Asian Journal of Physical and Chemical Sciences

4(2): 1-9, 2017; Article no.AJOPACS.37260
ISSN: 2456-7779

Thermal Radiation and Heat Absorption Effect on Heat and Mass Transfer over an Exponential Stretching Porous Surface with Viscous Dissipation

O. A. Esan[1], J. F. Baiyeri[1*], T. O. Ogunbayo[1] and O. E. Enobabor[1]

[1]Department of Mathematics, Yaba College of Technology, Yaba, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author OAE formulated the problem and the derivation of equations, author JFB solved the problem, did the table and the graphs. Author TOO carried out the mathematical analysis and discussion of result while author OEE managed the literature searches and review. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJOPACS/2017/37260
Editor(s):
(1) Macid Nurbas, Chemical Engineering Department, Eskisehir Osmangazi University, Turkey.
Reviewers:
(1) I. L. Animasaun, Federal University of Technology, Nigeria.
(2) Alok Kumar Pandey, Roorkee Institute of Technology, India.
(3) John Abraham, University of St. Thomas, USA.
(4) Sumit Gupta, Swami Keshvanand Institute of Technology, India.
Complete Peer review History: http://www.sciencedomain.org/review-history/22224

Original Research Article

Received 7th October 2017
Accepted 29th November 2017
Published 9th December 2017

ABSTRACT

The study of natural convective boundary layer flow of heat and mass transfer of incompressible viscous dissipative fluid over a porous stretching vertical surface in the presence of thermal radiation with heat absorption in a porous medium is considered. A similarity variables is used to reduce the governing system of PDEs to a set of nonlinear ordinary differential equations which are solved numerically using shooting technique coupled with fourth order Runge-Kutta method. The numerical computations are presented in graphically and tabular for various fluid parameters controlling the fluid flow of heat and mass transfer. It is observed that an increase in radiation produced a rise in the velocity, temperature and concentration profiles. Skin friction and Nusselt number increased with an increase in the radiation.

Keywords: Radiation; stretching surface; porosity; heat absorption; dissipation.

**Corresponding author: E-mail: baiyeri.funsho@gmail.com;*

1. INTRODUCTION

The study of compressible, laminar boundary layer flow of momentum, energy and species transfer over a stretching sheet are important from practical and theoretical point of view as a result of their wider applications in polymer technology and metallurgy. The thermal buoyancy forces arising due to the heating and flow species of stretching surface, under some circumstances, may alter significantly the flow, thermal and mass fields as well as the heat and mass transfer behaviour in the manufactuing processes [1-5]. As a result, [6] investigated the effects of radiation and heat source/sink on unsteady MHD boundary layer flow and heat transfer over a shrinking sheet with suction/injection. A study was carried out on the numerical solution for thermal radiation effect on inclined magnetic field of MHD free convective heat transfer dissipative fluid flow past a moving vertical porous plate with variable suction as in [7-10]. In the same vein, [11] investigated series solutions of unsteady magnetohydrodynamics flows of non-Newtonian fluids caused by an impulsively stretching plate. It was found out that for a fixed time with increasing Schmidt number, the concentration profiles reduces for fixed Schmidt number as time increases.

More also, [4] examined the influence of radiation and magnetic field effect on unsteady mixed convection flow over a vertical stretching/shrinking surface with suction/injection. The finding revealed that an increase in magnetic field parameter cause a decrease in the field flow rate. [12] presented the effect of heat generation and thermal radiation on MHD flow near a stagnation point on a linear stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer. The analysis shows that an increase in the Prandtl number leads to a decrease in the temperature profile, while a rise in the thermal or solutant Grasshof number leads to increase in the velocity profile. [13] reported on nonlinear thermal radiation and chemical reaction effects on MHD 3D Casson fluid flow in porous medium. Fluid viscosity is assumed to vary as a linear function of temperature. Also, [8] investigated analytic solution for axi-symmetric flow and heat transfer of a second grade fluid past a stretching sheet.

Moreover, several literature are presented on boundary layer flow over a stretching plate where the velocity of the stretching surface is assumed to be linearly proportional to the distance from the fixed origin. However, [14] established that stretching of plastic sheet may not necessarily be linear. [15] examined the heat and mass transfer in the boundary layers on an exponentially stretching surface. Suction and heat transfer characteristics in the flow over an exponentially stretching sheet was presented by [16]. Approximate analytic similarity solution for viscoelastic boundary layer flow over an exponentially stretching surface has been investigated by [17]. While, [18,19] studied the effects of thermal radiation on the flow due to an exponentially stretching surface. MHD boundary layer flow due to an exponentially stretching sheet with radiation effect was studied by [20,21]. An analysis on the effect of magnetic field on boundary layer flow and heat transfer of a dusty fluid over an exponentially stretching surface with an exponential temperature distribution was reported by [22,23] they considering the Saffman model for flow problem. From the results, it was obtained that the effect of pressure variations within the enclosed space has a negligible effect on the buoyancy and on the resulting surface of the heat transfer coefficients.

This present study examine the combine effects of thermal radiation and viscous dissipation on heat and mass transfer over an exponentially porous stretching surface with heat absorption in a porous medium. The study is implemented using Runge-Kutta method with shooting techniques. The system remains invariant due to some relations among the parameters of the transformations. In section 2, the introduction to the study is presented, while section 3 illustrated the numerical solution and section 4 depicted the results and discussion of all important embedded parameters in the flow.

2. FLOW MODEL FORMULATION

Considering a free convective, the boundary layer flow, heat and mass transfer of viscous incompressible fluid over an exponentially stretching surface. The flow is produced as a result of linear stretching of the surface, caused by the simultaneous action of two forces along the x-axis. Keeping the origin fixed, the plate is stretched with a velocity U_0, varying linearly with the distance from the slit. It is assumed that the stretching surface is kept at temperature T_W and the concentration C_w respectively. The ambient values are attained as $y \to \infty$, of T and C are represented by T_∞ and C_∞ respectively. Under the usual boundary layer approximations, The geometry and equations governing the fluid flow of heat and mass transfer according to Boussinesq model [9,17,22], are as follows:

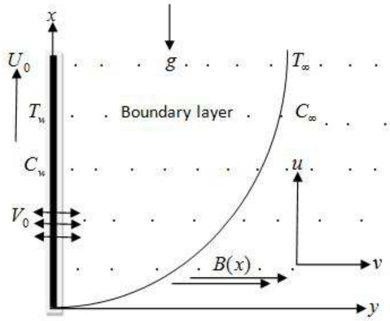

Fig. 1. The physical model and Coordinate System

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta_T(T-T_\infty)+g\beta_C(C-C_\infty)-\frac{\nu}{K}u \tag{2}$$

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

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

Subject to the following boundary conditions:

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

where u, u, C, and T are velocity component in the x direction, velocity component in the y direction, concentration of the fluid species, fluid temperature respectively. L is the reference length, U_0 is the reference velocity, V_0 is the permeability of the porous surface respectively. The physical quantities ρ, ν, D, k, C_p, K, Q_0 and γ are the density, fluid kinematics viscosity, coefficient of mass diffusivity, thermal conductivity of the fluid and specific heat, Porosity, heat 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. The Rosseland approximation is adopted for the expression of thick radiation heat flux in the heat equation with gray radiating liquid, non-scattering but with absorbing-emitting depending on wavelength [24,25]. 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. 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.

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

In order to transform the governing equations (1) to (5), the following similarity transformations variables are introduced [17].

$$\begin{gathered}\psi(x,y)=\sqrt{2\nu U_0L}e^{\frac{x}{2L}}f(\eta),\eta=y\sqrt{\frac{U_0}{2\nu L}}e^{\frac{x}{2L}},T\\=T_\infty+T_0e^{\frac{x}{2L}}\theta(\eta),\\C=C_\infty+C_0e^{\frac{x}{2L}}\phi(\eta)\end{gathered} \tag{8}$$

The governing equations reduces to system of ordinary differential equations as follow:

$$f'''+ff''-2f'^2+Gr\theta+Gc\phi-Daf'=0 \tag{9}$$

$$\left(1+\frac{4}{3}R\right)\theta''+P_rf\theta'-P_rf'\theta+PrEc(f'')^2-PrQ\theta=0 \tag{10}$$

$$\phi'' + S_c f\phi' - S_c f'\phi - Sc\lambda\phi = 0 \quad (11)$$

The corresponding boundary conditions take the form:

$$\begin{aligned} &f = f_w, f' = 1, \theta = 1, \phi = 1 \ \ at \ \ \eta = 0 \\ &f' = 0, \theta = 0, \phi = 0 \ \ as \ \ \eta \to \infty \end{aligned} \quad (12)$$

where $Da = \frac{2\nu L}{U_0 K} e^{-\frac{x}{L}}$ is the Darcy parameter, $Gr = \frac{2Lg\beta_T T_0}{U_0^2} e^{-\frac{3x}{2L}}$ is the thermal Grashof number, $Gc = \frac{2Lg\beta_C C_0}{U_0^2} e^{-\frac{3x}{2L}}$ is the solutant Grashof number, $Pr = \frac{\rho\nu C_p}{k}$ is the Prandtl number, $Q = \frac{2LQ_0}{U_0 \rho C_p} e^{-\frac{x}{L}}$ is the heat absorption parameter, $R = \frac{4\sigma_0 T_\infty^3}{\delta k}$ is the thermal radiation parameter, $Sc = \frac{\nu}{D}$ is the Schmidt number, $f_w = V_0 \sqrt{\frac{2L}{\nu U_0}} e^{-\frac{3x}{2L}}$ is the permeability of the plate, $\lambda = \frac{2L\gamma}{U_0} e^{-\frac{x}{L}}$ is the chemical reaction parameter, $Ec = \frac{U_0}{\rho(T - T\infty)}$ is the viscous dissipation parameter.

The skin friction coefficient C_{fx} , the Nusselt number Nu_x and the Sherwood Sh_x number are given by

$$C_{fx} = \frac{2\mu}{\rho u_w^2} \frac{\partial u}{\partial y}\bigg|_{y=0} = \sqrt{\frac{2x}{LRe_x}} f''(0) \quad (13)$$

$$Nu_x = -\frac{x}{T_w - T_\infty} \frac{\partial T}{\partial y}\bigg|_{y=0} = -\sqrt{\frac{xRe_x}{2L}} theta'(0) \quad (14)$$

$$Sh_x = -\frac{x}{C_w - C_\infty} \frac{\partial C}{\partial y}\bigg|_{y=0} = -\sqrt{\frac{xRe_x}{2L}} phi'(0) \quad (15)$$

3. METHOD OF SOLUTION

The governing equations of convection, heat and mass transfer in fluids are essentially nonlinear ordinary differential equations. Hence, the system of nonlinear ordinary differential equations together with the boundary conditions are solved numerically using fourth order Runge-Kutta scheme with a shooting technique see [25,26].

Let,

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \end{pmatrix} = \begin{pmatrix} \eta \\ f \\ f' \\ f'' \\ f''' \\ \theta \\ \theta' \\ \phi \\ \phi' \end{pmatrix} \quad (16)$$

Then, it becomes,

$$\begin{pmatrix} x_1' \\ x_2' \\ x_3' \\ x_4' \\ x_5' \\ x_6' \\ x_7' \\ x_8' \\ x_9' \end{pmatrix} = \begin{pmatrix} 1 \\ x_3 \\ x_4 \\ x_5 \\ x_5 + x_2 x_4 - 2x_3^2 + Grx_6 + Gcx_8 - Dax_3 \\ x_7 \\ \frac{-3(Prx_2x_7 - Prx_3x_6 - PrEc(x_4)^2 + PrQx_6)}{3+4R} \\ x_9 \\ -(Scx_2x_9 - Scx_3x_8 + Sc\lambda x_8) \end{pmatrix} \quad (17)$$

Table 1. Effect of f_w, G_r, G_c, S_c, P_r, R and λ on $f''(0)$, $\theta'(0)$ and $\phi'(0)$

P	values	$f''(0)$	$\theta'(0)$	$\phi'(0)$	P	values	$f''(0)$	$\theta'(0)$	$\phi'(0)$
f_w	0.5	-0.39356	-2.94639	-1.33911	S_c	0.2	-0.38511	-3.94712	-0.75191
	1.0	-0.72229	-3.81430	-1.51023		0.62	-0.72229	-3.81430	-1.51023
	1.5	-1.11098	-4.77441	-1.70001		1.2	-0.92066	-3.73435	-2.35701
	2.0	-1.54965	-5.79574	-1.90816		2.0	-1.05491	-3.68497	-3.39680
Da	0.01	-0.68253	-3.82420	-1.51312	P_r	0.7	0.35638	-1.36411	-1.54371
	0.5	-0.88962	-3.77138	-1.49830		1.5	-0.56375	-2.29442	-1.52252
	1.0	-1.08057	-3.72021	-1.48521		3.0	-0.72229	-3.81430	-1.51023
	1.5	-1.25528	-3.67160	-1.47372		5.0	-0.81614	-5.68088	-1.50489

$$\begin{pmatrix} x_1(0) \\ x_2(0) \\ x_3(0) \\ x_4(0) \\ x_5(0) \\ x_6(0) \\ x_7(0) \\ x_8(0) \\ x_9(0) \end{pmatrix} = \begin{pmatrix} 0 \\ f_w \\ 1 \\ a_1 \\ b_1 \\ a_2 \\ a_3 \\ 1 \\ a_4 \end{pmatrix} \qquad (18)$$

where $f_w, b_1, a_1, a_2, a_3, a_4$ are unknown constants to be determined.

The computations have been performed using a symbolic program and computational computer language MAPLE software.

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: $Sc = 0.62$, $Pr = 3$, $Da = 0.01$, $R = 0.1$, $\lambda = 1$, $fw = 1$, $Gr = 2$, $Gc = 2$, $Q = 0.5$, $Ec = 0.2$. All graphs are correspond to the value except otherwise indicated on the graph.

4. RESULTS AND DISCUSSION

Table 1 represent the numerical results of variation in Skin friction, Nusselt and Sherwood numbers at the surface with f_w, Da, S_c and P_r which are of physical and engineering interest. From the results it seen that an increase in f_w decreases the skin friction, Nusselt and Sherwood numbers respectively due to decrease in the boundary layers. An increase in the values of Da decreases the skin friction but increases the Nusselt and Sherwood profiles. Variations in the value of S_c decreases the wall layer of skin friction and Sherwood number but increase the Nusselt number. Also, increase in P_r decreases the skin friction and Nusselt number while it causes increase in the Sherwood number.

Fig. 2 shows the effect of thermal Grashof number Gr on the rate of fluid flow. From the figure, it is seen that increasing in the parameter Gr leads to an increase in the flow rate, as a result, the velocity boundary layer thickened. Hence, heat as a strong influence on flow rate. While, the effect of solutant Grashof number Gc on the velocity distribution is illustrated in Fig. 3. 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 distribution.

For variation in the values of radiation parameter R, the dimensionless velocity and temperature profiles are plotted in Figs. 3 and 4. 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. Figure 5 shows the velocity profiles for various values of the viscous dissipation parameter, Eckert number Ec. The Eckert number represent the relationship between the kinetic energy in the flow and the enthalpy. It contains the conservation of kinetic energy into internal energy by work done against the viscous fluid stress. Hence, it is found that as parameter Ec increases, the velocity distribution increases due to decrease in the fluid particle bounding forces.

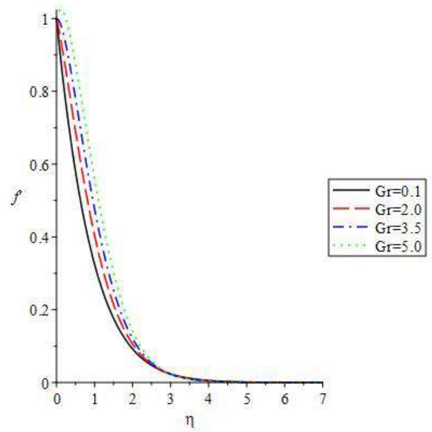

Fig. 2. Velocity Profiles for different values of Gr

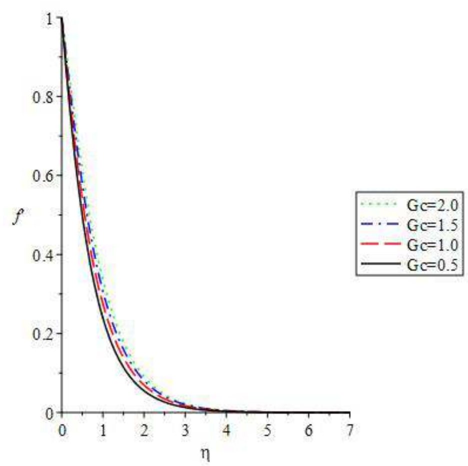

Fig. 3. Velocity Profiles for different values of Gc

Fig. 6 exhibits the effect of the suction or injection parameter on the dimensionless velocity profiles. It is shown from figure 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. This is due to the fact that larger suction leads to faster cooling of the plate surface thereby decreases the flow fluid rate in the system.

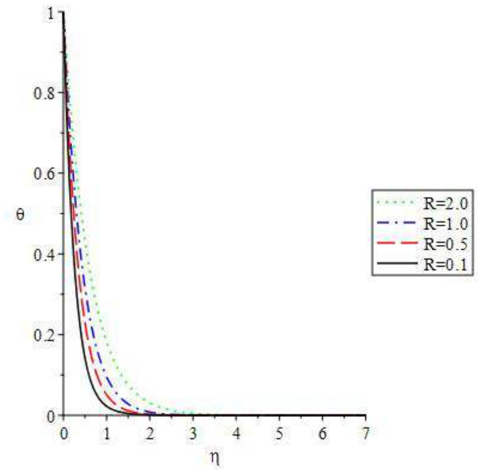

Fig. 4. Temperature Profiles for different values of R

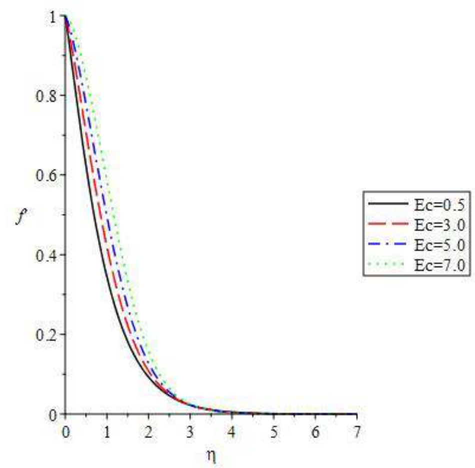

Fig. 5. Velocity Profiles for different values of Ec

The influences of the Prandtl number P_r on the temperature distribution are presented in Fig. 7. It can be noticed from the figure that as the Prandtl number P_r increases, the dimensionless temperature decreases, this is because, as the Prandtl number increases the thickness of the thermal boundary layer decreases and heat is able to diffuse out of the system, hence the temperature profiles decreases.

Fig. 8 depicts the behavior of Schmidt number S_c on the concentration profiles. Schmidt number can be define as the ratio of the momentum to the mass diffusivity. It is seen that the concentration profiles reduces as the

Schmidt number increases. Schmidt number quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic concentration boundary layers.

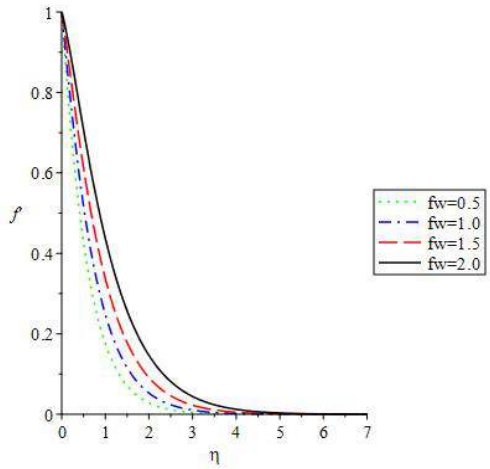

Fig. 6. Velocity Profiles for different values of f_w

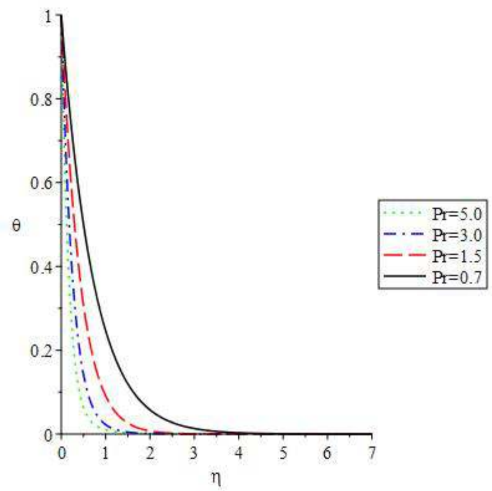

Fig. 7. Temperature Profiles for different values of Pr

Fig. 9 illustrates the effect of the porosity parameter Da on the velocity profiles. There are great changes that occur in the momentum boundary layers when changes are made to the values of porosity parameter. The velocity is decreased with an increase in the porosity parameter. Porosity resist free flow of fluid in the system.

The effects of the presence of heat sink Q on the temperature distribution is presented in figure 10. From the figure, It is found that variation in the values of heat absorption reduces energy transfer in the system by causing the temperature of the fluid to decrease. 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.

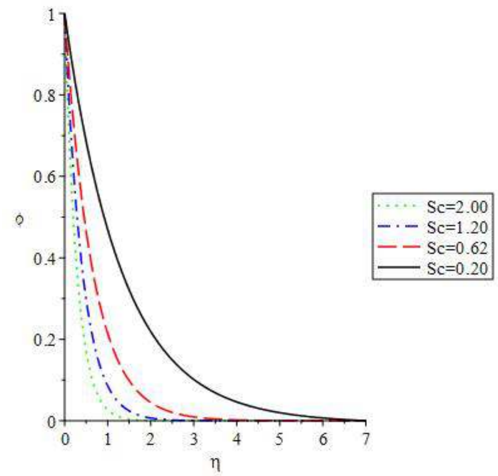

Fig. 8. Concentration Profiles for different values of Sc

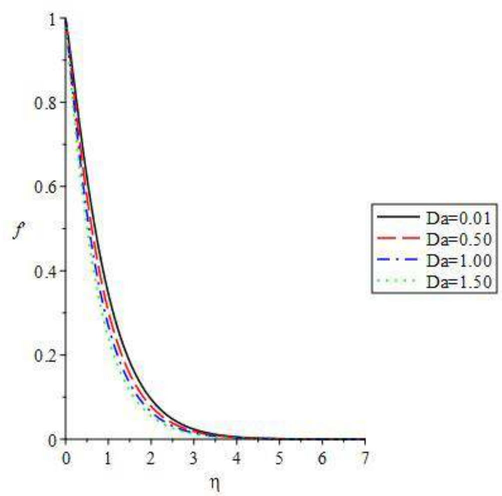

Fig. 9. Velocity Profiles for different values of Da

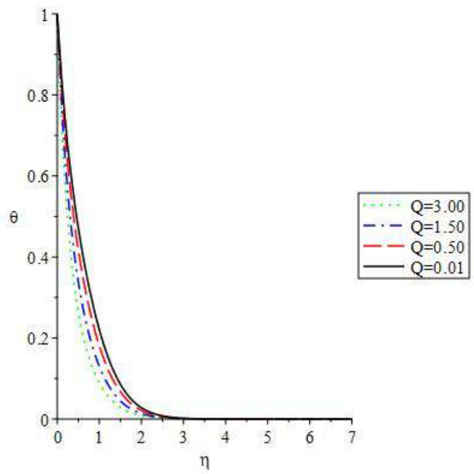

Fig. 10. Temperature Profiles for different values of Q

5. CONCLUSION

The effects of radiation, dissipation and chemical reaction on fluid flow, heat and mass transfer over an exponentially porous stretching surface in a porous medium was considered. The resulting governing equations are simplified and solved using fourth order Runge-Kutta method with shooting technique. The velocity distribution increases with an increase in the value of buoyancy forces but reduces as the porosity parameter rises. The fluid temperature profile increases with an increase in thermal radiation and thermal dissipation parameters while fluid temperature decreases with an increase in Prandtl number. Also, the concentration field decreases with an increase Schmidt number and chemical reaction term. The study is limited to Newtonian fluid. Hence, it can be extended to non-Newtonian fluid flow, turbulent and compressible flow.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ali M, Alam MS. Soret and hall effect on MHD flow, heat and mass transfer over a vertical stretching sheet in a porous medium due to heat generation. ARPN Journal of Engineering and Applied Sciences. 2014;9(3):361-371.
2. Ajayi TM, Omowaye AJ, Animasaun IL. Viscous dissipation effects on the motion of Casson fluid over an upper horizontal thermally stratified melting surface of a paraboloid of revolution: Boundary layer analysis. Journal of Applied Mathematics. 2017;13.
3. Hayat T, Abbas Z, Sajid M. Series solution for the upper convected Maxwell fluid over a porous stretching plate, Phys. Lett. A. 2006;358:396-403.
4. Sandeep N, Sulochana C, Sugunmma V. Radiation and magnetic field effect on unsteady mixed convection flow over a vertical stretching/shrinking surface with suction/injection. Industrial Engineering Letters. 2015;5(5):127-136.
5. Mukhopadhyay S. Slip effects on MHD boundary layer flow over an exponentially stretching sheet with suction/blowing and thermal radiation, Ain Shams Eng. Journal. 2012;10-17.
6. Bhattacharyya K. Effects of radiation and heat source/sink on unsteady MHDboundary layer flow and heat transfer over a shrinking sheet with suction/injection, Front.Chem. Sci. Eng. 2011;5:376-384.
7. Ali ME. On thermal boundary layer on a power law stretched surface with suction or injection, Int. J. Heat Fluid Flow. 1995;16: 280-290.
8. Hayat T, Sajid M. Analytic solution for axi-symmetric flow and heat transfer of a second grade fluid past a stretching sheet, Int. J. Heat Mass Transfer. 2007;50:75-84.
9. Dada MS, Salawu SO. Analysis of heat and mass transfer of an inclined magnetic field pressure-driven flow past a permeable plate. Applications and Applied Mathematics: An Int. J. 2017;12(1):189-200.
10. Animasaun IL, Aluko OB. Analysis on variable fluid viscosity of non-Darcian flow over a moving vertical plate in a porous medium with suction and viscous dissipation. IOSR Journal of Engineering (IOSRJEN). 2014;4:18-32.
11. Xu H, Liao SJ. Series solutions of unsteady magnetohydrodynamics flows of non-Newtonian fluids caused by an impulsively stretching plate. J. Non-Newtonian Fluid Mech. 2005;159:46-55.
12. Ibrahim SM, Sunnetha K. Effect of heat generation and thermal radiation on MHD flow near a stagnation point on a linear stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer. Journal of

Computational and Applied Research in Mechanical Engineering. 2015;4(2):133-144.
13. Sulochana C, Kumar MKK. Nonlinear thermal radiation and chemical reaction effects on MHD 3D casson fluid flow in porous medium. Chemical and Process Engineering Research. 2015;37:24-34.
14. Gupta PS, Gupta AS. Heat and mass transfer on a stretching sheet with suction or blowing. The Canadian Journal of Chemical Engineering. 1997;55(6):744-746.
15. Magyari E, Keller B. Heat and mass transfer in the boundary layers on an exponentially stretching continuous surface. Journal of Physics D: Applied Physics. 1999;32(5):577-585.
16. Elbashbeshy EMA. Heat transfer over an exponentially stretching continuous surface with suction. Archives of Mechanics. 2001;53(6):643-651.
17. Khan SK, Sanjayanand E. Viscoelastic boundary layer flow and heat transfer over an exponential stretching sheet. International Journal of Heat and Mass Transfer. 2005;48(8):1534-1542.
18. Sajid M, Hayat T. Influence of thermal radiation on the boundary layer flow due to an exponentially stretching sheet. International Communications in Heat and Mass Transfer. 2008;35(3):347-356.
19. Kalpna S, Sumit G. Analytical study of MHD boundary layer flow and heat transfer towards a porous exponentially stretching sheet in presence of thermal radiation. Int. J. Adv. Appl. Math. and Mech. 2016;4(1):1-10.
20. Ishak A. MHD boundary layer flow due to an exponentially stretching sheet with radiation effect. Sains Malaysiana. 2011;40(4):391-395.
21. Alok KP, Manoj K. Natural convection and thermal radiation influence on nanofluid flow over a stretching cylinder in a porous medium with viscous dissipation. Alexandria Eng. J. 2017;55-62.
22. Sparrow EM, Abraham JP. A new buoyancy model replacing the standard pseudo-density difference for internal natural convection in gases. International Journal of Heat and Mass Transfer. 2003;46:3583-3591.
23. Gireesha BJ, Pavithra GM, Bagewadi CS. Boundary layer flow and heat transfer of a dusty fluid over an exponentially stretching Sheet. British Journal of Mathematics & Computer Science, 2012;2(4):187-197.
24. Salawu SO, Fatunmbi EO. Dissipative heat transfer of micropolar hydromagnetic variable electric conductivity fluid past inclined plate with joule heating and non-uniform heat generation. Asian Journal of Physical and Chemical Sciences. 2017;2(1):1-10.
25. Boetcher SKS, Sparrow EM, Abraham JP. Numerical simulation of the radiative heating of a moving sheet. Numerical Heat Transfer. 2005;47:1-25.
26. Alok KP, Manoj K. Effect of viscous dissipation and suction/injection on MHD nanofluid flow over a wedge with porous medium and slip. Alexandria Engineering Journal. 2016;55(4):3115-3123.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/22224