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Flow and Heat Transfer Analysis MHD Nanofluid due to Convective Stretching Sheet

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Abstract

Objectives: The study of flow and heat transfer on a permeable stretching sheet of Magnetohydrodynamic nanofluid under the influence of convective boundary condition is presented in this article. Mathematical modeling for the law of conservation of mass, momentum, heat and concentration of nanoparticles is executed. **Methods:** Governing nonlinear partial differential equations are reduced into nonlinear ordinary differential equations and then shooting method with fourth order Adams-Moulton Method is employed for its solution. **Findings:** The effects of magnetic parameter $(0 \leq M \leq 2)$, Thermophoresis parameter $(0.1 \leq Nt \leq 0.7)$ Lewis number $(1 \leq Le \leq 4)$, Suction parameter $(0 \leq f_w \leq 3)$, Biot number$(0.1 \leq Bi \leq 0.7)$ and Viscous dissipation$(0 \leq Ec \leq 4)$ on axial velocity, temperature and concentration profiles are shown graphically. Numerical results were compared with another numerical approach and an excellent agreement was observed. The solutions under the impacts of different physical governing parameters are illustrated by means of graphs and tables. Effects of viscous dissipation is also discussed. **Novelty:** Despite the enormous importance and repeated application of nanofluids in industry and science, no attempt has been made to investigate the viscous dissipation effect on heat transfer with a permeable linear stretch sheet.

Keywords: MHD; Nanofluid; Stretching Sheet; Viscous dissipation; Shooting technique; Adams-Moulton Method

1 Introduction

The study of the boundary layer flow and heat transfer of fluids caused by moving or stretching surfaces has remarkable engineering and industrial applications like extrusion, wire drawing, melt-whirling, production of glass fiber, manufacturing of rubber sheets and cooling of huge metallic plates such as an electrolyte.

In the immediate surroundings of fluid, the light polymer sheet composes a non-uniformly moving plane. Through consecutive experiments, it is proved that the distance of the slot and velocity of stretching surface is consistent. The sheet bears the incompressible flow, which was initially explored by Crane [1] by providing uniform stress. Nanoparticles are particles between 1 and 100 nanometers in size. Nanofluids are obtained by the dispersion of nanoparticles with base fluid. This type of fluid is from a new class of nanotechnology which is based on heat transfer. The goal of nanofluids is to get maximal thermal characteristics while using the least amount of material. The developments of nanofluids possess superior thermal conductivity and enhanced heat transfer characteristics. Nanofluids are homogenous mixture of nanoparticles and base fluid. Some common nanoparticles include carbons in different forms like diamond and graphite carbon nanotubes, oxide ceramics.

All nonmetallic and metallic particles change the transport properties and heat conduction characteristics of the base fluids like water, organic liquids, e.g., ethylene, refrigerants, etc. In 1995, Choi [2] made the analysis of nanoparticles and he was the first who has done work in this direction. Buongiorno [3] showed the great fact that thermal conductivity of the conventional heat transfer liquids increased up to approximately two times by adding only the very small number of nanoparticles in the fluid, that is, less than 1 by volume.

Magnetohydrodynamic boundary layer stream is of great importance as it can be connected in various zones of businesses also in utilizations of geothermal. Because of its extensive variety of uses numerous scientists have examined the attractive field impact on the liquid stream issues. Recently, Anusha, T., Mahabaleshwar, U.S. and Sheikhnejad, Y [4] explained the work on 2D laminar magnetohydrodynamics couple stress hybrid nanofluid is performed with inclined magnetic field over the stretching/shrinking surface embedded in porous media. Ashraf A, Zhang Z, Saeed T, Zeb H, Munir T [5]. studied the combined effects of velocity slip and convective heat boundary conditions on a hybrid nanofluid over a nonlinear curved stretching surface. Heat transfer analysis in a thin-film MHD flow embedded in the hybrid nanoparticles, which combine the spherical copper and alumina dispersed in ethylene glycol as the conventional heat transfer Newtonian fluid model over a stretching sheet discussed by Nur Ilyana Kamis, Lim Yeou Jiann, Sharidan Shafie, Taufiq Khairi Ahmad Khairuddin, and Md Faisal Md Basir [6]. Muntazir RM, Mushtaq M, Shahzadi S, Jabeen K [7]. investigated the unsteady MHD nanofluids flow problem around a permeable linearly stretching sheet under the influence of thermal radiation and viscous dissipation. Isah, B.Y., Abdullahi, B, Seini, I.Y. [8] talked about the steady/transient magnetohydrodynamics heat transfer within a radiative porous channel due to convective boundary conditions.

It is important to mention here that some practical applications where the significant temperature distribution between the surface of the body and the temperature at infinity exists. The temperature distribution may cause the change in density within fluid medium or free convection due to more important existence of gravitational head. There are some circumstances where the liquid moves along with the vertical stretching sheet. In such instances, buoyancy forces may exist owing to force convection, with the heat transfer distribution dictated by two setups: stretched sheet movement and gravity factors. The thermal buoyancy is produced due to the heating/cooling of a vertical movement of stretching sheet that becomes a large influence on the flow and heat transfer mechanism when hot fluid is moving horizontally. Vishwambhar S. Patil, Pooja P. Humane & Amar B. Patil. [9] discussed the heat and mass transfer of MHD Williamson nanofluid flow past a porous stretching surface with thermal radiation and chemical reaction. Ramzan M, Dawar A, Saeed A, Kumam P, Watthayu W. [10] analyzed the magnetohydrodynamic flow of $Ag-MgO$ /water hybrid nano liquid with slip conditions via an extending surface.

Viscous dissipation is usually a minor effect, but when the fluid viscosity is extremely high, it can have a significant impact. Rate of heat transfer is affected by the variation in temperature distribution. MHD flow across a porous stretched sheet under the effect of viscous dissipation was investigated by K. Govardhan, G. Narender, G. Sreedhar Sarma. [11]. G. Thirupathi, K. Govardhan and G. Narender [12] explained the flow of micro polar fluid above a porous stretching sheet in the presence of viscous dissipation, thermal radiation, flow on an unsteady stretching surface and magnetohydrodynamic with heat transfer through moving fluid. G. Narender, G. Sreedhar Sarma and K. Govardhan [13] examined the heat transfer in the nanofluid flow along with the viscous dissipation. The heat transfer with MHD Casson fluid flow towards a linear stretching sheet with temperature distribution over the sheet has been analyzed by Kamatam Govardhan, Ganji Narender, Gobburu Sreedhar Sarma [14].

In the present paper, we have reviewed H. Ajam [15] MHD nanofluid flow at a boundary layer over a stretching sheet placed vertically and we have extended the study of H. Ajam [15] by adding additional effect of viscous dissipation.

2 Methodology

Consider the steady, laminar, incompressible nanofluid in the region $y > 0$ induced by a permeable stretching sheet located at $y = 0$ with a fixed origin at $x = 0$ as displayed in Figure 1. From the slot at the origin thin solid surface is extruded which is being stretched in $x-$ direction. The stretching velocity $u_w(x) = cx$ is assumed to vary linearly from the origin, where c is a positive constant$(c > 0)$.

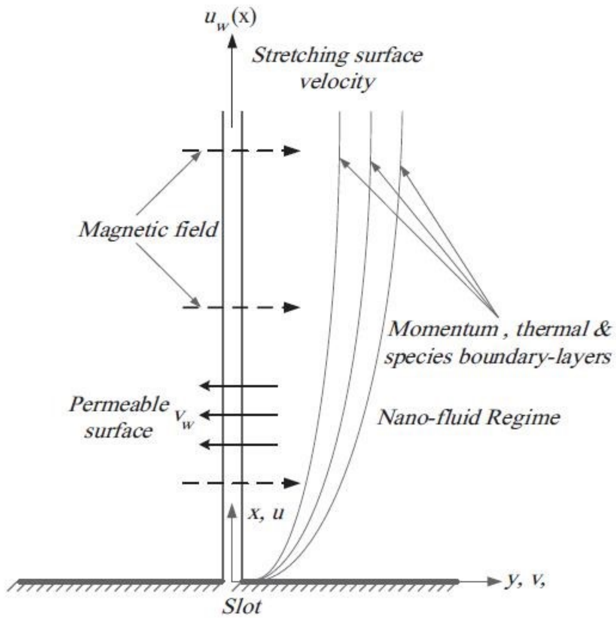

Fig 1. Geometry

It is also assumed that the plate must possess a constant temperature T_w and nanofluid volume fraction at the surface of the sheet C_w . The ambient fluid temperature is considered as T_∞ and the nanofluid volume fraction far from the surface of the sheet is C_∞. The constitutive equations of UCM nanofluid model under the assumed circumstances are given as

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial y^2}\right)+\frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2+\tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\left(\frac{\partial^2 C}{\partial y^2}\right)+\frac{D_T}{T_\infty}\left(\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

Where ρ is the fluid density, σ is the electrical conductivity,$v=\frac{\mu}{\rho}$ is the kinematic viscosity. A magnetic field B_0 is implemented perpendicular to the $x-$direction, Trepresents the temperature of fluid, thermal diffusivity is $\alpha, c_p$the specific heat capacity of the nanoparticle material, C the nanoparticle fluid concentration, D_B represents the Brownian diffusion coefficient, and D_T is the thermophoretic diffusion coefficient. The perpendicular and parallel coordinates to the surface are y and $x$the components of velocity are u, v and in the direction of x, y and Boundary conditions can be written as

$$\left.\begin{array}{l} u=u_w(x)=cx, \quad v=v_x, -K\dfrac{\partial T}{\partial y}=h_1\left(T_w-T\right) \\ -D_B\dfrac{\partial C}{\partial y}=h_2\left(C_w-C\right), \\ u\to 0, T\to T_\infty, C\to C_\infty \text{ as } y\to\infty. \end{array}\right\} \text{at } y=0, \left.\vphantom{\begin{array}{l}a\\a\\a\end{array}}\right\} \tag{5}$$

The modelled equations are made dimensionless by variables:

$$\left.\psi(x,y) = (cv)^{\frac{1}{2}} x f(\eta),\ \eta = \sqrt{\frac{c}{v}}y, \quad \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty},\ \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}\right\} \tag{6}$$

The resultant ODEs are

$$f''' + ff'' - (f')^2 - Mf' = 0 \tag{7}$$

$$\frac{\theta''}{\Pr} + f\theta' + Nb\theta'\phi' + Nt\left(\theta'\right)^2 + Ec\left(f''\right)^2 = 0 \tag{8}$$

$$\phi'' + Le\, f\, \phi' + \frac{Nt}{Nb}\theta'' = 0 \tag{9}$$

here,

$$\left.\begin{array}{l} M = \dfrac{\sigma B_0^2}{\rho c}, \Pr = \dfrac{\mu}{\alpha}, \quad Ec = \dfrac{u_w^2}{C_p\left[T_w - T_\infty\right]}, \quad Le = \dfrac{\alpha}{D_B} \\ Nb = \tau D_B \dfrac{(C_w - C_\infty)}{v}, Nt = \tau D_T \dfrac{(T_w - T_\infty)}{vT_\infty}. \end{array}\right\} \tag{10}$$

The BCs after the transformation get the following form:

$$\left.\begin{array}{l} f(0) = f_w, f'(0) = 1, \theta'(0) = -Bi\,1(1-\theta(0)), \phi'(0) = -Bi\,2(1-\phi(0)), \\ f'(\infty) \to 0, \quad \theta(\infty) \to 0, \quad \phi(\infty) \to 0 \end{array}\right\} \tag{11}$$

where

$$f_w = \frac{-v_w}{\sqrt{vc}}, Bi\,1 = \left(\frac{h_1}{k}\right)\sqrt{\frac{v}{c}}, Bi\,2 = \left(\frac{h_2}{D_B}\right)\sqrt{\frac{v}{c}}$$

3 Numerical solution

In order to solve the above obtained ordinary differential equations (ODE), we have used the shooting technique along with Adams-Moulton method. We are considering a finite domain as $[0, \eta_{\max}]$instead of$[0, \infty)$Let us use the notation f by y_1, θ by y_4 and ϕ by y_6 for converting the boundary value problem (BVP) to the following initial value problem (IVP):

$$\left.\begin{array}{ll} y_1' = y_2, & y_1(0) = f_w \\ y_2' = y_3, & y_2(0) = 1 \\ y_3^1 = \left[y_2^2 - y_1 y_3 + M y_2\right], & y_3(0) = s \\ y_4' = y_5, & y_4(0) = t \\ y_5^1 = -\Pr\left[-y_1 y_5 + Nb y_2 y_7 + Nt y_7^2 + Ec\left(f''\right)^2\right)\right], & y_5(0) = -Bi\,1(1-t) \\ y_6' = y_7, & y_6(0) = u \\ y_7' = -\dfrac{Nt}{Nb} y_5^1 - Le y_1 y_7, & y_7(0) = -Bi\,2(1-u) \end{array}\right\} \tag{12}$$

The above equations are solved using Adams-Moulton method of order 4 with an initial guess $s,\ t,\ u$ The missing initial conditions $s,\ t,\ u$ are to be chosen such that

$$y_2(\eta, s, t, u) = 0, \quad y_4(\eta, s, t, u) = 0, \quad y_6(\eta, s, t, u) = 0. \tag{13}$$

To solve the system of algebraic equations (13), we use the Newton's method. The iterative process is repeated until the following criteria is met.

$$\max\left\{\left|y_2\left(\eta_{\max}\right) - 0\right|, \left|y_4\left(\eta_{\max}\right) - 0\right|, \left|y_6\left(\eta_{\max}\right) - 0\right|\right\} < \xi.$$

Throughout this work, ξ has been taken as unless otherwise mentioned.

4 Results and Discussion

This section contains the numerical results have been displayed in graphical format. The effects of various parameters such as magnetic parameter, Brownian motion parameter, Thermophoresis parameter, Lewis number, Suction parameter, Thermal Biot number and concentration Biot number on velocity, temperature and concentration have been analyzed.

Table 1 shows the comparison of calculated values with [15] and strong agreement with the values is found which showed high confidence of present simulation. From table it is observed that Nusselt number is increased by increase of Prandtl number. Table 2 shows the skin-friction coefficient $(-f''(0))$increases by the increase of M. The effect of M on Nusselt number $(-\theta'(0))$and Sherwood number $(-\phi'(0))$is opposite as compared to skin-friction coefficient. The magnitude of skin-friction coefficient also increases by increasing the suction parameter. Sherwood number increases by increasing Lewis number. Effects of thermal and concentration Biot number are similar.

Table 1. Comparisonof results of$(-\theta'(0))$ in the absence of nanoparticles on various values of Prandtl number if $M = f_w = 0,$ Bil and $Bi\,2 \to \infty$

Pr	(10)	(11)	(14)	Current values
0.70	0.4539	0.4539	0.4539	0.45391
2.00	0.9114	0.9114	0.9114	0.91142
7.00	1.8954	1.8954	1.8954	1.895421

Table 2. Numericalvalues of $-f''(0), -\theta'(0)$ and $-\phi'(0)$for different parameters.

M	Le	f_w	Nt	Nb	$Bi1$	$Bi2$	$-f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0	1	1	0.1	0.1	0.1	0.1	1.076843	0.236882	0.337055
1							1.276822	0.226852	0.321237
2							1.364211	0.216853	0.317042
3							1.442316	0.202319	0.306048
1	1	1	0.1	0.1	0.1	0.1	1.076852	0.236849	0.307044
				0.3			1.076859	0.236855	0.307044
				0.5			1.076858	0.236855	0.307044
				0.7			1.076858	0.236854	0.307044
			0.1	0.1			1.076859	0.236854	0.307044
			0.3				1.176761	0.236859	0.307048
			0.5				0.307048	0.236860	0.307048
			0.7				1.396865	0.236861	0.307049
1	1	1	0.1	0.1	0.1	0.1	1.076862	0.236861	0.307049
	2						1.176853	0.246862	0.317051
	3						1.257686	0.256871	0.325052
	4						1.346869	0.266846	0.332054
1	1	0	0.1	0.1	0.1	0.1	1.076862	0.236864	0.307055
		1					1.176565	0.236861	0.307055
		2					1.276590	0.236859	0.307053
		3					1.366558	0.236858	0.307051
1	1	1	0.1	0.1	0.1	0.1	1.076561	0.236561	0.307053
					0.3		1.076563	0.236563	0.307055
					0.5		1.076564	0.236564	0.307056
					0.7		1.076565	0.236565	0.307058
1	1	1	0.1	0.1	0.1	0.1	1.076566	0.236567	0.307059
						0.3	1.076568	0.236568	0.307063
						0.5	1.076569	0.236569	0.307065
						0.7	1.076572	0.236569	0.307069

Figures 2, 3 and 4 show the effect of M *on velocity profile, temperature and concentration profiles respectively. It can be seen from the figures that thickness of velocity boundary layer is decreased by the increase of magnetic parameter whereas temperature and concentration distribution show a little increase with the increase in magnetic parameter. It is caused by the Lorentz force, which is produced when a magnetic field is applied to a conducting fluid. Lorentz force has the ability to lower flow speed, which validates our findings. When a magnetic field is applied to a fluid, the resistance of the fluid particles rises, resulting in an increase in temperature.*

Figure 5 represent the effect of thermophoresis parameter on the profile of concentration. An increasing thermophoresis parameter increase in the concentration distribution is seen. It can also be said that thermophoresis helps in diffusion of nano particles. Also, distribution of nano particles can be adjusted by adjusting Brownian motion parameter.

The influence of Lewis number on the concentration profile is seen in Figure 6. The ratio of thermal diffusion to molecular diffusion is determined by the Lewis number. It is useful for assisting us in determining the relationship between mass and the heat transfer coefficient. The concentration profile steepens as the Lewis number rises.

Figures 7, 8 and 9 represent the effect of suction parameter on velocity profile, temperature distribution and concentration distribution. By increasing the suction parameter, a decrease in velocity profile, temperature distribution and concentration distribution is observed. If suction is applied on vertical surface, it allows the fluid to draw in the surface which affects the boundary layer thickness.

Figures 10, 11 and 12 represent the effect of thermal Biot number and concentration Biot number on temperature and concentration distribution. Increase in thermal and concentration Biot number increases the temperature and concentration distribution. An increase in Biot numbers, increases heat transfer coefficient which increases the temperature.

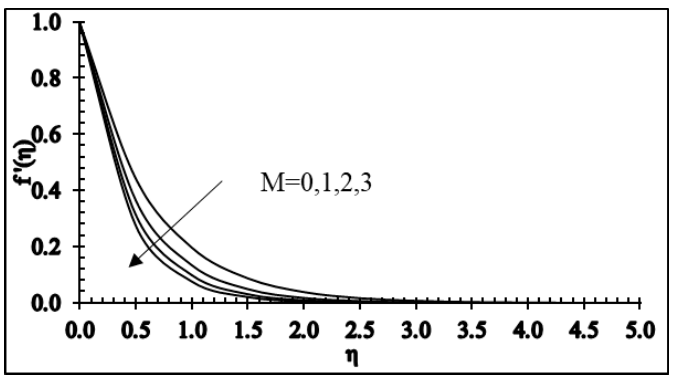

Fig 2. Influence of M on the dimensionless f velocity when $Nt = Nb = Bi\,1 = Bi\,2 = Ec = 0.1$ and $Le = f_w = 1$.

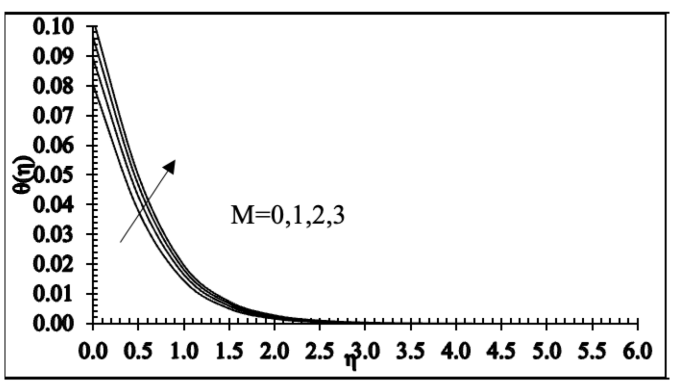

Fig 3. Influence of M on the dimensionless temperature $\theta(\eta)$when $Nt = Nb = Bi\,1 = Bi\,2 = Ec = 0.1$ and $Le = f_w = 1$.

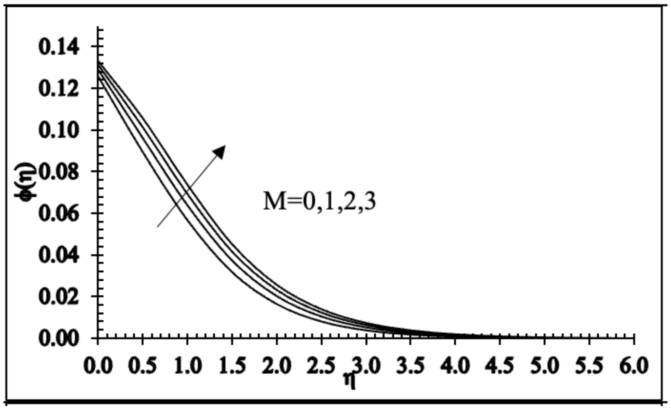

Fig 4. Influence of M on the dimensionless concentration $\phi(\eta)$ when$Nt = Nb = Bi\ 1 = Bi\ 2 = Ec = 0.1$ and $Le = f_w = 1$.

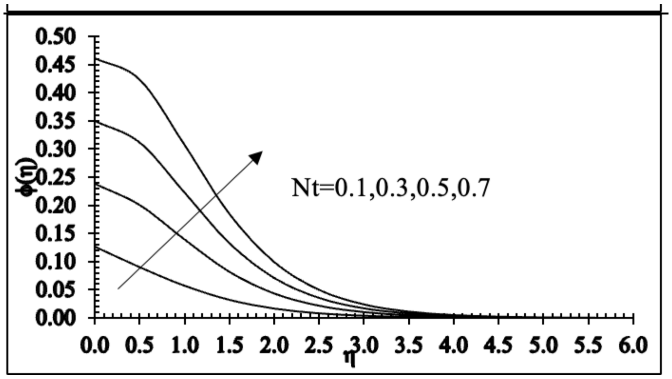

Fig 5. Influence of Nt on the dimensionless concentration $\phi(\eta)$when and $Nb = Bi\ 1 = Bi\ 2 = Ec = 0.1$ and $M = Le = f_w = 1$.

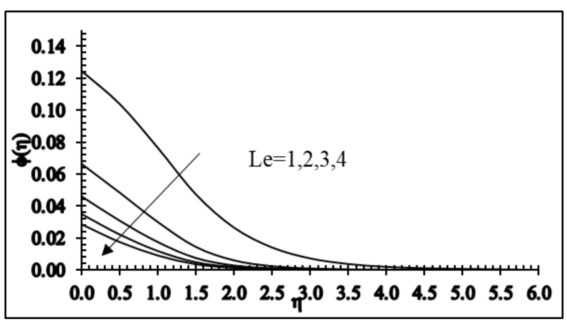

Fig 6. Influence of Le on the dimensionless concentration $\phi(\eta)$when $Nt = Nb = Bi\ 1 = Bi\ 2 = Ec = 0.1$ and $M = f_w = 1$.

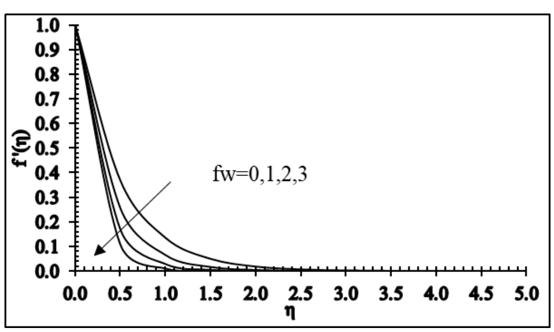

Fig 7. Influence of f_w on the dimensionless velocity f' when and $Nt = Nb = Bi\ 1 = Bi\ 2 = Ec = 0.1$ and $M = Le = 1$

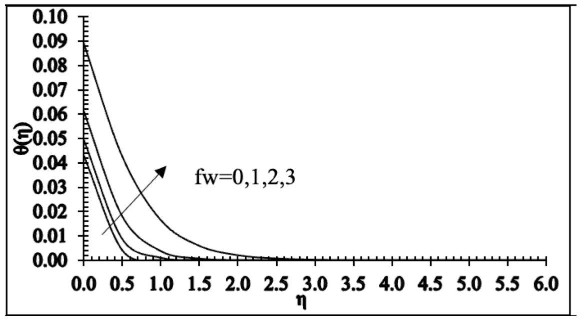

Fig 8. Influence of f_w on the dimensionless $\theta(\eta)$temperature when $Nt = Nb = Bi\,1 = Bi\,2 = Ec = 0.1$ and $Le = M = 1$.

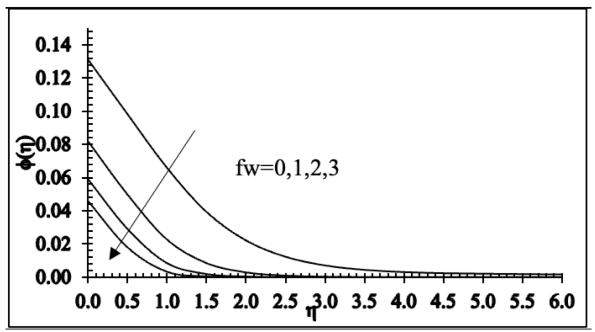

Fig 9. Influence of f_w on the dimensionless concentration $\phi(\eta)$when and $Nt = Nb = Bi\,1 = Bi\,2 = Ec = 0.1$ and $Le = M = 1$.

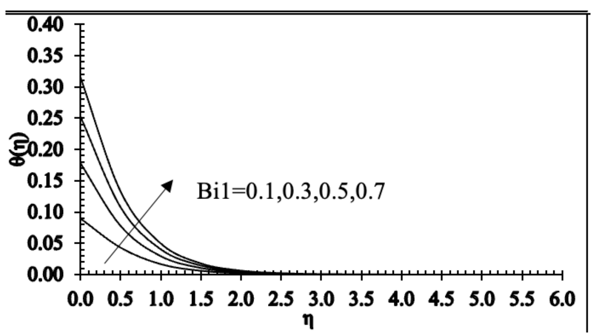

Fig 10. Influence of *Bi1* on the dimensionless temperature $\theta(\eta)$when $Nt = Nb = Bi\,2 = Ec = 0.1$ and $Le = M = f_w = 1$.

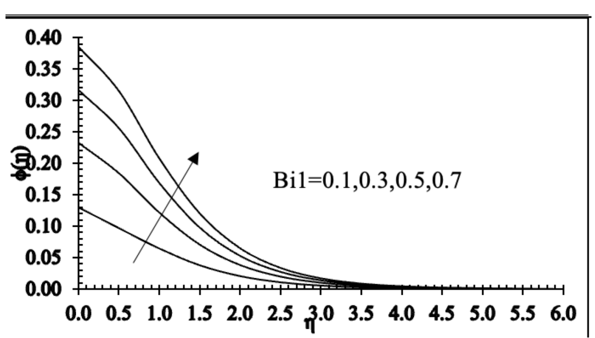

Fig 11. Influence of Bi1 on the dimensionless concentration $\phi(\eta)$ when $Nt = Nb = Bi\,2 = Ec = 0.1$ and $Le = M = f_w = 1$

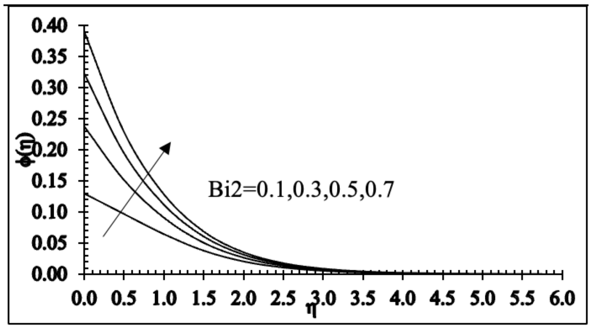

Fig 12. Influence of Bi 2on the dimensionless concentration $\phi(\eta)$ when $Nt = Nb = Bi\ 1 = Ec = 0.1$ and $Le = M = f_w = 1$

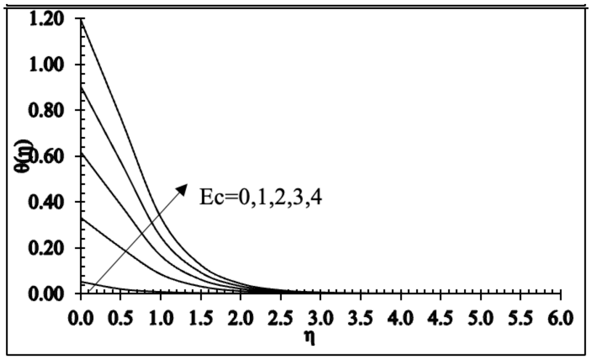

Fig 13. Influence of Ec on the dimensionless temperature $\theta(\eta)$when $Nt = Nb = Bi\ 2 = Bi\ 2 = 0.1$ and $Le = M = f_w = 1$.

5 Conclusion

In this article, the behavior of flow of MHD Nanofluid on a stretching sheet due to convective boundary conditions at the boundary layer is discussed. The obtained equations of the problem are converted into ODE's using similarity transformation. By the help of shooting method, the solution of given problem is obtained numerically and the following results are observed:

- Increase in magnetic parameter (*M)* decreases boundary layer thickness whereas increases temperature and concentration profile.
- Increasing the thermophoresis parameter (*Nt*) raises the concentration profile.
- Increase in suction parameter (*fw*) decreases velocity, temperature and concentration profile.
- Increase in thermal and concentration Biot number (*Bi1, Bi2*) increases temperature and concentration profile.
- Increase in viscous dissipation (*Ec*) increases temperature profile.

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