



Heat and Mass Transfer Effects on Unsteady MHD Fluid Embedded in Inclined Darcy-Forchemmer Porous Media with Viscous Dissipation and Chemical Reaction

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Authors' contributions

This work was carried out in collaboration among all authors. Author SAA designed the study in collaboration with other co-authors. Authors SAA and GA performed the numerical analysis. Authors SAA, GA and AOA decided and wrote the protocol. Authors SAA and AOA wrote the first draft of the manuscript. Authors GA and AOA managed the analyses of the study. Author AOA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The Darcy-Forchemmer in fluid-saturated porous media finds application in a variety of engineering processes such as heat exchanger devices, chemical catalytic reactors and metallurgical applications-hot rolling of wires, drawing of metals and plastic extrusion. Also, entrepreneurial development helps in developing MHD power generation systems. The study therefore, investigated unsteady nonlinear MHD fluid embedded in an inclined Darcy-Forchemmer in an inclined porous media. The governing partial differential equations of the model are reduced to a system of coupled nonlinear ordinary differential equations by applying similarity variables and solved numerically

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using shooting with fourth-order Runge-Kutta method. The local similarity solutions for different values of the physical parameters were presented for velocity, temperature and concentration. The results for Skin friction, Nusselt and Sherwood numbers were presented and discussed. The study included MHD fluid mechanisms in this presentation to justify advance in scientific research and the need for computational analysis and applications. The study reported the effects of unsteady MHD fluid flow in Darcy-Forchemmer in porous media and its implication as gateway to entrepreneurial development and National growth.

Keywords: *Magnetohydrodynamics fluid; viscous dissipation; chemical reaction; Darcy-forchemmer porous media; heat exchanger devices; chemical catalytic reactors.*

1. INTRODUCTION

Heat and mass transfer effects of unsteady Magnetohydrodynamics (MHD) fluid embedded over inclined Darcy-Forchemmer porous media with viscous dissipation and chemical reaction is of great concern in physical sciences, life sciences including entrepreneurial development research that supported national development. MHD fluid flow through porous media has wide spread applications in engineering industries and entrepreneurial development. Researchers have worked on combination of heat and mass transfer effects using various parameters but unsteady MHD fluid influence on heat and mass transfer through Darcy-Forchemmer porous medium is necessary as a result of its applications and effects over time and space.

The study of unsteady MHD flow over inclined plate with convective surface boundary conditions with dissipation and chemical reactions are concerns of the scholars. The reactions for the interest was born out of its significance in many industrial and manufacturing processes. In view of this [1] investigated friction Drag resulting from the simultaneously imposed motion of a free stream and its bounding surface. The authors developed models for determining the streamwise variation of the temperature of a moving sheet in the presence of a co-flowing fluid. Also, [2] reported universal solutions for the Streamwise variation of the temperature of a moving sheet in the presence of a moving fluid. Radiative MHD flow over a vertical plate with convective boundary conditions was investigated [3]. MHD boundary layer flow of heat and mass transfer over a vertical plate in a porous medium with suction and viscous dissipation was presented [4].

In recent time the following works relevant to this research were included, for example [5] used numerical approach to investigate boundary layer

stagnation-point flow past a stretching/shrinking sheet. [6] related dissipation effect on MHD mixed convective flow over a stretching sheet through porous medium with non-uniform heat source/sink. [7] studied the effect of radiation on MHD free convective flow over a stretching sheet in the presence of heat source / sink. In the same manner, [8] investigated the simultaneous effects of Chemical reaction and Ohmic heating with heat and mass transfer over a stretching surface using numerical approach. [9] investigated MHD boundary layer flow over an exponentially stretching sheet past a porous medium with uniform heat source. From those studies the following emanated:

- Transport of momentum and thermal energy in fluid saturated porous media with low porosities are commonly described as Darcy's model for conservation of momentum and by the energy equation based on the velocity field found from this model
- Viscous mechanical dissipation effects are important in geophysical flows and also in certain industrial operations and are usually characterized by the Eckert number.
- In some industrial applications such as fixed-bed catalytic reactor, packed bed heat exchangers and drying, the value of the porosity is maximum at the wall and minimum away from the wall so the porosity of the porous media should be taken as non-uniform. Porosity measurements should be noted not to be constant but varies from the wall to the interior of porous media due to which permeability also varies. Variation of porosity and permeability had greater influence on velocity distribution and on heat transfer.

Chemical reactions can either be homogeneous or heterogeneous processes. This is a function of whether they occur at an interface or as a single-phase volume reaction. In many chemical engineering processes, there occur the chemical reaction between a foreign mass and fluid in which the plate is moving.

The importance of heat and mass transfer in generating wealth for national development is therefore, pertinent and valuable now the research concentrates on entrepreneurial development. These areas where entrepreneurial activities are found include: transportation where this addresses engine cooling, automobile radiators, climate control, mobile food storage and so on. In healthcare and biomedical applications, we explore blood warmers, organ and tissue storage, hypothermia and so on. In comfort heating, ventilation and air-conditioning this centres on: air conditioners, water heaters, furnaces, chillers, refrigerators and so on. In the weather and environmental changes we think of making the environment conducive. In a renewable energy system: Flat plate collectors, thermal energy storage, photovoltaic (PV) module cooling, and so on are pertinent.

The mass transfer benefits are: humidification of air in a cooling tower, evaporation of petrol in carburetor of a petrol engine, evaporation of liquid ammonia in the atmosphere of hydrogen in electrolytic refrigerator, dispersion of oxides of sulphur (pollutants) from a power plant discharge of neutron in a nuclear reactor, estimation of depth to which carbon will penetrate in a mild steel specimen during the act of carburising [10]-[17]. We also found in literature that [18] investigated MHD free convective flow and heat transfer over non-linearly stretching sheet embedded in Darcy-forchemmer porous medium. [19] [20] and [21] had extensively evaluated the effect of viscous dissipation and Joule heating on MHD Jeffery nanofluid flow with and without multi-slip boundary conditions. In view of the above, this study therefore, sought to compute numerically heat and mass transfer effects of the unsteady MHD fluid flow in inclined Darcy-Forchemmer porous media with viscous dissipation and chemical reactions.

2. FORMULATION OF THE PROBLEM

In this research, consider a free convective, boundary layer flow, heat and mass transfer of viscous incompressible fluid considering exponentially-stretching surface. The flow direction emerging out of a slit at origin and moving with non-uniform velocity in the presence of thermal radiation. The free convective thermal radiation effect on heat and mass transfer of two dimensional fluid flow of a unsteady and incompressible fluid flow over inclined exponentially-stretching sheet under the action of thermal and solutal buoyancy forces. The flow was assumed to be in the x-direction with y-axis normal to it. The geometry and equations governing the fluid flow of heat and mass transfer is assumed as:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

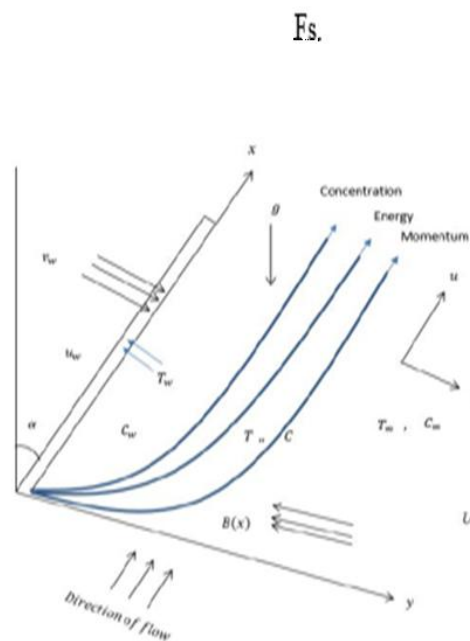


Fig. 1. The geometrical model and coordinate system

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \sigma B_0^2(x)u + \nu \frac{\partial^2 u}{\partial y^2} - \frac{\mu}{K}u - \frac{b}{\sqrt{K}}u^2 + g\beta_T(T - T_\infty)\cos(\alpha) + g\beta_C(C - C_\infty)\cos(\alpha) \tag{2}$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y} + Q_0 (T - T_\infty) + \mu \left(\frac{\partial u}{\partial y} \right)^2 + \sigma B_0^2 u^2 \quad (3)$$

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - \gamma (C - C_\infty) \quad (4)$$

Subject to the following boundary conditions:

$$\begin{aligned} u = U_0 e^{\frac{x}{L}}, v = -V_0 e^{\frac{x}{L}}, T = T_w = T_\infty + T_0 e^{\frac{x}{2L}}, C = C_w = C_\infty + C_0 e^{\frac{x}{2L}} \text{ at } y = 0 \\ u \rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty \text{ as } y \rightarrow \infty, \frac{\partial u}{\partial t} \neq 0, \frac{\partial T}{\partial t} \neq 0, \frac{\partial C}{\partial t} \neq 0 \end{aligned} \quad (5)$$

where u , v are velocity component in the x direction, velocity component in the y direction, C , and T are concentration of the fluid species and fluid temperature respectively. L is the reference length, $B(x)$ is the magnetic field strength, U_0 is the reference velocity and V_0 is the permeability of the porous surface. The physical quantities K , ρ , ν , σ , D , k , C_p ,

Q_0 and γ are the permeability of the porous medium, density, fluid kinematics viscosity, electric conductivity of the fluid, coefficient of mass diffusivity, thermal conductivity of the fluid, specific heat, rate of specific internal heat generation or absorption and reaction rate coefficient respectively. g is the gravitational acceleration, β_T and β_C are the thermal and mass expansion coefficients respectively. q_r is the radiative heat flux in the y direction. By using the Rosseland approximation according to [22] and [23], the radiative heat flux q_r is given by

$$q_r = -\frac{4\sigma_0}{3\delta} \frac{\partial T^4}{\partial y} \quad (6)$$

$$\frac{\partial u}{\partial t} + \frac{\partial \psi}{\partial y} \frac{\partial^2 \psi}{\partial x \partial y} - \frac{\partial \psi}{\partial x} \frac{\partial^2 \psi}{\partial y^2} = -\frac{\sigma}{\rho} B_0 e^{\frac{x}{2L}} \left(\frac{\partial \psi}{\partial y} \right) + \nu \frac{\partial^3 \psi}{\partial y^3} + g\beta_T (T - T_\infty) \cos(\alpha) + g\beta_C (C - C_\infty) \cos(\alpha) \quad (10)$$

$$\frac{\partial T}{\partial t} + \frac{\partial \psi}{\partial y} \frac{\partial T}{\partial x} - \frac{\partial \psi}{\partial x} \frac{\partial T}{\partial y} = \left(\frac{k}{\rho C_p} + \frac{16\sigma_0 T_\infty^3}{3\rho C_p \delta} \right) \frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{\rho C_p} (T - T_\infty) + \frac{\sigma}{\rho C_p} B_0^2 u^2 \quad (11)$$

$$\frac{\partial C}{\partial t} + \frac{\partial \psi}{\partial y} \frac{\partial C}{\partial x} - \frac{\partial \psi}{\partial x} \frac{\partial C}{\partial y} = D \frac{\partial^2 C}{\partial y^2} - \gamma (C - C_\infty) \quad (12)$$

where σ_0 and δ are the Stefan-Boltzmann and the mean absorption coefficient respectively. Assuming the temperature difference within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature, using Taylor series to expand T^4 about the free stream T_∞ and neglecting higher order terms, this gives the approximation

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \quad (7)$$

The magnetic field $B(x)$ is assumed to be in the form $B(x) = B_0 e^{\frac{x}{2L}}$.

Where B_0 is the constant magnetic field.

Introducing the stream function

$$u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x} \quad (9)$$

Continuity equation is satisfied when (9) is substituted in (1) and equations (2)-(4), give

The corresponding boundary conditions become:

$$\begin{aligned} \frac{\partial \psi}{\partial y} &= U_0 e^{\frac{x}{L}}, \frac{\partial \psi}{\partial x} = V_0 e^{\frac{x}{L}}, T = T_w = T_\infty + T_0 e^{\frac{x}{2L}}, \\ C &= C_w = C_\infty + C_0 e^{\frac{x}{2L}} \text{ at } y = 0 \\ \frac{\partial \psi}{\partial y} &\rightarrow 0, T \rightarrow T_\infty, C \rightarrow C_\infty \text{ as } y \rightarrow \infty, \frac{\partial u}{\partial t} \neq 0, \frac{\partial T}{\partial t} \neq 0, \frac{\partial C}{\partial t} \neq 0 \end{aligned} \quad (13)$$

In order to transform the equations (11), (12) and (13) as well as the boundary conditions into an ordinary differential equations, the following similarity transformations (variables) are introduced following [24],and [25].

$$\begin{aligned} \psi(x, y) &= \sqrt{2\nu U_0 L} e^{\frac{x}{2L}} f(\eta), \eta = y \sqrt{\frac{U_0}{2\nu L}} e^{\frac{x}{2L}}, T = T_\infty + T_0 e^{\frac{x}{2L}} \theta(\eta), \\ C &= C_\infty + C_0 e^{\frac{x}{2L}} \phi(\eta) \end{aligned} \quad (14)$$

Equations(11), (12)and(13) become

$$f''' - \frac{U}{2} f'' + ff'' - 2f'^2 - ((M + \frac{1}{B})f'(f'+U) - Fs(f'^2) + G_r \theta \cos(\alpha) + G_c \phi \cos(\alpha)) = 0 \quad (15)$$

$$\left(1 + \frac{4}{3}R\right)\theta'' - Pr\left(\left(\frac{\theta'U}{2} - f\theta'\right) - 2U - f' - f'\theta + Q\theta + Ec(f')^2 + MEc(f')^2\right) = 0 \quad (16)$$

$$\phi'' - Sc\frac{\phi U}{2} - Scf\phi' - 2USc\phi - Scf'\phi - Sc\lambda\phi = 0 \quad (17)$$

The corresponding boundary conditions take the form:

$$\begin{aligned} f &= f_w, f' = 1, \theta = 1, \phi = 1 \text{ at } \eta = 0 \\ f' &= 0, \theta = 0, \phi = 0 \text{ as } \eta \rightarrow \infty \end{aligned} \quad (18)$$

where $M = \frac{2\sigma L B_0}{\rho U_0} e^{\frac{x}{2L}}$ is the magnetic parameter, $G_c = \frac{2Lg\beta_T T_0}{U_0^2} e^{\frac{3x}{2L}}$ is the thermal Grashof

number, $G_c = \frac{2Lg\beta_C C_0}{U_0^2} e^{\frac{3x}{2L}}$ is the solutal Grashof number, $Pr = \frac{\rho\nu C_p}{k}$ is the Prandtl number,

$R = \frac{4\sigma_0 T_\infty^3}{\delta k}$ is the thermal radiation parameter, $Ec = \frac{u^2}{C_p(T_w - T_\infty)} = \frac{\mu}{\rho}$ is Eckert numbers,

$F_s = \frac{2bx}{\sqrt{K}}$ is Forchemmer parameter, U is unsteady parameter, B is the porosity parameter,

$Q = \frac{2LQ_0}{U_0\rho C_p} e^{\frac{x}{L}}$ is the heat generation parameter, $Sc = \frac{\nu}{D}$ is the Schmidt number, $\lambda = \frac{2L\gamma}{U_0} e^{\frac{x}{L}}$ is

the chemical reaction parameter, $f_w = V_0 \sqrt{\frac{2L}{\nu U_0}} e^{\frac{3x}{2L}}$ is the permeability of the plate.

The problem is a boundary value problem, applying a shooting technique (guessing the unknown values) to change the conditions to initial value problem. In order to integrate equations (15), (16) and (17) as IVPs, the values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ which were required for solution but no such values were given in the boundary. The suitable values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ were chosen and then integration was carried out. The researcher compared the calculated values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$ at $\eta = 3.5$ with the given boundary conditions $f'(3.5) = 0$, $\theta'(3.5) = 0$ and $\phi(3.5) = 0$. Then adjusted the estimated values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$, to give a better approximation for the solution. The researcher performed the series of values for $f''(0)$, $\theta'(0)$ and $\phi'(0)$, and then applied a fourth-order Runge-Kutta method with shooting techniques with step-size $h = 0.01$. The value of η_∞ is noticed to the iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$. The highest value of η_∞ to each parameter is determined when the values of the unknown boundary conditions at $\eta = 0$ does not change after successful loop with error less than 10^{-5} . The computations have been performed using a symbolic program and computational computer language Maple 18.

3. RESULTS AND DISCUSSION

From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which were respectively proportional to $f''(0)$, $\theta'(0)$ and $\phi'(0)$, at the plate were examined for different values of the parameters. The comparison of the present study with the skin friction of the existing works are presented in Table 1 for values of δ when $F_s = 0 = U = \alpha = 0$.

Table 1 shows numerical values of skin friction when compared with the existing literature and were in close agreement. The present study shows improvement over the previous studies. We validated our results by setting all newly introduced parameters U , Gr , G_c , λ and α zero and were found to be in excellent agreement with Kala et al (2014), Devi et al (2015). The following parameter values are adopted for computation as default number: $M=0.001$, $Gr = 1$, $G_c = 0.1$, $S_c = 0.35$, $P_r = 0.72$, $R = 0.5$, $Q = 0.5$, $U = f_w = 0.5$, $F_s = 1$, $B = 0.5$. All graphs were corresponded to the value except otherwise indicated on the graph.

Table 2 represents the numerical analysis of variation independent parameters (magnetic parameter, Darcy parameter, thermal Grashof number, Prandtl number, thermal radiation, Eckert, heat generation parameter, Schmidt number and chemical reaction and permeability of the plate surface) in explaining dependent parameters of Skin friction coefficient, Nusselt and Sherwood numbers at the surface. These further explain exponential analysis of velocity, temperature and concentration profiles thereby showing the effect of cross-diffusion on heat and mass transfer of unsteady MHD flow in porous media with dissipation and chemical reaction. All listed parameters are of physical and engineering interest. It was seen from the results that an increase in the values of M , Da , f_w , Sc , Pr and λ decrease the flow boundary layer while increase in G_c , Gr , R , Q increased the flow boundary layer. The table depicts that an increase in the values of M , Da , Q , Sc and λ thicken the thermal boundary layer by reducing the rate at which heat diffuse out of the system as well as chemical reaction. The increase in f_w and Pr reduce the thickness of the thermal boundary layer. It was also discovered that, increase in f_w , Q , Sc , R and λ cause thinning in the concentration boundary layer while M , Da and Pr thicken the mass boundary layer.

3.1 Graphical Presentation of the Study

Fig. 2, presented the effects of magnetic field parameter on fluid flow or velocity, temperature

Table 1. Effect of M on $f''(0)$ when present study is compared with earlier Research

Values	Present study	[26]	[25]
M	$f''(0)$	$f''(0)$	$f''(0)$
0.0	-0.000000	-1.000480	-1.000000
0.1	-0.876889	-0.872571	-0.872083
0.5	-0.646494	-0.591683	-0.591105

Table 2. Effect of M , f_w , G_r , G_c , S_c , P_n and R on $f''(0)$, $\theta'(0)$ and $\phi'(0)$ (P-Parameters)

P	Values	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$	P	Values	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
M	0.001	-3.8286	-3.1423	0.8538	Q	0.5	-3.0729	-1.4290	1.7644
	2	-4.2525	-2.8213	0.8457		0.8	-3.1352	-1.0542	1.7583
	3	-4.4485	-2.6984	0.8424		1.0	-3.1694	-0.8495	1.7549
	4	-4.6358	-2.5925	0.8394		1.5	-3.2372	-0.4433	1.7481
G_r	0.01	-4.2231	-2.8825	0.8446	Sc	0.35	-3.0131	-1.4348	1.2521
	3.1	-3.6806	-3.1316	0.8592		0.62	-3.0729	-1.4290	1.7644
	3.8	-3.5610	-3.1829	0.8622		1.50	-3.1945	-1.4219	3.1089
	5.0	-3.3585	-3.2669	0.8673		2.00	-3.2415	-1.4203	3.7810
G_c	1	-3.9391	-3.0503	0.8516	λ	0.5	-3.0729	-1.4290	1.7644
	2	-3.5671	-3.7308	0.8754		1.5	-3.0944	-1.4274	1.9670
	3	-3.1748	-4.3891	0.8981		2.5	-3.1125	-1.4261	-2.1469
	4	-2.7806	-4.9227	0.9187		4.0	-3.1353	-1.4247	-2.3873
f_w	1.00	-3.0729	-1.4290	1.7644	Fs	1.00	-3.0729	-1.4290	1.7644
	2.00	-3.4328	-1.3669	2.1657		2.00	-3.1787	-1.4260	1.7644
	3.00	-3.8715	-1.1770	2.6186		3.00	-3.2815	-1.4229	1.7592
	4.00	-4.3896	-0.8989	3.1121		5.00	-3.4792	-1.4167	1.7544
Pr	0.72	-3.0729	-1.4290	1.7644	Ec	0.06	-3.0021	-1.7805	1.7690
	0.74	-3.0639	-1.4874	1.7653		0.50	-3.0729	-3.1200	-1.0971
	0.80	-3.0368	-1.6658	1.7677		1.00	-3.1952	-0.5518	1.7534
	0.90	-2.9912	-1.9730	1.7717		2.00	-1.6782	0.4411	1.4193
R	0.50	-3.0729	-1.4290	1.7644	B	1	0.1632	-1.3289	1.8792
	1.70	-3.2246	-0.4942	1.7496		3	0.2545	-1.3128	1.8828
	4.70	-3.3048	-0.0414	1.7409		5	0.0528	-1.3403	1.8750
	7.00	-3.3235	0.0595	1.7387		7	-0.4037	1.3910	1.8578
U	0.10	-1.1678	0.4411	1.4193	α	5	-4.3419	-0.8901	0.8275
	0.20	-1.8531	0.2407	1.4614		8	-4.5375	-0.8357	0.8179
	0.30	-2.0223	0.0388	1.5024		11	-4.4686	-0.8554	0.8214
	0.50	-2.3445	-0.3704	1.5815		15	-4.8272	-0.7439	0.8021

and concentration profiles respectively. It was discovered in Fig. 2 that increase in M slowed down the rate of fluid flow thereby thinning the velocity boundary layer. It was discovered that

temperature and chemical reaction parameter or concentration decreased. In this case, temperature and concentration at the boundary layer got thinner as magnetic field increased.

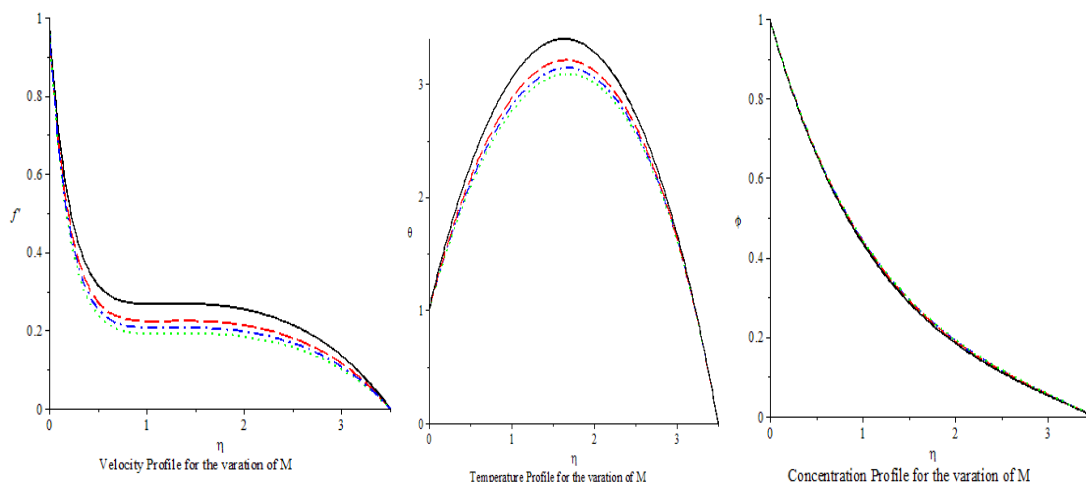


Fig. 2. Effects of Velocity, temperature and concentration on the variation of M

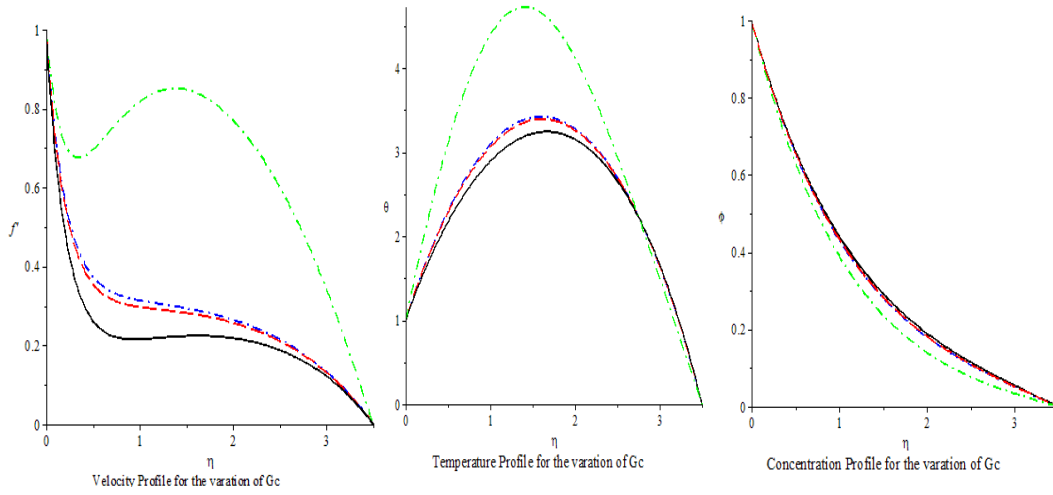


Fig. 3. Effects of Velocity, temperature and concentration on the variation of G_c

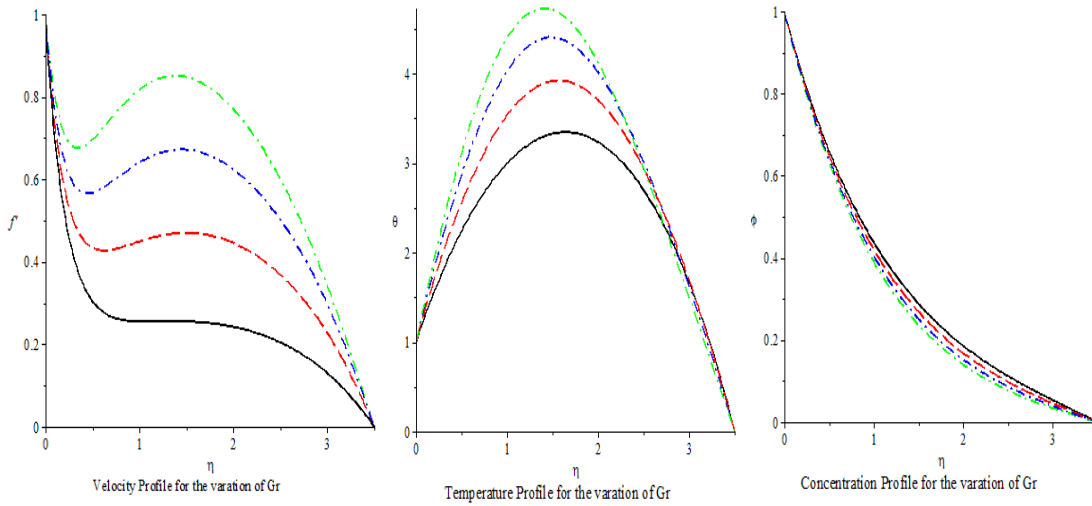


Fig. 4. Effects of Velocity, temperature and concentration on the variation of Gr

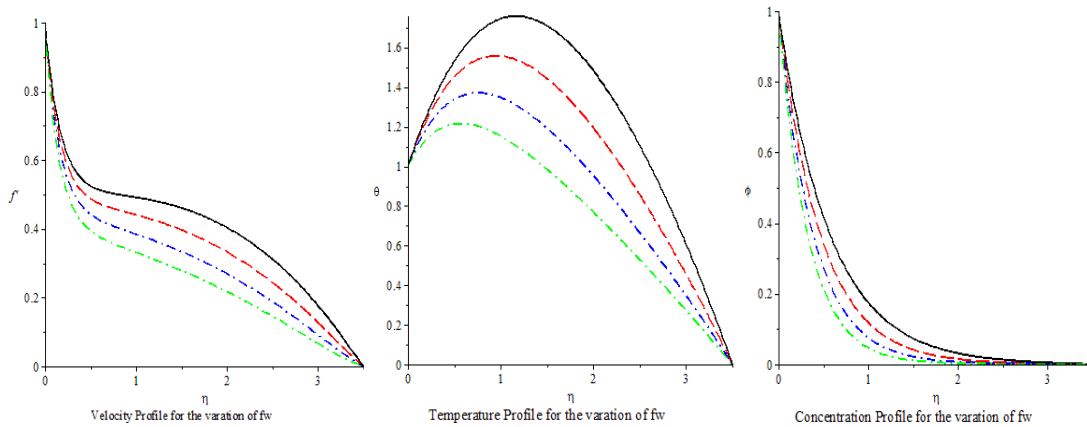


Fig. 5. Effects of Velocity, temperature and concentration on the variation of F_w

Fig. 3 exhibited the effects of G_c on the exponential velocity, temperature and concentration respectively. The effect of solutal Grashof number on velocity distribution was illustrated in Fig. 3. It was noticed that increase in G_c led to increase in exponential velocity. The values of temperature increased with varied solutal Grashof number but decreased concentration when Solutal Grashof increased. These analyses were true of the Fig. 3 due to the fact that G_c usually increased as one of the characteristics of free or natural convection thereby increasing the velocity boundary layer flow.

Fig. 4 exhibited the effects of increased thermal Grashof Gr parameter. It was discovered that velocity increased with increase in Gr but decreased in temperature and concentration profiles. The implication of this result suggested that slow rate of heat and free convective mass transfer was noticed. In this case, Gr slowed down the exponential temperature and concentration.

Fig. 5 presented the effects of fw on the velocity, temperature and concentration profiles respectively. It was discovered that increase in fw parameter led to proportional decrease in rate of fluid flow, temperature or heat transfer as well as concentration profile or mass transfer. This parameter has more influence on velocity parameter because it is the parameter that explained the concept of porosity or permeability. The negative values explain the concept of suction while positive values of the parameter reveal the concept of injection. It was observed that suction decreased the exponential velocity, thereby indicating that suction stabilised the boundary layer development. Injection increased the velocity at the boundary layer thereby indicating that injection supported the flow to penetrate more into fluid.

In Fig. 6, it was discovered that temperature decreased as injection decreased, this suggests that injection did not induce cooling hence, fluid transfers to the surface. On the other hand, temperature decreased as suction increased, this means that suction led to faster cooling of the plates. Fig. 6 revealed the fact that concentration decreased as the suction increased and increased as the injection increased due to respective thinner and thickness in mass boundary layer.

4. CONCLUSION

This study investigated unsteady MHD boundary layer flow, heat and mass transfer of an extended Darcy-Forchheimer incompressible viscous fluid over porous stretching inclined surface in the presence of dissipation and chemical reaction. Skin friction, Nusselt and Sherwood numbers increased with increase in thermal Grashof parameter. Permeability at the plate decreased the skin friction but increased Nusselt and Sherwood numbers. The results showed that the velocity decreased with the increase in the value of radiation R . The fluid temperature decreased with the increase in thermal radiation while fluid temperature increased with an increase in Prandtl number. Darcy Forchheimer parameter showed decrease in skin friction and Sherwood number, but increased Nusselt number. An increase in chemical reaction decreased skin friction and Nusselt number but increased Sherwood number. Eckert number increased the skin friction as well as Sherwood number but decreased the rate of heat in the flow. The study concluded that solutal Grashof, thermal Grashof, magnetic parameter, radiation parameter had significant effects on unsteady MHD fluid flow in porous media stretching surface. This study is recommended for use in metallurgical applications and MHD power generation systems.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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