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

Abstract

Heat and mass transfer effects of Magnetohydrodynamics (MHD) fluid embedded over inclined Darcy-Forcheimmer porous media with viscous dissipation and chemical reaction is of great concern in physical sciences, life sciences including entrepreneurial development research that support national development. The Darcy-Forcheimmer 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 nonlinear MHD boundary layer flow in 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 using shooting with fourth-order Runge-Kutta method. The local similarity solutions for different values of the physical parameters are presented for velocity, temperature and concentration. The results for Skin friction, Nusselt and Sherwood numbers are 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 MHD fluid flow in Darcy-Forcheimmer in porous media and its implication as gateway to entrepreneurial development and National growth.

Keywords: Magnetohydrodynamics, Dissipation, Chemical Reaction, Darcy-Forcheimmer, Entrepreneurial Development

INTRODUCTION

Magnetohydrodyanamics (MHD) fluid flow through porous medium has wide spread applications in engineering industries and enterpreneurial developement. 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–Forcheimmer porous medium is necessary as a result of its applications and effects over time and space.

The study of MHD flow over inclined plate with convective surface boundary conditions with dissipation and chemical reactions has attracted interest of the scholars. The reactions for the interest was born out of its significance in many industrial and manufacturing processes. In view of this, radiative MHD flow over a vertical plate with convective boundary conditions was investigated (Etwire and Seini, 2014). MHD boundary layer flow of heat and mass transfer over a vertical plate in a porous medium with suction and viscous dissipation was presented (Lakshmi, Reddyand Poornima 2012)

- Transport of momentum and thermal energy in fluid saturated porous media with low porosities is 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 mediam 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 medium due to which permeability als varies. Vatiation of porosity and permeability has 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 very pertinent and valuable now the research concentrates on enterpreneural development. These areas where enterpreneural 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 exlpore 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, 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 Kumar (2013). Kala, Singh and Kumar (2014) investigated MHD free convective flow and heat transfer over non-linearly stretching sheet embedded in Darcy-forcheimmer porous medium. Amoo and Babayo (2017), Amoo, Babayo and Amoo (2017) had extensively evaluated MHD boundary layer flow of Darcy-forcheimmer in porous media. In view of the above, this study therefore, sought to compute numerically the unsteady MHD flow and heat transfer in Darcy-Forcheimmer porous media with viscous dissipation and chemical reaction.

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:

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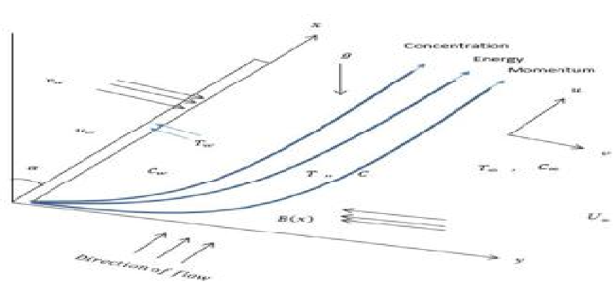


Figure 1: The Geometrical Model and Coordinate system

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

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

(2)

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

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

Subject to the following boundary conditions:

$$\begin{aligned} &u=U_0e^{\frac{x}{L}}, v=-V_0e^{\frac{x}{L}}, T=T_w=T_\infty+T_0e^{\frac{x}{2L}}, C=C_w=C_\infty+C_0e^{\frac{x}{2L}} \quad at \quad y=0 \\ &u\to 0, T\to T_\infty, C\to C_\infty \quad as \quad y\to\infty, \frac{\partial u}{\partial t}\neq 0, \frac{\partial T}{\partial t}\neq 0, \frac{\partial C}{\partial t}\neq 0 \end{aligned} \tag{5}$$

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, v , 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, Ibrahim and Suneetha (2015), Amoo (2017), the radiative heat flux q_r is given by

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

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

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \tag{7}$$

The magnetic field $B(x)$ is assumed to be in the form $B(x)=B_0e^{\frac{x}{2L}}$. (8)

Where B_0 is the constant magnetic field.

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

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

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

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

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

The corresponding boundary conditions become:

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

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 Sajid and Hayat (2008) and Amoo (2017).

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

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

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

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

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

The corresponding boundary conditions take the form:

$$f = f_w, f' = 1, \theta = 1, \phi = 1 \;\; at \;\; \eta = 0$$
$$f' = 0, \theta = 0, \phi = 0 \;\; as \;\; \eta \to \infty \qquad (18)$$

where $M = \frac{2\sigma L B_0}{\rho U_0} e^{\frac{x}{2L}}$ is the magnetic parameter, $Gc = \frac{2Lg\beta_T T_0}{U_0^2} e^{-\frac{3x}{2L}}$ is the thermal Grashof number, $Gc = \frac{2Lg\beta_C C_0}{U_0^2} e^{-\frac{3x}{2L}}$ 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 Forcheimmer parameter, U is unstable parameter, $B = \text{B}$ is the porous medium 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.

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 comarison of the present study with the skin friction of the existing works are presented in Table 1 for values of δ when Fs. = 0=U=0 = α =0 .

Values	Present study	Devi et al (2015)	Kala, et al (2014).
Values	$f''(0)$	$f''(0)$	$f''(0)$
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 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. Gc. λ and α zero and were found to be in excellent agreement with Kala *et al* (2014), Devi et al (2015). The computations have been performed using a symbolic program and computational computer language Maple 18. The step size is taken to be $\Delta\eta = 0.001$ to satisfy the convergence requirement of 10^{-5} in all cases. The value of η_∞ is noticed to the iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$. The highest value of η_∞ to each parameters are determined when the values of the unknown boundary conditions at $\eta = 0$ not changed to successful loop with error less than 10^{-5}.From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which are respectively proportional to f"(0) and ϕ '(0), at the plate have been examined for different values of the parameters are presented in a tabular form and discussed. The following parameter values are adopted for computation as default number: M=0.001, *Gr* =1, *Gc*= 0.1, S_C=0.35, P_r=0.72, R=0.5, Q=0.5, U=f_w=0.5, Fs=1 , B=0.5. All graphs were corresponded to the value except otherwise indicated on the graph.

Table2: Effect of M, f_w, G_r, G_c, S_c, P_r, 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
Gc.	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
fw.	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

GRAPHICAL PRESENTATION OF THE STUDY

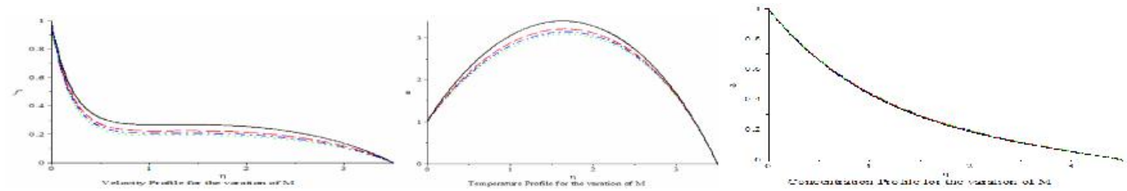
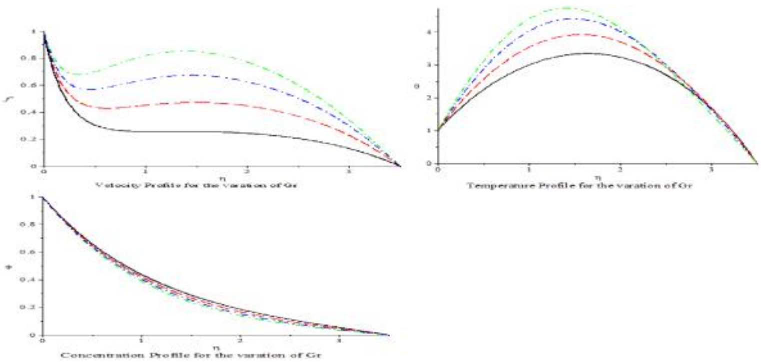


Figure 2



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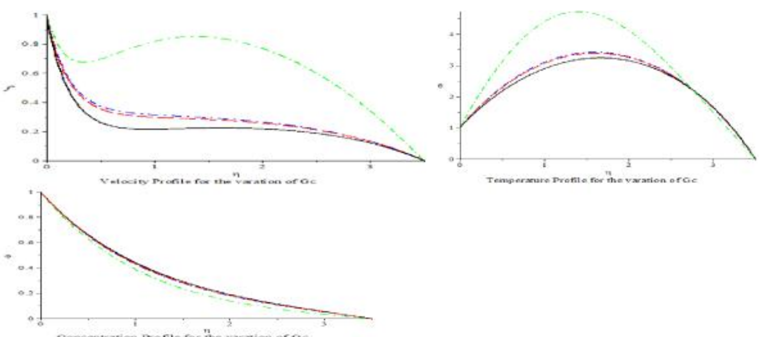

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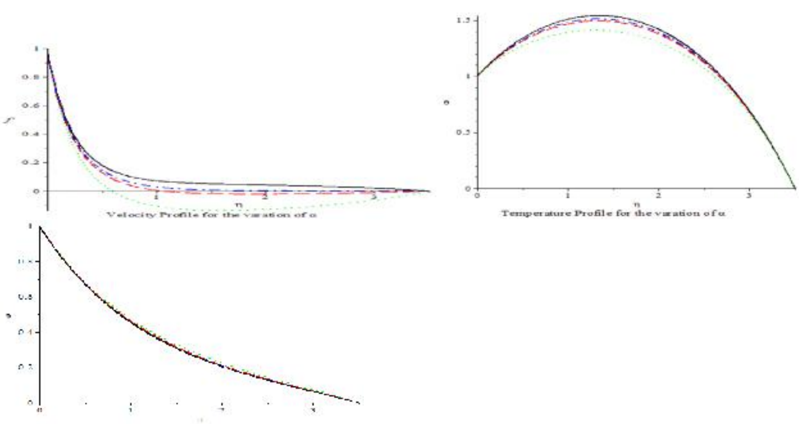

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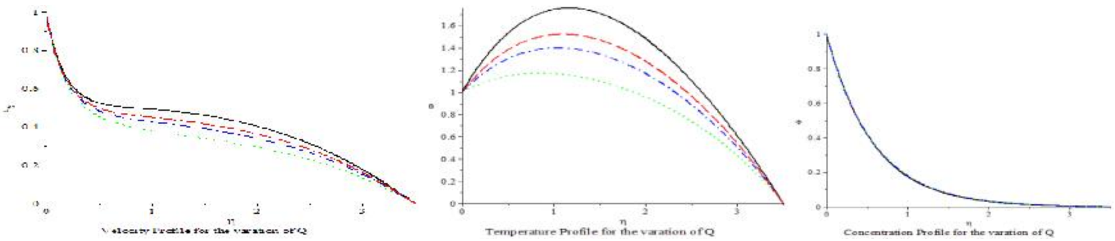

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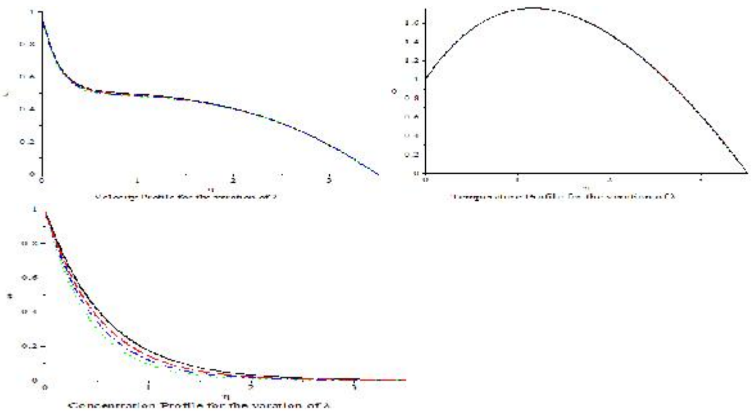

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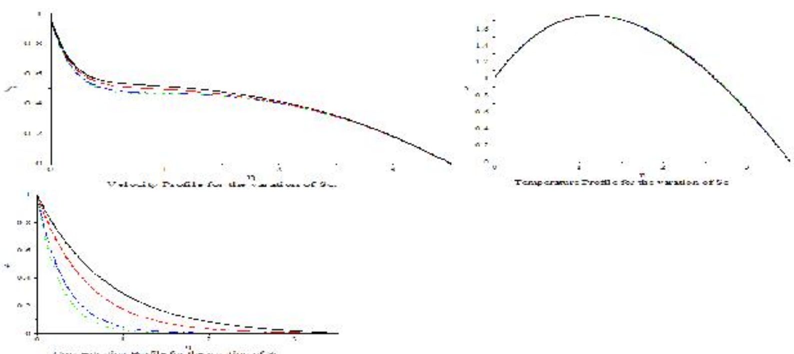

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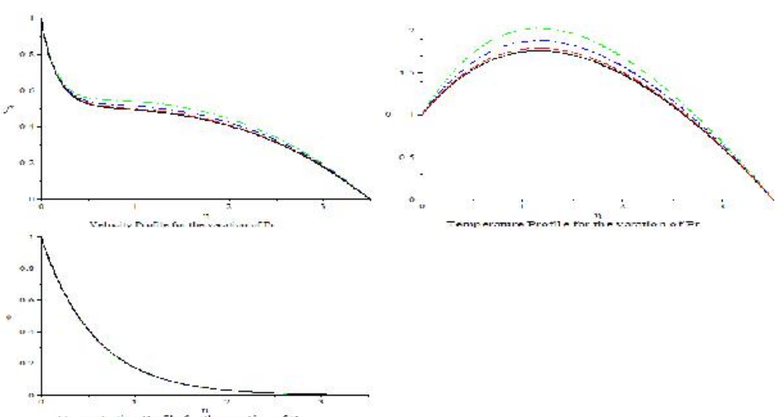

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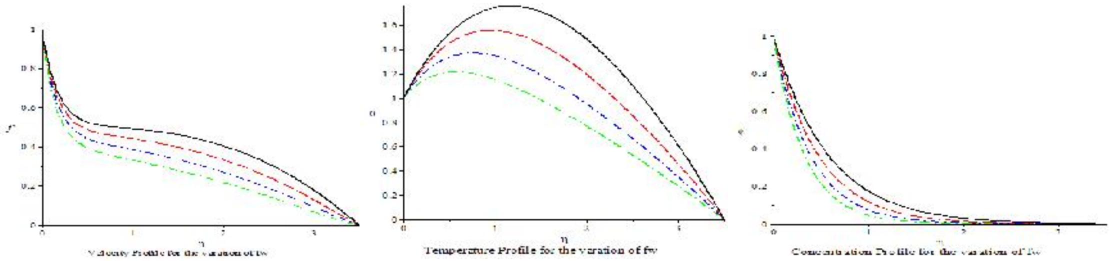

Figure 10

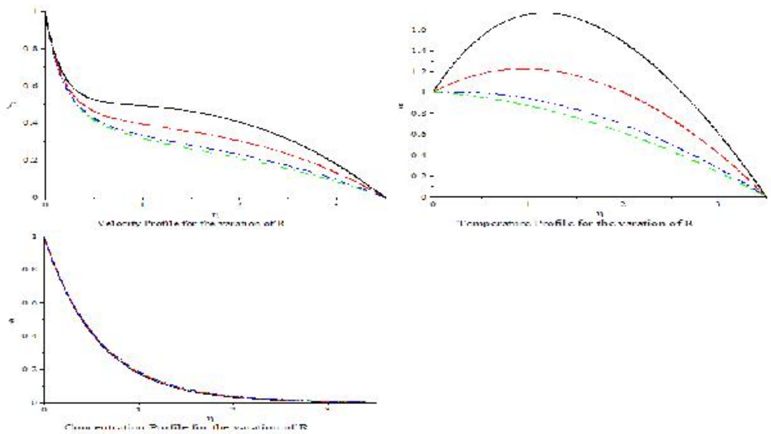

Figure 11

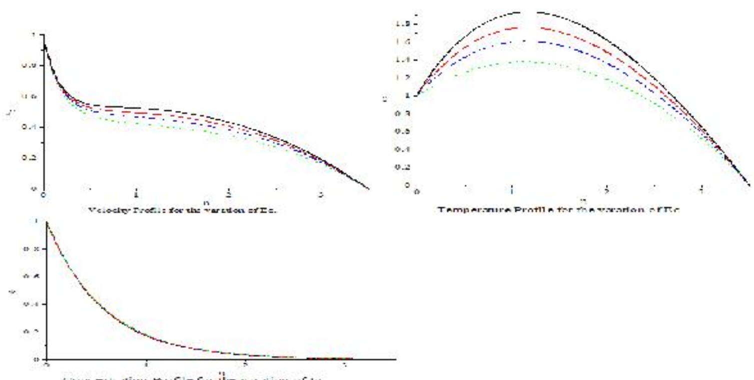

Figure 12

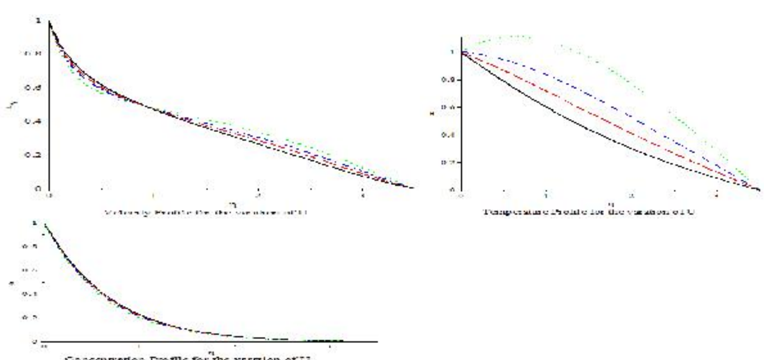

Figure 13

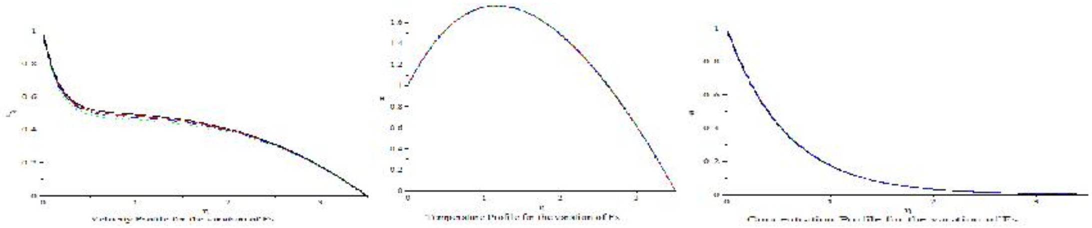

Figure 14

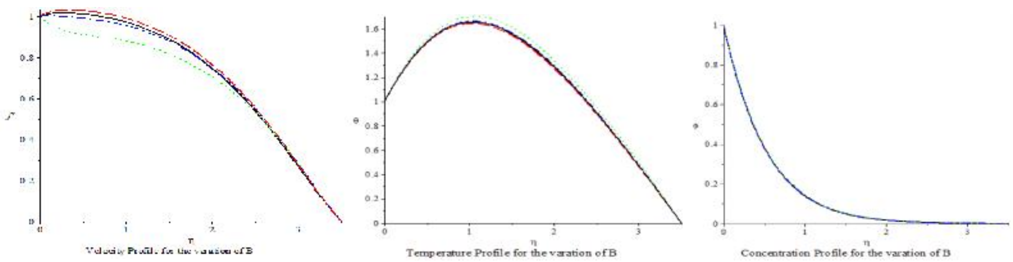

Figure 15

CONCLUSION

This study investigated unsteady MHD boundary layer flow, heat and mass transfer of an extended Darcy-Forcheimmer 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 Forcheimmer 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, Dufour and Soret numbers 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.

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