Impacts of chemical reaction on MHD double diffusive flow with suction/blowing and slip

A. Malarselvi¹, M. Bhuvaneswari², S. Sivasankaran³*, B. Ganga¹, A.K. Abdul Hakeem⁴

¹Department of Mathematics, Providence College for Women, Coonoor 643 104, India
²Department of Mathematics, King Abdulaziz University, Jeddah 21589, Saudi Arabia
³Department of Mathematics, Kongunadu Polytechnic College, D Gudalur, Tamilnadu, India
⁴Department of Mathematics, Sri Ramakrishna Mission Vidhyalaya College of Arts and Science, Coimbatore 641 20, India

*Email: sdsiva@gmail.com; sd.siva@yahoo.com (corresponding author)

Abstract. Unsteady double diffusive chemically reactive MHD thin fluid layer flow near the surface of an electrically conducting fluid with incompressibility past a flat surfaced plate is investigated by similarity analysis. The mathematically formulated PDEs are converted into ODEs by utilizing the similarity transforms. Then the numerical solution is determined for ODEs by operating Runge-Kutta method together with shooting technique. The impacts of varieties of parameters are scrutinized on stream velocity, energy distribution and solute dispensation through portraits. The inspection for the magnitude of local skin drag, rate of energy and solute transfer is executed through table.

Keywords: Boundary layer; Chemical reaction; Double diffusion; Unsteady; Slip.

1. Introduction

The abstraction of unsteady double diffusive MHD flow near the surface of an electrically conducting fluid has received much attention in recent years owing to its principal implementations in industrial domain and some of them are drafted as polymer solution, thermal reduction of nuclear power plant, electro chemistry, thermal insulation, EOR, aerodynamics etc. Sivasankaran et al. [1] scrutinized the domination of slip and radiant heat transport on MHD mixed convective flow with stagnation-point stream. It was reported that enhancing chemically reactive parametric values decline the speed of the stream. Gorla and Sidawi [2] reviewed 3D natural convective steady flow on an elongated surface with suction and blowing. Hakeem et al. [3] inspected the slip domination against MHD flow across expanding film with dissimilar heat source/sink and wall molecules transport. It was drafted that parametric values of magnetism pull down the stream velocity. Bhuvaneswari et al. [4] evaluated the heat transfer over an inclined surface in a penetrable medium. Muthucumaraswamy et al. [5] communicated sudden movement of an upright plate with heat flux and chemically reaction. Ganga et al. [6] assessed the MHD stream of Boungiorno model nanofluid past a vertical surface. It was recorded that Prandtl values enhance the stream velocity.

Bhattacharya and Layek [7] explored the impacts of chemical reaction on boundary layer stream through penetrable plate in the existence of stable magneto region. In their investigation the negative values of concentration were detected for larger numerals of Schmidt in the habitation of chemically reactive process. Tripathy et al. [8] reported the hydrodynamic chemically reactive viscous stream through a moving upright penetrable surface. They concluded that thermal buoyancy parameter decelerates the heat energy. Nabil et al. [9] analyzed time depending chemically reactive MHD natural convective stream through semi-infinite acting porous plate with radiant transfer. They illustrated that the absorption of radiant values enhance stream speed. Seddeek et al [10] scrutinized the influence of chemical reaction of MHD mixed convection heat and mass transfer of Hiemenz flow in the presence of magnetic field with variable viscosity. They concluded that the concentration is decelerated on improving the chemical reaction parameter and the Lewis number. Rout et al. [11] scanned the domination of internal energy source on MHD chemically reactive stream over active upright plate. They reported that chemical reacting substances accelerate the temperature.
et al. [12] investigated the time depending chemically reactive MHD mixed convective flow through a vertical cone. They indicated the magnitude of skin drag is enhanced by magnetic parameter.

Sameh et al. [13] performed an analysis to study the influence of thermal conductivity and dynamic viscosity of nano-fluid on boundary layer flow in the presence of heat generation/absorption over a permeable stretching tube. The results showed that the solute dispersion rate is increased by chemical reaction parameter. Ferdows et al. [14] explored naturally convective stream with energy transport through an inclined penetrable surface. They stated that stream speed is raised by porosity. Aziz [15] inspected the time dependent chemically reactive 2D stagnation point stream of a nanofluid over an elongated surface. He observed that molecule transport is stopped for particular numerals of Lewis number. Chemically reactive stream of an elongated film past a penetrable agency with energy and matter transport is surveyed in many Ref. [16-23].

The main objective of the present work is to perform numerical investigation on time dependent chemically reactive forced convective MHD stream flow with suction/injection over a flat surface for various parameters.

2. Mathematical configurations

The unsteady, chemically reactive, 2D laminar stream of a viscous electrically conducting fluid with incompressibility and solute distribution over a flat surface is considered. The surface is preserved at a consistent temperature $T_w$ and concentration $C_w$. In a stream, velocity factors $u$ and $v$ are forth $x$ and $y$ directions in order. The flow is presumed to be in $x$-direction. A magnetic field of consistent strength $B_0$ is activated in crosswise to the stream. At $t = 0$, the sheet is spontaneously elongated with the non-uniform speed $U_w(x, t)$. The $U_\infty$ is the free stream speed. $T_\infty$ and $C_\infty$ are the free stream temperature and concentration in order. The model for the stream, energy and the concentration are drafted as follows.

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

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

$$\frac{\partial T}{\partial t} + \frac{u}{\partial x} + \frac{\nu}{\partial y} = \alpha \frac{\partial^2 T}{\partial y^2} \quad (3)$$

$$\frac{\partial C}{\partial t} + \frac{u}{\partial x} + \frac{\nu}{\partial y} = D \frac{\partial^2 C}{\partial y^2} + R(C - C_\infty) \quad (4)$$

The boundary conditions are drafted as

$$u = ax + bx, \quad v = v_w = \frac{v_0}{\sqrt{x}}, \quad c = c_w, \quad T = T_w \quad at \ y = 0 \quad (5)$$

$$u \rightarrow u_\infty, \quad c \rightarrow c_\infty, \quad T \rightarrow T_\infty \quad as \ y \rightarrow \infty \quad (6)$$

In the present review, $t$, $u$, $v$, $\sigma$, $\rho$, $\theta$, $\varphi$, $A$, $k$, $P$, $C$, $c_P$, $D$, $n$ represent time, coefficient of viscosity, kinematic viscosity, electrical conductivity, density, temperature, concentration, unsteadiness parameter, thermal conductivity, pressure, mass concentration, specific heat, molecular diffusivity, order of chemical reaction, respectively. $R(x)$ is the variable reaction rate, $R(x) = \frac{L R_0}{x}$, $L$ is the reference length and $R_0$ is constant. $v_w$ is the prescribed suction/blowing at the plate and is given by $v_w = \frac{v_0}{\sqrt{x}}$, $v_0$ is constant with $v_0 < 0$ corresponds to suction, $v_0 > 0$ corresponds to blowing. We instigate similarity transforms as below.

$$\psi = \sqrt{\frac{at}{1-at}} \sigma(q), \quad \eta = \gamma \frac{a}{\sqrt{v(1-at)}}, \quad T = T_\infty + (T_w - T_\infty) \theta(q), \quad C = C_\infty + (C_w - C_\infty) \varphi(q) \quad (7)$$
The dimensionless system are
\[ f''(\eta) - \left[ f'(\eta) \right]^2 + f'(\eta) \left[ f(\eta) - \frac{1}{2} \eta A \right] - Af'(\eta) + \frac{Ha^2}{Re} [1 - f'(\eta)] = 0 \]  
(8)
\[ \theta''(\eta) + Pr \left[ f \theta' - A \left( \frac{3}{2} \theta + \frac{1}{2} \eta \theta' \right) \right] = 0 \]  
(9)
\[ \phi''(\eta) - \phi'(\eta) Sc \left[ \frac{1}{2} A \eta - f(\eta) \right] = Sc \beta \phi'(\eta) = 0 \]  
(10)
with boundary constraints
\[ f(\eta) = s \theta(\eta) = 1, \phi(\eta) = 1 \quad \text{at} \quad \eta = 0 \]
\[ f'(\eta) \to 0, \theta'(\eta) \to 0, \phi'(\eta) \to 0 \quad \text{as} \quad \eta \to \infty \]  
(11)
where \( Ha^2 = \frac{cB_0^2}{\rho u} \) is Hartmann number, \( Sc = \frac{V}{D} \) is Schmidt number, \( A = \frac{\alpha}{a} \) is unsteadiness parameter, \( a > 0 \) is the straining constant, \( Pr = \frac{Lk}{E} \) is Prandtl number, \( \beta = \frac{LR_1(C_W-C_u)^{-1}}{u_o} \) is the reaction rate parameter, \( Re = \frac{U \eta x}{\nu} \) is the local Reynolds number, \( s = -\frac{V_0}{\nu} \sqrt{x(Re)} \) is the suction parameter.

The non-dimensional form skin drag is \( Cf_s = \frac{\rho u \frac{\partial u}{\partial y}}{\mu \frac{\partial u}{\partial y}^2} \) which is obtained as \( Cf_s \sqrt{Re x} = f'(0) \)
and the Nusselt number is \( Nux = \frac{x q_w}{k(T_W-T_o)} \) where \( q_w = -K \left( \frac{\partial T}{\partial y} \right) \) at \( y=0 \), which is calculated as \( Nux = -\theta'(0) \sqrt{Re x} \). The local Sherwood number is \( Shx = \frac{x M_w}{D(C_W-C_u)} \) where \( M_w = D(\frac{\partial c}{\partial y}) \) at \( y=0 \) and it is derived as \( Shx = -\phi'(0) \sqrt{Re x} \). The mathematically formulated PDEs are changed into self-similar ODEs and the solution is obtained by Runge-Kutta integration linked to shooting scheme.

**Figure 1.** Velocity profiles for different d values with A=1, a=1, Cr=0.1, s=1.
3. Results and review
The mathematically formulated equations (8)-(10) with respect to boundary conditions (11) are solved numerically. The numerical evaluation of skin drag magnitude, rate of heat and solute transfer is obtained and is exhibited in Table 1. From the table it is quite interesting to notice that the solute transfer rate is accelerated by chemically reactive parametric values in the case of suction/injection. The same effect is observed in the absence of suction/injection at the plate. It is detected that both the magnitude of skin drag and solute transfer rate are boosted but heat transport rate is diminished by slip numerals with occurrence or non-occurrence of suction/injection. Unsteadiness implies improvement in solute transfer rate as well as heat transfer rate besides skin drag is mitigated with $s=1$ & $s=−1$. The suction/injection numerals boost the rate of heat transfer but they are not favour to both the skin drag and solute transfer rate.

Figure 2. Velocity profiles for different $A$ values with $d=1$, $a=1$, $Cr=0.1$, $s=1$.

Figure 3. Velocity profiles for different $s$ values with $d=1$, $a=1$, $Cr=0.1$, $A=1$. 
It is noticed from figure 1 that slip numerals decelerate the stream velocity. Figure 2 depicts that the values of the unsteadiness pull down the velocity of the stream. Figure 3 discloses that suction/injection parametric numerals reduce the speed of the stream. It is understood from the figure 4 that unsteady values decline the dimensionless concentration. It is concluded through the figure 5 that suction/injection numerals diminish the dimensionless concentration. It is significant to note through figure 6(a) that the chemical reaction parametric numbers decelerate the concentration boundary layer thickness with suction. It is evident from the figure 6(b) that also in the absence of suction/injection the chemically reactive parametric numbers diminish concentration. Through figure 6(c) the same trend is noticed for injection.

**Figure 4.** Concentration profiles for different A values with d=1, a=1, Cr=0.1, s=1.

**Figure 5.** Concentration profiles for different s values with d=1, a=1, Cr=0.1, A=1.

4. **Conclusion**

The solute transfer rate is accelerated by chemically reactive parametric values in the case of either occurrence or non-occurrence of suction/injection. Both the magnitude of skin drag and solute transfer rate are boosted but heat transport rate is diminished by slip numerals with existence or inexistence of suction/injection. Unsteadiness implies improvement in solute transfer rate as well as heat transfer rate besides skin drag is mitigated. Slip, unsteady and suction/injection values pull down the stream speed. Both the unsteady and suction/injection parametric numbers decline the dimensionless concentration. Chemically reactive parametric numbers diminish concentration either in the presence or absence of suction / injection.
Figure 6. Concentration for various Cr and s with A=1, a=1, d=1, (a) s=−1, (b) s=0, (c) s = 1.
Table 1. The values of $C_{f_x}$, $-\theta(0)$, $-\varphi'(0)$ with $Ha=0.1$, $Re=10$, $Pr=0.05$, $Sc=1$ and $a=1$.

| A | d | s | Cr | $C_{f_x}$ | $-\theta(0)$ | $-\varphi'(0)$ |
|---|---|---|----|----------|-------------|--------------|
| 1 | 1 | 1 | -0.2 | -0.619385 | 0.284025 | -0.150375 |
|   |   |   | -0.1 |          |             | -0.027961 |
|   |   |   | 0    |          |             | 0.070191  |
|   |   |   | 0.1  |          |             | 0.153779  |
|   |   |   | 0.2  |          |             | 0.227605  |
| 1 | 1 | 0 | -0.2 | -0.526063 | 0.262329 | 0.183050 |
|   |   |   | -0.1 |          |             | 0.307467  |
|   |   |   | 0    |          |             | 0.411708  |
|   |   |   | 0.1  |          |             | 0.502178  |
|   |   |   | 0.2  |          |             | 0.582670  |
| 1 | 1 | -1| -0.2 | -0.440935 | 0.242738 | 0.951319 |
|   |   |   | -0.1 |          |             | 1.032992  |
|   |   |   | 0    |          |             | 1.107317  |
|   |   |   | 0.1  |          |             | 1.175764  |
|   |   |   | 0.2  |          |             | 1.239402  |
| 1 | 0 | 1 | 0.1  | -1.875548 | 0.290602 | 0.113532 |
|   | 0.2|   |          | -1.310831 | 0.287968 | 0.127662 |
|   | 0.5|   |          | -0.917990 | 0.285854 | 0.140908 |
|   | 0.7|   |          | -0.768491 | 0.284966 | 0.146987 |
|   | 1  |   |          | -0.619385 | 0.284025 | 0.153779 |
| 1 | 0 | 0 | 0.1  | -1.320150 | 0.268784 | 0.379901 |
|   | 0.2|   |          | -1.096466 | 0.266486 | 0.422517 |
|   | 0.5|   |          | -0.740529 | 0.264380 | 0.462683 |
|   | 0.7|   |          | -0.635524 | 0.263415 | 0.481253 |
|   | 1  |   |          | -0.526063 | 0.262330 | 0.502178 |
| 1 | 0 | -1| 0.1  | -0.943821 | 0.248745 | 1.021353 |
|   | 0.2|   |          | -0.757217 | 0.246796 | 1.074046 |
|   | 0.5|   |          | -0.592284 | 0.244827 | 1.124775 |
|   | 0.7|   |          | -0.519774 | 0.243866 | 1.148595 |
|   | 1  |   |          | -0.440935 | 0.242738 | 1.175764 |
| 0 | 1 | -1| 0.1  | -0.567652 | 0.135609 | 0.080490 |
|   | 0.5|   |          | -0.595879 | 0.219214 | 0.100051 |
|   | 1  |   |          | -0.619385 | 0.284025 | 0.153779 |
|   | 1.5|   |          | -0.638825 | 0.337742 | 0.226920 |
|   | 2  |   |          | -0.655116 | 0.384215 | 0.303634 |
|   | 2.5|   |          | -0.669011 | 0.425979 | 0.378668 |
|   | 3  |   |          | -0.681054 | 0.463201 | 0.450589 |
| 0 | 1 | 1 | 0.1  | -0.567652 | 0.135609 | 0.080490 |
|   | 0.5|   |          | -0.595879 | 0.219214 | 0.100051 |
|   | 1  |   |          | -0.619385 | 0.284025 | 0.153779 |
|   | 1.5|   |          | -0.638825 | 0.337742 | 0.226920 |
|   | 2  |   |          | -0.655116 | 0.384215 | 0.303634 |
|   | 2.5|   |          | -0.669011 | 0.425979 | 0.378668 |
|   | 3  |   |          | -0.681055 | 0.463201 | 0.450589 |
| 1 | 1 | -1| 0.1  | -0.440934 | 0.242738 | 1.175764 |
|   | -0.5|   |          | -0.481663 | 0.252323 | 0.803976 |
|   | 0  |   |          | -0.526063 | 0.262330 | 0.502178 |
|   | 0.5|   |          | -0.572740 | 0.272857 | 0.285734 |
|   | 1  |   |          | -0.619385 | 0.284025 | 0.153779 |
References

[1] Sivasankaran S, Niranjan H and Bhuvaneswari M 2017 Chemical reaction, radiation and slip effects on MHD mixed convection stagnation point-flow in a porous medium with convective boundary condition Int. J. Numer. Meth. Heat Fluid Flow 27 pp 454-470

[2] Gorla RSR and Sidaway I 1994 Free convection on a vertical stretching surface with suction and blowing Appl. Sci. Res. 52 pp 247–257

[3] Hakeem AKA, Kalaivanan R, Ganesh NV and Ganga B 2014 Effect of partial slip on hydromagnetic flow over a porous stretching sheet with non-uniform heat source/sink, thermal radiation and wall mass transfer Ain Shams Eng. J. 5 pp 913-922

[4] Bhuvaneswari M, Sivasankaran S and Kim YJ 2012 Lie group analysis of radiation natural convection flow over an inclined surface in a porous medium with internal heat generation J. Por. Media 15 pp 1155-1164

[5] Muthucumaraswamy R and Ganesan P 2000 On impulsive motion of a vertical plate with heat flux and diffusion of chemically reactive species Forschung im Ingenieurwesen 66 pp 17-23

[6] Ganga B, Ansari SMY and Ganesh NV 2016 MHD flow of Bougiorno model nanofluid over a vertical plate with internal heat generation/absorption Propulsion and Power Research 5 pp 211-222

[7] Bhattacharyya K and Layek GC 2012 Similarity solution of MHD boundary layer flow with diffusion and chemical reaction over a porous flat plate with suction/blowing Meccanica 47 pp 1043-1048

[8] Tripathy RR, Dash GC, Mishra SR and Bagg S 2015 Chemical reaction effect on MHD free convective surface over a moving vertical plate through porous medium Alex. Eng. J. 54 pp 673-679

[9] El-dabe NTM, Hassan MA and Godih WA 2013 Unsteady magneto hydrodynamic free convection flow past a semi-infinite permeable moving plate through porous medium with chemical reaction and radiation absorption J. Heat Transf. 135 pp 024501-5

[10] Seddeek MA, Darwish AA and Abdel Weguid 2007 Effect of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation Comm. Nonlin. Sci. Numer. Sim. 12 pp 195-213

[11] Rout BR, Parida SK and Panda S 2013 MHD Heat and mass of chemical reaction fluid flow over a moving vertical plate in the presence of heat source with connective surface boundary condition Int. J. Chem. Eng. 296834

[12] Ravindran R, Ganapathi Rao M and Pop I 2014 Effect of chemical reaction and heat generation absorption on unsteady mixed convection MHD flow over a vertical cone with non-uniform slot mass transfer Int. J. Heat Mass Trans. 73 pp 743-751

[13] Ahmed S E, Hussain A K, Mohammed H A and Sivasankaran S 2014 Boundary layer flow and heat transfer due to permeable stretching tube in the presence of heat source/sink utilizing nano fluids Appl. Math. Comp. 238 pp 149-162

[14] Ferdows M, Kaino K and Sivasankaran S 2009 Free convection flow in an inclined porous surface J. por. media 12 pp 997-1003

[15] El-Aziz MA 2014 Effect of time dependent chemical reaction on stagnation point flow and heat transfer over a stretching sheet in a nano fluid Physica Scripta 89 085205

[16] Sivasankaran S, Bhuvaneswari M, Kandaswamy P and Ramasami EK 2006 Lie group analysis of natural convection heat and mass transfer in an inclined surface Nonlin. Anal. Model. Cont. 11 pp 201–212

[17] Kasmani RM, Sivasankaran S, Bhuvaneswari M, Hussein AK 2017 Analytical and numerical study on convection of nanofluid past a moving wedge with Soret and Dufour effects Int. J. Num. Meth. Heat Fluid Flow 27 pp 2333-2354

[18] Niranjan H, Sivasankaran S, and Bhuvaneswari M 2017 Chemical reaction, Soret and Dufour effects on MHD mixed convection stagnation point flow with radiation and slip condition Scientia Iranica Transaction of Mechanical Engineering B 24 pp 698 – 706

[19] Eswaramoorthi S, Bhuvaneswari M, Sivasankaran S and Rajan S 2016 Soret and Dufour effects on viscoelastic boundary layer flow over a stretching surface with convective boundary condition with radiation and chemical reaction Scientia Iranica Transactions of B Mechanical Engineering 23 pp 2575-2586
[20] Niranjan H, Sivasankaran S and Bhuvaneswari M 2016 Analytical and numerical study on magnetoconvection stagnation-point flow in a porous medium with chemical reaction, radiation and sip effects Math. Prob. Eng. Article ID 4017076 pp 1-12

[21] Karthikeyan S, Bhuvaneswari M, Sivasankaran S and Rajan S 2016 Soret and Dufour effects on MHD mixed convection heat and mass transfer of a stagnation point flow towards a vertical plate in a porous medium with chemical reaction, radiation and heat generation J. Appl.Fluid Mech. 9 pp 1447-1455

[22] Kasmani RM, Sivasankaran S, Bhuvaneswari M and Siri Z 2016 Effect of chemical reaction on convective heat transfer of boundary layer flow in nanofluid over a wedge with heat generation/absorption and suction J. Appl. Fluid Mech. 9 pp 379-388

[23] Bhuvaneswari M, Sivasankaran S and Ferdows M Lie group analysis of natural convection heat and mass transfer in an inclined surface with chemical reaction Non-lin. Anal. Hybrid Sys. 3 pp 536-542