

# MHD Momentum Transfer Flow of a Non-Newtonian Walters' Liquid Over a Quadratic Stretching Porous Sheet

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**Abstract:** MHD boundary layer momentum transfer flow of a non-Newtonian Visco-elastic Walters' liquid B' model in a saturated porous medium over a quadratic porous stretching sheet have been presented in the paper. The boundary conditions of the problem are constituted by the typical choice of quadratic stretching boundary including a linear mass flux in the velocity normal and a quadratic part in velocity parallel to the boundary sheet through Visco-elastic fluid. The effect of various non dimensional parameters on velocity profiles, stream line patterns and skin friction co-efficient are discussed and presented through graphs.

**Keywords:** Non-newtonian walters' liquid, stretching sheet, porosity, MHD, streamlines.

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## 1. Introduction

Enormous applications of Visco-elastic fluids in many industrial manufacturing processes have led to renewal interest among researchers to study boundary layer flow problems over a stretching sheet. In this regard Sakiadis [1] was the first researcher who did the pioneering work on the boundary layer flow of a viscous incompressible fluid over continuous solid surface. A significant effort has been made to study the boundary layer flow of viscous fluid past a porous sheet with Suction/Blowing has been studied by Dandapat and Gupta [2], Rollins and Vajravelu [3], Char [4], Lawrence and Rao [5], Acharya [6]. Amkadni [7] have studied the exact solutions of MHD laminar flow over a flat stretching sheet. Das [8] have discussed about the mixed convective heat and mass transfer flow of a viscous incompressible fluid past a vertical porous plate with periodic permeability. Idrees [9] have made a study on visco-elastic flow past a stretching sheet in a porous media. Mukhyo Padhyay [10] have investigated the study of MHD boundary layer flow over a heated stretching sheet with variable viscosity. Pantokratoras [11] has made a reinvestigation on the MHD boundary layer flow over a heated stretching sheet with variable viscosity. Sanyal [12] presented an analysis about the study on steady heat transfer flow of a conducting fluid caused by stretching porous wall.

However Gupta and Gupta [13] have made a point that in reality, stretching of the sheet might not be necessarily be linear. This situational study was made by Kumaran and Ramanaiah [14]. Their work is confined to boundary layer viscous fluid flow over a quadratic stretching sheet in the absence of magnetic field and without skin friction analysis. Thus in view of

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this and motivated by above studies in the present paper the authors made an attempt to investigate and analyze the MHD visco-elastic (Walters' liquid B') fluid flow through porous medium over a quadratic stretching of a sheet. The aim of the present work is to study by considering an electrically conducting fluid region exposed to uniform / transverse magnetic field and the effect of permeability of the porous medium; non-Newtonian parameter, magnetic parameter and mass flux parameters which appears in linear and quadratic stretching of the boundary on the stream line function and skin friction co-efficient. Sahoo [21] studied about the MHD convective boundary layer flow and heat transfer past a stretching porous sheet in a porous medium for viscous fluid. Khan [22] made an investigation on boundary layer MHD flow of a visco-elastic fluid through porous medium over a stretching sheet.

## 2. Mathematical Analysis

A two-dimensional free convective steady laminar boundary layer flow of an electrically conducting visco-elastic fluid in a porous medium over a stretching porous sheet in a semi-infinite region  $y > 0$  is considered for the study. The flow is assumed to be generated solely due to the stretching of the adjacent flat boundary sheet in such a way that no free stream velocity exists within the boundary layer. The sheet is stretched along X – axis and stretching is being done by applying two equal and opposite forces keeping the fixed region. The sheet velocity is a quadratic polynomial of the distance from the origin and there is a linear mass flux in addition to constant mass flux to the boundary layer region. The magnetic Reynolds (Ratio of inertial force to the magnetic diffusivity) number is assumed it be very small so that the induced magnetic field is negligible in comparison with the applied magnetic field. Under the above mentioned assumptions, the basic governing boundary layers equations in the present flow situation are the modified versioned of Beard and Walters' [15] and of Andersson [16] which are given by

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

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \nu \frac{\partial^2 u}{\partial y^2} - k_0 \left\{ u \frac{\partial^3 u}{\partial x \partial y^2} + v \frac{\partial^3 u}{\partial y^3} - \frac{\partial u}{\partial y} \cdot \frac{\partial^2 u}{\partial x \partial y} + \frac{\partial u}{\partial x} \cdot \frac{\partial^2 u}{\partial y^2} \right\} - \frac{\sigma \beta_0^2 u}{\rho} - \frac{\nu}{k'} u \quad (2)$$

Where all the special symbols have their usual meaning. The momentum equation (2) is valid for small values of elastic parameter  $k_0$ , with appropriate boundary conditions chosen in such a way that the porous sheet is assumed to be stretched quadratically along X-direction so that the constant and linear mass fluxes through the pores of the boundary influence the boundary layer flow. Thus the boundary conditions are

$$\begin{aligned} u &= bx + ax^2, \quad v = v_w + dx \quad \text{at } y = 0 \\ u &= 0, \quad \frac{\partial u}{\partial y} = 0 \quad \text{as } y \rightarrow \infty \end{aligned} \quad (3)$$

where  $b, a, v_w$  and  $d$  are constants and are the linear stretching rate, quadratic stretching rate, constant mass flux respectively and  $\delta x$  is the linear mass flux to the boundary layer region. Free stream velocity is being taken as zero at the outer boundary as the boundary conditions as  $y \rightarrow \infty$  in equation (3) are due to the stress-free conditions. It is interesting to note that the quadratic stretching part  $ax^2$  along X-directional velocity is accompanied by the linear mass flux  $dx$  along Y-directional velocity in order to satisfy the equation of continuity automatically.

### 3. Momentum Transfer Analysis

To seek self similar solution of equation (2) the following type of stream function is considered which is defined

$$\psi = \sqrt{cv}xg - \frac{\delta}{2}x^2g_\eta \text{ with } \eta = \sqrt{\frac{c}{v}} \tag{4}$$

Which yields

$$u = \frac{\partial\psi}{\partial y} = cxg_\eta(\eta) - \frac{\delta}{2}\sqrt{\frac{c}{v}}x^2g_{\eta\eta}(\eta) \tag{5a}$$

$$v = -\frac{\partial\psi}{\partial x} = -\sqrt{cv}g + \delta xg_\eta \tag{5b}$$

Substituting equations (4), (5a) and (5b) in equation (2) and then equating the coefficients of  $x$ ,  $x^2$ , and  $x^3$  of the resultant equations to zero, the following non-linear differential equations are obtained,

$$g_\eta^2 - gg_{\eta\eta} - g_{\eta\eta\eta} - k_1 \{2g_\eta g_{\eta\eta\eta} - gg_{\eta\eta\eta\eta} - g_{\eta\eta}^2\} - M_1g_\eta(\eta) = 0 \tag{6}$$

$$g_\eta g_{\eta\eta} - gg_{\eta\eta\eta} = g_{\eta\eta\eta\eta} - k_1 \{g_\eta g_{\eta\eta\eta\eta} - gg_{\eta\eta\eta\eta} - g_{\eta\eta}^2\} - M_1g_{\eta\eta} \tag{7}$$

$$g_{\eta\eta}^2 - g_\eta g_{\eta\eta\eta} = k_1 \{g_\eta g_{\eta\eta\eta\eta} - 2g_{\eta\eta} g_{\eta\eta\eta\eta} + g_{\eta\eta\eta}^2\} \tag{8}$$

Where  $M_1 = M_n + k_2$  and  $M_n = \sqrt{\frac{\sigma}{\rho b}} B_0$  the magnetic parameter,  $k_2 = \frac{\nu}{k'c}$  permeability parameter and  $k_1 = \frac{k_0c}{\nu}$  the visco-elastic parameter. The corresponding boundary conditions of equation (3) in non- dimensional form are derived as

$$g = -N; \quad g_\eta = 1; \quad g_{\eta\eta} = \frac{-2\alpha}{\delta} \sqrt{\frac{\nu}{C}} \text{ at } \eta = 0 \tag{9a}$$

$$g_\eta = 0; \quad g_{\eta\eta} = 0 \text{ at } \eta \rightarrow \infty \tag{9b}$$

Where  $N = \frac{Vw}{\sqrt{Cv}}$  suctionparameter. Equation (7) does not have any mathematical importance since it is obtained from equation (6) by simple differentiation.

### 4. Analysis of Results

**Case 1:** For suction  $Vw = 0$  at  $\eta = 0$  and  $g_\eta = 0$  as  $\eta \rightarrow \infty$ , Rajgopal [17] obtained the corresponding solution of equation (6) where as Troy [18] obtained the unique solution of equation (6) in the following form

$$g(\eta) = \sqrt{1 - k_1^*} \left( 1 - \exp \left( \frac{-\eta}{\sqrt{1 - k_1^*}} \right) \right) \tag{10}$$

**Case 2:** Further Chang [19] proved that the solution of equation (6) with boundary conditions (9a) and (9b) was not unique one and hence he took the value of visco-elastic parameter  $k_1^* = \frac{1}{2}$  and derived other form of solution as follows

$$g(\eta) = \sqrt{2} \left( 1 - \exp \left( \frac{-\eta}{\sqrt{2}} \right) \cos \sqrt{\frac{3}{2}} \eta \right) \tag{11}$$

**Case 3:** Another closed form solution for the interval of range when  $k_1^* \in (-1, 0)$  is derived by Rao (2) in the following way

$$g(\eta) = B \left( 1 - \exp \left( \frac{-B\eta}{2} \right) \cos \sqrt{3} B \eta + \left( \frac{1 + 2k_1^*}{\sqrt{3}} \right) \sin \left( \sqrt{3} B \eta / 2 \right) \right) \tag{12}$$

Where  $B = \text{reciprocal SQRT} [\text{negative of } k_1^*]$ . Among all the above three cases, solution (10) is realistic since in limiting case only  $k_1^* \rightarrow 0$ , the Navier-Stokes solution can be recovered. Also for non-Newtonian visco-elastic Walters' liquid  $B'$ , the elastic parameter  $k_1^*$  should be small and real positive value. Solution (10) is the only real solution of the problem which is obtained with respect to the three boundary conditions in which the first two boundary conditions of (9a) and 1<sup>st</sup> boundary condition of (9b). There fore presently in view of all the above ambiguiing nature of the solutions and boundary conditions we seek the solution of equation (6) with all prescribed boundary conditions (9a) and (9b) in the following form

$$g(\eta) = \alpha_1 + \alpha_2 e^{-H\eta} \tag{13}$$

$$\alpha_1 = \frac{H^2 - M_1}{H}; \quad \alpha_2 = -\frac{1}{H} \tag{14}$$

And hence we obtain

$$g(\eta) = \frac{1}{H} [H^2 - M_1 - e^{-H\eta}] \tag{15}$$

Where H is the real positive root of the following fourth degree equation

$$H^4 - M_1 H^2 + \frac{(k_2 + M_n^2 - M_1)}{k_1^*} = 0 \tag{16}$$

Where  $H = \frac{SQRT[M_1 + \sqrt{M_1^2 - 4Z}]}{2}$  and  $Z = \frac{k_2 + M_n^2 - M_1}{k_1^*}$ .

### 5. Skin Friction

The skin friction co-efficient for a non-Newtonian fluid is defined as

$$\tau_0 = \mu \frac{\partial u}{\partial y} - k_0 \frac{\partial^2 u}{\partial y^2} \text{ and is derived as} \tag{17}$$

$$= -Re_x [\mu H + (\mu b_0 Re - k_1^* \sqrt{bv}) H^2 + k_1^* b_0 x H^3] \tag{18}$$

Where  $Re_x = \frac{\sqrt{bv}x}{\nu} = \text{Local Reynolds number}$ .

### 6. Analysis of Flow Characteristics

To analyze the flow characteristics conveniently, it is further introduced the non-dimensional quantities in the following manner.

$$\Psi^* = \frac{\psi}{v}, \quad \xi = x \sqrt{\frac{c}{v}} \text{ and } c_0 = \frac{d}{2c} \tag{19}$$

Then equation (4) takes the following form

$$\Psi^* = \xi g(\eta) - c_0 \xi^2 g_\eta(\eta) \tag{20}$$

And equation for stream line function  $\eta$  can be derived as

$$\eta = \frac{1}{H^2} \left\{ \log \left( c_0 \xi^2 + \frac{\xi}{H^2} \right) - \log \left[ \frac{H^3 - M_2^2 - k_2}{H^2 [1 + k_1^* H^3]} \ \&- \ < 1 \right] \right\} \tag{5}$$

where

$$C_1 = \Psi^*, \text{ a constant along the stream} \tag{21}$$

line, As the limiting case, our result (21) reduces to the results of Kumaran and Ramaniah [14] for  $M_n$  and  $k_2 = 0$  in case of viscous fluid.

Graphs:

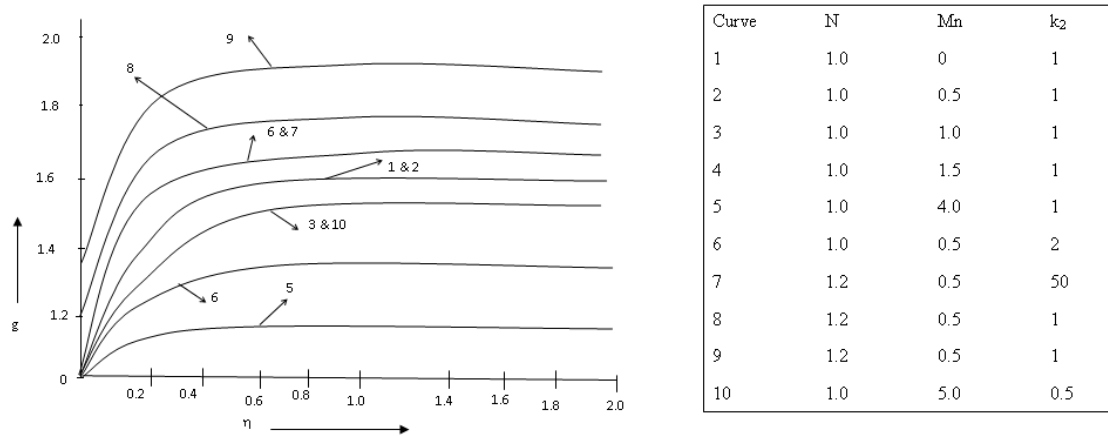


Figure 1. Effect of suction parameter  $N$ , magnetic parameter  $M_n$  and Permeability parameter  $k_2$  on transverse Velocity profiles for fixed values of  $K_1^* = 10^{-10}$

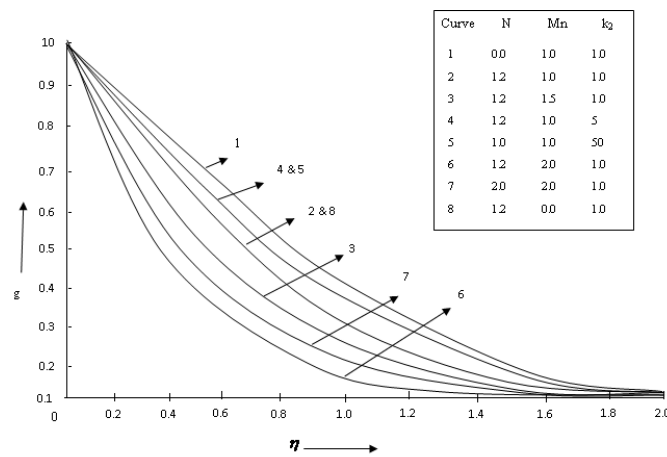


Figure 2. Effect of  $N$ ,  $M_n$ , and  $k_2$  on longitudinal velocity profiles for fixed value of  $K_1^* = 10^{-10}$

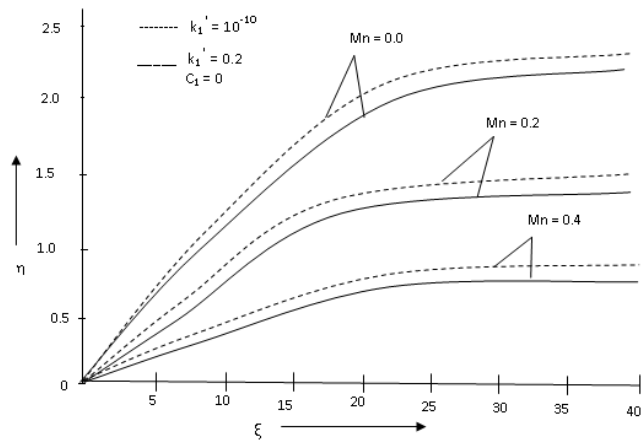


Figure 3. Graph of stream line pattern for various values of visco-elastic parameter  $k_1^*$  and magnetic parameter  $M_n$  where permeability parameter  $k_2 = 0.1$ , suction parameter  $N = 0.06$ , Stretching rate  $C = 0.2$

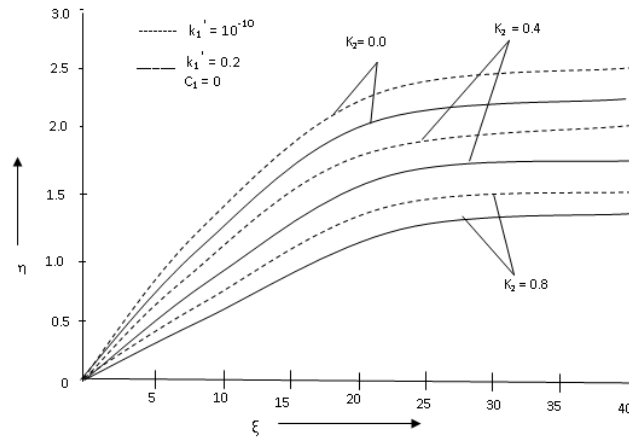


Figure 4. Graph of stream line function for various values of visco-elastic parameter  $k_1^*$  and permeability parameter  $k_2$  for fixed values of  $M_n = 0.5$ ,  $N = 0.06$ , Stretching rate  $c = 0.2$

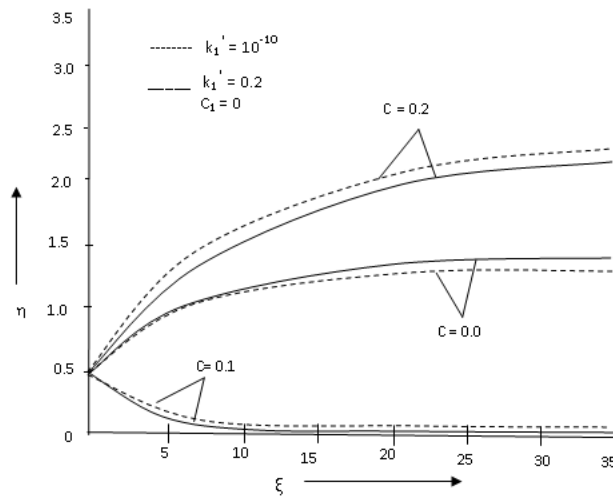


Figure 5. Graph of stream line function for various values of  $k_1^*$  and stretching rate  $C_0 = 0.0, 0.1, 0.2$  and fixed values of  $N = 0.424$ ,  $k_2 = 0.5$ ,  $M_n = 1.0$

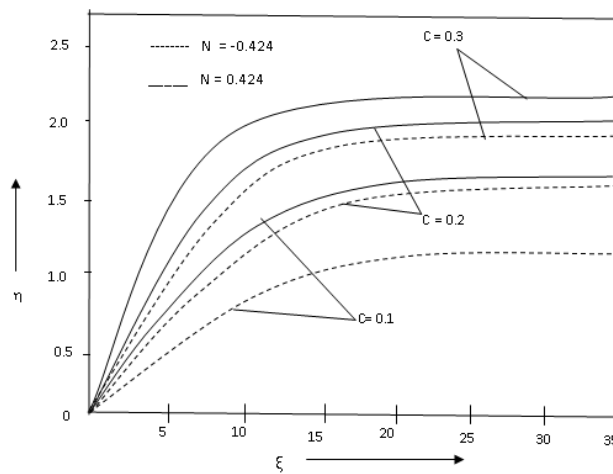


Figure 6. Graph of stream line function for various values of stretching rate  $C$  and  $k_1^* = 0.5$ ,  $k_2 = 0.5$ ,  $M_n = 1.0$

$k_1^*$	N	C	Re $x$	$k_2$	$t_{xy}(M_n = 0.0)$	$t_{xy}(M_n = 0.5)$	$C_f(k_2 = 0.0)$	$C_f(k_2 = 0.5)$
$10^{-10}$	-0.424	-0.2	0.5	0.0	1.465	1.767	1.454	1.766
0.05					0.647	0.766	0.643	0.778
$10^{-10}$		-0.2		0.5	1.769	2.018	1.767	2.029
0.05					0.768	0.889	0.778	0.890
$10^{-10}$		0.0		0.0	1.455	1.787	1.469	1.782
0.02					0.636	0.754	0.637	0.769
$10^{-10}$		0.0		0.5	1.785	2.047	1.782	2.050
0.02					0.789	0.877	0.769	0.879
$10^{-10}$		-0.01		0.0	1.358	1.761	1.356	1.668
0.05					0.589	0.779	0.629	0.782
$10^{-10}$		0.0		0.5	1.659	1.903	1.668	1.931
0.02					0.785	0.909	0.782	0.913
$10^{-10}$		-0.01		0.0	1.376	1.700	1.365	1.682
0.02					0.631	0.764	0.625	0.776
$10^{-10}$		-0.01		0.5	0.599	0.741	0.601	0.738
0.02					0.301	0.357	0.283	0.353

Table 1.

$M_n$	$k_2$	$k_1$	N	t (Present)	t (Sahoo)
0.5	1.0	$10^{-10}$	0.424	-1.617177	-1.628286
1.0	1.0	$10^{-10}$	0.424	-1.933550	-1.943560
0.5	10.0	0.2	0.424	-1.218703	-1.219804
0.5	1.0	0.2	0.424	-1.858584	-1.869694

Table 2.

## 7. Results and Discussion

In the present paper the problem of steady MHD Visco-elastic (Walters’ liquid B’) in-compressible fluid flow caused by stretching porous sheet embedded within a porous medium in the presence of uniform transverse magnetic field has been studied. The effects of various physical flow parameters on longitudinal velocity, transverse velocity have been studied and are presented in figures (1) and (2). Further different stream line patterns of the flow characteristics are discussed through graphs in the figures (3) to (6). Effects of various parameters like visco-elastic parameter, magnetic parameter, suction parameter and permeability parameter on skin friction are studied.

Figure 1 Predicts the effect of magnetic parameter  $M_n$ , permeability parameter  $k_2$ , suction parameter N and Visco-elastic parameter  $k_1^*$  on dimensionless transverse velocity field. From the figure and boundary conditions (9a) and (9b) it is evident that transverse velocity distribution is equal to the suction parameter on the surface of the sheet. It is revealed from 8<sup>th</sup> and 9<sup>th</sup> curves that for higher values of suction, transverse velocity distribution increases uniformly. Due to the influence of magnetic field and porosity, transverse velocity profile decreases. Hence, physically it predicts that the Lorentz force reduces the velocity distribution along transverse direction. From the curves 1 and 2 it reveals that there is no considerable change in the velocity distribution where as there is significant increase in transverse velocity where there is change in the value concluded that magnetic field and porous matrix is effective to modify the elastic flow field. From figure (2), it is seen that the effect of magnetic, porous and suction parameter on longitudinal velocity profiles. It is clear from the figure that for increasing values of  $M_n$  there is fall in the longitudinal velocity distribution because of the retarding effect of Lorentz force. Further due to the effect of magnetic field and elastic parameter, the velocity boundary layer thickness is reduced. For increasing values of suction parameter, velocity distribution is lessened longitudinally. Again in the absence of porous

media, longitudinal velocity profiles is increasing as there is no such resistance offered by the permeability parameter along the flow direction. This result is in good agreement with the previous published results of Sahoo [21] and Pantokratoras [11] for viscous case.

Figure 3 is the representation of pattern of stream lines for various values of  $k_1^*$ -the visco-elastic parameter and  $M_n$ -magnetic parameter. From the graph the revealed fact is that the effect of visco-elasticity is to shift the location of stream line towards the stretching sheet. Similarly increasing values of magnetic parameter is also to shift the location point of the streamline towards the boundary of the stretching sheet. Thus the combined effect of  $k_1^*$  and  $M_n$  is to suppress the flow of the elastic boundary layer region which clearly mentions the fact of thinning of the boundary layer. The combined effect of visco-elastic parameter  $k_1^*$  and permeability parameter  $k_2$  in the stream line function is shown in Figure 4. It is depicted from the graph that analysis of  $k_1^*$  and  $k_2$  is to suppress the visco-elastic boundary layer flow largely shifting stream line patterns towards the stretching surface.

The stream line pattern for different values of elastic parameter  $C_0$  (i.e. local mass flux parameter) is depicted in the Figure 5. It is analyzed from the graph that the combined effect of  $k_1^*$  and  $C_0$  is in shifting of the location of streamline away from the stretching surface which means that as thickness of the boundary layer increases, there is enhancement in boundary layer visco-elastic flow. Also as linear mass flux parameter  $C_0$  takes zero value then the slope of the stream line also vanish which reveals the fact that boundary layer flow is completely undisturbed. When  $C_0$  is very small and negative with  $C_0 = -0.1$ , the slope of the streamline is also negative which imparts the boundary layer is suppressed through the porous boundary.

The stream line patterns for different values of suction parameter (constant mass flux parameter)  $N$  and stretching rate parameter  $C_0$  (local mass flux parameter) is presented through Figure 6. From the graph it is observed that the effect of  $C_0$  is same as in Figure 5. That is for little larger values of  $C_0 = 0.2, 0.3$  it keeps the stream line away from the stretching boundary having a positive slope whereas the negative value of  $C_0 = -0.1$  suppresses the flow and hence the stream line takes negative slope. It is also revealed from the Figure 6 that the effect of suction parameter  $N$  is to dislocate the pattern of stream line by shifting them away from the stretching surface.

Table 1 presents values of skin friction co-efficient  $t$  for different sets of values of physical parameters like magnetic parameter  $M_n$ , permeability parameter  $k_2$ , suction parameter  $N$ , stretching rate  $C_0$ , Reynolds number  $Re_x$  and significant values of elastic parameter  $k_1^*$ . An adequate analysis of the table reveals the fact that the effect of increasing values of  $k_2$  and  $M_n$  is also to increase the skin friction co-efficient  $t$ . The effect of  $N$  and  $Re_x$  is to decrease the skin friction where as the effect of  $C_0$  i.e. of  $a$  is to increase the skin friction values in the case of visco-elastic (Walters' B' liquid) flow. And our present results are in good agreement with previous published results of Khan [22]. Thus in order to minimize the skin friction co-efficient which are very useful in an industrial application, we need to decrease the values of  $k_2$ ,  $M_n$  and  $C_0$  and to increase the values of visco-elastic parameter  $k_1^*$ .

From the Table 2 it is observed and interesting to note that all the entries are negative even the fluid is visco-elastic. This result of skin friction parameter values have significant applications in polymer industries. It is also seen from the table that the effect of magnetic, porous and suction parameters is to decrease the tangential stress, at the stretching surface which intern in places the fact that all the frictional forces reduces the frictional resistance at the surface. Present results are in a very good agreement with the results of Sahoo [21] for viscous fluid case.

## 8. Conclusion

Theoretical study of MHD momentum transfer flow of a non-Newtonian visco-elastic Walters' liquid B' fluid over a quadratic non-linear stretching porous sheet in the presence of uniform transverse magnetic field is studied. Some of the important



findings of mathematical and graphical analysis of the present problem are listed below :

- (1). The effects of magnetic field and porous fields is to reduce the transverse velocity and longitudinal velocity distribution and skin friction co-efficient.
- (2). The combined effect of visco-elastic parameter  $k_1^*$  with permeability  $k_2$  and with magnetic parameter  $M_n$  is to shift the location of the stream line patterns towards the stretching sheet.
- (3). Depending upon the values of stretching rate parameter  $C_0$  as positive, negative and zero stream line attains positive, negative and zero slope respectively.
- (4). For little large and positive values of stretching rate parameter  $C_0$ , the flow is enhanced significantly due to the quadratic stretching of the boundary layer and for less and negative value of  $C_0$ , the flow suppressed significantly.
- (5). For decreasing values of all forcing forces the frictional resistance reduces at the stretching surface which has very much significance to minimize the skin friction in industrial applications.

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