Comparison of Numerical solutions of non-linear and linear unsteady Burgers' fluid with MHD flow using the shooting technique

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Abstract- This article aims to compare the solutions of linear state and non-linear state unsteady (Non-Newtonian) Burgers' fluid flow along with the influence of magnetohydro dynamic. In this present paper, we find out the numerical solutions by using Runge-Kutta fourth order with the shooting technique. In this current analysis consider the thermosolutal boundary layer in the presence of heat source/sink. The working fluid in the two-state analysis is compared for several parameters in a tabular form and graphically. The best agreement of the current results has been ascertained by comparing it with the existent literature results. We observed in this analysis very quickly the boundary layer at the linear state gets heat than the boundary layer at the non-linear state with time-dependent. The flow controlled by the magnetic field effect and this observed more in the non-linear unsteady state than the linear unsteady state

Keywords: linear state, non-linear state, heat source/sink, thermosolutal, boundary layer.

I. INTRODUCTION

The one-dimensional Burgers' equation was first used by Beteman(1915) and later processed by Burger(1948). One of the leading cognitive factors of Burgers' equation is due to in-viscid boundary layers produced by the steeping effect of non-linear temperature change term in the equation, which affects the execution of the numeral or about methods used. In a recent time period, many researchers have applied different numerical methods to work out the Burgers' equation. From the last century so many researchers are analyzing the magneto-hydro-dynamic with the non-Newtonian fluids because due to its applications that are MHD generators used in the modern power plant, Pumps and flow meters, metal casting, nuclear fusion reactor, air conditioning, refrigeration, and human body blood flowing, etc., Based on these applications we have done literature survey in that recent researcher's analysis are, Hayat et al.[1] established the Burgers' fluid model solutions with viscoelastic periodic flows. Khan et al. [2] The one more researcher analyzed unidirectional of viscoelastic fluid flows between a couple of parallel plates with divisional Burgers' fluid model by Hyder Ali [3]. Liancun Zheng et al. [4] investigated the heat transfer of Burgers' fluid flow in the magnetic field over an exponential accelerating plate. Most of the scientist's analysis falls on the solve the Burgers' equations with different numerical methods because of its several applications in different fields [5-7].

Moreover, to observe the heat and mass transfer of Burgers' fluid flow with MHD or with different aspects of the fluid flow over several geometrical figures. Khan et al. [8] analyzed the Burgers' fluid flow at the boundary layer flow of a stretched sheet with the influence of steady free convection. The challenging problems of the different steady convection state Burgers' fluid model with a time of three initial boundaries layer analyzed by Tuma et al. [9]. A new method wavelet Galerkin method introduced to convert the partial differential equation to the ordinary differential equation of Burgers' equation by Wang Jizeng et al. [10]. Jianhong Kang et al.[11] have investigated the unsteady state of Burgers' fluid flow over a plate it has two side walls and perpendicular to a plate with the case of first and second Rayleigh-Stokes problems. Awais et al. [12] have investigated the steady-state Burgers' fluid flow over a stretching street for the analysis of heat transfer during the melting process. Mabood et al. [13] have analyzed heat transform on the steady of two-dimensional mixed convection of a non-Newtonian fluid flow at the boundary layer of the stretching surface. Masood Khan et al. [14] have presented the heat and mass transform of three dimensional steady of Burgers' nanofluid flow cross bidirectional stretching sheet. Tasawar Hayat et al. [15] examined the heat transform of unsteady mixed convection Oldroyd-B fluid flow towards stretched sheet.

The examination of the magnetohydrodynamic flow of a non-Newtonian electrically conducting fluid over a stretching sheet is essential in modern scientific discipline and processes of metal-working. A magnetic field is applying to the priming of metals in an electrical chamber. One more example of the magnetic field application is, the cooling process of the first wall where hot plasma is isolated inside a nuclear reactor vessel. Muhammad Awais et al. [16] have investigated the Burgers' nanofluid flow with a magnetic field effect due to the inclined wall. Dharmendar Reddy et al. [17] discussed the heat transfer rate of MHD non-Newtonian fluid flow at the boundary layer due to the exponentially stretching surface along with chemical reaction and thermal radiation. Madasi Krishnaiah et al. [18] have analyzed the mass and heat transform of Casson nanofluid flow with a magnetic field effect due to the exponentially stretching surface. Like this, so many researchers have done their investigation on several non-Newtonian fluids flow with magnetohydrodynamic effect in the presence of different convections of a heat source/sink [19-26].

Motivated by the above studies, we discussed the unsteady linear and non-linear state Burgers' fluid flow in the influence of magnetohydrodynamic effect due to the stretching surface with time-dependent. Thermal radiation examined with numerical solutions. Bvp5c Matlab package is used to solve the governing PDEs. We studied the heat transfer and volume fraction of mass transfer based on the effect of thermophoresis and Brownian motion. With the help of graphically and tabulation values compare the unsteady linear and non-linear non-Newtonian fluid flow heat source/sink.

II. FORMULATION OF THE PROBLEM:

Consider an unsteady non-linear and linear two-dimensional magnetohydrodynamic laminar flow of in-compressible Burgers' fluid over a stretching sheet. The concentration at the boundary layer of the sheet and the away from the stretching sheet as (C_s, C_∞), similarly the temperature at the boundary layer of the sheet and away from the stretching sheet as (T_s, T_∞).

Let velocity $u_w = \frac{ax}{1-ct}$ along X-axis, where the plate is stretched and normal on Y-axis. In u_w expression let a be the stretching parameter and c be the unsteadiness positive parameter.The heat absorption or source and viscous dissipation are supplementary into the flow. For the current paper, the basic governing equations are

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

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \alpha_1\left(2uv\frac{\partial^2 u}{\partial x\partial y} + u^2\frac{\partial^2 u}{\partial x^2} + v^2\frac{\partial^2 v}{\partial y^2}\right) + \alpha_2\left[\begin{array}{l} u^2\left(2\frac{\partial^2 u}{\partial x\partial y} + \frac{\partial^2 u}{\partial x^2}\frac{\partial u}{\partial x} - \frac{\partial^2 v}{\partial x^2}\frac{\partial u}{\partial y}\right) + u^3\frac{\partial^3 u}{\partial x^3} + v^3\frac{\partial^3 u}{\partial y^3} \\ +3uv\left(u\frac{\partial^3 u}{\partial x^2\partial y} + v\frac{\partial^3 u}{\partial x\partial y^2}\right) + 3v^2\left(\frac{\partial^2 u}{\partial x\partial y}\frac{\partial u}{\partial y} + \frac{\partial^2 u}{\partial y^2}\frac{\partial v}{\partial y}\right)\end{array}\right]$$

$$-\frac{\sigma\beta_0^2}{\rho} = v\left[\alpha_3\left(u\frac{\partial^3 u}{\partial x\partial y} + v\frac{\partial^3 u}{\partial y^3} - \frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2}\right)\right] + g\beta_T\left(T_0 - T_\infty\right) + g\beta_T\left(T_0 - T_\infty\right)^2$$

$$+g\beta_C\left(C_0 - C_\infty\right) + g\beta_C\left(C_0 - C_\infty\right)^2 \tag{2}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \kappa\frac{\partial^2 T}{\partial y^2} + \tau\left[D_\beta\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] + q''' + \frac{1}{\rho C_\rho}\left[\mu\left(\frac{\partial u}{\partial y}\right)^2\right] \tag{3}$$

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

The relevant physical boundary conditions are

If $y \to 0$ then $u = u_w, v = 0, T_0 = T_w, C_0 = C_w$

If $y \to \infty$ then $u \to 0, T_0 \to T_\infty, C_0 \to C_\infty$

Where u is the velocity of the component along x-axis direction and v is the velocity of the component along the y-axis direction. The stream function is defined as $u = \frac{\partial\psi}{\partial y}$ and $v = -\frac{\partial\psi}{\partial x}$.

Let q''' is the heat absorption or generation and it has taken as

$$q''' = \left(\frac{\kappa U_w(x,t)}{xv}\right)\left(Q_0\left(T_w - T_\infty\right)f' + Q_1\left(T - T_\infty\right)\right) \tag{5}$$

Where Q_0 and Q_1 are the parameters of space and temperature-dependent heat generation/absorption. The positive values of Q_0 and Q_1 represents the heat generation and similarly internal heat absorption has happened in the negative values of Q_0 and Q_1.

Substituting equations (5) in equation (3) we get

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\kappa\frac{\partial^2 T}{\partial y^2}+\tau\left[D_\beta\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right]+\left(\frac{\kappa U_w(x,t)}{xv}\right)\left(Q_0\left(T_w-T_\infty\right)f'+Q_1\left(T-T_\infty\right)\right)$$
$$+\frac{1}{\rho C_\rho}\left[\mu\left(\frac{\partial u}{\partial y}\right)^2\right] \quad (6)$$

The governing partial differential equations can be rendered to ODEs with the help of following similarity transformations

$$u=\left(\frac{ax}{1-ct}\right)f'(\eta),\quad v=\left(\frac{av}{ct-1}\right)^{\frac{1}{2}}f(\eta),\quad \eta=y\left(\frac{a}{\nu(1-ct)}\right)^{\frac{1}{2}}$$
$$T=T_\infty+(T_w-T_\infty)\theta(\eta),\quad C=\left(C_w-C_\infty\right)\phi(\eta) \quad (7)$$

Where η is the similarity transformation, $f(\eta),\theta(\eta) and \phi(\eta)$ are the dimensionless stream function, temperature and concentration functions differentiate with respect to η.

Using equations (7), the governing equations (2), (4) and (6) with relevant boundary conditions are transform into the following form

$$f^{iv}=\frac{1}{\left(\beta_2 f^3-\beta_3 f\right)}\left[\begin{array}{l}f'^2-Mf'+Af'+\frac{1}{2}A\eta f''-ff''-\beta_1 f^2 f'''-f'''-\beta_3 f''^2\\-\xi_1\left(\theta+N\phi\right)-\xi_2\left(\theta^2+N^2\varphi^2\right)\end{array}\right] \quad (8)$$

$$\theta''=\left[0.5P_r\eta A\theta'-\left(Q_1 f'+Q_2\theta\right)-P_r f\theta'+q_n\theta e^{-n\eta}-P_rN_b\theta'\phi'-P_rN_t\theta'^2-P_rE_c f''^2\right] \quad (9)$$

$$\phi''=\frac{\eta A}{2}S_c\phi'-S_c f\phi'-\frac{N_t}{N_b}S_c\theta'' \quad (10)$$

The transformed corresponding boundary conditions are as follows

If $\eta\to 0$ then $f(\eta)=0,\ f'(\eta)=1,\theta(\eta)=1,\theta'(\eta)=B_{i_1}(1-\theta),\phi(\eta)=1,\phi'(\eta)=B_{i_2}(1-\phi)$

If $\eta\to\infty$ then $f(\eta)=0,\ f'(\eta)=0,\theta(\eta)=0,\phi(\eta)=0$ (11)

Where $M=\frac{\sigma\beta_0^2(1-ct)}{a\rho}$ is the magnetic field, $A=\frac{c}{a}$ is the non-dimensionless unsteadiness parameter, $\upsilon=\frac{\mu}{\rho}$ is Kinematic viscosity of fluid, $P_r=\frac{\upsilon}{\alpha}$ is exist Prandtl number, $S_C=\frac{\alpha}{D_B}$ is Schmidt number, $N_b=\frac{D_{Br}\tau\left(C_w-C_\infty\right)}{\upsilon}$ is the parameter of Brownian motion, $N_t=\frac{D_T\tau(T_w-T_\infty)}{T_\infty\upsilon}$ is the parameter of thermophoresis, $N=\frac{\beta_C\left(C_w-C_\infty\right)}{\beta_T\left(T_w-T_\infty\right)}$ is the buoyancy of the thermal effect, $\beta_1=\frac{t_1 a}{(1-ct)},\beta_2=\frac{t_2 a^2}{(1-ct)^2},\beta_3=\frac{at_3}{(1-ct)}$ are Deborah number and also viscoelastic fluid parameter for temperature, $Gr_x=\frac{g\beta_T\left(T_w-T_\infty\right)x^3}{\upsilon^2}$ is Grashof number, $E_C=\frac{U_w^2}{(T_w-T_\infty)C_p}$ is Eckret number, and $\mathrm{Re}_x=\frac{U_w x}{\upsilon}$ is Reynolds number.

The main significant physical quantities of the current research problem coefficients are Skin friction C_S, Local Nusselt number Nu and Local sherwood number Sh.

$$C_S = \frac{\tau_w}{\frac{\rho}{2} u_w^2}, \quad Nu_x = \frac{-x}{(T_w - T_\infty)}\left(\frac{\partial T}{\partial y}\right)_{y=0}, \quad Sh_x = \frac{-x}{(C_w - C_\infty)}\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

Where $\tau_w = u\left(\frac{\partial u}{\partial y}\right)_{y=0}$ is Skin-friction on the surface of the plate.

III. NUMERICAL SOLUTION:

The higher order differential equations can be solved using the numerical method Runge-kutta fourth order with the shooting method. This process has done with the help of software Matlab.

IV. RESULT AND DISCUSSION

The subject of this section examines the effect of numerous physical parameters such as magnetic field parameter, Prandtl parameter, Brownian motion parameter, thermophoresis parameter and some more parameters on the following profiles velocity, concentration and temperature in the linear and non-linear unsteady state of non-Newtonian MHD fluid flow. Also studied the same parameters on heat transfer rate, mass transfer rate and skin friction

Table-1comparision of linear and non-linear unsteady state skin friction, local Nusseltand local Sherwood with various parameters based on time-dependent.

M	N	N_t	N_b	B_i	Linear unsteady state				Non-linear unsteady state			
					Skin friction	Nu	Sh	Time	Skin friction	Nu	Sh	Time
0.1					-1.205081	0.094096	0.121865	2.811480	-1.229941	0.090423	0.121076	2.430384
0.5					-1.100443	0.106407	0.125280		-1.141947	0.103613	0.124488	
1.0					-1.082355	0.110606	0.126773		-1.112703	0.108874	0.126254	
	1				-0.969638	0.074795	0.076695	4.383241	-0.943151	0.073507	0.078304	4.315230
	2				-0.939065	0.074584	0.076619		-1.000955	0.072446	0.078226	
	3				-1.050879	0.074306	0.076602		-1.082132	0.070583	0.078018	
		0.2			-1.087746	0.072327	0.079317	1.823090	-1.070871	0.072087	0.079308	1.463466
		1.2			-1.055240	0.072098	0.084420		-1.045710	0.071966	0.084553	
		2.2			-1.018081	0.071934	0.089807		-1.012305	0.071869	0.089937	
			0.3		-1.031875	0.071773	0.078170	3.255862	-1.082132	0.070583	0.078018	2.490905
			3.3		-1.055367	0.069618	0.077314		-1.104020	0.068338	0.076939	
			6.3		-1.067809	0.067650	0.077163		-1.113864	0.066355	0.076793	
				0.1	-1.122806	0.073607	0.077847	6.621523	-1.122806	0.073607	0.077847	5.626819
				0.2	-0.982985	0.074673	0.083098		-0.982985	0.074673	0.083098	
				0.3	-0.802358	0.075585	0.085545		-0.802358	0.075585	0.085545	

We observed the numerical values of the Skin friction, local Nusslet number and Sherwood number of the numerous parameters in the above table. It clearly shows that the non-linear unsteady state fluid flow process has taken less time compare to the linear unsteady state fluid flow with the several parameters. The effect of the magnetic field on the linear unsteady fluid flow and the non-linear unsteady state, the fluid flow is very smooth in the non-linear unsteady state than the linear unsteady state. There is a fluctuation in linear unsteady state changes of the buoyancy effect, but in the non-linear unsteady state, the buoyancy effect controls the fluid flow. Moreover, all the parameters control the fluid flow is more in the non-linear unsteady state than the linear unsteady state.

Figures 1, 2 and 3 show the effect of the magnetic field on Local Sherwood, Nusslet number and velocity in the linear and non-linear unsteady state with varying values of η. We observed the magnetic field effects the fluid flow in various aspects, especially in dissipation. Momentum boundary layer reduces at both the states as increases magnetic field. Eventually, analysis of the unsteady fluid flow of the linear and non-linear state in the velocity, concentration and temperature profiles at the different parameters. Similarly, thermophoresis and mass transfer are increased by increases the effect of the magnetic field. Conversely, velocity as decreases and the flow rate fluctuate more in the linear state than the non-linear state

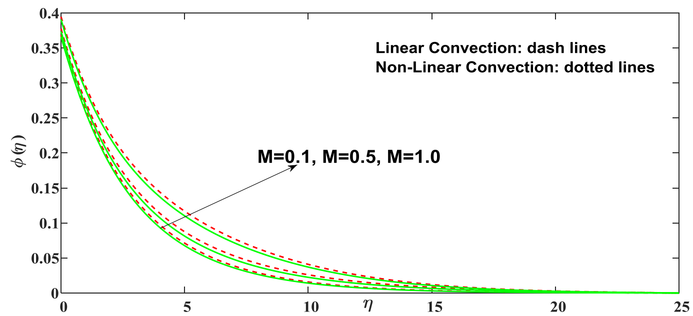

Figure 1. Effect of Magnetic field on concentration

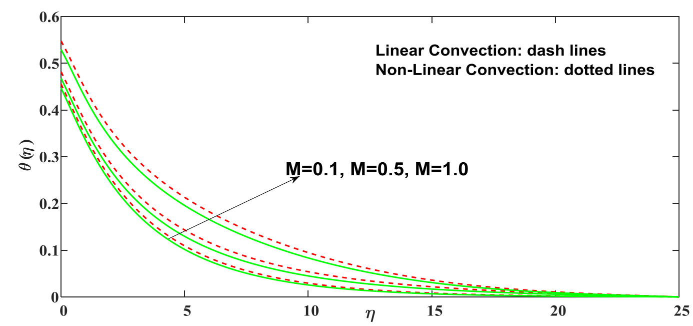

Figure 2.Effect of Magnetic field on temperature

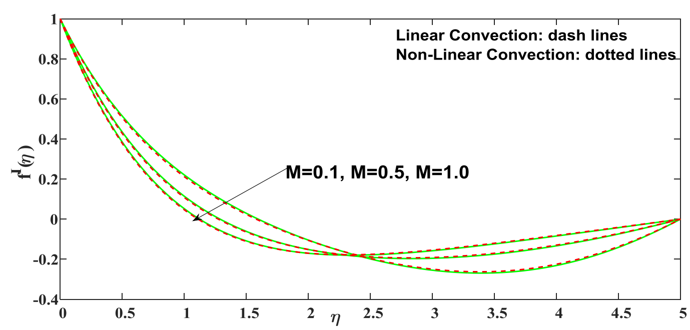

Figure 3. Effect of Magnetic filed on volume

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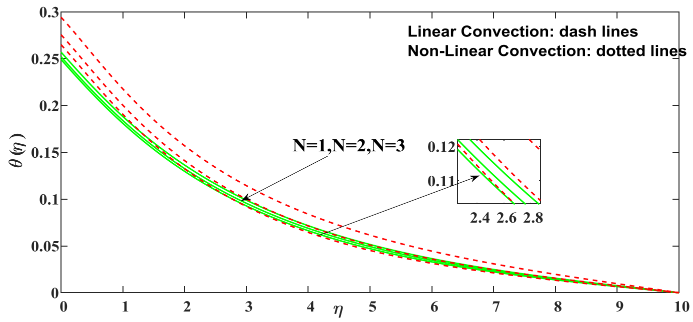

Figure 4. buoyancy effect on temperature.

Physically the smaller buoyancy force works on the fluid flow we have observed depreciation in temperature, concentration and velocity fields with varying M, R and P_r. These conspiracies are shown in Figures 4, 5, and 6. From these graphs, we validated the behavior of buoyancy force on non-linear state flow more effective than linear state unsteady fluid flow.

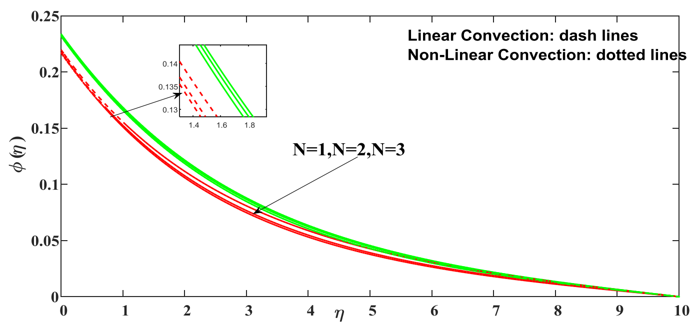

Figure 5. buoyancy effect on concentration

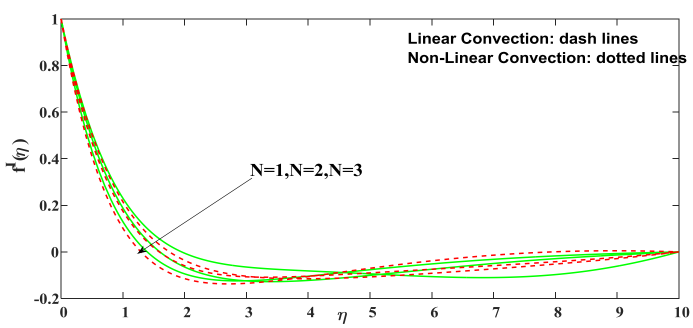

Figure 6. buoyancy effect on velocity

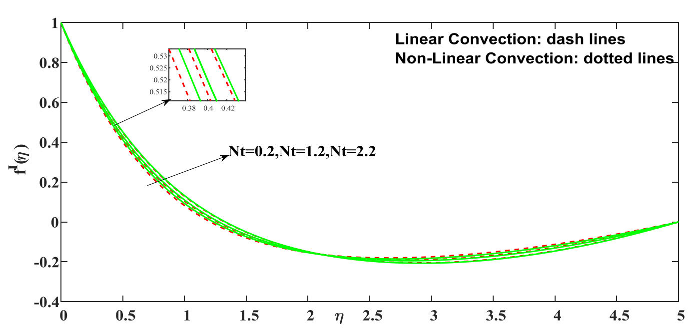

Figure 7. Thermophersis effect on velocity

Figures 7, 8 and 9 show the influence of the thermophoresis parameter on velocity, concentration and temperature in linear and non-linear unsteady fluid flow. It is clear that the rising thermophoresis parameter improves the velocity and temperature and its quite opposite in the velocity field. The mass transfer rate is no changes in both the state but the raising thermophoresis improves the particle interaction when enhancement of heat transfer and velocity rates more in non-linear convection than the linear convection.

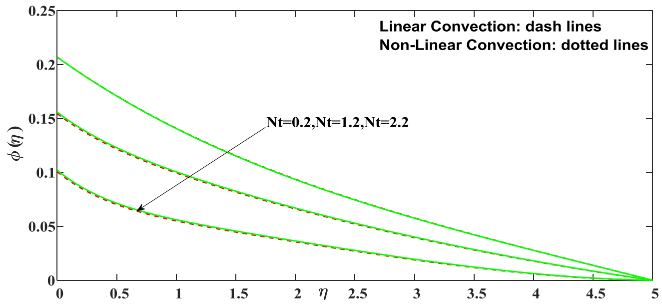

Figure 8. Thermophersis effect on concentration

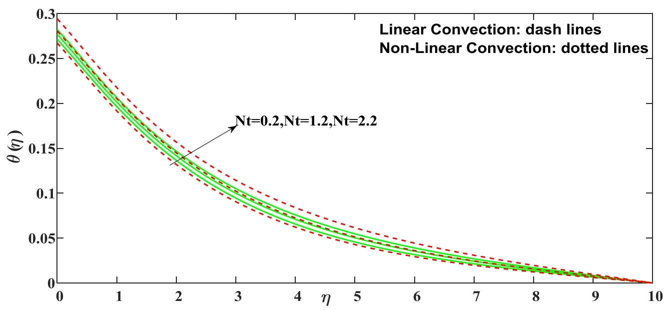

Figure 9. Thermophersis effect on temperature

The influence of the Brownian motion parameter with a constant magneticfield and Prandtl number parameter on both linear and non-linear convection as shown in figures 10, 11 and 12. We noticed that the effect of the rising Brownian motion parameter increases the temperature and concentration profile and exactly the opposite trend in the velocity profile.

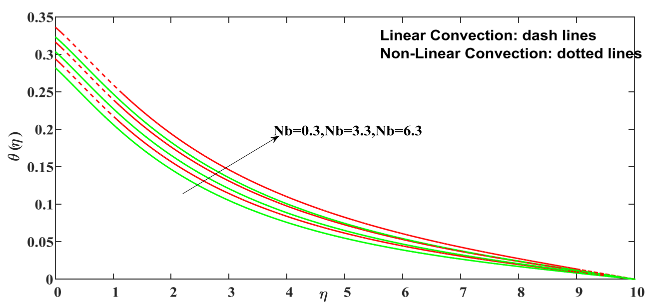

Figure 10. Brownian motion effect on temperature

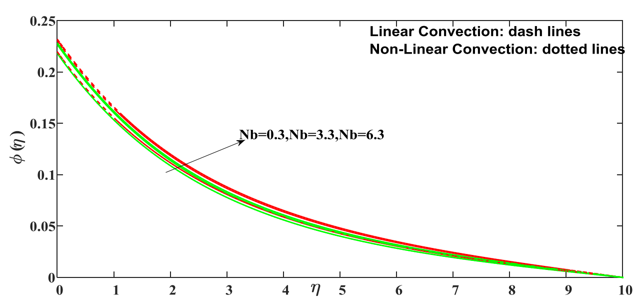

Figure 11. Brownian motion effect on concentration

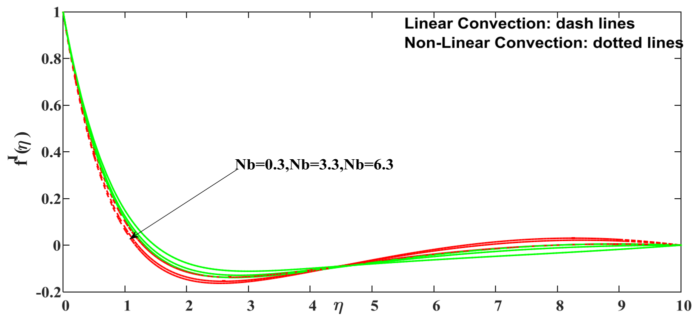

Figure 12. Brownian motion effect on velocity

V. CONCLUSION

The current analysis focused on the heat and mass transfer of the MHD Burger's fluid flow over a Stretching sheet under the linear and non-linear unsteady states. We analyzed based on time-dependent and theoretically in which states boundary layer thickness reduces very quickly, and natural convection on heat and mass transfer of radiating stretching surface.

The flow controlled by the magnetic field effect. This can be observed from the graphs; the magnetic field parameter reduces the velocity, heat transfer rate and mass transfer rate (Based on Lorentz force) and varying of different parameters. This is caused by the drag force in the flow. It's observed more in the non-linear unsteady state than the linear unsteady state

The buoyancy parameter lessens the temperature, concentration and velocity fields. From these results, we can highlight that the buoyancy is useful for controlling the flow behavior.This behavior we observed more in the non-linear unsteady state than the steady-state. There is a slight difference in the buoyancy effect in both states.

In this article clearly we can observe the thermodiffusion of both the state when the thermodiffusion is more in the linear unsteady state than the non-linear unsteady state. Very quickly the boundary layer at the linear state gets heat than the boundary layer at the non-linear state.

The Brownian motion effect is more in the linear unsteady state than the non-linear state, the fluid particle motion control is more is in the linear unsteady state.

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