Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 3, June 2021:580- 590

Research Article

Numerical Analysis of the Impact of Magnetohydrodynamics on Steady Boundary Layer Slip Flow

Yousef Methkal Abd Algani[1], Chitra M[2], Utpal Saikia[3], Sathiyaraj K[4], Firos A[5]

Abstract

We will look at Magneto hydrodynamics on two-dimensional steady boundary layer slip flow and heat transfer over a flat plate in this article. The governing flow equations' non-linear partial differential equations are modified into a system of coupled non-linear ordinary differential equations using appropriate similarity transformations, and the resulting equations are numerically solved using the Runge-kutta fourth order method and the shooting technique. For various governing parameters, the velocity and temperature distributions are determined. Graphs are used to investigate the impact of various non-dimensional parameters such as the Magnetic parameter and the Suction/Blowing parameter. For different values of the magnetic parameter, the skin-friction coefficient and the Local Nusselt number are compared to various slip parameters. With the support of graphs and table values, these findings are discussed.

Keywords: *Heat transfer, Porous medium, Boundary layer slip flow, MHD*

---

[1]Faculty of Education, Department of Teaching Mathematics, Sakhnin College, Israel.
Faculty of Education, Department of Teaching Mathematics, The Arab Academic College for Education in Israel-Haifa. Israel. yusefabdalgani@gmail.com ORCID: 0000-0003-2801-5880
[2]Assistant professor, Department of Mathematics, AVS college of Arts and science, salem -636106
[3]Assistant Professor, Department of Mathematics, Silapathar College, Dhemaji. Email: utpalsaikiajorhat@gmail.com
[4]Assistant professor, Department of Mathematics, AVS college of Technology, Salem 636106
[5]Assistant Professor, Department of computer Science and Engineering, Rajiv Gandhi University (A central university), Rono-Hills, Doimukh-791112, Arunachal pradesh, India. Email: firos.a@rgu.ac.in
Received Accepted

Introduction

Magnetohydrodynamic (MHD) with heat transfer for viscous incompressible fluid flow over a porous plate is beneficial to heat exchanger systems, petroleum reservoirs, chemical catalytic reactors and processes, geothermal and geophysical engineering, aerodynamic engineering, and other engineering fields. In the field of fluid dynamics, the MHD theory is regarded as an essential tool for changing the structure of the boundary layer to influence the flow field in the desired direction. Many engineering and geophysical fields use convection heat transfer and fluid flow through porous media, including geothermal and petroleum resources, solid matrix heat exchanges, filtration and purification processes, thermal insulation drying of porous solids, enhanced oil recovery, and nuclear reactor cooling. This is also used in other practical and fascinating studies, such as agriculture engineering's underground water resource.Many researchers have studied MHD free convective heat and mass transfer flow through porous medium in light of these applications.

Several scientists, including Chen and Char [2], Aziz A [10], Krishnendu Bhattacharyya et al.,[14], have investigated the effects of heat and mass transfer in the presence of a magnetic field under various physical conditions. Recently, Aziz [10] investigated the heat and mass transfer over a vertical plate with a convective surface boundary condition using hydromagnetic mixed convection. T.Watanable and I.Pop [3] have published their findings on the Hall effects on MHD boundary layer flow with a continuous moving semi-infinite flat plate in a viscous incompressible electrically conducting fluid. Salem and Abd El-Aziz [8] investigated the effect of MHD flow on a stretching vertical surface with internal heat generation or absorption in the presence of hall currents and chemical reaction, and Seddeek et al.,[10] extended this work for Hiemenz flow, and Patil and Kulkarni[9] extended this work for Polar fluid.

M.Prasanna Lakshmi et al.,[16] investigated the effects of MHD on the steady free convective boundary layer flow of a viscous incompressible fluid over a linearly moving porous vertical semi-infinite plate with suction and viscous dissipation over a linearly moving porous vertical semi-infinite plate with suction and viscous dissipation. With the aid of a magnetic field, O. D. Makinde [11] investigated convective heat exchange at the surface with the surroundings. Abolbashari et al., [20], Khalili et al., [19], Freidoonimehr et al., [21], and Abolbashari et al., [20] have studied heat and mass transfer as well as entropy production for a steady laminar nanofluid flow in the presence of velocity slip solved analytically using the optimal homotopy analysis process. The issue of transient MHD laminar-free convection flow of nanofluid past a vertical surface was demonstrated by Freidoonimehr et al. [21].

Khalili et al. [19] designed a steady mixed convection boundary layer flow in a porous medium with heat generation and absorption with a specified heat flux. In the presence of magnetic field, thermal radiation, viscous dissipation, and chemical reaction results, Eshetu Haile and B. Shankar [18] investigated the study of boundary layer through porous medium.

In the presence of ohmic heating and viscous dissipation, Kandasamy and Palanimani [5] investigated the effects of chemical reactions, heat, and mass transfer on nonlinear magnetohydrodynamic boundary layer flow over a wedge with a porous medium. Postelnicu [6] investigates the effects of Soret and Dufour on heat and mass transfer with chemical reactions through natural convection from vertical surfaces in porous media. The Steady Flow has been discussed by the authors above. In the presence of slip, S. Mukhopadhyay [12] investigated an unsteady mixed convective boundary layer flow and heat transfer over a stretching vertical surface. The effects of a magnetic field and a chemical reaction on heat and mass transfer flow along a semi-infinite horizontal plate were investigated by Anjalidevi and Kandaswamy [4]. Seddeek[7] investigates the effects of chemical reaction and viscosity variation on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation.

Khalili et al.,[17], investigate mixed convection on a permeable stretching cylinder with a prescribed surface heat flux in a porous medium with heat generation or absorption. Makinde [11] investigates the effect of temperature-dependent viscosity on free convective flow past a vertical porous plate in the absence of a magnetic field, thermal radiation, or chemical reaction. A. A. Bakr [13] investigated MHD heat and mass transfer in a revolving frame of reference for micropolar fluid. Variable thermal conductivity and chemical reaction on steady mixed convection boundary layer flow with heat and mass transfer within a cone due to a point were determined by V. Bisht, M. Kumar, and Z. Uddin [15]. There has been huge interest on heat and mass transfer with chemical reaction of an electrically conducting fluid in the different geometry is analysed. Chambre and Young [1] described the diffusion of a chemically reactive species in a laminar boundary layer flow over a flat plate. The diffusion of a chemically reactive species in a laminar boundary layer flow over a flat plate was presented by Chambre and Young [1].

In the absence of MHD, Asim Aziz, J.I. Siddique, and Taha Aziz [10] investigated steady boundary layer slip flow along heat and mass transfer in porous medium. This gives us a glimpse into what I'm working on now. Due to a void in this analysis, we decided to look into the effects of MHD boundary layer slip flow on heat transfer.

Mathematical Analysis

Consider a two-dimensional laminar flow of an incompressible viscous fluid with heat transfer through a porous flat plate in the presence of a transverse magnetic field embedded in the porous medium. The following assumptions are made to make the model simpler:

Assume that the fluid flow is steady and that no body forces exist.

The system of equations for heat transfer are taken in the following form.

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

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \frac{\nu}{k}u + \frac{\sigma B_0}{\rho}(u) \qquad (2)$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} \qquad (3)$$

where u and v denote velocity components in the x and y directions.

T - fluid temperature,

μ - coefficient of fluid viscosity

ρ - fluid density

σ -constant electrical conductivity of the fluid

$\nu = (\mu/\rho)$ - kinematic fluid viscosity.

k - permeability of porous material

C_p -specific heat at constant pressure

κ - thermal conductivity of the fluid

$B(x)$ - magnetic field in the y-direction and is given by$B(x) = B_0/(x)^{1/2}$.

Boundary conditions are,

$$u = u_w + A_1\left(\frac{\partial u}{\partial y}\right), v = v_w \text{ at y=0; } u \to U_\infty \text{ as } y \to \infty, \tag{4}$$

$$T = T_w + B_1\left(\frac{\partial T}{\partial y}\right) \text{ at } y = 0; T \to T_\infty \text{ as } y \to \infty\ , \tag{5}$$

where $A_1 = A(Re_x)^{1/2}$ - velocity slip factor

$B_1 = B(Re_x)^{1/2}$ - thermal slip factor

We introduce the stream function $\psi(x, y)$ as

$$u = \frac{\partial\psi}{\partial y}\ ,\ v = -\frac{\partial\psi}{\partial x} \tag{6}$$

The similarity transformations are,

$$\psi = \sqrt{U_\infty \gamma x}v(\eta), \theta(\eta) = \frac{T-T_\infty}{T_w-T_\infty} \tag{7}$$

where η is similarity variable defined as $\eta = \sqrt{Re_x}(y/x)$.

Self-similar differential equations are,

$$v''' + \frac{1}{2}vv'' - k^*(v' - 1) - M(v' - 1) = 0, \tag{8}$$

$$\theta'' + \frac{1}{2}Prv\theta' = 0, \tag{9}$$

where $k^* = 1/Da_xRe_x$ permeability of porous medium

$M = \frac{\sigma B_0^2 x}{\rho U_\infty}$ is the magnetic parameter,

$Pr = \mu C_p/\kappa$ is the Prandtl number.

The boundary conditions become,

$$v(\eta) = S, \quad v'(\eta) = \delta v''(\eta) \ \text{ at } \ \eta = 0; \qquad v'(\eta) \to 1 \text{ as } \eta \to \infty \tag{10}$$

$$\theta(\eta) = 1 + \beta\theta'(\eta) \ \text{ at } \ \eta = 0; \qquad \theta(\eta) \to 0 \text{ as } \eta \to \infty \tag{11}$$

where $S = (-2v_w/U_\infty)(Re_x)^{1/2}$, $S > 0$ (i.e.$v_0 < 0$) corresponds to suction and $S < 0$ (i.e.$v_0 > 0$) corresponds to blowing, $\delta = AU_\infty/\gamma$ is the velocity slip parameter, $\beta = BU_\infty/\gamma$ is the thermal slip parameter.

The fourth order Runge-Kutta Method is used to solve the nonlinear coupled ordinary differential equations (8)-(9) with boundary conditions (10)-(11).

$$v' = w, \;\; w' = r, \;\; r' = -0.5rv + k^*(w-1) + M(w-1), \tag{12}$$

$$\theta' = z, \quad z' = -0.5Prvz, \tag{13}$$

and boundary conditions becomes,

$$v(0) = S, \; w(0) = \delta v(0), \quad \theta(0) = 1 + \beta z(0) \tag{14}$$

The skin-friction coefficient C_f , the local Nusselt number Nu_x are given by,

Skin-friction Co-efficient: $C_f = \frac{\tau_w}{\rho U_w^2 x}$

Local Nusselt Number: $Nu_x = \frac{xq_w}{k(T_w - T_\infty)}$

Where $\tau_w$is the skin-friction, q_w is the heat flux

$$\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0}, \;\; q_w = -k\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

Applying the non-dimensionless transformations (7) and we obtain,

$$v''(0) = C_f(Re_x)^{1/2}$$

$$-\theta'(0) = Nu_x(Re_x)^{-1/2}$$

where $Re_x = \frac{xU_w}{\nu}$ is a local Reynolds number.

Results and Discussion

The numerical computations are carried out for a variety of values of the dimensionless parameters in the equations, including the magnetic parameter M, the velocity slip parameter, the thermal slip parameter, and the Prandtl number Pr. Some graphs are plotted to analyse the calculated results and understand the behaviour of various physical parameters of the flow.The figures can be drawn for under the slip and no-slip boundary conditions :

Here solid line δ=β=0.0

Broken line δ=β=0.5

The effect of the magnetic parameter M on velocity profiles in the presence and absence of slip at the boundary is now presented. Figures 1 and 2 depict the effect of the magnetic field parameter M on the velocity and temperature profiles of a flow in the presence and absence of slip at the boundary, respectively. The difference in velocity filed for various values of the magnetic parameter M is shown in Figure 1. The velocity $v'(\eta)$ along the plate increases in both slip and no-slip situations, and the thickness of the boundary layer decreases as a result. The Lorentz force, which is caused by the magnetic field, thins the boundary layer. Figure 2 depicts the temperature difference for various values of the magnetic parameter M. It shows that for slip and no-slip conditions, the temperature $\theta(\eta)$ at a point decreases with M. The thickness of the thermal boundary layer is reduced as the magnetic parameter M is increased.

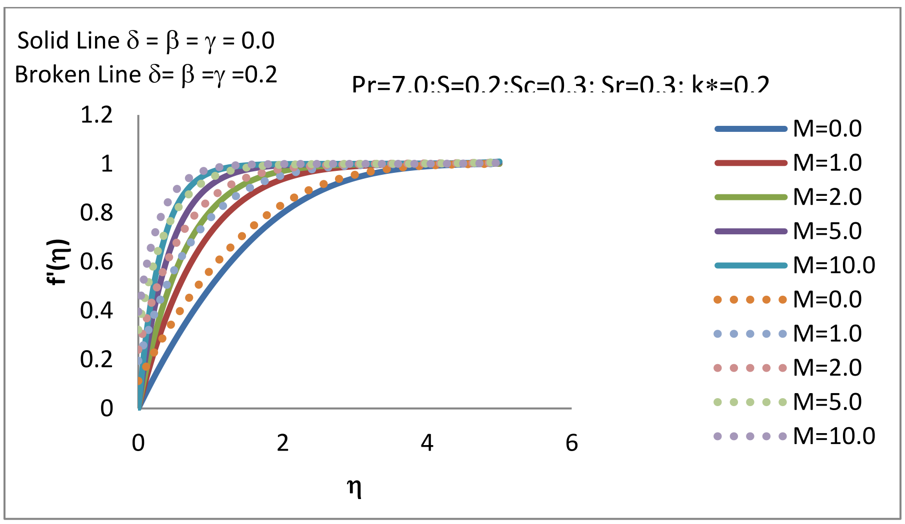

Fig.1. Velocity profiles $v'(\eta)$ for various values of M

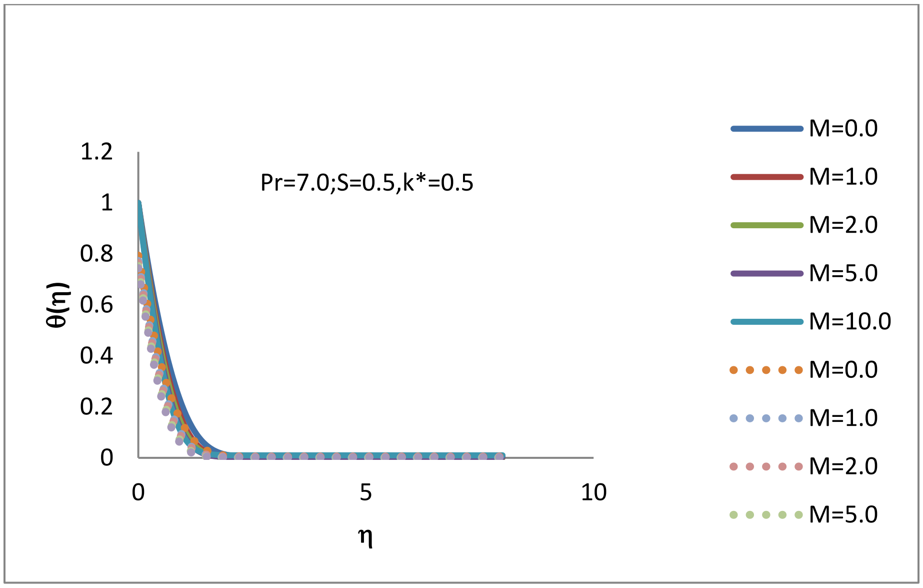

Fig.2. Temperature profiles $\theta(\eta)$ for various values of M

Fig.3. shows the variation in temperature gradient profiles $\theta'(\eta)$ for several values of magnetic parameter M against η. It exhibits that the temperature gradient profiles $\theta'(\eta)$at a point increases with M.

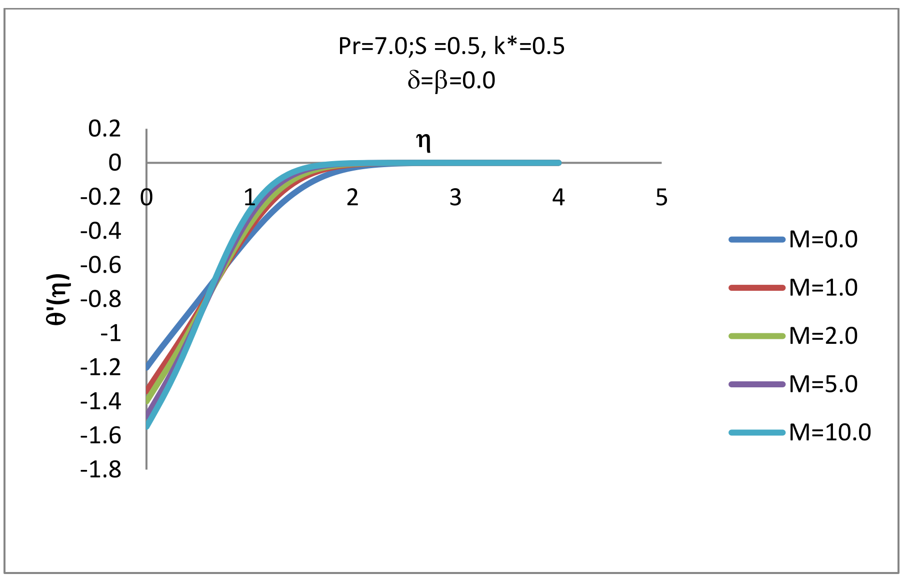

Fig.3. Temperature gradient at the plate $\theta'(\eta)$ against η for various values of M

Next, the effects of the slip parameter on the velocity and temperature profiles are shown in Fig.4. The velocity profiles for different slip parameter values are shown in Fig.4. The fluid velocity increases monotonically as the value of δ increases. The velocity of the fluid adjacent to the plate has a positive value due to the slip condition at the plate, and as a result, the thickness of the momentum boundary layer decreases. **Fig.5**. shows the temperature profiles $\theta(\eta)$for various values of slip parameter δ. It is observed that the temperature decreases with an increase in slip parameter δ.

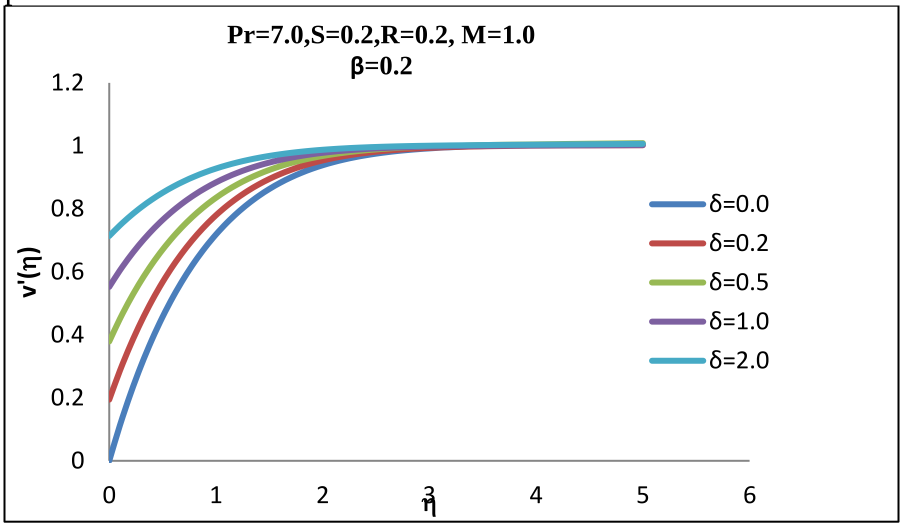

Fig.4. Velocity profiles $v'(\eta)$ for various values of δ.

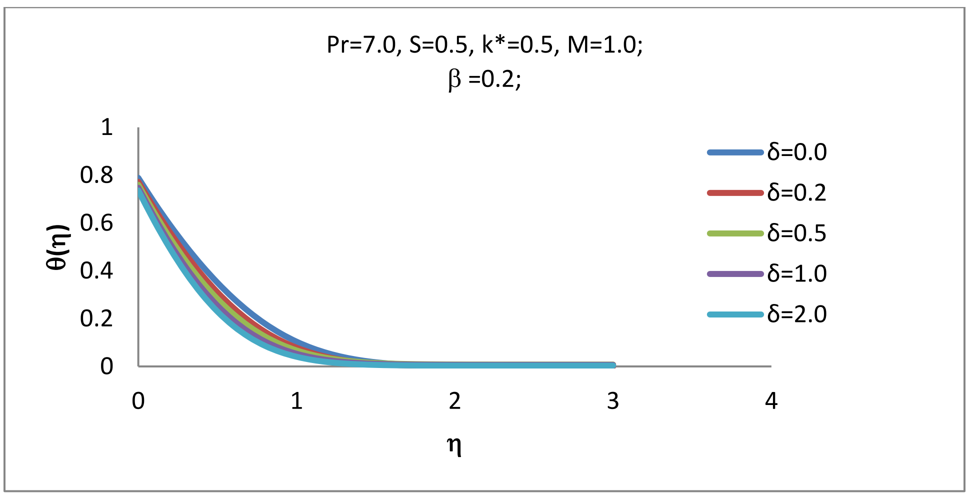

Fig.5. Temperature profiles $\theta(\eta)$ for various values of δ.

Table 1: For different values of the magnetic parameter M, the skin-friction coefficient v'' (0) is plotted against δ. The skin-friction coefficient is used to calculate the viscous stress acting on the plate's surface. As the slip parameter increases and the magnetic field changes, it is obvious that skin friction decreases rapidly and reaches zero. i.e., the increase in M is reflected in the increase in δ.

M	□	**v''**
0	0	0.611723913
0	0.5	0.494502611
0	1	0.405691291

0.2	0	0.76321942
0.2	0.5	0.571917632
0.2	1	0.451711753
0.5	0	0.945686295
0.5	0.5	0.657954801
0.5	2	0.334896544
1	0	1.189455801
1	0.5	0.757781299
1	1	0.552214947

Table I :Values of Skin-friction coefficient $v''(0)$ against δ for various values of magnetic parameter M. Keeping the following physical parameters as fixed. Pr=7.0, k*=0.2, β=0.2

Next, we observed that the effect of temperature gradient is nothing but rate of heat transfer $\theta'(0)$ against the slip parameters δ and β for various values of magnetic parameter M. These values are shown in **Table 2**

M	□	□'	□	□'
0	0	-0.965943513	0	-1.312979695
0	0.5	-1.11098642	0.5	-0.790123412
0	1	-1.186109865	1	-0.565432949
0.2	0	-0.99878025	0	-1.359298139
0.2	0.5	-1.143299878	0.5	-0.807949239
0.2	1	-1.21432183	1	-0.571768492
0.5	0	-1.025484567	0	-1.412163976
0.5	0.5	-1.170973193	0.5	-0.829078753
0.5	1	-1.237097319	1	-0.582908773
1	0	-1.056934392	0	-1.465369589
1	0.5	-1.20185266	0.5	-0.841946533
1	1	-1.264310186	1	-0.594194636

Table 2 :Values of Rate of heat transfer $\theta'(0)$ against δ and β for various values of magnetic parameter M. Keeping the following physical parameters as fixed. Pr=7.0, k*=0.2, β=0.2,γ=0.2 against δ and Pr=7.0, k*=0.2, δ=0.2 against β.

Conclusion

The impact of magneto hydrodynamics on two-dimensional steady boundary layer slip flow and heat transfer over a flat plate is investigated in this paper. The governing flow equations' non-linear partial differential equations are translated into a system of coupled non-linear ordinary differential equations using appropriate similarity transformations, and the resulting equations are solved numerically using the Runge-kutta fourth order method and the shooting technique. For various governing parameters, the velocity and temperature distributions are determined.

The skin-friction coefficient is used to calculate the viscous stress acting on the plate's surface. As the slip parameter δ increases and the magnetic field changes, it is obvious that skin friction decreases rapidly and reaches zero. i.e., as shown in Table 1, as M increases, it increases.

Table 2 shows that the rate of heat transfer $\theta'(0)$ decreases as the slip parameter and magnetic field M increase, while the rate of heat transfer $\theta'(0)$ increases as the slip parameter and magnetic field M increase.

References

Chambre PL, Young JD (1958), On diffusion of a chemically reactive species in a laminar boundary layer flow. Phys Fluids 1:48–54

C.K Chen and M.I Char (1988),Heat transfer of a continuous stretching surface with suction and blowing, Journal of Mathematical Analysis and Applications, Vol.135, No.2, pp.568-580

T. Watanabe, I. Pop (1995), Hall effects on magnetohydrodynamic boundary layer flow over a continuous moving flat plate, Acta Mechanica, Volume 108, Issue 1, pp 35-47

S.P. Anjalidevi and R. Kandasamy (1999), Effects of chemical reaction, heat and mass transfer on laminar flow along a semi infinite horizontal plate, Heat and Mass Transfer, vol. 35, no. 6, pp. 465–467, 1999.

Kandasamy R, Palanimani PG(2007), Effects of chemical reactions, heat, and mass transfer on nonlinear magnetohydrodynamic boundary layer flow over a wedge with a porous medium in the presence of ohmic heating and viscous dissipation. J. Porous Media;10:489-502

Postelnicu A(2007), Influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces in porous media considering Soret and Dufour effects. Heat Mass Transfer;43:595-602.

M. A. Seddeek, A. A. Darwish, and M. S. Abdelmeguid(2007), Effects of chemical reaction and variable viscosity on hydromagnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation, Communications in Nonlinear Science and Numerical Simulation, vol. 12, no. 2, pp. 195–213.

A. M. Salem and M. Abd El-Aziz(2008),Effect of Hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation/absorption, Applied Mathematical Modelling, vol. 32, no. 7, pp. 1236–1254.

P. M. Patil and P. S. Kulkarni(2008),Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation, International Journal of Thermal Sciences, vol. 47, no. 8, pp. 1043–1054.

Asim Aziz, J.I. Siddique, Taha Aziz(2014), Steady boundary layer slip flow along with heat and mass transfer over a flat porous plate embedded in a porous medium, PLoS ONE 9(12):e114544.

O. D. Makinde(2010), Similarity solution of hydromagnetic heat and mass transfer over a vertical plate with a convective surface boundary condition, International Journal of the Physical Sciences Vol. 5(6), pp. 700-710.

S. Mukhopadhyay(2010), Effects of Slip on Unsteady Mixed Convective Flow and Heat Transfer Past a Stretching Surface, CHIN. PHYS. LETT. Vol. 27, No. 12; 124401

A. A. Bakr(2011),Effects of chemical reaction on MHD free convection and mass transfer flow of a micropolar fluid with oscillatory plate velocity and constant heat source in a rotating frame of reference,Communications in Nonlinear Science and Numerical Simulation, vol. 16, no. 2, pp. 698–710.

Krishnendu Bhattacharyya, Swati Mukhopadhyay, G. C. Layek(2011), MHD Boundary Layer Slip Flow and Heat Transfer over a Flat Plate, CHIN. PHYS. LETT. Vol. 28, No. 2 ; 024701

V. Bisht, M. Kumar, and Z. Uddin(2011), Effect of variable thermal conductivity and chemical reaction on steady mixed convection boundary layer flow with heat and mass transfer inside a cone due to a point, Journal of Applied Fluid Mechanics, vol. 4, no. 4, pp. 59–63.

M.Prasanna Lakshmi, N. Bhaskar Reddy and T.Poornima(2012), MHD Boundary Layer Flow of Heat and Mass Transfer over a Moving Vertical Plate in a Porous Medium with Suction and Viscous Dissipation, International Journal of Engineering, Vol. 2, Issue 5,pp.149-159

Khalili S, Khalili A, Kafashian S, Abbassi A (2013) Mixed convection on a permeable stretching cylinder with prescribed surface heat flux in porous medium with heat generation or absorption. J Porous Media 16(11):967–977.

Eshetu Haile and B. Shankar(2014), Heat and Mass Transfer Through a Porous Media of MHD Flow of Nanofluids with Thermal Radiation, Viscous Dissipation and Chemical Reaction Effects, American Chemical Science Journal 4(6): 828-846.

Khalili S, Dinarvand S, Hosseini R, Tamim H, Pop I (2014) Unsteady MHD flow and heat transfer near stagnation point over a stretching/shrinking sheet in porous medium filled with a nanofluid. Chin Phys B 23:048203

Abolbashari MH, Freidoonimehr N, Nazari F, Rashidi MM (2015) Analytical modeling of entropy generation for Casson nano-fluid flow induced by a stretching surface. Adv Powder Technol 26:542–552

Freidoonimehr N, Rashidi MM, Mahmud S (2015) Unsteady MHD free convective flow past a permeable stretching vertical surface in a nano-fluid. Int J Therm Sci 87:136–145