THERMAL RADIATION EFFECTS ON HEAT AND MASS TRANSFER OF MHD FLOW IN POROUSMEDIA OVERAN EXPONENTIALLY STRETCHING SURFACE

Supported by
tetfund
TERTIARY EDUCATION TRUST FUND

S. A. Amoo[1] and A. S. Idowu[2]
[1]Department of Mathematics & Statistics, Federal University Wukari, PMB 1020, Nigeria
[2]Department of Mathematics, University of Ilorin, Nigeria
*Corresponding author: drsikiruamoo@gmail.com
Received: August 20, 2016 **Accepted:** January 14, 2017

Abstract: The study investigated thermal radiation effect on heat and mass transfer of magnetohydrodynamic (MHD) boundary layer fluid flow in a porous medium over an exponentially porous stretching sheet in the present of heat generation and chemical reaction. The governing boundary layer equations of the model were transformed to a system of ordinary coupled differential equations. The coupled system of equations were then solved numerically by a fourth order Runge-Kutta method along with shooting technique. A parametric study on the effect of variations in the fluid parameters on velocity, temperature and concentration were conducted and presented graphically. Also, the effect of radiation on heat and mass transfer as well as effects on skin friction, Nusselt and Sherwood number on some physical parameters were verified and discussed in detail. Thefindings included the numerical variation in Skin friction, Nusselt and Sherwood numbers at the surface with the introduced parameters i.e. Magnetic parameter, Darcy porosity parameter, permeability at the plate, Schmidt, Prandtl ratios, radiation and chemical reaction parameters which are of physical and engineering interest were presented. It can be seen from the results that an increase in the values of all listed parameters except thermal radiation decrease the flow boundary layer while increase in heat generation and thermal radiation increase the flow boundary layer. This study compares favourably with some existing studies in literature. Also, the effect of skin friction, Nusselt and Sherwood number on some physical parameters are verified and discussed in detail.
Keywords: Exponentially stretching, MHD flow,porous media,thermal radiation

Introduction

The heat source effects in thermal convection are significant where there is existence of high temperature differences between surface (space craft body) and ambient fluid. On the other hand, the heat transfer and viscous flow in the boundary layer region due to stretching surface has several theoretical, practical, experimental and technical applications in extrusion, glass fibre productions, aerodynamics and food processing industries. The study of thermal radiation effects on heat and mass transfer of MHD flow in fluid mechanics is very important to the engineers giving meaning to this field in our economic growth. In recent time, MHD flow problem has become so important and in view of its significance in industries and its associated environmental advantages. The studies relating to this type of flow are so enormous due to the relevance of its applications in day-to-day affairs of running industries within the environment they are situated. The applications of this study in fluid dynamics extend to human body, air conditioning system, electronic equipment, power plants, and refrigerating systems (Bhattacharya, 2011; Dinarrand *et al.*, 2014). The manufacturers of hot rolling wire drawing, paper films, metal and metal spinning and polymer extrusions are making use of the outcome of this study. The kinematics of stretching, simultaneous or multiple heating or cooling during the processes involved have a decisive influence on the quality of the products as well as maintenance processes. In the same perspective, the radiation effects, and the application of heat and mass transfer problems are often controlled by injecting or withdrawing of fluid through porous bounding heated surface. This, with MHD can lead to overheating or cooling of systems, and can delay transition from laminar to turbulent flow.

In boundary layer phenomena, radiation effects on MHD fluid flow, heat and mass transfers in porous media is significant because of its extension over an exponentially stretching porous surface. The study keeps paving ways for further studies due to its enormous usage in every facets of life. The simultaneous or multiple usage of this study in human life have made it stand out among researchers to concentrate on how such studies can improve our nation's economy, thereby benefiting the inhabitants. The investigation such as this can be modeled and solved experimentally, analytically or numerically. In doing this, the existing models are either modified or adjusted to reflect the current trends in academics as well as in industries that make use of such research reports. In a study like this, boundary layer flow on a continuous stretching sheet or surface has attracted considerable attentions.

Thermal radiation and its effects on MHD flow are major input of researchers in recent past. In the areas of influence of thermal radiation on boundary layer flow, reference is made to the efforts of Bhattacharya (2011) who examined the effects of radiation and heat source/sink on unsteady MHD boundary layer flow. The effect on heat transfer over shrinking sheet with suction/injection was reported. Similarly, Devi *et al.* (2014) examined the radiation effects on MHD free convective boundary layer flow over a stretching sheet in the presence of radiation. Heat source and transfers are important factors in boundary layer problems because of its universality. In the same perspective, exact analytical solution for heat and mass transfer of MHD slip flow in nanofluids had been carried out by Turkyilmazogiu (2012). The slip effect on MHD boundary layer over exponentially stretching sheet was examined by Mukhopadhyay (2012) while Sharman (2004) studied unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heating flux in rotating system, whereas in convective fluid, when the flow of mass is caused by a temperature difference, thermal diffusion effects cannot be neglected. Nalinakshi *et al.* (2013) related the effect of variable fluid properties and MHD on mixed convection heat transfer from a vertically heated plate embedded in a sparsely packed porous medium. Serkhar (2014) carried out analysis on the boundary layer phenomena of MHD flow and heat transfer over an exponentially stretching sheet embedded in a thermally stratified medium. Serkhar neglected the chemical reaction and discovered that temperature gradient increases consistently with increase in stratification parameter. Also, Ibrahim and Suneetha (2015) presented the effects of heat generation and thermal radiation on steady MHD flow near a stagnation point on a stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer, it was discovered that temperature increased with increasing radiation parameter R and concentration decreased with increasing Schmidt number. Unsteady MHD flow and heat transfer of nanofluid over a permeable shrinking sheet with thermal radiation and chemical reaction was recently analysed by Srivas and Kishan (2015). The effect of magnetic field was diminution with velocity of fluid flow in a study. Hussain and Ahmad (2015) verified the unsteady MHD flow and heat transfer for Newtonian fluids over an exponentially stretching sheet.

Radiation effect on MHD slip flow over a stretching sheet with variable and heat source/sink was investigated by Devi *et al*. (2015). Kala *et al.* (2014) analyzed steady MHD free convective flow and heat transfer over non linearly stretching sheet embedded in an extended Darcy-Forcheimmer porous medium with viscous dissipation. MHD boundary layer flow due to an exponentially stretching sheet with radiation effect was presented by Ishak (2011).In this study, the Darcy porosity, thermal Grashof number, solutal Grashof number, permeability at the plate and chemical reaction parameter were introduced.

In view of the above studies, the present study examined the thermal radiation effects on heat and mass transfer of MHD in porous media over an exponentially stretching surface. In order to validate the new models, comparison were made by setting the newly introduced parameters to zero thereby comparing the existing studies with this study. The juxtaposed outcomes were presented in Table 1.

Formulation of the problem

Consider the free convective thermal radiation effect on heat and mass transfer of MHD flow of an electrically conducting and incompressible fluid flow past an exponentially stretching sheet under the action of thermal and solutal buoyancy forces. A uniform transverse variable magnetic field $B(x)$ is applied perpendicular to the direction of flow with chemical reaction is taking place in the fluid flow. The flow is assumed to be in the x-direction with y-axis normal to it. The plate is maintained at the temperature and species concentration T_w, C_w and free stream temperature and species concentration T_∞, C_∞, respectively. The physical model and equations governing the thermal radiation effect on heat and mass transfer of MHD fluid flow in a porous medium over an exponentially stretching sheet are as follows:

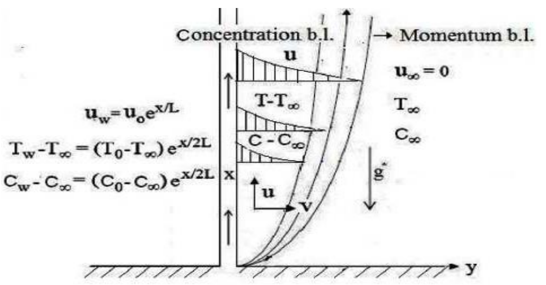

Figure 1: Physical model and coordinate system.

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\sigma B(x)u+\nu\frac{\partial^2 u}{\partial y^2}+g\beta_T\left(T-T_\infty\right)+g\beta_C\left(C-C_\infty\right)-\frac{\nu}{K}u \qquad (2)$$

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

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

Subject to the following boundary conditions:

$$u=U_0e^{\frac{x}{L}},v=-V_0e^{\frac{x}{L}},T=T_w=T_\infty+T_0e^{\frac{x}{2L}},C=C_w=C_\infty+C_0e^{\frac{x}{2L}} \quad at \quad y=0$$
$$u\to 0,T\to T_\infty,C\to C_\infty \quad as \quad y\to\infty$$

(5)

where u, v, C, and T are velocity component in the x direction, velocity component in the y direction, 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 Ibrahim and Suneetha (2015),the radiative heat flux q_r is given by

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

where σ_0 and δ are the Stefan-Boltzmann and the mean absorption coefficient respectively. Assume 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

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

The magnetic field $B(x)$ is assumed to be in the form

$$B(x)=B_0e^{\frac{x}{2L}} \qquad (8)$$

where B_0 is the constant magnetic field.

Introducing thestreamfunction $\psi(x,y)$ such that:

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

In this case when stream function is substituted in (1), continuity equation is identically satisfied and equations (2)-(4) become

$$\frac{\partial\psi}{\partial y}\frac{\partial^2\psi}{\partial x\partial y}-\frac{\partial\psi}{\partial x}\frac{\partial^2\psi}{\partial y^2}=-\frac{\sigma}{\rho}B_0e^{\frac{x}{2L}}\left(\frac{\partial\psi}{\partial y}\right)+\nu\frac{\partial^3\psi}{\partial y^3}+g\beta_T\left(T-T_\infty\right)+g\beta_C\left(C-C_\infty\right)$$
$$-\frac{\nu}{K}\left(\frac{\partial\psi}{\partial y}\right)$$

(10)

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

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

The corresponding boundary conditions become:

$$\begin{aligned}&\frac{\partial\psi}{\partial y}=U_0e^{\frac{x}{L}},\frac{\partial\psi}{\partial x}=V_0e^{\frac{x}{L}},T=T_w=T_\infty+T_0e^{\frac{x}{2L}},\\&C=C_w=C_\infty+C_0e^{\frac{x}{2L}}\ \ at\ \ y=0\\&\frac{\partial\psi}{\partial y}\to 0,T\to T_\infty,C\to C_\infty\ \ as\ \ y\to\infty\end{aligned} \quad (13)$$

In order to transform the equations (10), (11) and (12) as well as the boundary conditions (13) into an ordinary differential equations, the following similarity transformations variables are introduced following Sajid and Hayat (2008):

$$\psi(x,y)=\sqrt{2\nu U_0 L e^{\frac{x}{2L}}}f(\eta),\eta=y\sqrt{\frac{U_0}{2\nu L}}e^{\frac{x}{2L}},T=T_\infty+T_0e^{\frac{x}{2L}}\theta(\eta), \quad (14)$$
$$C=C_\infty+C_0e^{\frac{x}{2L}}\phi(\eta)$$

The equation becomes

$$f'''+ff''-2f'^2-(M+D_a)f'+G_r\theta+G_c\phi=0 \quad (15)$$

$$\left(1+\frac{4}{3}R\right)\theta''+P_rf\theta'-P_rf'\theta+P_rQ\theta=0 \quad (16)$$

$$\phi''+S_cf\phi'-S_cf'\phi-S_c\lambda\phi=0 \quad (17)$$

The corresponding boundary conditions take the form:

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

where $M=\frac{2\sigma LB_0}{\rho U_0}e^{\frac{x}{2L}}$ is the magnetic parameter, $Da=\frac{2\nu L}{U_0K}e^{-\frac{x}{L}}$ is the Darcy porosity parameter, $Gc=\frac{2Lg\beta_TT_0}{U_0^2}e^{-\frac{3x}{2L}}$ is the thermal Grashof number, $Gc=\frac{2Lg\beta_CC_0}{U_0^2}e^{-\frac{3x}{2L}}$ is the solutant Grashof number, $Pr=\frac{\rho\nu C_p}{k}$ is the Prandtl number, $R=\frac{4\sigma_0T_\infty^3}{\delta k}$ is the thermal radiation 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.

Method of Solution

Shooting technique along with Runge-Kutta method has been adopted as the numerical scheme for this research work. It is a step by step process where a table of function values for a range of values of *x* is accumulated. Several intermediate calculations are required at each stage, but these are straight forward and present little difficulty. Numerical method was employed in solving the models equations i.e. the boundary valued problems (BPV). By numerical method, shooting method together with fourth order Runge-Kutta integration method were used. Shooting method reformulates the BVP to Initial Value Problem (IVP) by adding sufficient number of conditions at one end and adjust these conditions until the given conditions are satisfied at the other end while Runge-Kutta method solve the initial value problems. The several steps involved are: (i) the method replace the given BVP by a sequence of IVPs for the same ODE with initial conditions, (ii) Integrating the sequence of IVPs using fourth order Runge-Kutta scheme, (iii) Identifying the initial slopes for the missing conditions using Newton-Raphson method, (iv) The integration length varies with the parameter values and it has been suitably chosen each time such that the boundary conditions at the outer edge of boundary layer are satisfied, and (v) Repeating this procedure till the convergence is obtained satisfying the boundary conditions.

The governing equations of heat and mass transfer of MHD fluids are essentially nonlinear ordinary differential equations. Hence, the systems of nonlinear ordinary differential equations together with the boundary conditions are solved numerically using fourth order Runge-Kutta scheme with shooting techniques.

Here fourth order Runge-Kutta techniques is used to find the root and the scheme for the fourth order Runge-Kutta is

$$y_{n+1}=y_n+\frac{h}{6}(k_1+2k_2+2k_3+k_4) \quad (19)$$

Where`

$$k_1=(x_n,y_n)$$
$$k_2=\left(x_n+\frac{h}{2},y_n+\frac{hk_1}{2}\right)$$
$$k_3=\left(x_n+\frac{h}{2},y_n+\frac{hk_2}{2}\right)$$
$$k_4=(x_n+h,y_n+hk_3)$$

The numerical code that incorporate the methods described were incorporated there by using maple 18 to tackle the problems. Therefore, the equations (15), (16) and (17) were non-linear coupled differential equations and they satisfy the boundary conditions (18). Equations (15-17) along with the boundary conditions (18) are solved numerically by applying Nachtsheim-Swigert shooting iteration technique along with Runge-Kutta fouth-order integration scheme. The step size is taken to be $\Delta\eta=0.001$ to satisfy the relative 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 parameteris determined when the values of the unknown boundary conditions at $\eta=0$ does not change after 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 $f''(0)$, $\theta'(0)$ and $\phi'(0)$, 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: $Q=0.07$, $f_w=0.0$, $M=0.5$, $R=0.01$, $Sr=0.62$, $\lambda=Da=0.5$, $Pr=0.72$. All graphs plotedcorrespond to the given values except otherwise indicated on the graph. However, for the purpose of validation, the following parameters: G_r, G_c, D_a and Q were made zero as η tends to ∞ in Table 1, then the numerical results of this study are presented in Table 2.

Table 1: Comparison of θ (0) at the sheet for different values of Pr, M and R when the introduced parameters are

P_r	M	R	Present Study	Devi *et al*. (2014)	Ishak (2011)	Bindi and Nazar (2009)
1			-0.957645	-0.957433	-0.9548	-0.9548
2			-1.47084	-1.47898	-1.4715	-1.4714
3			-1.86854	-1.86443	-1.8691	-1.8691
5			-2.49973	-2.500615	-2.5001	
10			-3.66005	-3.60024	-3.6604	
1	1		-0.873094	-0.861390	-0.8611	
1	0	1	-0.56534	-0.563196	-0.5312	-0.5315
1	2	1	-0.43194	-0.450533	-0.4505	

Table 2: Effect of M, Da, f_w, Q, Sc, Pr, R and λ 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	0.5	-0.90292	3.07220	1.34867	Sc	0.2	-0.72474	1.58873	0.64472
	1.0	-1.17287	3.01874	1.32684		0.35	-0.82566	1.52836	0.92085
	2.0	-2.01655	2.84577	1.26691		0.62	-0.93922	1.44666	1.35472
	3.0	-3.01715	2.63251	1.21136		1.5	-1.11612	1.32221	2.55712
Da	0.5	-0.93922	1.44666	1.35472	Pr	0.72	-0.50695	0.30456	1.42614
	3.0	-1.66350	1.16745	1.30666		1.5	-0.67270	0.63647	1.39768
	7.0	-2.49883	0.55847	1.26531		3.0	-0.93922	1.44666	1.35472
	10	-2.99424	0.00506	1.24694		5.0	-1.11303	2.45629	1.33276
f_w	0.0	-0.28569	0.37706	1.04940	R	0.01	-1.20211	3.36232	1.32427
	0.5	-0.57097	0.84792	1.19148		0.5	-1.05871	2.06369	1.33887
	1.0	-0.93921	1.44666	1.35472		1.5	-0.83797	1.08151	1.37026
	2.0	-1.77956	2.66953	1.76329		3.0	-0.65125	0.58784	1.40133
Q	0.07	-1.21820	3.63447	1.32306	λ	0.5	-0.93922	1.44666	1.35472
	0.7	-1.21315	3.55855	1.32346		3.0	-1.04016	1.37184	1.95184
	1.0	-1.17287	3.01874	1.32684		7.0	-1.11445	1.32503	2.59263
	1.5	-1.13239	2.57105	1.33056		10	-1.14873	1.30680	2.97178

Results and Discussion

Table 2 represents the numerical results of variation in Skin friction, Nusselt and Sherwood numbers at the surface with magnetic parameter M, Darcy porosity parameter D_a, permeability parameter f_w, Schmidt number S_c, Prandtl number P_r, radiation parameter R and reaction parameter λ which are of physical and engineering interest. It can be seen from the results that an increase in the values of M, D_a, f_w, S_c, P_r and λ decrease the flow boundary layer while increase in heat source Q and R increase the flow boundary layer. Table 1 depicts that an increase in the values of M, D_a, Q, S_c, R and λ thicken the thermal boundary layer by reducing the rate at which heat diffuse out of the system while increase in f_w and P_r reduces the thickness of the thermal boundary layer. Also, the results show that increase in f_w, Q, S_c, R and λ cause thinning in the concentration boundary layer while M, D_a and P_r thicken the mass boundary layer.

Figures 2, 3 and 4 represent the effect of magnetic field parameter M on the flow, temperature and concentration profiles, respectively. It is found from Fig. 2 that increasing the parameter M slow down the rate of fluid flow and resulted to the thinning of the velocity boundary layer while in Figs. 3 and 4 it is observed that an increase in the values of M causes respective increase in the temperature and concentration profiles because the temperature and concentration boundary layer get thicker as the magnetic parameter increases. Fig. 5 shows the effect of thermal Grashof number Gr on the rate of fluid flow. From the Figure, it is seen that increase in the parameter Gr leads to an increase in the flow rate, as a result, the velocity boundary layer thickened. Hence, heat has an influence on flow rate.The effect of solutant Grashof number on the velocity distribution is illustrated in Fig. 6. It is noticed from the figure that the velocity increases with an increase in the values of the parameter Gc due to the fact that Gc increases free convection current and thereby increases the velocity.

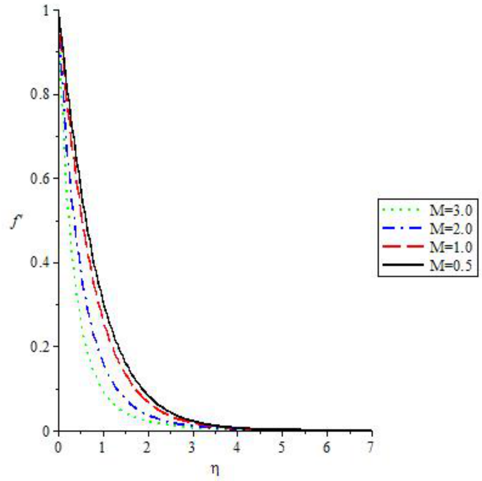

Fig. 2 : Velocity profiles for different values of M

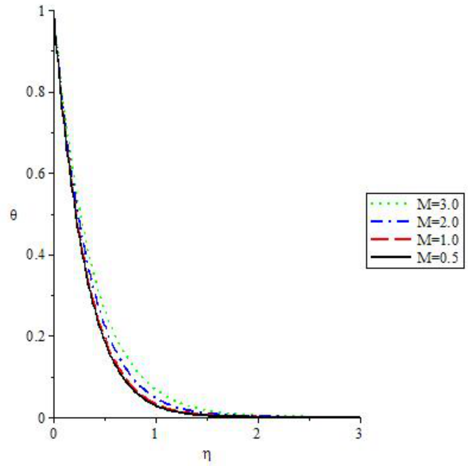

Fig. 3: Temperature profiles for different values of M

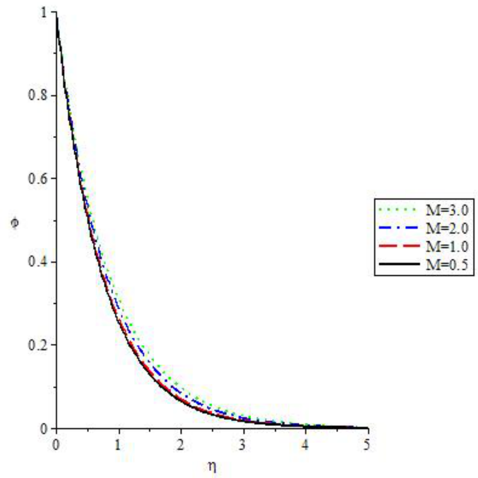

Fig. 4: Concentration profiles for different values of M

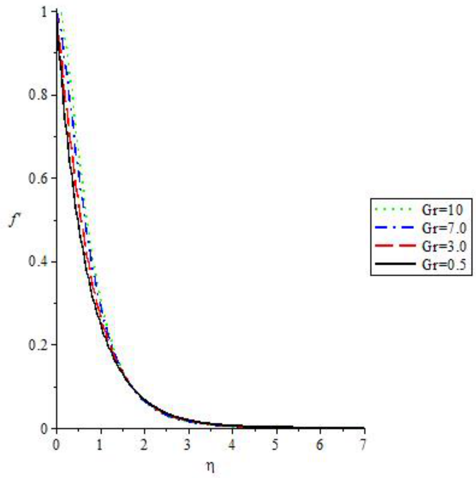

Fig. 5: Velocity profiles for different values of Gr

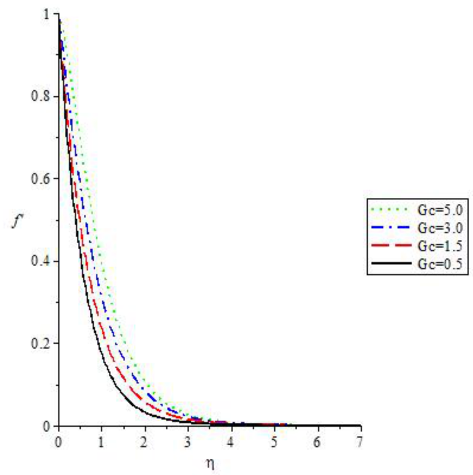

Fig. 6: Velocity profiles for different values of Gc

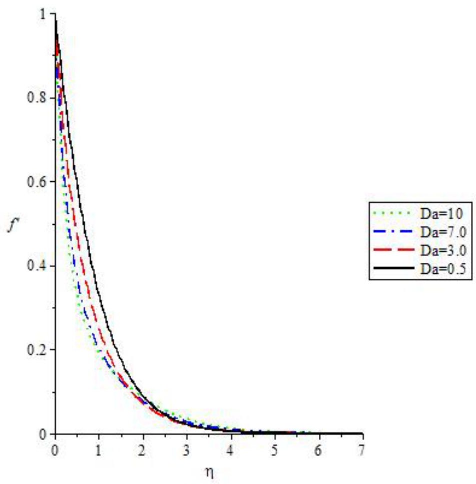

Fig. 7: Velocity profiles for different values of Da

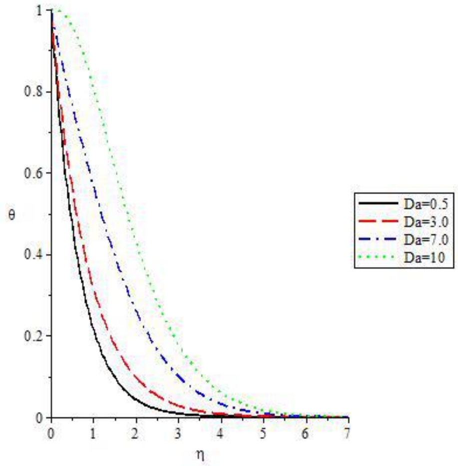

Fig. 8: Temperature profiles for different values of Da

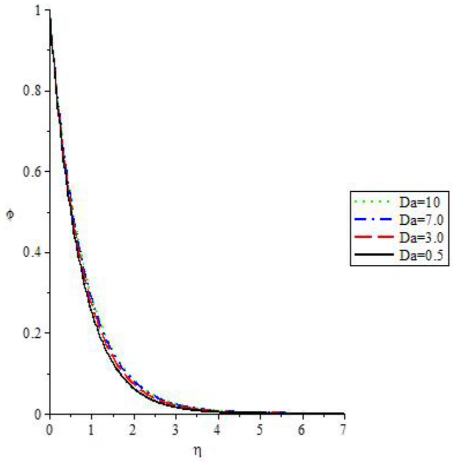

Fig. 9: Concentration profiles for different values of Da

Figures 7, 8 and 9 present the effect of the porosity parameter Da on the velocity, temperature and concentration profiles respectively. There are great changes that occur in both momentum and thermal boundary layers while there is very small changes that occur in concentration boundary layer when changes are made in the values of porosity parameter. The velocity is decreased with increase in the porosity parameter. But the temperature and concentration are increased on increasing the porosity parameter. It is only in the pure convection situations that both the shear layer, thermal boundary layer and mass boundary layer have similar characteristic but in cases where the heat transfer is either influenced by conduction or radiation as in the present study the boundary layers for the flow, temperature and concentration exhibit different behavior.

For variation in the values of radiation parameter R, the dimensionless velocity and temperature profiles are plotted in Figs. 10 and 11. It is obvious from the distribution that velocity and temperature increases with an increase in the radiation parameter. The effects is as a result of thickness in the momentum and thermal boundary layers. Figs. 12 to 14 exhibit the effect of the suction or injection parameter on the dimensionless velocity, temperature and concentration profiles, respectively. It is shown from Fig. 12 that the suction parameter causes decrease in the velocity indicating the fact that suction stabilizes the boundary layer development, while the injection increases the velocity at the boundary layer indicating that injection supports the flow to penetrate more into the fluid. In Fig. 13, it is observed that the temperature decreases as the suction parameter increases. This is due to the fact that larger suction leads to faster cooling of the plate, also the temperature increases as the injection parameter increases, this means that heat is transfered from the fluid to the surface. Fig. 14 shows that the concentration decreases as the suction parameter increases and increases as the injection parameter increases due to respective thinner and thicker in the mass boundary layer.

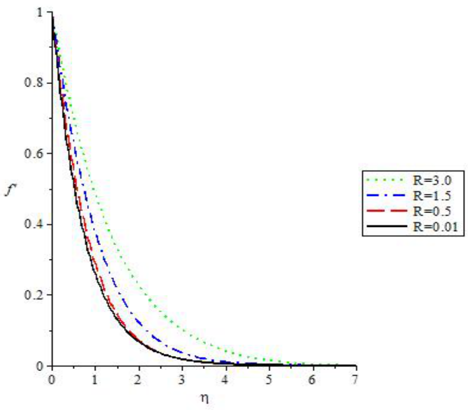

Fig. 10: Velocity profiles for different values of R

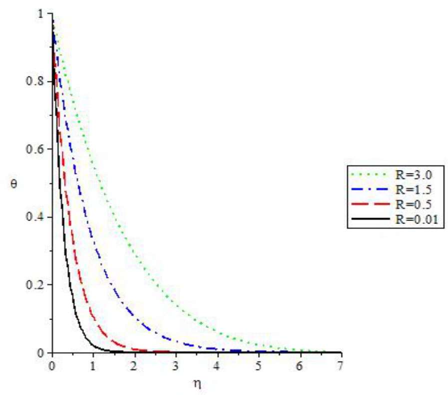

Fig. 11: Temperature profiles for different values of R

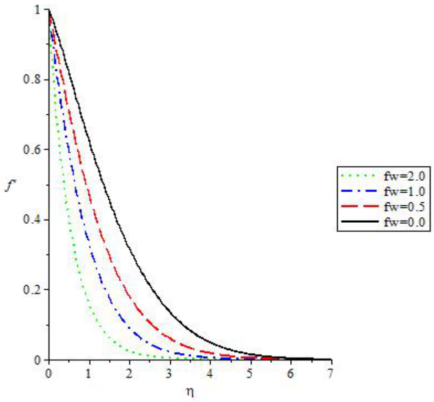

Fig. 12: Velocity profiles for different values of f_w

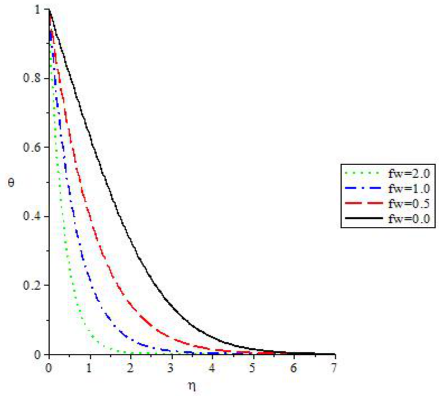

Fig. 13: Temperature profiles for different values of f_w

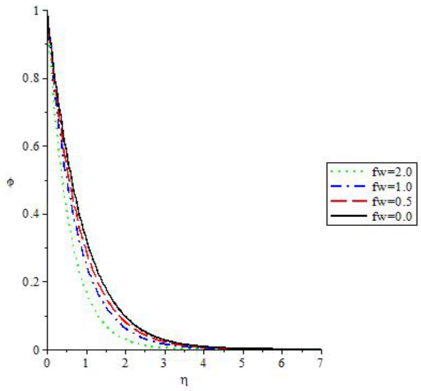

Fig. 14: Concentration profiles for different values of f_w

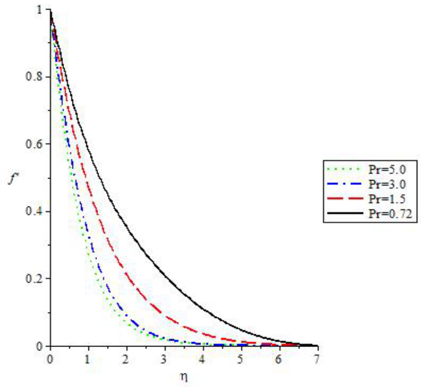

Fig. 15: Velocity profiles for different values of Pr

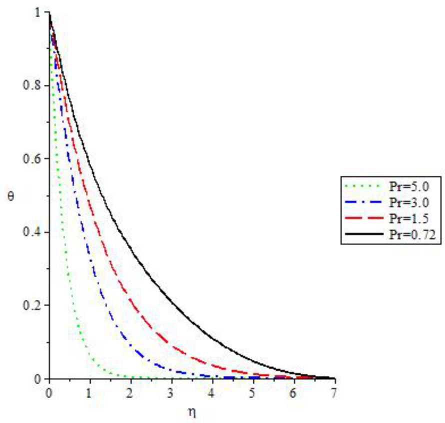

Fig. 16 : Temperature profiles for different values of Pr

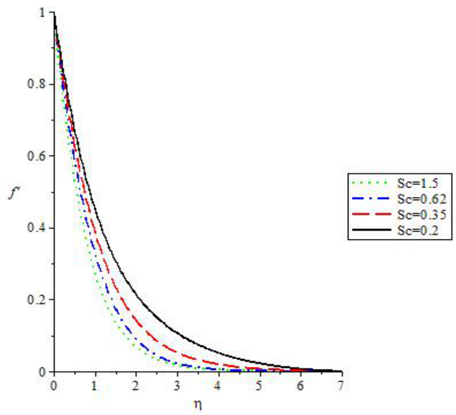

Fig. 17 : Velocity profiles for different values of Sc

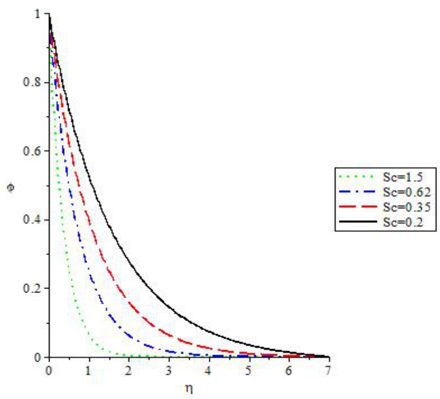

Fig. 18: Concentration profiles for different values of Sc

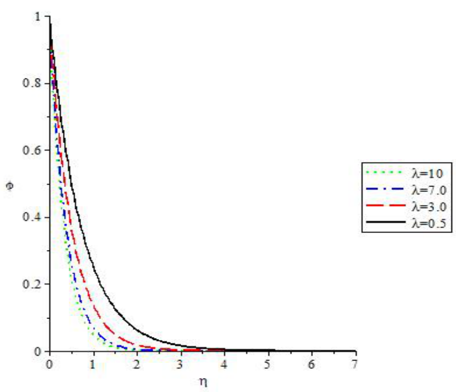

Fig. 19: Concentration profiles for different values of λ

The influences of the Pr on the velocity and temperature distribution are presented in Figs. 15 and 16, respectively. It can be noticed from the figures that as the Pr increases, the dimensionless velocity decreases near the surface and dimensionless temperature also decreases, this is because, as the Pr increases the thickness of the thermal boundary layer decreases and heat is able to diffuse out of the system, hence, the temperature profiles decreases. Figs. 17 and 18 depict the behavior of Sc on the velocity and concentration profiles. Schmidt number can be define as the ratio of the momentum to the mass diffusivity. It is seen that the velocity and concentration profiles reduces as the Schmidt number increases. Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic velocity and concentration boundary layers. Fig. 19 examines the effects of the chemical reaction parameter λ on the concentration distribution. It is seen clearly that when the parameter λ increases there is a decrease in the mass boundary layer thickness. Hence, the concentration distributions decreases.

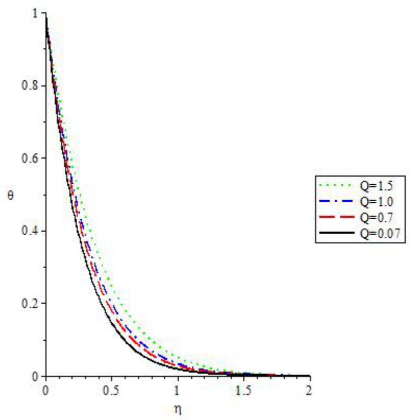

Fig. 20: Temperature profiles for different values of Q

The effects of the presence of heat source $(Q \succ 0)$ or heat sink $(Q \prec 0)$ in the boundary layer on temperature distribution is presented in Fig. 20. It is found that variation in the values of heat source generates energy which causes the temperature of the fluid to increase. Therefore, the presence of heat sink in the boundary layer absorbs energy which influence the temperature of the fluid to decrease, and this corresponds with the observation in the figure, in which it is noticed that the dimensionless temperature increases with the heat source $(Q \succ 0)$ increasing, while it decreases with the heat sink $(Q \prec 0)$ increasing.

Conclusion

In the present study, a steady magnetohydrodynamic (MHD) flow in a porous medium over an exponentially stretching porous surface with thermal radiation of heat transfer by taking mass transfer, heat source/sink and chemical reaction into account are analyzed. The governing equations of the model are approximated to a system coupled non-linear ordinary differential equations by similarity transformation. Numerical analysis are carried out for various values of the dimensionless parameters of the modeled problem. The results show that the momentum boundary layer thickness decreases, while both thermal and mass boundary layer thicknesses increase with an increase in the magnetic field and porosity parameters. The flow velocity, temperature and concentration boundary layers decreases with an increase in the porosity of the plate, Prandtl and Schmidt numbers. It is also observed that the velocity profiles increases with corresponding increase in the thermal and solutant Grashof numbers. An increase in the velocity and temperature distribution is also recorded in the variation in the values of radiation parameter. Moreover, it is found that concentration decreases with increasing in chemical reaction parameter while temperature increases with increase in heat source parameter. The outcome of this research paper are useful to real life especially in broadcasting of radio, microwaves, X-ray, cosmic rays. It will also help the end users to determine how electromagnetic waves are capable of carrying energy form one location to another.

References

Ali M & Alam MS 2014. Soret and hall effect on MHD flow, heat and mass transfer over a vertical stretching sheet in a porous medium due to heatgeneration . *ARPN J. Engr. & Appl. Sci.*, 9(3): 361-371.

Aziz MAE 2014. Unsteady mixed convection heat transfer along a verticalstretching surface with variable viscosity and viscous dissipation. *J. Egyptian Mathematical Soc.*, 22: 529-537.

Bhattacharyya K 2011. Effects of radiation and heat source/sink on unsteady MHD boundary layer flow and heat transfer over a shrinking sheet with suction/injection. *Front. Chem. Sci. Engr*., 5: 376-384.

Bhattacharyya K 2012. Steady boundary layer flow and reactive mass transfer past an exponentially stretching surface in an exponentially moving free stream, *J. Egypt. Math. Soc.*, 20: 223-228.

Bidin B & Nazar R 2009. Numerical solution of the boundary layer flow over an exponentially stretching sheet with thermal radiation. *Eur. J. Sci. Res.*, 33(4): 710-717.

Cortell R 2005. Flow and heat transfer of a fluid through a porous medium over a stretching surface with internal heat generation/ absorption and suction/blowing, fluid dynamics. *Eur. J. Sci. Res*., 37: 231-245.

Cortell R 2006. Effects of viscous dissipation and work done by deformation on the MHD flow and heat transfer of a viscoelastic fluid over a stretching sheet, *Phys. Lett. A* 357: 298-305.

Devi RLVR, Neeraja A & Reddy NB 2015. Radiation effect on MHD slip flow past a stretching sheet with variable viscosity and heat source/sink. *Int. J. Scientific & Innovative Maths. Res.*, 3(5): 8-17.

Dinarrand S, Khalil S, Hossein R, Dehkordi IR & Tamim H2014. Stagnation point flow and heat transfer of a nanofluid adjacent to linearly stretching/shrinking sheet: A numerical study. *Res. J. of Appl. Sci. Eng. & Techn.*, 7(1): 83-90.

Hayat T, Abbas Z & Sajid M 2006. Series solution for the upper convected Maxwellfluid over a porous stretching plate. *Phys. Lett., A* 358: 396-403.

Hayat T & Sajid M 2007. Analytic solution for axi-symmetric flow and heattransfer of a second grade fluid past a stretching sheet. *Int. J. Heat Mass Transfer*, 50: 75-84.

Hussain S & Ahmad F 2015. Unsteady MHD flow and heat transfer for Newtonianfluids over an exponentially stretching sheet. *Sci Int. (Lahore)*, 27(2): 853-857.

Ibrahim SM & Sunnetha K 2015. Effect of heat generation and thermal radiationon MHD flow near a stagnation point on a linear stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer. *J. Computational & Appl. Res. Mechanical Engr.,* 4(2): 133-144.

Ishak A 2011. MHD boundary layer flow due to an exponentially stretching sheet with radiation effects. *Sain Malaysiana,* 40(4): 391-395.

Kala BS, Singh M & Kumar A 2014. Steady MHD free convective flow and heat transfer over nonlinearly stretching sheet embedded in an extended Darcyforcheimmer porous medium with viscous dissipation. *J. Global Res. Inmathematical Achives,* 1-5.

Khan SK 2006. Boundary layer viscoelastic fluid flow over an exponentiallystretching sheet. *Int. J. Appl. Mech. Eng.* 11: 321-335.

Magyari E & Keller B 1999. Heat and mass transfer in the boundary layers on an exponentially stretching continuous surface. *J. Physics D: Appl. Physics,* 32: 577-585.

Mohanty A, Rath PK & Dash GC 2014. Unsteady flow of a visco-elastic fluid along vertical porous surface with fluctuating temperature and concentration. *IOSR J. Engr.,* 4(4): VI, 46-57.

Mukherjee B & Prasad N 2014. Effects of radiation and porosity parameteron hydromagnetic flow due to exponentially stretching sheet in a porous medium. *Int. J. Engr. Sci. & Techn.,* 6(1): 58-70.

Mukhopadhyay S & Gorla RSK 2012. Effects of partial slip on boundary layerflow past a permeable exponential stretching sheet in presence of thermal radiation, heat mass transfer. *Ain Shams Eng. J.,* 10.1007/00231-012-1024-8.

Mukhopadhyay S 2012. Slip effects on MHD boundary layer flow over an exponentiallystretching sheet with suction/blowing and thermal radiation, *Ain. Shams Eng. J.*, 2012.10.007.

Nadeem S, Zaheer S & Fang T 2011. Effects of thermal radiation on the boundary layer flow of a Jeffrey fluid over an exponentially stretching surface. *Numerical Algorithm.,* 10.1007/s11075-010-9423-8.

Nalinakshi N, Dinesh PA & Chandrashekar DV 2013. Effect of variable fluidproperties and MHD on mixed convection heat transfer from a vertically heated plate embedded in a sparsely packed porous Medium. *IOSR J. Mathematics,* 7(1): 20-31.

Pal D 2010. Mixed convection heat transfer in the boundary layer on an exponentially stretching surface with magnetic field. *Appl. Math. Comput.* 217: 2356-2369.

Rauta AK & Mishra 2014. Heat transfer of a Dusty fluid over a stretching sheetwith internal heat generation/absorption. *Int. J. Res.Engr. & Techn.,* 28-43.

Rehman A, Nadeem S & Malik MY 2013. Stagnation flow of couple stress nanofluidover an exponentially stretching sheet through a porous medium. *J. Power Techn.,* 93(2): 122-132.

Sajid M & Hayat T 2008. Influence of thermal radiation on the boundary layer flowdue to an exponentially stretching sheet. *Int. Commun. Heat Mass Transfer,* 35: 347-356.

Sandeep N, Sulochana C & Sugunmma V 2015. Radiation and magnetic field effect on unsteady mixed convection flow over a vertical stretching/shrinking surfacewith suction/injection. *Indus. Engr. Letters,* 5(5): 127-136.

Sanjayanand F & Khan SK 2006. On heat and mass transfer in a viscoelasticboundary layer flow over an exponentially stretching sheet. *Int. J. Therm. Sci.,* 45: 819-828.

Sharma PK 2004. Unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat transfer past a semi-infinite vertical porous plate. *J. Computational Materials & Sci.,* 40: 186-192.

Sharma PR, Sharma M & Yadav RS 2014. Viscous dissipation and mass transfer effects on unsteady MHD free convective flow along a moving vertical porous plate in the presence of internal heat generation and variable suction. *Int. J. Sci. & Res. Publications,* 4(9): 1-9.

Shekkar KVC 2014. Boundary layer phenomena of MHD flow and heat transfer over an exponentially stretching sheet embedded in a thermally stratified medium. *Int. J. Sci. Engr. & Techn. Res.,* 3(10):2715-2721.

Srihari K, Amand RJ & Kishan N 2006. MHD free convection flow of anincompressible viscous dissipative fluid in an infinite vertical oscillating plate withconstant heat flux. *Int. J. Energy, Heat & Mass Transfer,* 28: 19-28.

Srivas M & Kishan N 2015. Unsteady MHD flow and heat transfer of nanofluidover a permeable shrinking sheet with thermal radiation and chemical reaction. *Ame. J. Engr. Res.,* 4(6): 68-79.

Sulochana C & Kumar MKK 2015. Nonlinear thermal radiation and chemical reaction effects on MHD 3D casson fluid flow in porous medium. *Chemical & Process Engr. Res.,* 37: 24-34.

Turkyilmazoglu M 2012. Exact analytical solutions for heat and mass transfer of MHD slip flow in nanofluids, *Chem. Eng. Sci.,* 84: 182-187.

Uwanta LJ & Isah BY 2012. Boundary layer fluid flow in a channel with source, Soret effects and slip condition. *Nig. J. Basic & Appl. Sci.,* 20(4): 327-340.

Vajravelu K & Cannon JR 2006. Fluid flow over a nonlinear stretching sheet. *Appl. Mathematics Computing,* 181: 609-618.