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Rakesh Kr Saha, Hiranmoy Maiti, Swati Mukhopadhyay*

University of Burdwan, Burdwan, West Bengal, India
*e-mail: swati_bumath@yahoo.co.in

Mass diffusion of MHD flow over an unsteady stretched surface with moving free stream

Abstract. An exploration is carried out to examine mass diffusion of unsteady 'boundary layer' (bl) motion of viscous liquid passed a stretched leaky piece with variable mass flux. For several engineering applications, moving free stream is considered here. This makes this research unique. The leading 'partial differential equations' (PDEs) accompanied by the 'boundary conditions' are converted to 'ordinary differential equations' (ODEs) with the help of 'similarity transformations' and 'numerical solutions' are attained by MATLAB software. The effect of pertinent 'parameters' on fluid 'flow, concentration, skin friction coefficient' and wall concentration are discussed 'graphically' and numerically. When suction/blowing parameter increases from -0.2 to 0.2, skin friction coefficient decreases 18.235%. Fluid concentration reduces with growing values of velocity ratio parameter λ for all cases considered. Compared to the case for static free stream, fluid velocity is higher when the free stream moves. Also higher concentration is noted in presence of moving free stream. The presence of moving free stream causes to diminish the effect of suction/blowing on flow and concentration fields. The increasing strength of suction causes to decrease the fluid velocity more significantly than that for blowing.

Key words: Unsteady stretching sheet, MHD, Mass diffusion, Variable free stream, Variable mass flux.

Introduction

Mass transport phenomenon in the branch of 'fluid mechanics' has achieved huge attention of the researchers due to its frequent occurrence in natural processes as well as industrial processes. Basically by mass transfer we mean the movement of molecules of substances or chemical species within or between fluid mediums. Generally this mass transfer process can be completed by two processes, diffusion and convection. There are several key factors which influence the rate of mass transfer including concentration difference, diffusion coefficient, temperature, surface area, fluid velocity etc. Mass transfer plays a crucial role in controlling and optimizing several processes across different sectors including chemical reactors, distillation, gas-liquid extraction, crystallization, waste water treatment, air pollution control, fermentation, fuel cells, batteries, micro fluidic devices etc. In these applications, product quality, environmental sustainability are improved by manipulating mass transfer. Chambre and Young [1] considered chemically reactive species, diffused into the fluid showed its effect on mass transfer. Mukhopadhyay [2] examined solute transfer for laminar bl flow through a stretched 'cylinder' and for motion of fluid and mass transport, numerical solutions were obtained. Mukhopadhyay and Gorla [3] studied mass transfer in a 'upper convected Maxwell' liquid flow taking homogeneous/heterogeneous chemical reaction over an unsteady stretched sheet. Their study explored that speed of mass transport from the exterior was enhanced by the reaction rate. Srinivas et al. [4] analysed the mass transfer and fluid flow in an absorbent 'channel' having static or 'moving walls' in attendance of compound response. Mukhopadhyay et al. [5] considered a chemically reactive fluid flow over a moving plate. Maleque [6] investigated mass transfer of 'unsteady bl flow' influenced by natural convection and binary chemical reaction. Mukhopadhyay et al. [7] studied mass diffusion in an incompressible 'viscous' liquid 'flow' owing to a stretched permeable exterior by taking stratified medium. Mukhopadhyay [8] examined the transportation of mass in a chemically reactive liquid 'flow' through a stretched 'cylinder' in an absorbent 'medium'.

Magnetohydrodynamics (MHD) refers to the study of 'electrically conducting' liquid flows in attendance of ‘magnetic field’. In MHD, ‘magnetic’ properties and performance of ‘electrically conducting’ liquids such as salt water, plasma, liquid metals are generally studied. The ‘interaction between’ applied ‘magnetic field’ and moving fluid generates Lorentz forces which in turn affect the original flow. In several sectors viz. in industrial and engineering sectors where electrically conducting fluid and magnetic field are used, MHD has huge applications. Some of the applications include magnetic pumps, MHD power generation, micro fluidic devices, liquid metal cooling in Nuclear reactors, MHD heat transfer etc. Hayat et al. [9] analyzed mass transfer of an elastic ‘viscous’ liquid and showed the effect of ‘magnetic field’ applying homotopy analysis method. Shehzadi et al. [10] examined MHD flow of casson fluid and studied the mass transport behaviour. Babu et al. [11] inspectd the consequences of mass transfer and viscous dissipation in ‘MHD’ convective flow of micropolar liquid over moving permeable plate. Nayak et al. [12] considered ‘free convective’ flow of ‘viscoelastic’ liquid over an ‘inclined plate’. They also analyzed the consequences of ‘magnetic field’ on ‘flow and mass’ transport. The impact of magnetic field on convective viscous dissipative fluid flow was investigated by Reddy [13]. Agarwalla and Ahmed [14] also studied ‘MHD’ convection fluid ‘flow and mass transport’. But they found the exact solutions by taking variable plate velocity. Swain and Barik [15] considered ‘MHD’ mixed convective second grade fluid motion passing an upright infinite plate.

In the field of fluid mechanics, a stretching sheet is a thin material continuously stretched in one direction. For the understanding of bl flows, fluid-solid interactions, heat transport features, liquid motion due to a stretched piece plays important role. In several scientific fields and industrial processes, its applications including polymer and fibre production, metal sheet forming, coating processes, material science and engineering, modelling biological fluids, optimizing industrial processes, paper production become valuable tools. Researchers generally investigate flow due to a stretched piece in their studies considering different types of stretching velocities viz. linear stretching velocity, power-law stretching velocity, exponential stretching velocity, unsteady strething velocity etc. Kandasamy et al. [16] studied ‘mass’ transport of laminar flow past a porous stretched piece with Soret and Dufour consequences, thermophoresis and chemical reaction by group theoretic approach. Elbashbeshy and Sedki [17] examined the influence of compound response on solute transport passed a stretched exterior in absorbent ‘medium’. Rosly et al. [18] considered unsteady flow near a ‘stagnation point’ with ‘mass’ transport due to a porous surface and presented stability analysis. Takhar et al. [19] considered ‘electrically conducting viscous’ liquid flow past a stretched exterior and examined flow and mass transfer properties. Afify [20] analyzed consequences of ‘magnetic field’ on ‘mass’ transport of ‘chemically reactive’ convective motion past a stretched piece. Bhattacharyya et al. [21] examined MHD chemically reacting bl ‘flow’ past a permeable stretched piece. Mazid et al. [22] inspectd the combined impacts of chemical reaction, Soret and suction on motion of ‘Maxwell ferro’ liquid considering ‘magnetic dipole’.

Consideration of mass flux condition at the boundary makes the mass transfer characteristics more interesting and meaningful in case of viscous fluid flow. Mass flux is mostly applied in designing and analyzing pipe flow for transporting liquid, gases, in heat exchangers, water treatment plant, ventilation system, chemical industries etc. Ganesan and Palani [23] developed a fluid model for an unsteady convective ‘MHD flow’ past an ‘inclined plate’. Using ‘finite difference method’, they showed the consequences of mass flux on ‘flow’ characteristics. Saravana et al. [24] considered the impact of constant ‘mass’ flux on mass transfer for ‘MHD viscous flow’ over ‘an infinite upright plate’. ‘Unsteady convective’ flow of ‘viscous’ liquid over a upright ‘plate’ was measured by Loganathan and Sivapoornapriya [25] and impact of mass flux was shown in their work. Abbasi et al. [26] explored the effects of ‘mass flux’ on MHD ‘flow of Jeffrey’ fluid. Das et al. [27] considered unsteady ‘convective flow’ past an upright ‘plate’ with mass flux. Ghosh and Mukhopadhyay [28] analyzed ‘flow, heat and mass’ transport in nanoliquid past an exponentially shrinking piece with mass flux. Palaniammal and Saritha [29] examined the concequences of ‘mass flux’ on fluid characteristics for MHD casson fluid flow.

The above discussion of existing literature encourages us to investigate mass diffusion of ‘MHD’ bl ‘flow’ past an unsteady stretching piece with variable mass flux, ‘suction’/blowing and moving free stream. From existing literature, it is noted that some researchers analyzed ‘MHD flow’ owing to ‘unsteady’ stretched piece, some of them investigated MHD 'flow and mass' transport over an 'unsteady' stretched exterior by considering chemical reaction. But as per author's knowledge, no one has yet considered MHD 'flow' and mass transport owing to an unsteady stretched surface with changeable chemical reaction, variable mass flux at the surface in presence of moving free stream. To fill this research gap, we have inspected the problem. Here lies the novelty of the present work. Our investigation will sort out the answers for the following questions:

(i) What are the key features of flow and mass transfer when moving free stream is considered?

(ii) How does variable mass flux influence mass transfer and concentration of the fluid?

(iii) How do unsteadiness and magnetic field influence the 'flow' and concentration 'fields' in attendance of moving free stream?

Mathematical formulation

A 2D (two-dimensional) unsteady laminar bl flow of 'viscous electrically conducting' liquid in attendance of applied 'magnetic field', chemical reaction and variable mass flux at the boundary is modelled in the current investigation. The liquid is assumed to flow over a porous stretched piece which is stretched with time dependent velocity $U_w(x,t)=\dfrac{bx}{1-\alpha t}$ where α being invariable of dimension $(time)^{-1}$ and b is another constant. The geometry of this fluid model is provided in Figure1.

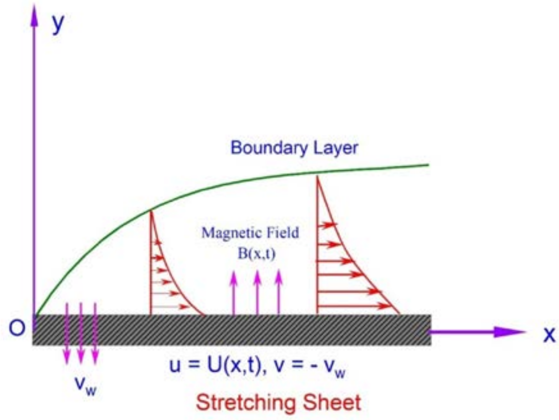

Figure 1 – Sketch of the physical flow problem

Here, moving free stream having velocity $U_\infty=\dfrac{ax}{1-\alpha t}$, a is a constant, is considered. By considering the above suppositions, the leading 'equations' of motion for this problem are as follows:

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+\frac{\partial U_\infty}{\partial t}+U_\infty\frac{\partial U_\infty}{\partial x}-\frac{\sigma B^2(x,t)}{\rho}(u-U_\infty), \tag{2}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-\mathrm{K}(x,t)(C-C_\infty). \tag{3}$$

Moving free stream is considered. So the boundary conditions are given by

$$u=U_w(x,t)=\frac{bx}{1-\alpha t},\quad v=-\frac{v_0}{\sqrt{1-\alpha t}}=-v_w,\ \text{at}\ y=0,\quad -D\frac{\partial C}{\partial y}=q_m(x,t) \tag{4}$$

$$u\to U_\infty(x,t)=\frac{ax}{1-\alpha t},C\to C_\infty\ \text{as}\ y\to\infty. \tag{5}$$

Here x axis is taken alongside the stretched piece and y axis is assumed perpendicular to the piece. u and v are considered as 'velocity components' of the fluid respectively along x axis and y axis. υ is the 'kinematic' coefficient of 'viscosity', ρ denotes 'density' of liquid and σ is considered as 'electrical conductivity' of the fluid.

$B(x,t)=\dfrac{B_0}{(1-\alpha t)}$ represents the variable 'magnetic field' strength applied perpendicular to the sheet i.e. parallel to y axis and B_0 is the uniform strength of the magnetic field. C denotes the 'concentration' of the fluid, D denotes 'diffusion coefficient', C_∞ represents constant concentration distant from the sheet and $\mathrm{K}(x,t)$ represents variable reaction rate of solute which is defined as $\mathrm{K}(x,t)=\dfrac{\mathrm{K}_0}{(1-\alpha t)}$ where K_0 is uniform reaction rate. v_w represents 'suction/blowing through' the permeable piece and defined as $v_w=\dfrac{v_0}{\sqrt{1-\alpha t}}$, where $v_0<0$ defines blowing and $v_0>0$ defines suction, $q_m(x,t)$ denotes the variable surface mass flux and is given by $q_m(x,t)=\dfrac{C_0 dx^{\mathrm{r}}}{(1-\alpha t)^{\mathrm{m}+\frac{1}{2}}}$ where C_0 is constant value of reference concentration and d is also constant; r, m are power-law indices and r represents space variation of mass flux whereas m denotes the time variation of mass flux.

Similarity transformations

In order to solve the PDEs (1)-(3) subject to the 'conditions' at the 'boundary' given by (4)-(5) respectively, these PDEs are converted to ODEs. For this, suitable similarity transformations are employed which are given by:

$$\psi=\sqrt{\upsilon x U(x,t)}\,f(\eta),\ \eta=y\sqrt{\frac{U(x,t)}{\upsilon x}},$$
$$C=C_\infty+C_0\frac{dx^{\mathrm{r}}}{D\sqrt{\frac{b}{\upsilon}}}(1-\alpha t)^{-\mathrm{m}}\phi(\eta), \tag{6}$$

where ψ denotes 'stream function' and given by

$$u=\frac{\partial\psi}{\partial y},v=-\frac{\partial\psi}{\partial x}. \tag{7}$$

Using (6) and (7) in (1) – (5) we get the transformed 'equations'

$$f'''+ff''-f'^2-\mathrm{A}\left(\frac{\eta}{2}f''+f'\right)-$$
$$-\mathrm{M}(f'-\lambda)+\mathrm{A}\lambda+\lambda^2=0, \tag{8}$$

$$\frac{1}{\mathrm{Sc}}\phi''-\mathrm{A}(\mathrm{m}\phi+\frac{\eta}{2}\phi')-\mathrm{r}f'\phi+f\phi'-\mathrm{k}_1\phi=0, \tag{9}$$

with the 'boundary conditions'

$$f'(0)=1, f(0)=\mathrm{S}, \phi'(0)=-1 \text{ at } \eta=0, \tag{10}$$

$$f'(\eta)\to\lambda \text{ and } \phi(\eta)\to 0 \text{ as } \eta\to\infty. \tag{11}$$

Here $\mathrm{A}=\dfrac{\alpha}{b}$ represents unsteadiness parameter, $\mathrm{M}=\dfrac{\sigma B_0^2}{\rho b}$ denotes the 'magnetic parameter', $\mathrm{Sc}=\dfrac{\upsilon}{b}$ is the 'Schmidt number' and $\mathrm{k}_1=\dfrac{\mathrm{K}_0}{\mathrm{b}}$ represents chemical reaction parameter. $\mathrm{S}=\dfrac{v_0}{\sqrt{\upsilon b}}$ represents suction (>0) /blowing (<0) parameter, $\lambda=\dfrac{a}{b}$ denotes velocity ratio parameter.

Numerical computations and its validation

The reduced the ODEs (8) and (9) are solved by numerically by considering the boundary conditions (10) and (11). For numerical computation, famous package of solving boundary value problem called bvp4C in MATLAB platform is employed. Before preceding the detail computations for the current problem, comparisons of the received data have been made with the available data found from existing literatures for checking the correctness of the 'numerical scheme'. In Table-I, $f''(0)$ for different data of 'unsteadiness parameter' A received for $\lambda=0$ [i.e. when the free stream is not moving ($U_\infty=0$)] are evaluated with the outcomes obtained by Sharidan et al. [30], Chamkha et al. [31]

and Bhattacharyya et al. [21]. Another comparison for the outcomes related to $f''(0)$ for some 'values of' unsteadiness parameter A, magnetic parameter M and 'suction/blowing parameter' S received in our case for $\lambda = 0$ is completed with the outcomes obtained by Bhattacharyya et al. [21] which is shown in Table-II. In both cases, an excellent agreement has been found.

Results and discussions

The influences of the non-dimensional parameters on velocity $f'(\eta)$, concentration $\phi(\eta)$, velocity gradient at the surface $f''(0)$ and surface concentration $\phi(0)$ have been presented through Table III, Figures 2-16 and analysed by taking some numerical values of the parameters available in existing literature.

Table I – Values of $f''(0)$ for various values of A with M=0, S=0 and $\lambda = 0$

A	$f''(0)$			
	Sharidan et al. [30]	Chamkha et al. [31]	Bhattacharyya et al. [21]	Present Study
0.8	-1.261042	-1.261512	-1.261487	-1.26106
1.2	-1.377722	-1.378052	-1.377910	-1.3779

Table II – Values of $f''(0)$ for various values of A, M and S for $\lambda = 0$

A	M	S	$f''(0)$	
			Bhattacharyya et al. [21]	Present Study
0	1	1	-1.9994675	-2.0
0.5	1	1	-2.1052957	-2.10567
1	1	1	-2.2085607	-2.20858
0.5	0	1	-1.7474293	-1.74853
0.5	0.5	1	-1.9389309	-1.93907
0.5	1	-1	-1.1300147	-1.13084
0.5	1	0	-1.5387832	-1.53905

Table III – Values of $f''(0)$ and $\phi(0)$ for various values of S for $\lambda = 0$ and $\lambda = 0.1$ when A=0.2, M=0.5, m=2, r=2, Sc=0.7, k_1=0.5

S	$f''(0)$		$\phi(0)$	
	$\lambda = 0$	$\lambda = 0.1$	$\lambda = 0$	$\lambda = 0.1$
-0.2	-1.18795	-1.12083	0.792108	0.781387
-0.15	-1.21084	-1.14187	0.783064	0.772279
-0.1	-1.23421	-1.16332	0.774098	0.763254
0	-1.28241	-1.20748	0.756398	0.745453
0.1	-1.33257	-1.25332	0.739007	0.727986
0.15	-1.35838	-1.27687	0.730426	0.719379
0.2	-1.38468	-1.30083	0.721922	0.710855

The influences of magnetic parameter (M) on velocity and concentration when suction and blowing are separately applied to the flow field are depicted in Figure 2 and 3 respectively. Figure 2 depicts that the velocity of the fluid decreases with enhancing values of M for both cases of suction and blowing. But for blowing velocity decreases quicker than for suction. The nature of this velocity profiles is fundamentally true as the enhancing values of M generates resistve force known as Lorentz force which opposes the motion of the fluid. Also for moving free stream thinning of boundary layer occurs. The influences of M on concentration are depicted in Figure 3 which explores that for both suction and blowing concentration increases with enhancing values of M. The enhancing values of M causes to decrease the fluid velocity which in turn causes to increase the fluid concentration.

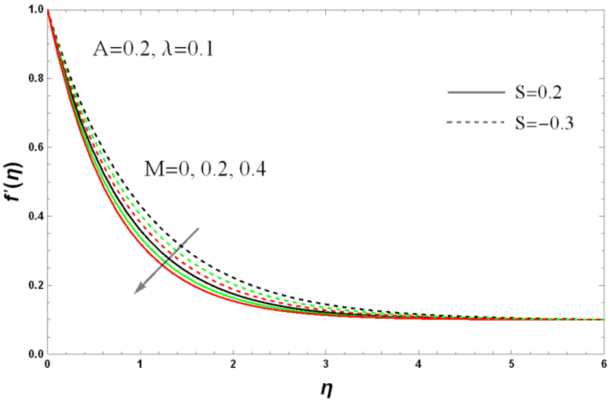

Figure 2 – Variations of velocity $f'(\eta)$ for various values of M

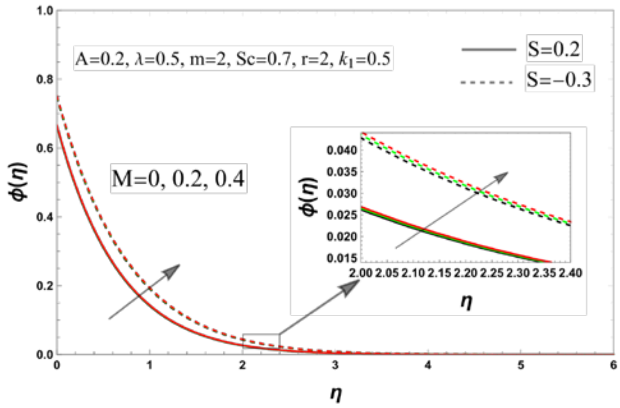

Figure 3 – Variations of concentration $\phi(\eta)$ for various values of M

Figure 4 explores that velocity of the fluid decreases with enhancing values of unsteadiness parameter (A) for both suction and injection cases. Physically the enhancing values of A adds to higher resistance in the fluid motion which reduces the fluid velocity. Higher velocity is noted for blowing compared to suction. From Figure 5 it is seen that the concentration of the fluid decreases with enhancing values of A. Solute bl thickness diminishes for unsteadiness. It is also observed that compared to blowing more decrease in concentration is noted for suction.

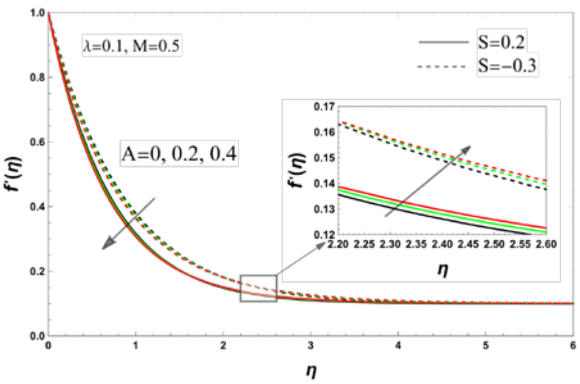

Figure 4 – Variations of velocity $f'(\eta)$ for various values of A

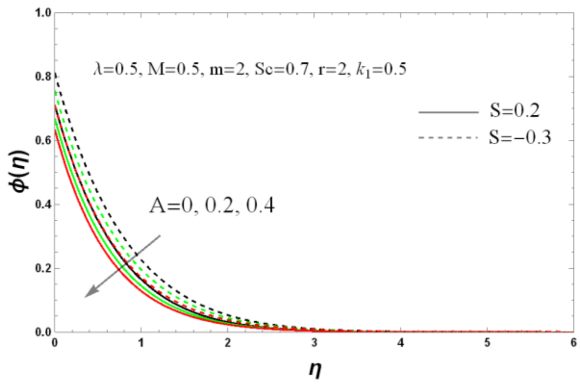

Figure 5 – Variations of concentration $\phi(\eta)$ for various values of A

The rising values of suction/blowing parameter S compresses the fluid velocity which is presented in Figure 6. Fluid velocity is slightly higher for steady case compared to unsteady flow. Thickness of bl reduces with the rise in S. Figure 7 shows the effect of suction/blowing parameter S on fluid concentration. From this figure it is shown that fluid concentration decreases with increasing values of S. It is also observed that concentration decreases more in unsteady flow which is obvious. Here also width of solute bl becomes thinner for rising S.

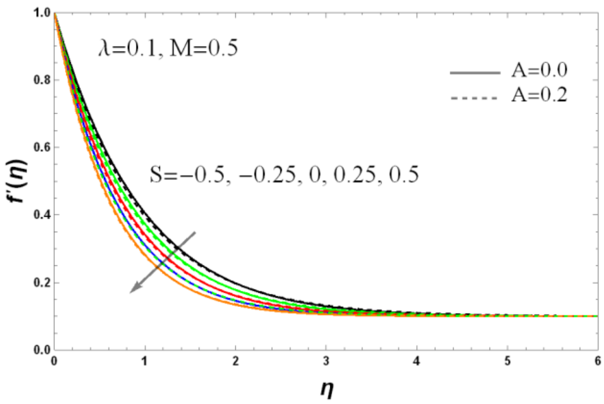

Figure 6 – Variations of velocity $f'(\eta)$ for various values of S

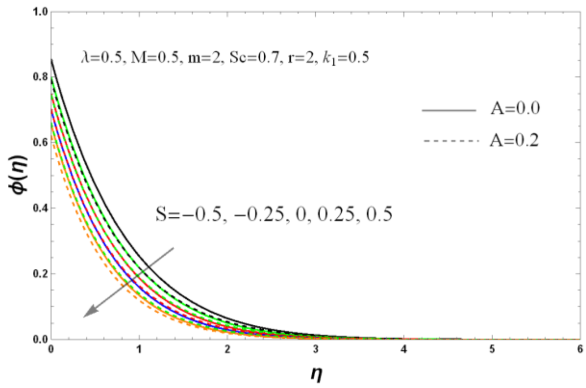

Figure 7 – Variations of concentration $\phi(\eta)$ for various values of S

Figures 8(a)-(b) depict the variation of velocity ratio parameter λ on velocity of the fluid. It is evident that the velocity of the fluid rises with enhancing values of λ and bl formation is observed [Figure 8(a)] for $\lambda < 1$. $\lambda = 0$ means the free stream is not moving. So, one can conclude that moving free stream compels the fluid to move faster [Figure 8(a)]. When the sheet is stretched with equal velocity as of free stream velocity i.e. for $\lambda = 1$, no bl formation is noted and an inverted bl is created when free stream velocity is greater than the stretching velocity which is depicted in Figure 8(b). From Figure 8(a), it is also observed that the effects of both suction and blowing gradually decreases with increasing values of λ.

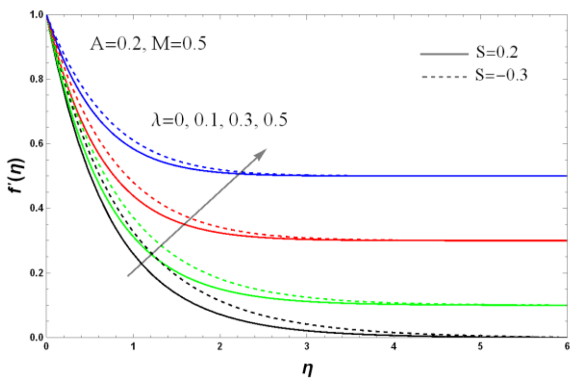

Figure 8a – Variations of velocity $f'(\eta)$ for various values of $\lambda(<1)$

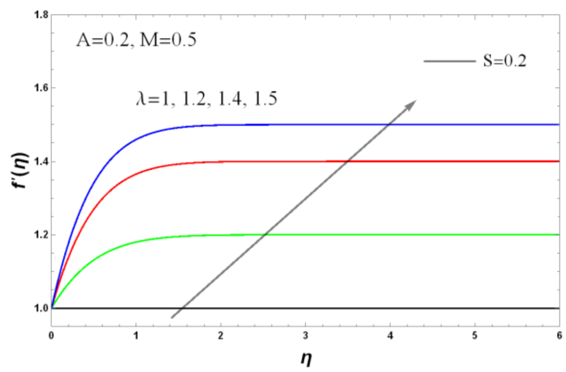

Figure 8b – Variations of velocity $f'(\eta)$ for various values of $\lambda(\geq 1)$

From Figures 9(a)-(b) it is noticed that concentration of the fluid deceases with increasing values of velocity ratio parameter λ both for $\lambda < 1$ [Figure 9(a)] and $\lambda \geq 1$ [Figure 9(b)]. Higher concentration is noted when the free stream is not moving [Figure 9(a)].

The fluid concentration decreases with enhancing values of Schmidt number Sc which is depicted in Figure 10. This figure also shows that suction compresses the fluid concentration more than that of blowing.

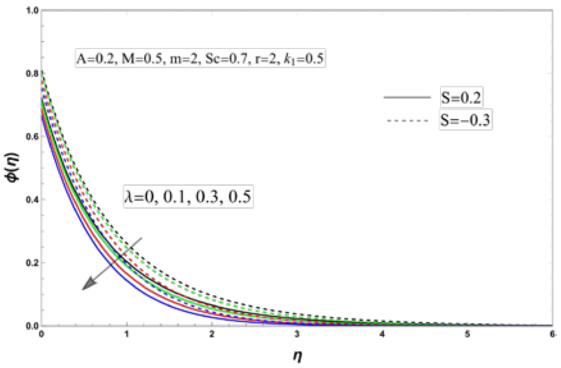

Figure 9a – Variations of concentration $\phi(\eta)$ for various values of $\lambda(<1)$

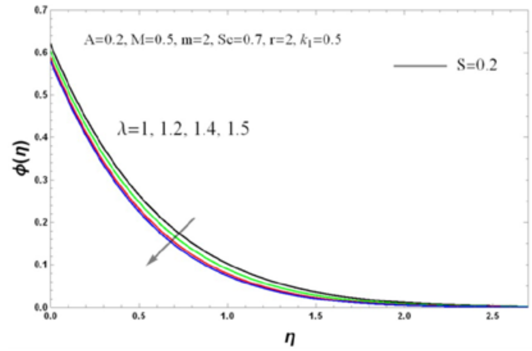

Figure 9b – Variations of concentration $\phi(\eta)$ for various values of $\lambda(\geq 1)$

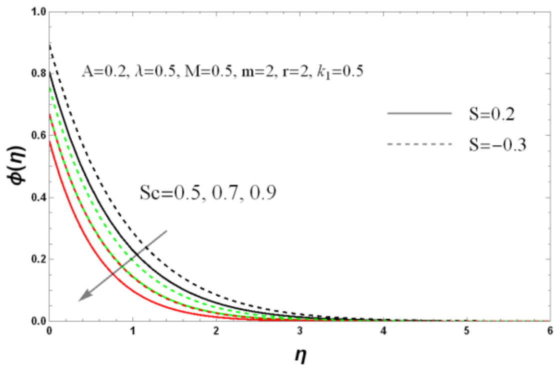

Figure 10 -Variations concentration $\phi(\eta)$ for various values of Sc

Variable mass flux at the boundary plays an important role which can be viewed by the impact of the variations of m and r on concentration profiles. Figures 11 and 12 represent the behaviours of fluid concentration for different values of m and r respectively. These figures explore that concentration of the fluid decreases with increasing values of both m and r for both suction and blowing. But the enhancing values of r [Figure 12] affect the fluid concentration more than that of m [Figure 11]. Physically this can be explained as: with rising values of m unsteadiness of mass flux increases which in turn causes to decrease the fluid concentration. This is obvious and one can easily understand this feature from the last condition given by Equation (5). Moreover, thinner solute bl is observed as the mass flux differs with time and distance along the surface i.e. for higher values of power indices m and r.

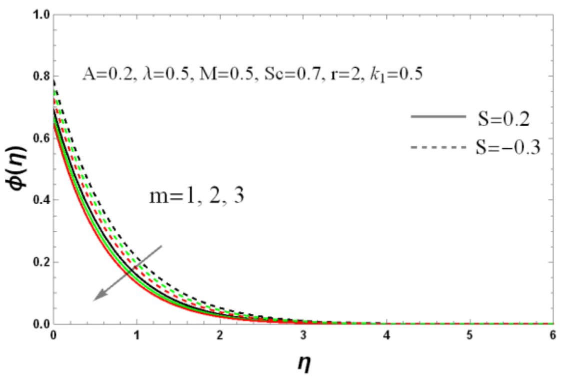

Figure 11 – Variations of concentration $\phi(\eta)$ for various values of m

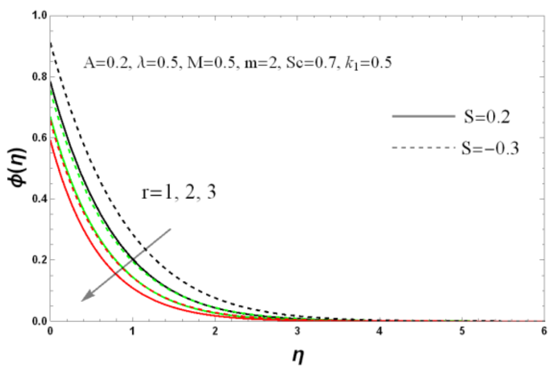

Figure 12 – Variations of concentration $\phi(\eta)$ for various values of r

The impact of chemical reaction parameter k_1 on concentration of the fluid is explored in Figure 13 which shows that fluid concentration decreases with increasing values of chemical reaction parameter $\mathbf{k_1}$ for both suction and blowing. Here, $\mathbf{k_1} = 0$ means there is no chemical reaction.

The behaviours of velocity gradient at the surface $f''(0)$ with A for different values of magnetic parameter M are shown in Figures 14. We know that skin friction coefficient is proportional to $f''(0)$ so one can say from Figure 14 that skin friction coefficient decreases with rising values of M. The developed resisting force by enhancing magnetic field causes the decrement of skin friction coefficient. It is also observed that skin friction coefficient is compressed when moving outer flow is taken into account [Table III]. Figure 15 shows the variation of wall concentration with A for different values of M. In the figure wall concentration increases with enhancing values of M whereas it diminishes with the rising values of unsteadiness parameter A [Figure 15].

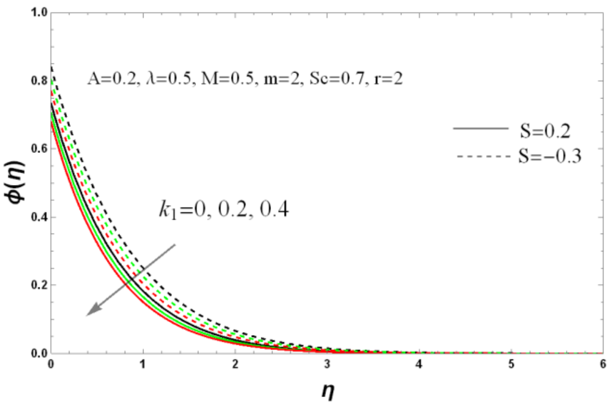

Figure 13 – Variations of concentration $\phi(\eta)$ for various values of $\mathbf{k_1}$

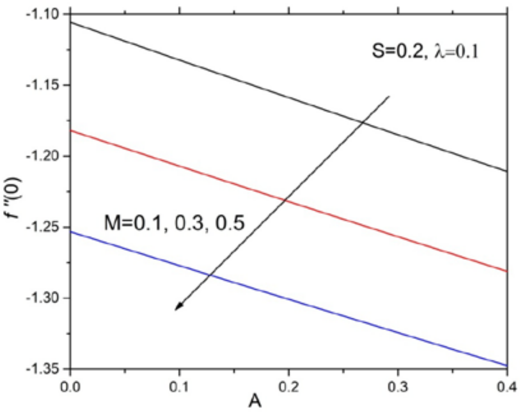

Figure 14 – Variations of velocity gradient at the wall $f''(0)$ with A for different values of M

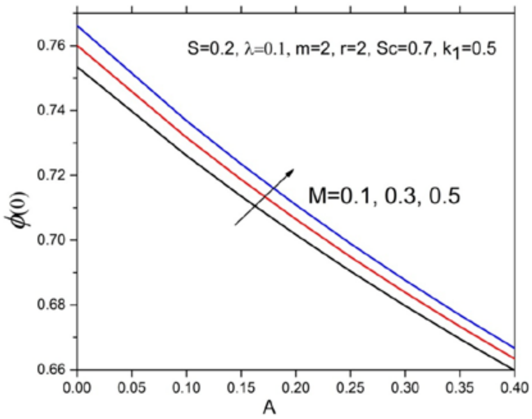

Figure 15 – Variations of wall concentration $\phi(0)$ with A for different values of M

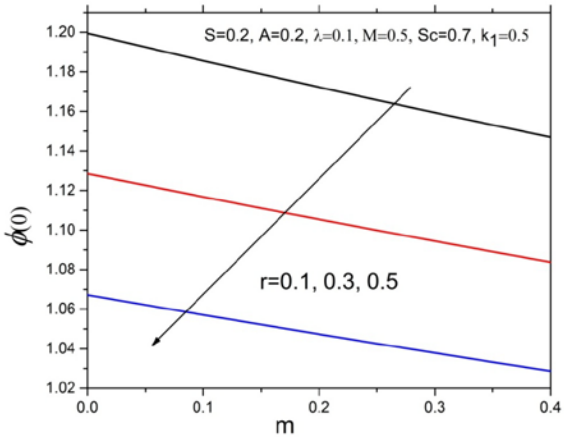

Figure 16 – Variations of wall concentration $\phi(0)$ with m for different values of r

Wall concentration decreases with increasing values of m and r which is depicted in Figures 16. Variations of surface shear stress $f''(0)$ and wall concentration $\phi(0)$ for different values of S are numerically presented in Table III. From this table it is observed that when the values of S increases from -0.2 to 0.2, $f''(0)$ decreases from -1.18795 to -1.38468 for static free stream ($\lambda = 0$) whereas for moving free stream ($\lambda = 0.1$) it decreases from -1.12083 to -1.32521. Consequently, it is concluded that moving free stream compresses the skin friction coefficient. Similar type of behaviour is observed for wall concentration which is shown in Table III.

Conclusions

Mass transfer of an unsteady chemically reactive MHD boundary layer flow over a stretching sheet in presence of variable mass flux and moving free stream is considered. Suitable similarity transformations are employed to find self-similar equations which are solved numerically with the help of bvp4C. The impact of several controlling parameters on flow and mass transfer are analysed graphically and demonstrated comprehensively through tables. Following are the remarkable observations of this study:

(i) The rising values of magnetic parameter M, unsteadiness parameter A, suction/blowing parameter S compress the fluid velocity.

(ii) Fluid velocity is found to rise for improved values of λ and bl structure is noted for $\lambda < 1$. Inverted bl structure is observed for $\lambda > 1$ and no bl structure is observed for $\lambda = 1$.

(iii) Fluid concentration reduces with growing values of velocity ratio parameter λ for all cases considered.

(iv) Compared to the case for static free stream, fluid velocity is higher when the free stream moves. Also higher concentration is noted in presence of moving free stream.

(v) The presence of moving free stream causes to diminish the effect of suction/blowing on flow and concentration fields.

(vi) The increasing strength of suction causes to decrease the fluid velocity more significantly than that for blowing.

(vii) Fluid concentration decreases with enhancing values of chemical reaction parameter k_1, power-law indices r and m whereas concentration is found to increase for increasing values of magnetic parameter M.

(viii) Skin friction coefficient decreases whereas wall concentration increases with the rising values of M.

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Information about authors:

Rakesh Kr Saha – M.Sc , Research scholar of Department of Mathematics, The University of Burdwan, (Burdwan-713104, West Bengal, India);

Hiranmoy Maiti – M.Sc, Research scholar of Department of Mathematics, The University of Burdwan, (Burdwan-713104, West Bengal, India);

Swati Mukhopadhyay – (corresponding author), Doctor of science, Professor of Department of Mathematics, The University of Burdwan, (Burdwan-713104, West Bengal, India, e-mail: swati_bumath@yahoo.co.in).

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