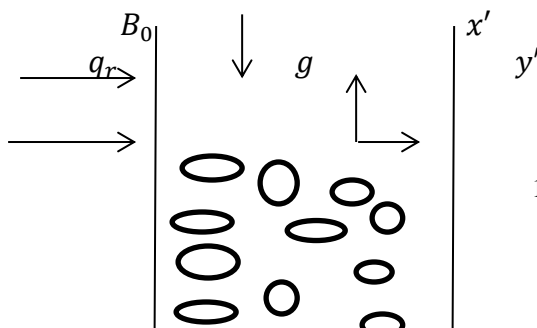
It's also the irreversible process by means of which the work done by a fluid on adjacent layers due to the action of shear forces is transformed into heat. It was also defined as the aspect of fluid dynamics: the drag due to viscosity (the tendency of moving fluid to drag along adjacent fluid), a force which slows down (dissipates) fluid flows, producing heat, converting kinetic energy to heat energy. Viscous dissipation is generally talked about in high-speed turbulent flows, especially in cases where heat transfer is extremely important. Kar *et al.* (2019) studied the effect of viscous dissipation and chemical reaction on the MHD flow of a viscous incompressible fluid past a semi-infinite vertical plate. Alok and Manoj (2016) studied the effects of viscous dissipation and suction/injection on MHD flow of a nanofluid past a wedge with convective surface in the appearance of slip flow and porous medium. Kameswaran *et al.* (2012) investigated the convective heat and mass transferring fluid flow over a stretching sheet when subjected to hydro magnetic, viscous dissipation, chemical reaction, and Soret effects. Hassan *et al.* (2022) insight into the Significance of Viscous dissipation and heat generation/absorption in magneto-hydrodynamic radiative Casson fluid flow with first-order chemical reaction. Rajashekar and Shankar (2016) investigated the effects of chemical reaction on unsteady MHD heat and mass transfer flow past a semi-infinite vertical porous moving plate under the influence of a uniform transfer magnetic field in the presence of viscous dissipation with the temperature gradient. Also, Dero *et al.* (2022) investigated the thermal stability of hybrid nanofluid with viscous dissipation and suction/injection applications: Dual branch framework. Jaber (2014) studied the effects of viscous dissipation and Joule heating on MHD flow of a fluid with variable properties past A stretching vertical plate. Mehdi and Kourosh (2021) studied viscous dissipation effects in the free convection of a non-Newtonian fluid with heat generation or absorption effect on the vertical wavy surface. Moraa *et al.* (2023) investigated the effects of viscous dissipation on the temperature distribution of blood plasma in the presence of a magnetic field. Khalid *et al.* (2022) studied the impact of viscous dissipation and Coriolis effects in heat and mass transfer analysis of the 3D non-Newtonian fluid flow. Aiyashi *et al.* (2023) studied the effect of viscous dissipation and induced magnetic field on an unsteady mixed convective stagnation point flow of a nonhomogeneous nanofluid. Reddy *et al.* (2015) investigated the effects of viscous dissipation and heat source on unsteady MHD flow over a stretching sheet.

Tafida *et al.* (2020) also studied the effects of variable viscosity and viscous dissipation on free convective Couette flow in a vertical channel: The Homotopy perturbation method approach. Fahad *et al.* (2017) investigated the combined effect of viscous dissipation and radiation on unsteady free convective non-Newtonian fluid along a continuously moving vertically stretched surface with no-slip phenomena. Ajibade and Tafida (2019) studied the viscous dissipation effect on a steady generalized Couette flow of heat-generating/absorbing fluid in a vertical channel. However, Muhammad *et al.* (2016) studied the effects of viscous dissipation on MHD boundary layer flow of Seiko fluid over a stretching cylinder. Abiodun *et al.* (2021) investigated an analytical study on the effects of viscous dissipation and suction/injection on a steady MHD natural convection Couette flow of heat-generating/absorbing fluid. Peng *et al.* (2016) investigated the effect of viscosity of the viscous medium on formability of A11060-O sheet in viscous pressure forming (VPF): an experimental study. Kaladhar *et al.* (2016) considered the effect of radiation and thermal diffusion on mixed convection flow of couple stress through a channel. Oni and Jha (2020) put forth a theoretical examination of steady and unsteady mixed convective flow formation towards a vertical micro-channel, taking into account the influence of wall zeta potentials in the existence of an electric body force.

2.0 FORMULATION OF THE PROBLEM

The following assumptions have been made,

1. Consider the unsteady free convection flow of viscous incompressible fluid past a vertical channel with viscous dissipation.
2. A magnetic field B_0 of uniform strength is applied transversely to the direction of the flow.
3. The x -axis is taken along the plate in the vertically upward direction
4. The y -axis is normal to the plate in the direction of the applied magnetic field.
5. The viscous dissipation in the energy equation has been assumed for higher-speed flow.
6. The suction is assumed in all three equations for observing its effects on the flow.
7. The magnetic Reynolds number is assumed to be very small, and hence the induced magnetic field is compared with the applied magnetic field in the absence of any input electric field.
8. Since the plate is infinite and the fluid motion is unsteady, all the flow variables depend only on y and time (t).



$$\begin{array}{ccc}
 T = T'_w & u' & T = T'_0 \\
 C = C'_w & & C = C'_0 \\
 \\
 y' = 0 & & y' = H
 \end{array}$$

Figure 1: Coordinate System for the Physical Model of the Problem

Then, the fully developed flow is governed by the following set of equations:

$$\frac{\partial u'}{\partial t'} + v \frac{\partial u'}{\partial y'} = v \frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma \beta_0^2 u'}{\rho} - \frac{v}{k^*} u' + g \beta (T' - T'_0) + g \beta^* (C' - C'_0) \tag{1}$$

$$\frac{\partial T'}{\partial t'} + v \frac{\partial T'}{\partial y'} = \frac{k_0}{\rho C_p} \frac{\partial}{\partial y'} \left[1 + \alpha (T' - T'_0) \right] \frac{\partial T'}{\partial y'} - \frac{1}{\rho C_p} \frac{\partial q_r}{\partial y'} + \frac{Ec}{\rho c \rho} \left(\frac{\partial u'}{\partial y'} \right)^2 \tag{2}$$

$$\frac{\partial C'}{\partial t'} + v \frac{\partial C'}{\partial y'} = D \frac{\partial^2 C'}{\partial y'^2} - R^* (C' - C'_0) \tag{3}$$

With corresponding boundary conditions,

$$\begin{array}{l}
 t \leq 0, \quad u' = 0, \quad T' = 0, \quad C' = 0 \quad \forall \quad y' \\
 t > 0 \left\{ \begin{array}{l} u' = 0, \quad T' = T'_w, \quad C' = C'_w \quad \text{at } y' = 0 \\ u' = 0, \quad T' = 0, \quad C' = 0 \quad \text{at } y' = H \end{array} \right. \tag{4}
 \end{array}$$

To acquire the solutions of equations (1), (2) and (3) subject to the boundary conditions (4) in non-dimensional form, we introduce the following non-dimensional quantities:

$$\begin{array}{l}
 u = \frac{u'}{u_0}, \quad t = \frac{t' u_0}{H^2}, \quad y = \frac{y'}{H}, \quad \theta = \frac{T' - T'_0}{T'_w - T'_0} \\
 C = \frac{C' - C'_0}{C'_w - C'_0}, \quad \text{Pr} = \frac{u_0 \rho C_p}{k_0}, \quad M = \frac{\sigma \beta_0 H^2}{\rho u_0} \\
 Sc = \frac{u_0}{D}, \quad k = \frac{k u_0}{v H^2}, \quad K_r = \frac{R^* H^2}{u_0} \\
 \lambda = \alpha (T'_w - T'_0), \quad R = \frac{16 a \sigma_0 H T_0'^3}{k u_0^2} \tag{5}
 \end{array}$$

$$Gr = \frac{H^2 g \beta (T'_w - T'_0)}{u_0^2}, \quad Ec = \frac{1}{\rho c \rho} \left(\frac{\partial u'}{\partial y'} \right)^2$$

$$Gc = \frac{H^2 g \beta^* (C'_w - C'_0)}{u_0^2}, \quad V = \frac{v}{u_0}$$

So that the basic governing equations becomes:

$$\frac{\partial u}{\partial t} + V \frac{\partial u}{\partial y} = v \frac{\partial^2 u}{\partial y^2} - Mu - \frac{1}{k^*} u + Gr\theta + GcC \tag{7}$$

$$\text{Pr} \frac{\partial \theta}{\partial t} + \text{Pr} V \frac{\partial \theta}{\partial y} = (1 + \lambda\theta) \frac{\partial^2 \theta}{\partial y^2} + \lambda \left(\frac{\partial \theta}{\partial y} \right)^2 + Ec \left(\frac{\partial u}{\partial y} \right) - R\theta \tag{8}$$

$$\frac{\partial C}{\partial t} + V \frac{\partial C}{\partial y} = \frac{1}{Sc} \frac{\partial^2 C}{\partial y^2} - KrC \tag{9}$$

With corresponding boundary conditions,

$$t \leq 0, u = 0, \theta = C = 0 \quad \text{for all } y$$

$$t > 0, u = 0, \theta = 1, C = 1 \quad \text{at } y = 0$$

$$u = 0, \theta = 0, C = 0 \quad \text{at } y = 1 \tag{10}$$

3.0 NUMERICAL SOLUTION METHOD

To solve the unsteady non-linear coupled partial differential equations (7) - (9) with the initial and boundary conditions (10), an implicit finite difference technique has been engaged. The finite difference equations equivalent to equations (7)-(9) using the method are as follows:

$$\frac{u_i^{j+1} - u_i^j}{\Delta t} + V \left(\frac{u_{i+1}^j - u_i^j}{\Delta y} \right) = \frac{1}{(\Delta y)^2} (u_{i+1}^{j+1} - 2u_i^{j+1} + u_{i-1}^{j+1}) - Mu_i^j - \frac{1}{k} u_i^j + Gr\theta_i^j + GcC_i^j \tag{11}$$

$$\text{Pr} \left(\frac{\theta_i^{j+1} - \theta_i^j}{\Delta t} \right) + \text{Pr} V \left(\frac{\theta_{i+1}^j - \theta_i^j}{\Delta y} \right) = \frac{(1 + \lambda\theta_i^j)}{(\Delta y)^2} (\theta_{i+1}^{j+1} - 2\theta_i^{j+1} + \theta_{i-1}^{j+1}) + \lambda (\theta_{i+1}^j - \theta_i^j)^2 + Ec \left(\frac{u_{i+1}^j - u_i^j}{\Delta y} \right) - R\theta_i^j \tag{12}$$

$$\left(\frac{C_i^{j+1} - C_i^j}{\Delta t} \right) + V \left(\frac{C_{i+1}^j - C_i^j}{\Delta y} \right) = \frac{1}{Sc(\Delta y)^2} (C_{i+1}^{j+1} - 2C_i^{j+1} + C_{i-1}^{j+1}) - KrC_i^j \tag{13}$$

The Solutions of equations (11), (12) and (13) are as follows:

$$-r_1 u_{i-1}^{j+1} + r_3 u_i^{j+1} - r_1 u_{i+1}^{j+1} = r_4 u_i^j - r_2 u_{i+1}^j + r_5 \theta_i^j + r_6 C_i^j \tag{14}$$

$$-r_7 \theta_{i-1}^{j+1} + r_{12} \theta_i^{j+1} - r_7 \theta_{i+1}^{j+1} = r_{11} \theta_i^j - r_8 \theta_{i+1}^j + r_9 \left(\frac{\theta_{i+1}^j - \theta_i^j}{\Delta y} \right)^2 + r_{10} \left(\frac{u_{i+1}^j - u_i^j}{\Delta y} \right)^2 \tag{15}$$

$$-r_1 C_{i+1}^{j+1} + r_{14} C_i^{j+1} - r_1 C_{i-1}^{j+1} = r_{15} C_i^j - r_{13} C_{i+1}^j \tag{16}$$

The initial and boundary conditions may be expressed as:

$$\left. \begin{aligned} u_{i,j} &= 0, & \theta_{i,j} &= 0, & C_{i,j} &= 0 \\ u_{0,j} &= 0, & \theta_{0,j} &= 1, & C_{0,j} &= 1 \\ u_{H,j} &= 0, & \theta_{H,j} &= 0, & C_{H,j} &= 0 \end{aligned} \right\} \tag{17}$$

The skin-friction coefficient, Nusselt number and Sherwood number are the important physical parameters for this type of boundary layer flow, which in non-dimensional form respectively are given by:

$$C_f = \left(\frac{\partial u}{\partial y} \right)_{y=0}, \quad Nu = - \left(\frac{\partial \theta}{\partial y} \right)_{y=0}, \quad Sh = \left(\frac{\partial C}{\partial y} \right)_{y=0} \tag{18}$$

4.0 RESULT AND DISCUSSION

This section, constitute the analysis of the fluid flow. Numerical computations is carried out for various values of the major parameters such as, Viscous Dissipation (Ec), Magnetic field (M), thermal Grashof number (Gr), Solutal Grashof number (Gc), Porous (K), Variable thermal conductivity (λ), Radiation (R), Prandtl number (Pr), Schmidt number (Sc) and Chemical reaction (K_r). Therefore, this study is focused on the effects of these governing parameters on the transient velocity, temperature as well as concentration profiles.

The default values of the thermo physical parameters are specified as follows:

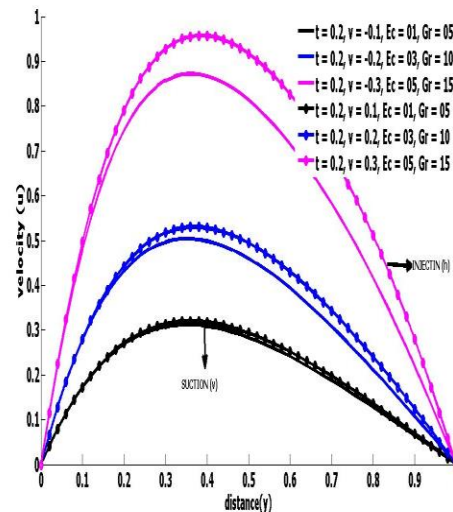
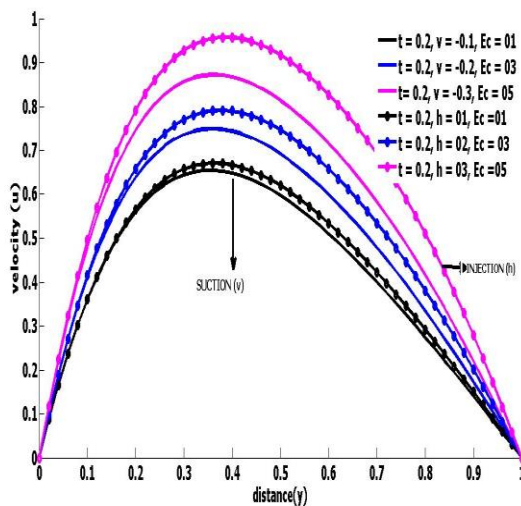
$$Gr = 5, Gc = 5, M = 2, Pr = 0.71, k = 0.5$$

$$R = 5, \lambda = 0.5, Kr = 1, Sc = 0.60$$

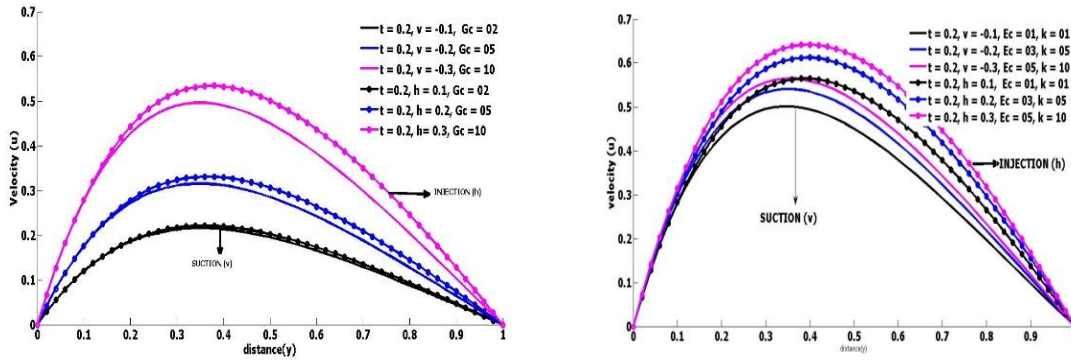
Figures (4.1) and (4.2) demonstrate the influence of viscous dissipation Ec and thermal Grashof number Gr in the case of cooling the plate. It is shown that an increase in Ec and Gr results in an increase in the velocity. It is due to the facts that increase in the values of Ec and Gr has the tendency to increase the thermal and viscous effect. This gives rise to an increase in the fluid flow both in case of suction and injection. In figure (4.3) and (4.4) it is noticed that increase in Gc and k result in an increase in the velocity. It is due to the fact that increase in the values of Gc has tendency to increase mass buoyancy effect this gives rise to an increase in the induced flow. The effect of Magnetic field parameter M in case of cooling the plate on the velocity profile is depicted in Figure (4.5). It is observed that the velocity profile decreases with increasing Magnetic field M parameter

due to suction and increases due to injection. Figures (4.6) and (4.7) illustrate the effect of viscous dissipation Ec and variable thermal conductivity (λ) on the temperature profile. An increase in temperature with increasing in viscous dissipation Ec as well as variable thermal conductivity (λ) is observed from these figures both in terms of suction and injection. The temperature increases which is physically true because thermal conductivity of fluid increases with increasing in Prandtl number which resulting in thermal boundary layer thickness thereby increasing the temperature profiles. Figure (4.8) it is evident from this figure that as R increases considerable reduction is observed in temperature profile. Figures (4.9) and (4.10) represent the behavior of concentration profiles for different values of Chemical reaction Kr and Schmidt number Sc parameters. A decrease in concentration with increasing Kr and Sc is detected from these figures. It is noticed that the concentration boundary layer becomes thin as the Chemical reaction parameter increases as well as the Schmidt number also increases.

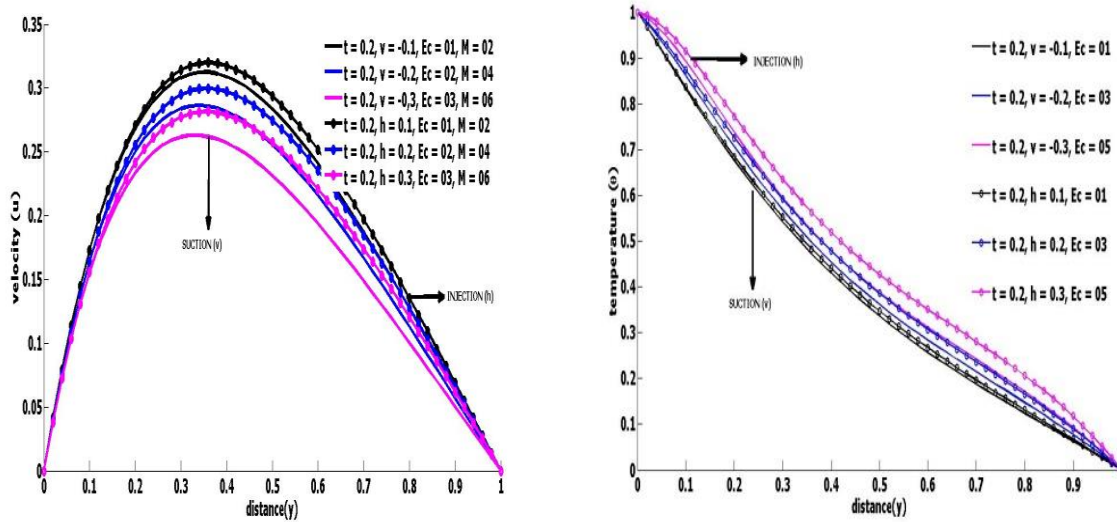
Figures.4.11 (a) and (b) shows the variation of skin friction profiles with respect to porous parameter (k). Thermal grashof number (Gr), Solutal Grashof number (Gc) and Suction/injection (V) parameters. It is observed the skin friction coefficient rises with increase in these parameters. Figs.4.12 (a) and (b) illustrates the graph of Nusselt number. It is observed that Nusselt number decreases with increasing values of Prandtl number (Pr), Variable thermal conductivity (λ) and Suction/injection (V) parameters. Figure 4.13 (a) demonstrates the graph of Sherwood number and noticed that Sherwood number decreases with the increase in Schmidt number (Sc) and Chemical reaction (Kr) parameters.



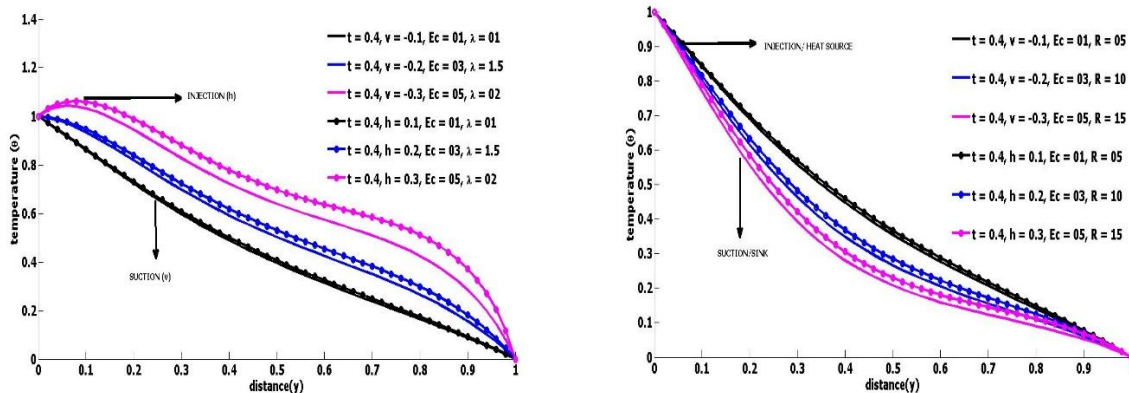
Figures 4.1 & 4.2: Velocity profiles showing the effects of viscous dissipation (Ec) and thermal Grashof number (Gr).



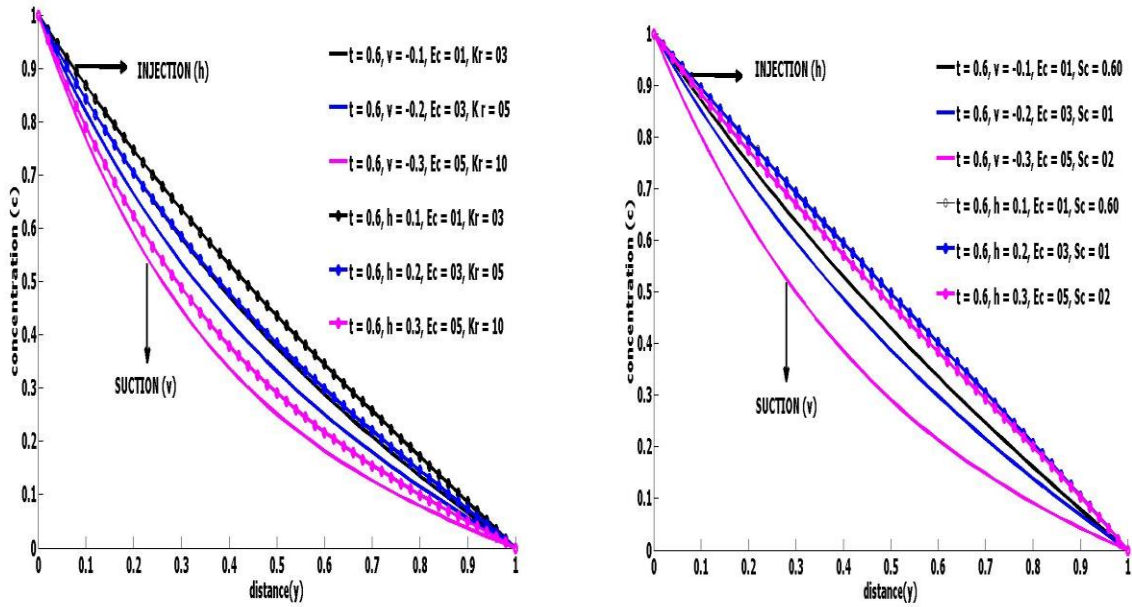
Figures 4.3 & 4.4 Velocity profiles showing the effects of Solutal Grashof number (Gc) and Porous (k).



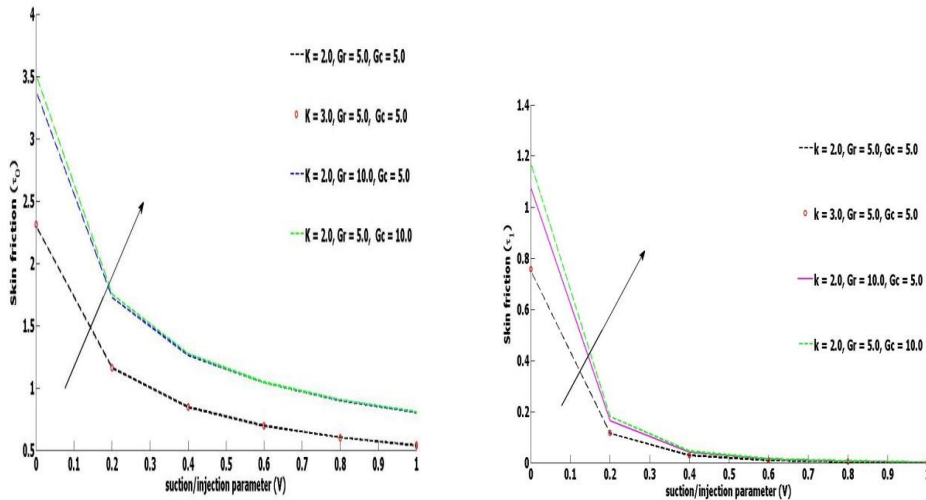
Figures 4.5 & 4.6 Velocity profile showing the effect of Magnetic field parameter (M) and Temperature profile for different values of viscous dissipation (Ec) parameter.



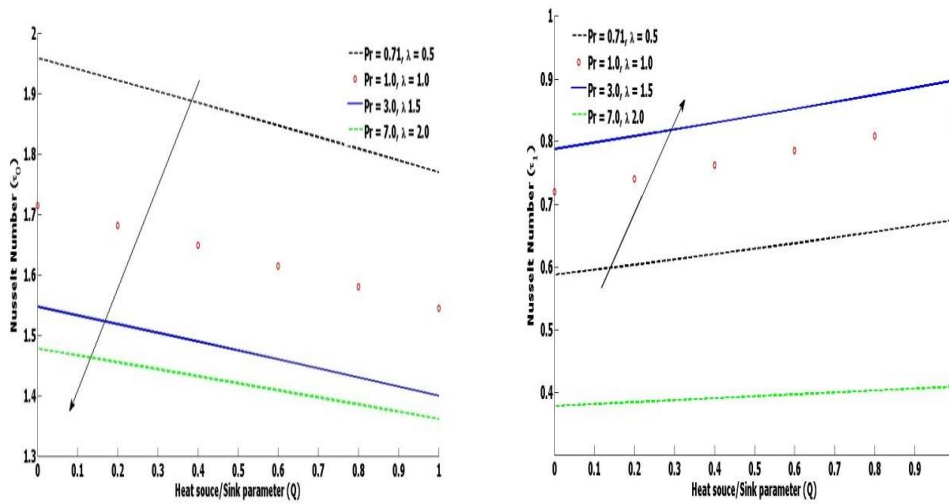
Figures 4.7 & 4.8: Temperature profiles showing the effects of Variable thermal conductivity (λ) and Radiation (R).



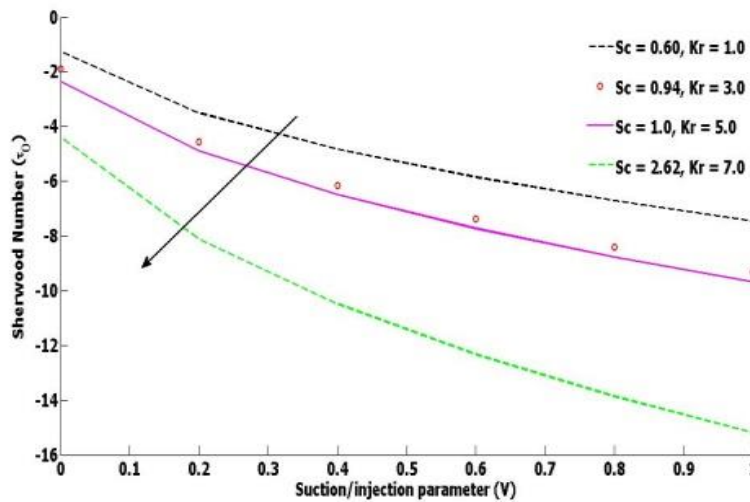
Figures 4.9 & 4.10: Concentration profiles showing the effects of Chemical reaction (Kr) and Schmidt number (Sc).



Figures 4.11: (a) & (b): Effect of suction/injection (V) on skin friction with $k = 2.0$, $Gr = 5.0$, $Gc = 5.0$, $V = 0, 0.2, 0.4, 0.6, 0.8$ & 1 .



Figures 4.12(a) & (b): Effect of Suction/injection (V) on nusselt number with $Pr = 0.71$, $Lmd = 0.5$, $V = 0, 0.2, 0.4, 0.6, 0.8$ & 1 .



Figures 4.13: Effect of suction/injection (V) on Sherwood number with $Sc = 0.60$, $Kr = 1.0$, $V = 0, 0.2, 0.4, 0.6, 0.8$ & 1 .

5.0 CONCLUSION

In view of the above findings, the significance of considering viscous dissipation in designing systems for optimal heat and mass transfer is highlighted, which the anchor model lacked. Future research can be extended by incorporating the impact of the heat source/sink to advance this present work and strengthen it.

6.0 ACKNOWLEDGEMENT

The authors extend their appreciation to Tertiary Education Trust Fund (TETFund) and Federal Polytechnic Kaura Namoda, Nigeria, for funding this research with a grant number TETF/ES/DR&C/CE/POLY/KAURA-NAMODA/IBR/2025/VOL.1. 12th.BATCH.

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NOMENCLATURE

Symbols	Descriptions
B_0	"Magnetic field of constant strength"
C	"Concentration"
C_f	"Skin friction"
C_r	"Chemical reaction parameter"
C_p	"Specific heat at constant pressure"
D	"Mass diffusivity"
g	"Acceleration due to gravity"
G_c	"Solutal Grashof number"
Gr	"Grashof number"
K	"Porous parameter"
M	"Magnetic field parameter"
Nu	"Nusselt number"
Pr	"Prandtl number"
R	"Radiation parameter"
Sc	"Schmidt number"
Sh	"Sherwood number"
Ec	"Viscous dissipation"
T	"Temperature"
u, v	"Velocity in X direction and y -direction respectively"
V	"Suction/injection"



x, y "Cartesian coordinates along the plate and normal to it respectively"

Greek Symbols

Symbol	Description
β^*	"Coefficient of expansion with concentration"
β	"Coefficient of thermal expansion"
ρ	"Density of fluid"
σ_0	"Stefan Boltzmann constant"
λ	"Variable thermal conductivity"
σ	"Electrical conductivity of the fluid"

APPENDIX

$$r_3 = 1 + 2r_1; r_4 = 1 + r_2 - P\Delta t; r_5 = \Delta t Gr \theta_i^j \text{ and } r_6 = \Delta t Gc C_i^j$$

$$\alpha = 1 + \lambda \theta_i^j; r_8 = \frac{\Delta t V Pr}{\Delta y}; r_7 = \frac{\Delta t \alpha}{(\Delta y)^2}; r_9 = \Delta t \lambda; r_{10} = \Delta t Ec;$$

$$r_{12} = Pr + 2r_7; r_{11} = (Pr + r_8 + \Delta t - \Delta t R); r_{13} = \frac{Sc V \Delta t}{\Delta y}; r_1 = \frac{\Delta t}{(\Delta y)^2};$$

$$r_{14} = (Sc + 2r_1); r_{15} = (Sc + r_{13} - \Delta t Sc Kr)$$