EFFECT OF THERMAL RADIATION ON MAXWELL FLUID FLOW OVER A STRETCHING SURFACE WITH SLIP EFFECT

Elsayed M.A. Elbashbeshy
Mathematics Department, Faculty of Science, Ain Shams University, Abbassia, Cairo, Egypt
K.M. Abdelgaber
Department of Physics & Engineering Mathematics,
Faculty of Engineering - Mataria, Helwan University, Cairo, Egypt
N.M. Badra
Department of Physics and Engineering Mathematics,
Faculty of Engineering, Ain Shams University, Cairo, Egypt
K.K. Ahmed
Department of Mathematics, the German University in Cairo-GUC,
New Cairo City-Main Entrance Al Tagamoa Al Khames, Cairo, Egypt

Abstract: The influence of thermal radiation on flow and heat transfer of a chemically reacting Maxwell fluid past a linearly stretching surface with the effect of slipping is discussed numerically. The governing boundary layer partial differential equations are reduced to a system of ordinary differential equations with the help of suitable similarity transformations. Mathematica has been used to solve such kind of system after obtaining the missing initial conditions. Comparison of obtained numerical results is made with previously published results in some special cases and is found to be in a very favorable agreement with them.

Keywords: Stretching Surface, Maxwell Fluid, Thermal Radiation, Slip Effect, Chemical Reaction.

Introduction: The boundary layer behavior on a moving continuous solid surface in a viscous fluid at rest is considered by Sakiadis [1, 2]. The same study was applied for a continuous moving surface by Tsou et al. [3]. There are numerous industrial applications based on the study of flow over a stretching sheet such as polymer extraction where the object enters the fluid for cooling below a certain temperature, chemical processes, nuclear reactors, casting, aerodynamic extrusion of plastic sheets, and rolling wire drawing. Then, mathematical model was introduced to study the flows over a stretching sheet by Crane [4] whose work was consequently extended by [5-27]. In many studies of fluid flows, the slipping boundary condition is not considered. Although, there are many situations wherein the slipping boundary condition holds. Muthucumaraswamy et al. [28] studied the effects of heat and mass transfer on an unsteady flow through an impulsively vertical plate. Also, the flow affected by the transfer of the heat and mass was studied by Kar et al. [29] and Vedavathi et al. [30].

In the design of many advanced energy conversion systems operating at high temperatures, the role of the thermal radiation must be considered. In these systems, the thermal radiation usually comes from the emission between the working fluid and the medium. Many processes in new engineering areas occur at high temperature so it is very important to know the radiative heat transfer to make an efficient design of the pertinent equipment. Gas turbines, nuclear power plants, and the various propulsion engines for aircraft and space vehicles are real life examples for such engineering areas.

On the other hand, the flow over stretching surfaces with different assumptions on the flow was discussed by Mukhopadhyay [31], Abbasi et al. [32], and Bhattacharyya et al. [34]. From the nature of Maxwell fluid, it is a non-Newtonian fluid. Recently, there are a very wide range of usage of non-Newtonian fluids because of their tremendous applications in petroleum production, chemical, and power engineering.

In the present study, the Maxwell fluid flow over a linearly stretching sheet with slip effect under the influence of thermal radiation is considered numerically using similarity transformations that transform the system of partial differential equations into a system of ordinary differential equations.

Mathematical Model: Consider a two-dimensional steady laminar flow of Maxwell fluid of concentration $C_w = C_0$ over a linearly stretching sheet with surface temperature $T_w = T_0$. Also, assume that the sheet is stretched with velocity $U_w(x) = cx$ where c is the stretching rate. The x −axis is taken along the sheet in the direction of the motion and y −axis is perpendicular to it as shown in Fig. 1.

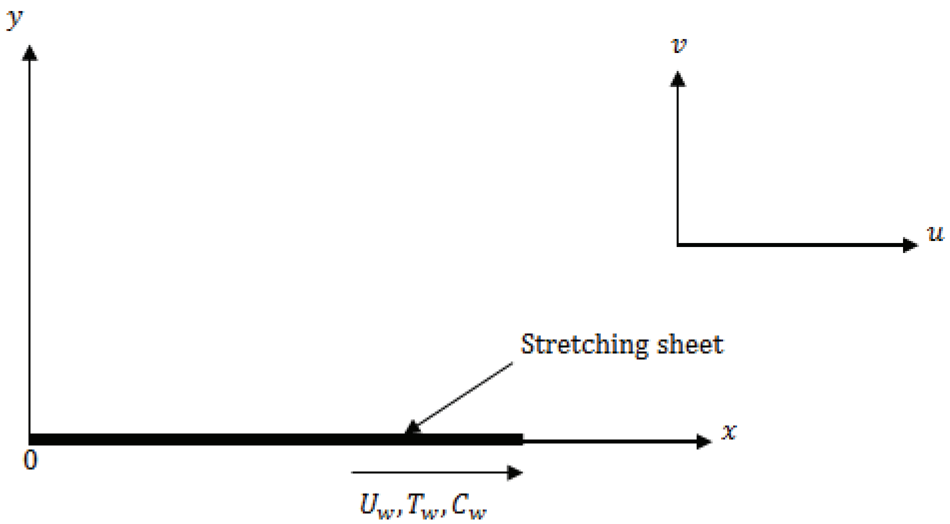

Fig. 1: Physical Model and Coordinate System

Then, for the system shown above the two-dimensional boundary layer governing equations of an incompressible Maxwell fluid are given as follows:

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \lambda_1\left[u^2\frac{\partial^2 u}{\partial x^2} + v^2\frac{\partial^2 u}{\partial y^2} + 2uv\frac{\partial^2 u}{\partial x \partial y}\right] = \nu\frac{\partial^2 u}{\partial y^2}, \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}, \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} \tag{4}$$

with the following associated boundary conditions:

$$\begin{aligned} &\text{at } y = 0: \quad u = U_w + A\frac{\partial u}{\partial y}, v = 0, T = T_w, C = C_w \\ &\text{as } y \to \infty: \quad u \to 0, v \to 0, T \to T_\infty, C \to C_\infty \end{aligned} \tag{5}$$

where u and v are the velocity components in the x and y directions, respectively; ν is the kinematic viscosity, T is fluid temperature, λ_1 is the relaxation time of the period which can characterize the time-dependency of a non-Newtonian fluid when stress is applied to it, the resulting strain can be time dependent, A is a constant, ρ is the fluid density, c_p is the specific heat at constant pressure, α is the thermal diffusivity, k^* is the mean absorption coefficient, T_∞ is the free stream temperature, D_B is the mass diffusivity, q_r is radiation heat flux, C is the concentration of the Maxwell fluid, and T_0 and C_0 are the reference temperature and concentration, respectively.

It is assumed that the viscous dissipation is neglected and the physical properties of the fluid are constants. Using the Rosseland approximation for radiation [22] simplifies the radiative heat flux as

$$q_r = -\frac{4\sigma^*}{3\alpha^*}\frac{\partial T^4}{\partial y}, \qquad (6)$$

where σ^* and α^* are the Stefan-Boltzman constant and the mean absorption coefficient, respectively. The temperature differences within the flow are assumed such that the term T^4 may be expressed as a linear function of temperature. Hence, expanding T^4 in a Taylor series about T_∞ and neglecting higher-order terms lead to

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

By using eqs (6-7), the energy eq (3) becomes

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \frac{16\sigma^*}{3k^*\rho c_p}\frac{\partial^2 T}{\partial y^2}, \qquad (8)$$

The equation of continuity is satisfied if a stream function $\psi(x,y)$ is chosen such that $u = \partial\psi/\partial y$ and $v = -\partial\psi/\partial x$. The mathematical analysis of the problem is simplified by introducing the following dimensionless variables:

$$\eta = \sqrt{\frac{c}{\nu}}\,y \qquad (9)$$

$$\psi(x,y) = x\sqrt{c\nu}\,f(\eta) \qquad (10)$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_0}, \phi(\eta) = \frac{C - C_\infty}{C_w - C_0} \qquad (11)$$

Substituting eqs (9-11) into eqs (2), (4), and (8) yields

$$f''' + De[2ff'f'' - f^2 f'''] + ff'' - f'^2 = 0. \qquad (12)$$

$$\theta'' + \frac{Pr}{1+R}[f\theta' - f'\theta] = 0 \qquad (13)$$

$$\phi'' + S_c[f\phi' - f'\phi] = 0 \qquad (14)$$

with the corresponding boundary conditions:

$$f(0) = 0,\ f'(0) = 1 + S_l f''(0),\quad \theta(0) = 1,\quad \phi(0) = 1$$
$$\lim_{\eta\to\infty} f'(\eta) = 0,\quad \lim_{\eta\to\infty}\theta(\eta) = 0,\quad \lim_{\eta\to\infty}\phi(\eta) = 0 \qquad (15)$$

where the prime denotes the differentiation with respect to η, $De = \lambda_1 c$ is the Deborah number, $Re_x = U_w\, x/\nu$ is the local Reynolds number, $R = 16\sigma^* T_\infty^3/3k^*\rho c_p$ is the thermal radiation parameter, $Pr = \nu/\alpha$ is the Prandtl number, $S_c = \nu/D_B$ is the Schmidt number, and $S_l = A\sqrt{c/\nu}$ is the velocity slip parameter. The parameters of physical interest for the present problem are the local skin friction coefficient C_f, the local Nusselt number Nu_x, and Sherwood number Sh_x which are defined as

$$C_f = \frac{\tau_w}{\rho U_w^2}, \qquad Nu_x = \frac{xq_w}{k(T_w - T_\infty)}, \qquad Sh_x = \frac{xq_m}{D_B(C_w - C_\infty)} \qquad (16)$$

where $\tau_w = -\mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is the wall shear stress, $q_w = -k\left(\frac{\partial T}{\partial y}\right)_{y=0}$ is the surface heat flux. and $q_m = -D_B\left(\frac{\partial C}{\partial y}\right)_{y=0}$ is the surface mass flux.

Substituting the similarity transformations, eqs (9-11), into eq (16) yields the skin friction coefficient, the local Nusselt, and Sherwood numbers in dimensionless forms as follows:

$$\sqrt{Re_x}C_f = (1 + De)f''(0), \qquad \frac{Nu_x}{\sqrt{Re_x}} = -\theta'(0), \qquad \frac{Sh_x}{\sqrt{Re_x}} = -\phi'(0) \qquad (17)$$

Numerical Solutions

Firstly, the partial differential eqs (12-14) are converted into the following linear system of first order ordinary differential equations as follows:

$$y_1' = y_2 \qquad (18)$$

$$y_2' = y_3 \qquad (19)$$

$$y_3' = \frac{1}{1 - De\, y_1^2}[y_2^2 - y_1 y_3 - 2De\, y_1 y_2 y_3] \qquad (20)$$

$$y_4' = y_5 \qquad (21)$$

$$y_5' = \frac{P_r}{1+R}[y_2 y_4 - y_1 y_5] \qquad (22)$$

$y_6' = y_7$ (23)

$y_7' = S_c[y_2 y_6 - y_1 y_7]$ (24)

where $y_1 = f,\ y_4 = \theta$, and $y_6 = \phi$

the corresponding initial conditions are:

$$y_1(0) = 0, \quad y_2(0) = 1 + S_l y_3(0), \quad y_3(0) = S, \quad y_4(0) = 1, \quad y_5(0) = K, \quad y_6(0) = 1 \text{, and } y_7(0) = L \tag{25}$$

where S, K, and L are priori unknowns to be determined as a part of the numerical solution.

The system of eqs (18-24) subjected to the initial conditions in eq (25) are solved using fourth/fifth order Runge-Kutta method with the aid of shooting method as used and detailed by Elbashbeshy et al. [35]. The accuracy of the numerical method is checked out by performing various comparisons at different conditions with previously published papers. The results for the local Nusselt number $-\theta'(0)$ are compared with those reported in Grubka and Bobba [8] for different values of Pr which are found to be in a favorable agreement as shown in Table 1. Also, the results for the skin-friction coefficient $-f''(0)$ are compared with those reported in Mukhopadhyay [31] for different values of De which are found to be in a very good agreement as shown in Table 2.

Results and Discussions: Further, the effects of various physical parameters such as Deborah number (De), thermal radiation parameter (R), the Schmidt number (Sc), the velocity slip parameter (S_l), and Prandtl number (Pr) on velocity, temperature, and concentration have been discussed in detail as shown in Table 3. Numerical values for skin friction coefficient, the local Nusselt, and Sherwood numbers are given in Table 3.

Table 1: Comparison of $-\theta'(0)$ for various values of Pr when $De = R = Sc = S_l = 0$.

Pr	Grubka and Bobba [8]	Present Results
0.01	0.0197	0.01969
0.72	0.8086	0.79199
1.0	1.0000	1.0000
3.0	1.9237	1.9186
10.0	3.7207	3.71798
100.0	12.2940	12.29035

Table 2: Comparison of $-f''(0)$ for various values of De when $Pr = R = Sc = S_l = 0$.

De	Mukhopadhyay [31]	Present results
0	0.999963	0.99995
0.2	1.051949	1.05271
0.4	1.101851	1.100351
0.6	1.150162	1.150162
0.8	1.196693	1.196693

Figures 2-10 were drawn to know the attitude of velocity, temperature, and concentration distribution under the influence of different governing parameters. The effect of Deborah number (De) on temperature, velocity, and concentration profiles, respectively is exhibited in Figs 2, 3, and 4. These figures enable us to conclude that an increase in the values of De slows down the velocity profiles but enhances the fluid temperature and concentration significantly. Higher values of De correspond to more relaxation time which reduces the momentum boundary layer thickness and increases the temperature and concentration boundary layer thickness. Figure 5 depicts the influence of Prandtl number (Pr) on temperature distribution. It is evident that the fluids with higher values of Pr have lower temperature. Also, the influence of increasing the Prandtl number Pr is to decrease the thickness of the temperature boundary layers. The variation in temperature profiles for different values of thermal radiation (R) was given in Fig.6. It is known that an increase in the values of R produces heat in the flow. So, a boost in temperature profiles is observed. Figure 7 is plotted to examine the behavior of concentration profiles for different values of Schmidt number (Sc). From this figure, it can be noticed that increasing values of Sc suppress the concentration distribution. In the case of thinner concentration boundary layers, the concentration slopes will be enhanced making a decrease in concentration of species in the boundary layer. The effects of velocity slip parameter on the velocity component, temperature distribution, and concentration are demonstrated in Figs. 8, 9, and 10, respectively. The fluid velocity is reduced till a certain value of η which is 1.4 as it is shown below in Fig. 9 then its behavior is reversed by increasing η. Temperature and concentration distribution enhances by increasing the values of the velocity slip parameter. In other words, less amount of flow is drawn and pushed away in the velocity direction, as the slip gets stronger.

Table 3: The values of $-(1+De)\,f''(0), -\theta'(0)$ and $-\phi'(0)$ for various values of Pr, De, R, S_l and Sc

Parameters (fixed values)	Parameter	Parameter (different values)	$-(1+De)\,f''(0)$	$-\theta'(0)$	$-\phi'(0)$
$Pr=7, Sc=1.0, R=1.0, S_l=1.0$	De	1.0	0.45605	1.51306	0.697938
		3.0	0.49124	1.40822	0.616178
		5.0	0.51529	1.33032	0.559008
		8.0	0.54107	1.24072	0.495141
$Pr=7, Sc=1.0, De=1.0, S_l=1.0$	R	0	0.45605	2.23416	0.697938
		0.5	0.45605	1.78274	0.697938
		1.0	0.45605	1.51306	0.697938
		1.5	0.45605	1.32868	0.697938
$Pr=7, R=1.0, De=1.0, S_l=1.0$	Sc	0.5	0.45605	1.51306	0.427155
		1.0	0.45605	1.51306	0.697938
		1.5	0.45605	1.51306	0.724599
		2.0	0.45605	1.51306	1.086277
$Sc=1.0, R=1.0, De=1.0, S_l=1.0$	Pr	0.7	0.45605	0.32586	0.697938
		4.5	0.45605	1.16660	0.697938
		7.0	0.45605	1.51306	0.697938
		100	0.45605	6.33238	0.697938
$Pr=7, Sc=1.0, R=1.0, De=1.0$	S_l	0	1.24174	2.01458	0.905766
		0.4	0.71200	1.72303	0.787015
		1.0	0.45605	1.51306	0.697938
		2.0	0.29344	1.32567	0.616209

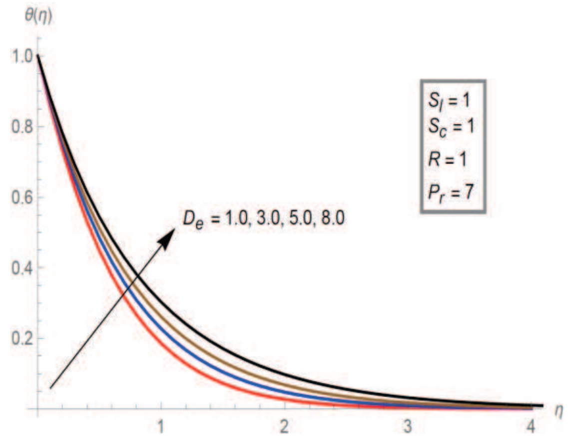

Fig. 2: The temperature profiles $\theta(\eta)$ for various values of De at $S_l = S_c = R = 1, Pr = 7$

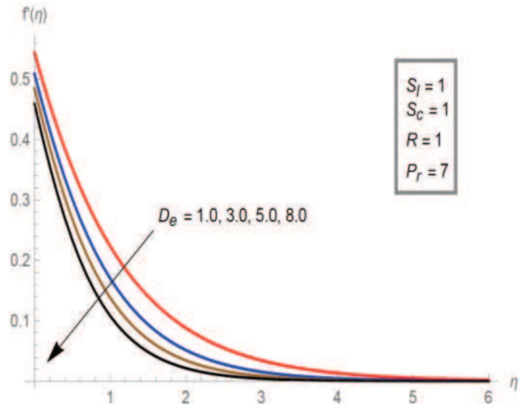

Fig. 3: The velocity profiles $f'(\eta)$ for various values of De at $S_l = S_c = R = 1, Pr = 7$

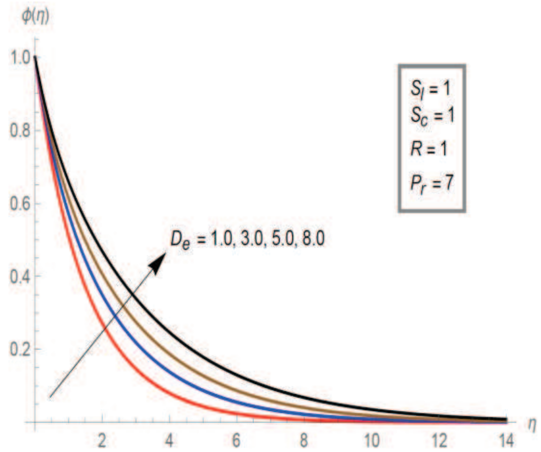

Fig. 4: The concentration profiles $\phi(\eta)$ for various values of De at $S_l = S_c = R = 1, Pr = 7$

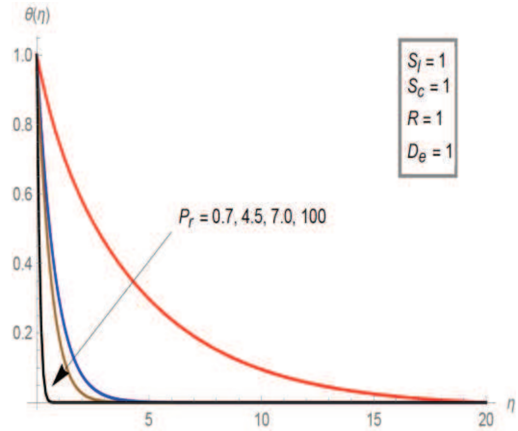

Fig. 5: The temperature profiles $\theta(\eta)$ for various values of Pr at $S_l = S_c = R = De = 1$

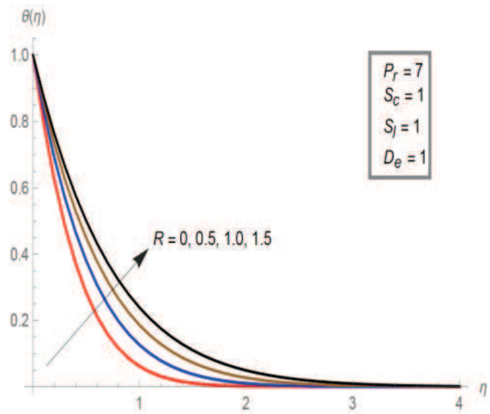

Fig. 6: The temperature profiles $\theta(\eta)$ for various values of R at $S_l = S_c = De = 1, Pr = 7$

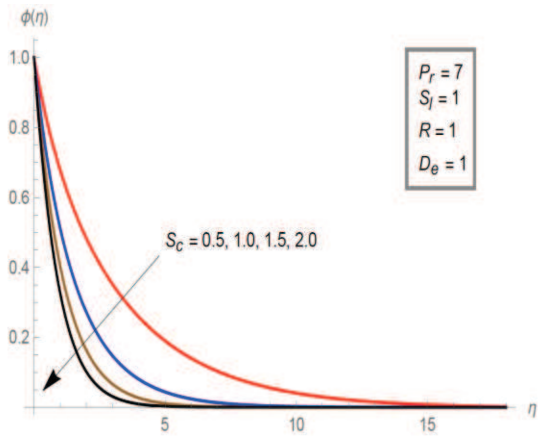

Fig. 7: The concentration profiles $\phi(\eta)$ for various values of S_c at $S_l = De = R = 1, Pr = 7$

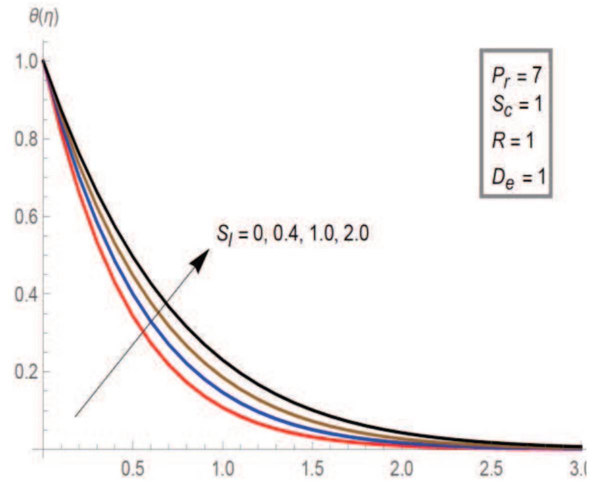

Fig. 8: The temperature profiles $\theta(\eta)$ for various values of S_l at $R = S_c = De = 1, Pr = 7$

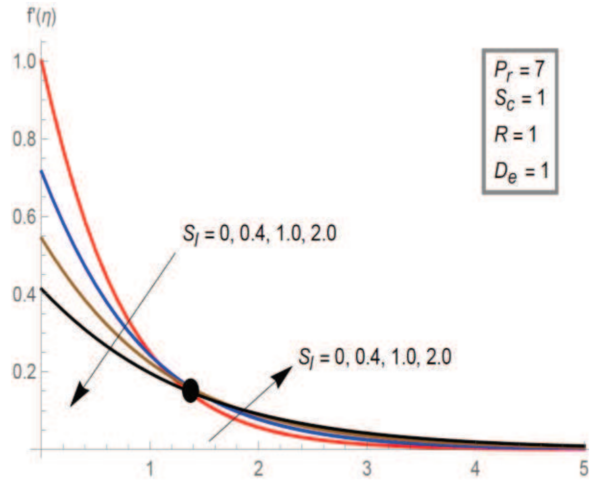

Fig. 9: The velocity profiles $f'(\eta)$ for various values of S_l at $R = S_c = De = 1, Pr = 7$

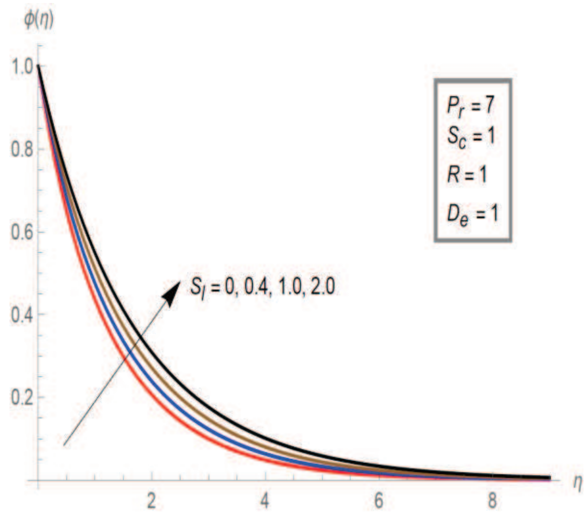

Fig. 10: The concentration profiles $\phi(\eta)$ for various values of S_l at $R = S_c = De = 1, Pr = 7$

Conclusion: Numerical solutions have been obtained for the effects of the thermal radiation and heat transfer of a Maxwell fluid over a linearly steady stretching surface with slip effect. An appropriate similarity transformed was used to transform the system of time -dependent partial differential equations to a set of ordinary differential equations. These equations are solved numerically by applying the shooting technique together with Runge-Kutta fourth/fifth order integration scheme. Numerical computations show that the present values of the rate of heat transfer are in a close agreement with those obtained by previous investigations in the absence of thermal radiation, Deborah number, Schmidt number and no slip effect. The governing features of the presented system are given below:

1. Deborah number effectively increases the temperature field and also the concentration, but an opposite trend is observed in the case of fluid velocity.
2. Increasing value of Schmidt number reduces the concentration of the fluid.
3. Slip effect parameter has a different behavior for the velocity component, but when it increases this enhance the temperature field and also the concentration.

Nomenclature:

C	concentration of the fluid in the boundary layer
C_0	reference concentration
C_f	local skin-friction coefficient
c_p	specific heat due to constant pressure
c	stretching rate,
C_w	concentration near the surface
C_∞	concentration far away from the surface
D_B	mass diffusivity
De	Deborah number
f'	dimensionless velocity of the fluid
k	thermal conductivity of the fluid
k^*	mean absorption coefficient
Nu_x	local Nusselt number
Pr	Prandtl number
q_r	radiation heat flux
q_w	surface heat flux
q_m	surface mass flux
R	thermal radiation parameter
Re_x	Reynolds number
Sc	Schmidt number
Sh_x	local Sherwood number
T	temperature of the fluid in the boundary layer
T_0	reference temperature of fluid
T_w	temperature of fluid near the surface
T_∞	ambient temperature of fluid
S_l	velocity slip parameter
u, v	velocity components along x, y −directions respectively
U_w	stretching surface velocity
x, y	Cartesian coordinates along the surface and normal to it, respectively

Greek letters:

α^*	mean absorption coefficient,
α	the thermal diffusivity,
η	similarity variable,
θ	similarity temperature function,
κ	thermal conductivity,
λ_1	relaxation time of the period,
μ	dynamic viscosity of the fluid,
ν	kinematic viscosity,
ρ	density of fluid,
σ^*	Stefan-Boltzman constant,
τ_w	wall shear stress,
ψ	stream function,

Superscript:

$'$	differentiation with respect to η

Subscripts:

w surface conditions

∞ conditions far away from the surface

References:

1. Sakiadis, B.C., Boundary layer behaviour on continuous solid surface I. Boundary-layer equations for two dimensional and axisymmetric flow. AIChE J 7 (1961) 1, pp. 26-28.
2. Sakiadis, B.C., Boundary layer behaviour on continuous solid surface II. Boundary layer behaviuor on continuous flat surface. AIChE J 7 (1961) 1, pp. 221-235.
3. Tsou, F.K., Sparrow, E.M., Goldstien, R.J. Flow and heat transfer in the boundary layer on a continuous moving surface, Int. J Heat Mass Transfer 10 (1967), pp. 219-235.
4. Crane, L. J. Flow past a stretching plate, Zeitschrift Fur Angewandte Mathematik und Physik ZAMP, Vol. 21, (1970), pp. 645-647.
5. Vulgar, J., Laminar boundary layer behaviour on continuous accelerating surfaces, Chem. Eng. Sci., 32 (1977), pp. 1517-1525.
6. Gupta, P.S., Gupta, A.S., Heat and mass transfer on a stretching sheet with suction or blowing, Canadian J Chem. Eng., 55 (1979) 6, pp. 744-746.
7. Soundalgekar, V. M., Ramana, T.V., Heat transfer past a continuous moving plate with variable temperature, Warme- Und Stoffuber tragung, 14 (1980), pp. 91-93.
8. Grubka, L. J., Bobba, K. M., Heat transfer characteristics of a continuous stretching surface with variable temperature, J Heat Transfer, 107 (1985), pp. 248-250.
9. Ali, M.E., Heat transfer characteristics of a continuous stretching surface, Warme-Und Stoffubertragung, 29 (1994), pp. 227-234.
10. Banks, W.H.H., Similarity solutions of the boundary layer equation for a stretching wall, J Mac. Theo. Appl. 2 (1983), pp. 375-392.
11. Ali, M. E., On thermal boundary layer on a power law stretched surface with suction or injection. Int. J. Heat Mass Flow 16 (1995), pp. 280-290.
12. Elbashbeshy, E. M. A., Heat transfer over a stretching surface with variable heat flux, J Physics D: Appl. Physics., 31 (1998), pp. 1951-1955.
13. Elbashbeshy, E. M. A., Bazid, M. A. A., Heat transfer over a continuously moving plate embedded in a non-Darcian porous medium Int. J. Heat and Mass Transfer, 43 (2000), pp. 3087-3092.
14. H.T. Andersson, H.T., Aarseth, J. B., Dandapat, B.S., Heat transfer in a liquid film on an unsteady stretching surface, Int. J. Heat Transfer, 43 (2000), pp. 69-74.
15. Elbashbeshy, E. M. A., Bazid, M. A. A., Heat transfer over an unsteady stretching surface, Heat Mass Transfer, 41 (2004), pp. 1-4.
16. Ishak, A., Nazar, R., Pop, I., Heat Transfer over an unsteady stretching surface with Prescribed heat flux, Can. J. Phys., 86 (2008), pp. 853-855.
17. Ishak, A., Nazar, R., Pop, I., Heat transfer over an unsteady stretching permeable surface with prescribed wall temperature, Nonlinear Analysis: Real World Applications, 10 (2009), pp. 2909-2913
18. Ali, A., Mehmood, A., Homotopy analysis of unsteady boundary layer flow adjacent to permeable stretching surface in a porous medium. Commun. Nonlinear Sci. Numer. Simul. 13 (2008), pp. 340-349.
19. Elbashbeshy, E. M. A., Dimian, M.F., Effects of radiation on the flow and heat transfer over a wedge with variable viscosity, Appl. Math. Comp., 132 (2002), pp. 445-454 (2008).
20. Hossain, M. A., Alim, M. A., Rees, D., The effect of radiation on free convection from a porous vertical plate, Int. J. Heat Mass Transfer, 42 (1999), pp. 181-191.
21. Hossain, M.A., Khanfer, K., Vafai, K., The effect of radiation on free convection flow of fluid with variable viscosity from a porous vertical plate, Int. J. Therm. Sci., 40(2001), pp. 115-124.
22. Chen, C. H., MHD mixed convection of a power-law Fluid past a stretching surface in the presence of thermal radiation and internal heat generation /absorption, Int. J. of Nonlinear Mechanics, 44(2008), pp. 296-603.
23. Bataller, R. C., Radiation effects in the Blasius flow, Appl. Math. Comput. 198 (2008), pp. 333-338.

24. Fang, T, Zhang, J., Thermal boundary layers over a shrinking sheet: an analytical solution. Acta Mechanica 209 (2010), pp. 325-343.
25. Fang, T.-G., Zhang, J., Yao, S.-S., Viscous flow over an unsteady shrinking sheet with mass transfer. Chin. Phys. Lett. 26 (2009), pp. 014703-1 – 014703-4.
26. Ali, M. E., Magyari, E., Unsteady fluid and heat flow induced by a submerged stretching surface while its steady motion is slowed down gradually. Int. J. Heat Mass Transf. 50 (2007), pp. 188-195
27. Shamara, P. R., Effects of Ohmic heating and viscous dissipation on steady MHD flow near a stagnation point on an isothermal stretching sheet, Thermal Science, 13 (2010), 1, pp. 5-12.
28. Muthucumaraswamy, R., Ganesan, P. and Soundalgekar, V.M. Heat and mass transfer effects on flow past an impulsively started vertical plate, Acta Mechanica, Vol. 146, (2001), pp. 1-8.
29. Kar, M., Sahoo, S. N., Rath, P. K. and Dash, G. C. Heat and mass transfer effects on a dissipative and radiative visco-elastic MHD flow over a stretching porous sheet, Arabian Journal of Science and Engineering, Vol. 39, (2014), pp. 3393-3401.
30. Vedavathi, N., Ramakrishna, K. and Jayarami Reddy, K. Radiation and mass transfer effects on unsteady MHD convective flow past an infinite vertical plate with dufour and soret effects, Ain Shams Engineering Journal, Vol. 6, (2015), pp. 363-371.
31. [31]S. Mukhopadhyay. Heat Transfer Analysis of the Unsteady Flow of a Maxwell Fluid over a Stretching Surface in the Presence of a Heat Source/Sink, Chinese Physical Society, Vol. 29, No. 5 (2012) 054703
32. Abbasi, F. M., Shehzad, S. A., Hayat, T., and Ahmad, B. Doubly. stratified mixed convection flow of Maxwell nanofluid with heat generation/absorption, Journal of Magnetism and Magnetic Materials, Vol. 404, (2016), pp. 159-165.
33. Mukhopadhyay, S. and Bhattacharyya, K. Unsteady flow of a Maxwell fluid over a stretching surface in presence of chemical reaction, Journal of Egyptian Mathematical Society, Vol. 20, (2012), pp. 229-234.
34. Bhattacharyya, K., Layek, G. C. and Gorla, R. S. R. Boundary layer slip flow and heat transfer past a stretching sheet with temperature dependent viscosity, Thermal Energy and Power Engineering, Vol. 2, (2013), pp. 38-43.
35. Elbashbeshy, E.M.A, T.G.Emam, M.S.El-Azab, K.M.Abdelgaber. Effect of thermal radiation on flow, heat, and mass transfer of a nanofluid over a stretching horizontal cylinder embedded in a porous medium with suction/injection, Journal of Porous Media, Vol. 18(3), (2015), pp. 215-229.

***