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Heat transfer in a MHD Viscoelastic Fluid over a Stretching Sheet with Internal heat generation,viscous dissipation and Work due to Deformation

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I. INTRODUCTION

Boundary-layer behavior over a moving continuous solid surface is an important type of flow occurring in several engineering processes. Such processes include heat-treated materials travelling between a feed roll and a wind-up roll or materials manufactured by extrusion and many others. Since the pioneering work of Sakiadis [1], various aspects of the problem have been investigated by many authors. Crane [2], Gupta and Gupta [3] have analyzed the stretching problem with constant surface temperature, while Soundalgekar [4] investigated the Stokes problem for a viscoelastic fluid. This flow was examined by Siddappa and Khapate [5] for a special class of non-Newtonian fluids known as second-order fluids, which are viscoelastic in nature. Danberg and Fansler [6] studied the solution for the boundary layer flow past a wall that is stretched with a speed proportional to the distance along the wall.

Rajagopal et al. [7] independently examined the same flow as in [5] and obtained similarity solutions of the boundary-layer equations numerically for the case of small viscoelastic parameter k_1. It is shown that skin-friction decreases with increase in k_1. Dandapat and Gupta [8] examined the same problem with heat transfer. In [8], an exact analytical solution of the non-linear equation governing this self-similar flow which is consistent with the numerical results in [7] is given and the solutions for the temperature for various values of k_1 are presented. Later, Cortell [9] extended the work of Dandapat and Gupta [8] to study the heat transfer in an incompressible second-order fluid caused by a stretching sheet with a view to examining the influence of the viscoelastic parameter on that flow. It is found that the temperature distribution depends on k_1, in accordance with the results in [8].

In the case of fluids of differential type (see Ref. [10]), the equations of motion are in general one order higher than the Navier–Stokes equations and, they need additional boundary conditions to determine the solution completely. These important issues were studied in detail by Rajagopal [10], [11] and Rajagopal and Gupta [12]. On the other hand, Abel and Veena [13] investigated a viscoelastic fluid flow and heat transfer in a porous medium over a stretching sheet and observed that the dimensionless surface temperature profiles increases with an increase in viscoelastic parameter k_1; however, later, Abel et al. [14] studied the effect of heat transfer on MHD viscoelastic fluid over a stretching surface and an important finding was that the effect of visco-elasticity is to decrease the dimensionless surface temperature profiles in that flow. Furthermore, Char [15] studied MHD flow of a viscoelastic fluid over a stretching sheet; however, only the thermal diffusion is considered in the energy equation. Vajravelu and Rollins [16] obtained analytical solution for heat transfer characteristics in viscoelastic second order fluid over a stretching sheet with frictional heating and internal heat generation. Later, Sarma and Rao [17] extended the work of

Vajravelu and Rollins [16] and studied the effect of work due to deformation in the energy equation. Vajravelu and Roper [18] and Cortell [19] analyzed the effects of work due to deformation in viscoelastic second grade fluid over a stretching sheet. Another effect which bears great importance on heat transfer is the viscous dissipation. When the viscosity of the fluid and/or velocity gradient is high, the dissipation term becomes important. Consequently, the effects of viscous dissipation are also included in the energy equation

In the present paper, heat transfer of an incompressible MHD viscoelastic fluid past stretching sheet with internal heat generation, viscous dissipation and work due to deformation terms are considered in the energy equation.Nonlinear boundary layer equations are solved using Quasilinearization technique. The thermal boundary condition is taken as the sheet with Prescribed Surface Temperature (PST case). Results are in good agreement with available studies. This paper highlights the effect of work due to deformation on heat transfer characteristics of the fluid.

II. MATHEMATICAL FORMULATION

Following the postulates of gradually fading memory, Coleman and Noll [20] derived the constitutive equation of second-order fluid flow in the form

$$T = -pI + \mu A_1 + \alpha_1 A_2 + \alpha_2 A_1^2 \qquad (1)$$

where T is the Cauchy stress tensor, $-PI$ is the spherical stress due to constraint of incompressibility,μ is the dynamics viscosity,α_1,$\alpha_2$are the material constants andA_1 and $A_2$are the first two Rivlin–Ericken tensors [21] defined as

$$A_1 = (grad\ v) + (grad\ v)^T \qquad (2)$$

$$A_2 = \frac{dA_1}{dt} + A_1(grad\ v) + (grad\ v)^T A_1 \qquad (3)$$

Here,v denotes the velocity field and d/dt is the material time derivative. If the fluid of second grade modeled by (1) is to be compatible with thermodynamics and is to satisfy the Clausius-Duhem inequality for all motions and the assumption that the specific Helmholtz free energy of the fluid is a minimum when it is locally at rest, Dunn and Fosdick [22] found that the material moduli must satisfy

$$\mu \geq 0, \alpha_1 \geq 0, \alpha_1 + \alpha_2 = 0 \qquad (4)$$

But later on Fosdick and Rajagopal [23] have reported, by using the data reduction from experiments that in the case of a second order fluid the material constants μ, α_1, α2should satisfy the relation

$$\mu \geq 0, \alpha_1 \leq 0, \alpha_1 + \alpha_2 \neq 0 \qquad (5)$$

They also reported that that the fluids modeled by (1) with the relationship (5) exhibit some anomalous behavior. A critical review on this controversial issue can be found in the work of Dunn and Rajagopal [24]. It was mentioned that second-order fluid, obeying model equation (1) with$\alpha_1<\alpha2$,$\alpha_1<0$ although exhibits some undesirable instability characteristics, the second order approximations are valid at low shear rate. Now in literature the fluid satisfying the model equation (1) with$\alpha_1<0$ is termed as second-order fluid and with$\alpha_1>0$ is termed as second grade fluid.

In present study, it is considered a laminar steady flow of an incompressible MHD viscoelastic (Walters' liquid B model) fluid over a wall coinciding with the plane y = 0, the flow being confined to y > 0.Two equal and opposite forces are applied along the x-axis, so that a sheet is stretched with a velocity proportional to the distance from the origin. The resulting motion of the quiescent fluid is thus caused solely by the moving surface. The flow satisfies the rheological equation of state derived by Beard and Walters [25].
The governing boundary layer equations for momentum, in the usual form, are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (6)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-k_0\left\{\frac{\partial}{\partial x}\left(u\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2}+v\frac{\partial^3 u}{\partial y^3}\right\}-\frac{\sigma B_0^2 u}{\rho} \quad (7)$$

$$where\ \ \upsilon=\frac{\mu}{\rho},\ k_0>0$$

Where u and v are the velocity components along the x and y directions respectively, ν are the kinematic viscosity, $k_0 = -\alpha_1/\rho$ is the co-efficient of elasticity, and ρ is the density. Hence, in the case second order fluid flow k_0 takes positive value as α_1 takes negative value and other quantities have their usual meanings. In deriving (7) it is assumed that the normal stress is of the same order of magnitude as that of the shear stress, in addition to usual boundary layer approximations.

The boundary conditions for the velocity field are:

$$u=u_w=bx,\ \ v=0 \qquad at\ y=0, b>0$$

$$u\to 0,\frac{\partial u}{\partial x}\to 0\ as\ y\to\infty \quad (8)$$

The condition $\frac{\partial u}{\partial y}\to 0\ as\ y\to\infty$ is the augmented condition since the flow is in an unbounded domain, which has been discussed by Rajgopal [10]. In this case, the flow is caused solely by the stretching of the sheet, since the free stream velocity is zero.

Defining new variables:

$$u=bxf_\eta(\eta),\ v=-\sqrt{b\upsilon}\,f(\eta),\ \eta=\sqrt{b/\upsilon}\,y \quad (9)$$

Where $f_\eta(\eta)$ denotes differentiation with respect to η. Clearly u and v defined above satisfy the continuity equation (6), and equation (7) is transformed as

$$f_\eta^2-ff_{\eta\eta}=f_{\eta\eta\eta}-k_1\left\{2f_\eta f_{\eta\eta\eta}-ff_{\eta\eta\eta\eta}-f_{\eta\eta}^2\right\}-Mnf_\eta \quad (10)$$

The boundary conditions (8) become

$$f(0)=R, f_\eta(0)=1 \quad (11a)$$

$$f_\eta(\eta)\to 0, f_{\eta\eta}(\eta)\to 0\ \ as\ \eta\to\infty \quad (11b)$$

where k1=k_0b/ν is the viscoelastic parameter, $Mn=\alpha B_0^2/\rho b$ is magnetic parameterand R= ($v_0/\sqrt{b/\upsilon}$) is the suction parameter.

III. HEAT TRANSFER ANALYSIS

By using boundary layer approximations, and taken into account internal heat generation, viscous dissipation and work due to deformation, the equation of energy for temperature T is given by

$$\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k\frac{\partial^2 T}{\partial y^2}+\mu\left(\frac{\partial u}{\partial y}\right)^2-\rho k_0\frac{\partial u}{\partial y}\left[\frac{\partial}{\partial y}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)\right]+Q(T-T_\infty) \quad (12)$$

Where k is the thermal diffusivity and C_p the specific heat of a fluid at constant pressure. The thermal boundaryconditions depend on the type of heating process under consideration. Here it is considered as Prescribed Surface Temperature (PST case).

3.1 Prescribed Surface Temperature (PST case)

For this circumstance, the boundary conditions are

$$T = T_w [= T_\infty + A\left(\frac{x}{l}\right)^2 \quad \text{at } y=0 \tag{13a}$$

$$T \to T_\infty \qquad as \quad y \to \infty \tag{13b}$$

Where *l* is the characteristic length.
Using (9), equation (12) reduces to

$$\theta'' + \Pr\, f\theta' - \Pr(2f' - \alpha)\theta = -\Pr\, Ec\left[(f'')^2 - k_1 f''(ff'' - ff''')\right] \tag{14}$$

where $\Pr = \mu\, c_p / k$, Prandtl number, where $Ec = bl^2 / c_p A$, Eckert numberand $\alpha = Q/(b\rho\, c_p)$, heat source/sink parameter.

with boundary conditions

$$\theta(0) = 1,\ \theta(\infty) \to 0$$

IV. NUMERICAL SOLUTION OF THE PROBLEM

The flow equation (10) coupled with energy equation (14) become set of nonlinear differential equations. A numerical method, Quasilinearization technique [26], is in most cases directly applicable to computer aided solutions of non-linear two-point boundary value problems. So this method is used to solve this system.

For convenience equations (10), (14) are rearranged as

$$f^{iv} = \frac{1}{k_1 f}\left[(f')^2 - ff'' - f''' + Mnf' + 2k_1 f f''' - k_1 (f'')^2\right] \tag{15}$$

$$\theta'' = -\Pr\, f\theta' + \Pr(2f' - \alpha)\theta - \Pr\, Ec\left[(f'')^2 - k_1 f''(ff'' - ff''')\right] \tag{16}$$

with boundary conditions:

$$f = R,\ f' = 1,\ \theta = 1 \qquad at \quad \eta = 0 \tag{17a}$$

$$f' \to 0,\ f'' \to 0,\ \theta \to 0 \quad as\ \eta \to \infty \tag{17b}$$

In order to implement the Quasilinearization method, the equations (15) and (16) are converted to a system of first order differential equations by substituting

$$(f, f', f'', f''', \theta, \theta') = (x_1, x_2, x_3, x_4, x_5, x_6)$$

Then equations (15) and (16) give

$$\frac{dx_1}{d\eta} = x_2$$

$$\frac{dx_2}{d\eta} = x_3$$

$$\frac{dx_3}{d\eta} = x_4$$

$$\frac{dx_4}{d\eta} = \frac{1}{k_1 x_1}\left\{x_2^2 - x_1 x_3 - x_4 + Mnx_2 + 2k_1 x_2 x_4 - k_1 x_3^2\right\} \tag{18}$$

$$\frac{dx_5}{d\eta} = x_6$$
$$\frac{dx_6}{d\eta} = -\Pr x_1 x_6 + \Pr(2x_2 - \alpha)x_5 - \Pr Ec\left[x_3^2 - k_1 x_3 (x_2 x_3 - x_1 x_4)\right]$$

Using Quasilinearization technique, the system (18) can be linearized as

$$\frac{dx_1^{r+1}}{d\eta} = x_2^{r+1}$$
$$\frac{dx_2^{r+1}}{d\eta} = x^{r+1}$$
$$\frac{dx_3^{r+1}}{d\eta} = x_4^{r+1}$$
$$\frac{dx_4^{r+1}}{d\eta} = \left(\frac{-1}{k_1 (x_1^r)^2}\left((x_2^r)^2 - x_4^r + Mnx_2^r + 2k_1 x_2^r x_4^r - k_1 (x_3^r)^2\right)\right)x_1^{r+1}$$
$$+\left(\frac{1}{k_1 x_1^r}(2x_2^r + 2k_1 x_4^r)\right)x_2^{r+1}$$
$$+\left(\frac{1}{k_1 x_1^r}(-x_1^r - 2k_1 x_3^r)\right)x_3^{r+1}$$
$$+\left(\frac{1}{k_1 x_1^r}(-1 + 2k_1 x_2^r)\right)x_4^{r+1} + \left(\frac{-x_4^r + Mnx_2^r}{k_1 x_1^r}\right) \qquad (19)$$
$$\frac{dx_5^{r+1}}{d\eta} = x_6^{r+1}$$
$$\frac{dx_6^{r+1}}{d\eta} = (-\Pr x_6^r - \Pr Eck_1 x_3^r x_4^r)x_1^{r+1} + (2\Pr x_5^r + \Pr Eck_1 (x_3^r)^2)x_2^{r+1}$$
$$+(-2Ec\Pr x_3^r + \Pr Eck_1(2x_2^r x_3^r - x_1^r x_4^r))x_3^{r+1} - (\Pr Eck_1 x_1^r x_3^r)x_4^{r+1} + \Pr(2x_2^r - \alpha)x_5^{r+1}$$
$$+(-\Pr x_1^r)x_6^{r+1} + \left(Ec\Pr(x_3^r)^2 + \Pr x_1^r x_6^r - 2\Pr x_2^r x_5^r - 2\Pr Eck_1 x_3^r (x_2^r x_3^r - x_1^r x_4^r)\right)$$

The above system of equations (19) is linear in$(x_i^{r+1}, i = 1,2, \dots 6)$ and general solution can be obtained by using the principle of superposition.
The boundary conditions reduce to

$$x_1^{r+1}(\eta) = 0,\ x_2^{r+1}(\eta) = 1,\ x_5^{r+1}(\eta) = 1 \qquad at\ \eta = 0$$
$$x_2^{r+1}(\eta) \to 0, x_3^{r+1}(\eta) \to 0, x_5^{r+1}(\eta) \to 0 \qquad as\ \eta \to \infty$$

The initial values are chosen as follows:

For the homogeneous solution:

$$x_i^{h_1}(\eta) = [0\ 0\ 1\ 0\ 0\ 0]$$
$$x_i^{h_2}(\eta) = [0\ 0\ 0\ 1\ 0\ 0] \qquad (20)$$
$$x_i^{h_3}(\eta) = [0\ 0\ 0\ 0\ 0\ 1]$$

For particular solution:

$$x_i^p(\eta) = [R\,1\,0\,0\,1\,0] \qquad (21)$$

The general solution of system of equations is given by

$$x_i^{r+1}(\eta) = c_1 x_i^{h_1}(\eta) + c_2 x_i^{h_2}(\eta) + c_3 x_i^{h_3}(\eta) + x_i^p(\eta) \qquad (22)$$

where C_1, C_2, C_3 are the unknown constants and are determined by considering the boundary conditions as η → ∞. This solution(x_1^{r+1}, $i=1,2,\ldots 6$)is then compared with solution at the previous step(x_1^r, $i=1,2,\ldots 6$) and next iteration is performed if the convergence has not been achieved or greater accuracy is desired.

V. RESULTS AND DISCUSSIONS

Here, a study is presented on heat transfer of an incompressible MHD viscoelastic fluid past a stretching sheet. The nonlinear differential equations of flow and heat transfer were solved by Quasilinearization technique. The energy equation includes internal heat generation, viscous dissipation and the work due to deformation.

Fig 1 shows the effect of Magnetic field parameter on temperature distribution. Temperature profile increases with increase in Magnetic field. Since increase of magnetic field increases the thermal boundary layer thickness. The increasing frictional drag due to Lorentz force is responsible for increasing the thermal boundary layer thickness.

Fig 2 reveals the effect of Prandtl number (Pr) on non-dimensional temperature θ (η) profiles are shown. Temperature $\theta(\eta)$ decreases with increase in the Prandtl number Pr. This is consistent with the fact that the thermal boundary layer thickness decreases with increasing values Prandtl number Pr.

Fig 3 depicts the effect of suction parameter(R) on the heat transfer θ (η). Temperature profiles decreases with increasing values of suction parameter(R). Due to suction parameter(R) there will be loss of fluid in the boundary layer region, hence there will be less scope for heat transfer from the sheet to the fluid. This causes the declination in the heat transfer for increasing values of suction parameter.

Fig 4 displays that temperature profiles decreases with increasing values of viscoelastic parameter (k_1) , this is an important finding in MHD viscoelastic fluid , where opposite behavior can be seen in viscoelastic fluid flows.

In Fig 5, non-dimensional temperature $\theta(\eta)$and temperature gradient $\theta'(\eta)$profiles are plotted for various values internal heat source/sink parameter α. It shows that $\theta(\eta)$increases with increasing values α. This is due to the fact that heat is generated inside the boundary layer for increasing values of heat source/sink parameter α. The magnitude of$|-\theta'(0)|$ decreases with increasing values of α.

In Fig6, temperature$\theta(\eta)$ and temperature gradient$\theta'(\eta)$ are drawn for various values of Eckert number (Ec). Temperature$\theta(\eta)$ increases with increase in viscous dissipation, because heat energy is stored in the fluid due to frictional heating. The values$|-\theta'(0)|$ decrease with increase in viscous dissipation, which yields augment in fluid's temperature.

The effect of work due to deformation term in the energy equation can be analyzed from Table 1 and Table 2. It can be seen from both the tables that, at a given point, temperature$\theta(\eta)$ decreases with increase in viscoelastic parameterk_1. From Table 2, it is observed that when work due to deformation is taken into account, for given k_1, temperature$\theta(\eta)$decreases, which is in contrast to the second grade fluids [16]. And values of$|-\theta'(0)|$in Table 2 are larger than in Table1. Physically it means that heat transfer rate is more from the sheet, which results in decrease in temperature$\theta(\eta)$.

VI. CONCLUSIONS:

From our numerical results, it can be concluded that:

i. Temperature profiles increases with increase magnetic field parameter (Mn).
ii. Thermal boundary layer thickness decreases with increase in Prandtl number (Pr).
iii. Temperature profiles decreases with increasing values viscoelastic parameter (k_1), which is an

important finding in MHD viscoelastic fluids in contrast to viscoelastic fluids.

iv. Work done deformation term in energy equation reduces the temperature profiles, this is in contrast to the second grade fluids.

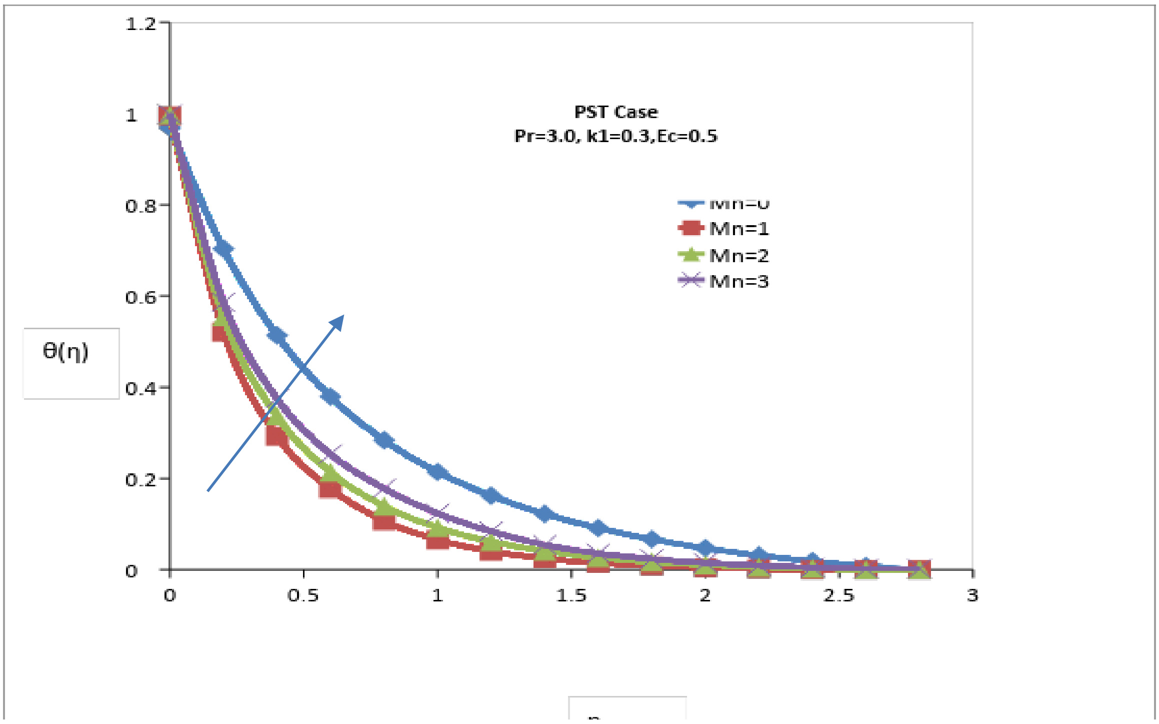

Fig 1. Effect of Magnetic field parameter (Mn) on temperature distribution θ(η)

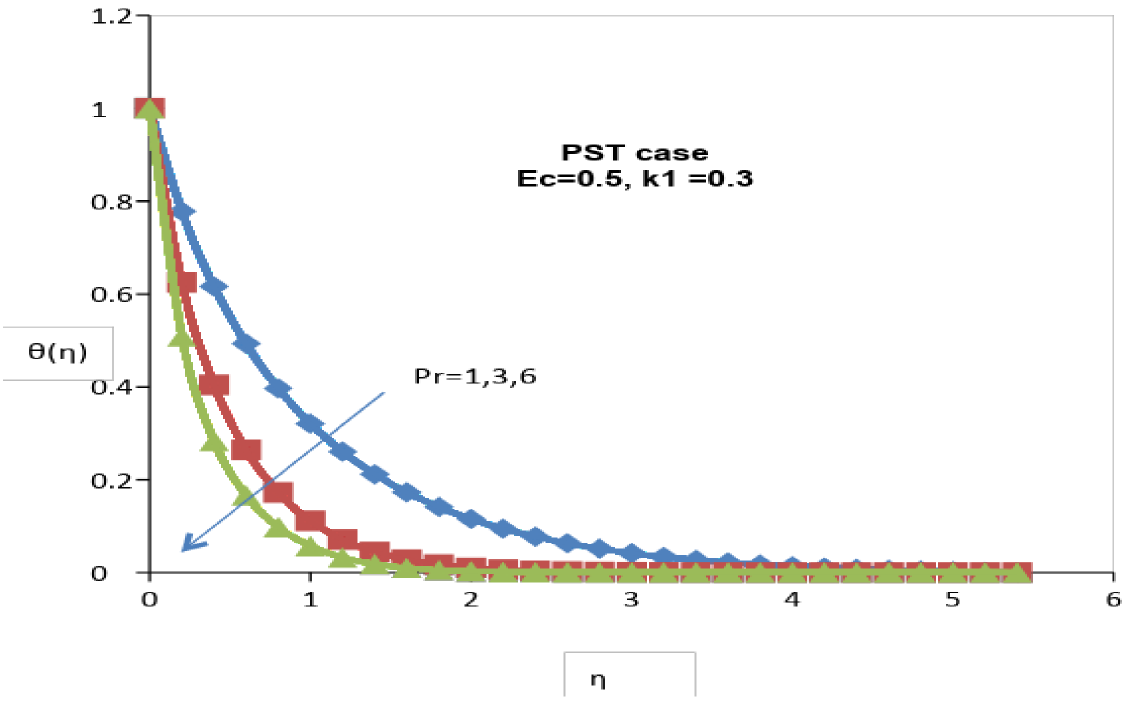

Fig 2.Effect of Prandtl number on Temperature profiles.

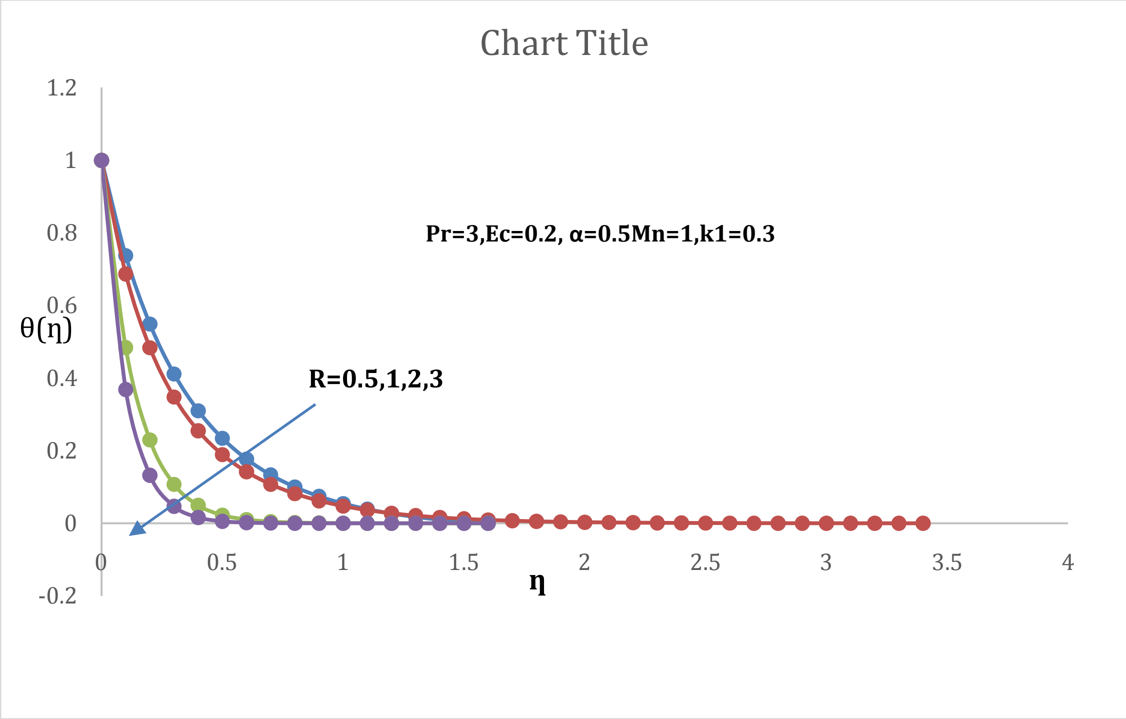

Fig3. Effect of suction parameter (R) on temperature distributionθ (η).

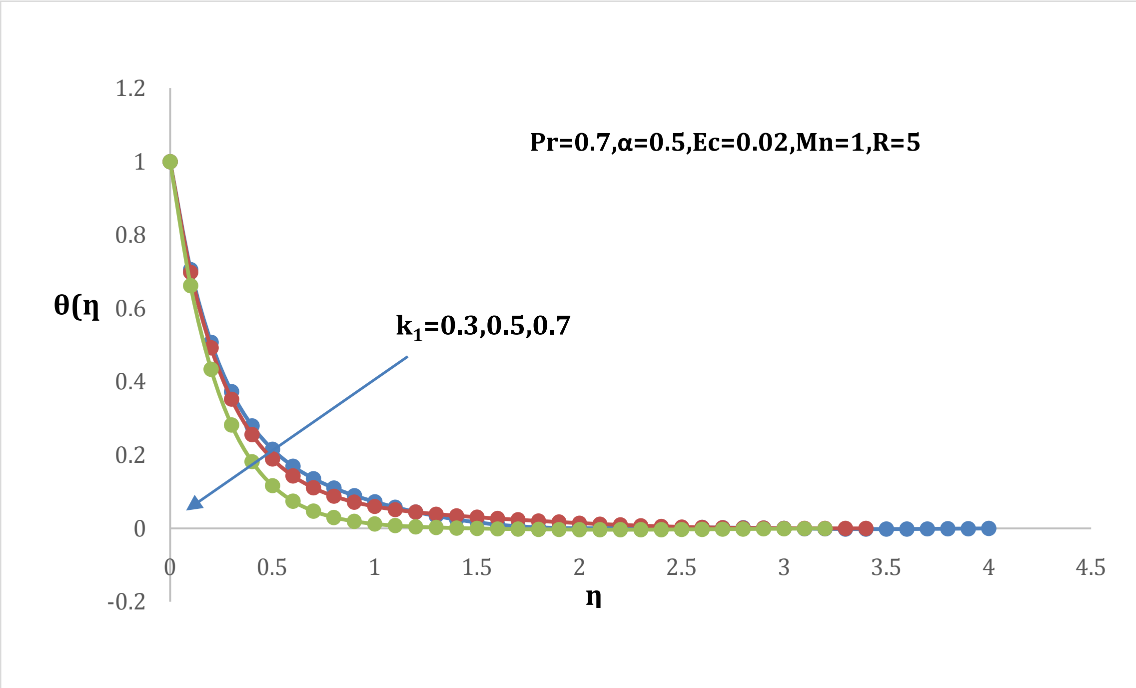

Fig4. Effect of viscoelastic parameter (k1) on temperature distributionθ (η).

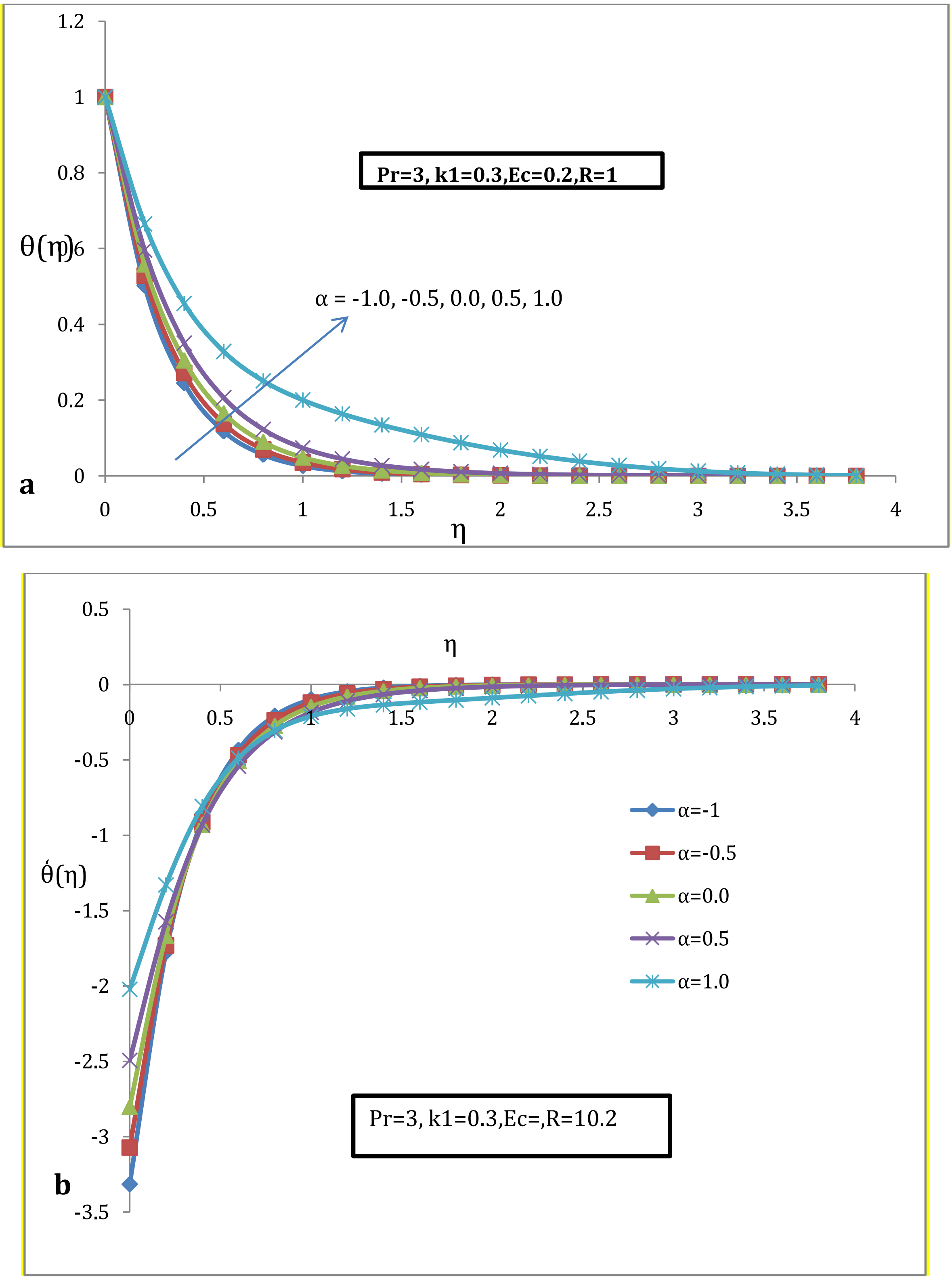

Fig 5: Effect of heat source/sink parameter (α) on (a). Temperature θ (η), (b). Temperature gradient θ' (η)

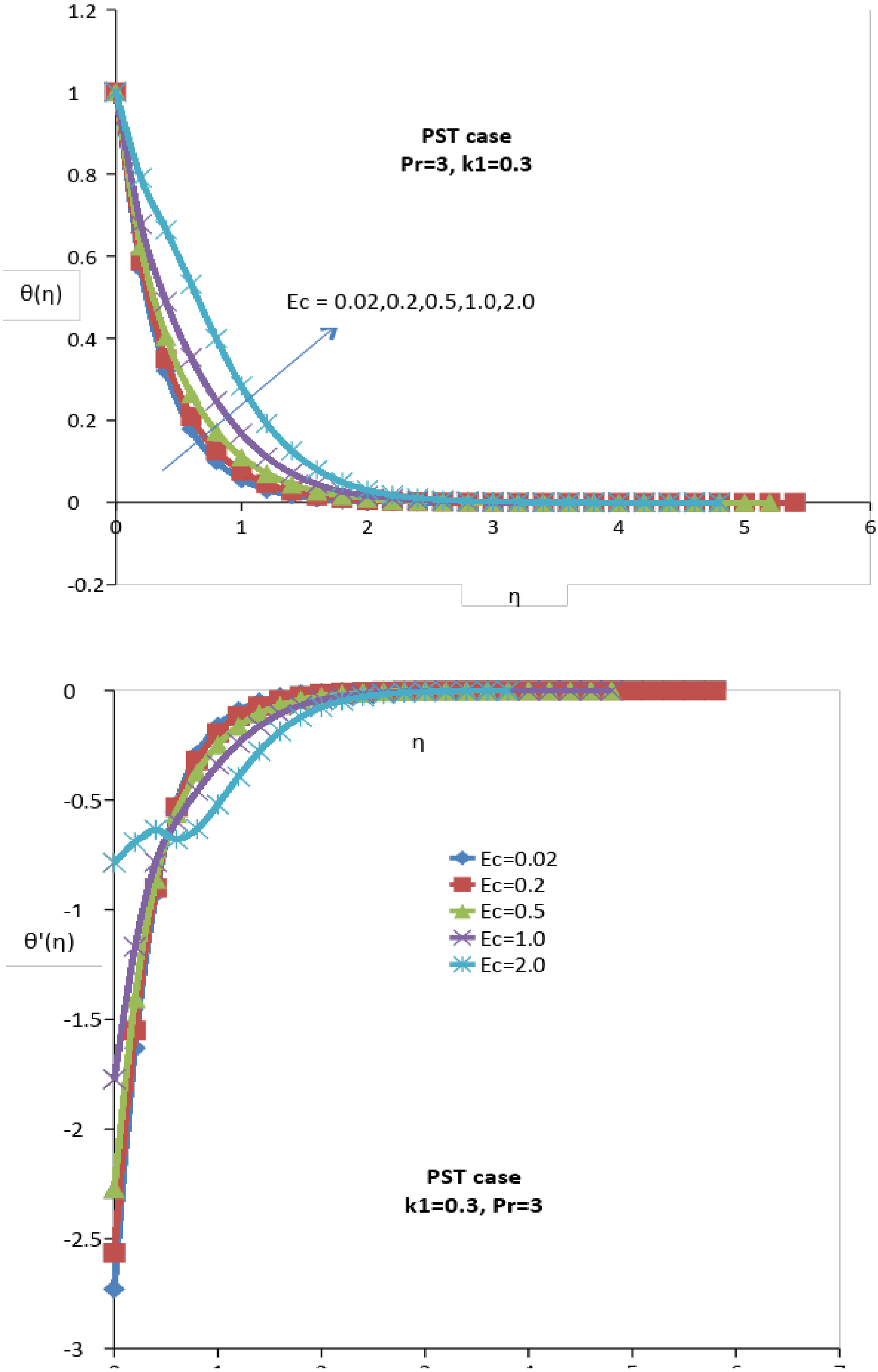

Fig 6. Effect of Eckert number (Ec) on (a) Temperature θ(η) (b) Temperature gradient θ'(η) in PST case with Pr=3, k_1=0.3

Table1:Values of θ (η), θ' (η) with Pr=0.7, Mn=1, R=5, Ec=0.02, α=0.5 When work due to deformation is not taken into account

	η	θ(η)	θ'(η)
k1=0.3			
	0.0	1.00000	-3.19772
	0.2	0.54716	-1.55587
	0.4	0.31885	-0.81985
	0.6	0.19467	-0.46172
	0.8	0.12313	-0.27270
	1.0	0.08007	-0.16799
	1.4	0.03494	-0.07398
	1.8	0.01406	-0.03426
	2.0	0.00862	-0.02063
	2.4	0.00420	-0.00407
	2.8	0.00343	-0.00160
	3.0	0.00299	-0.00286
	3.4	0.00150	-0.00396
	3.8	0.00028	-0.00189
	4.0	0.00001	-0.00088
k1=0.5			
	0.0	1.00000	-3.44788
	0.2	0.51812	-1.61352
	0.4	0.28873	-0.78818
	0.6	0.17370	-0.40971
	0.8	0.11194	-0.22918
	1.0	0.07620	-0.13793
	1.4	0.03940	-0.06013
	1.8	0.02183	-0.03198
	2.0	0.01620	-0.02476
	2.4	0.00829	-0.01558
	2.8	0.00339	-0.00916
	3.0	0.00183	-0.00657
	3.4	0.00000	-0.00291
k1=0.7			
	0.0	1.00000	-4.03528
	0.2	0.43955	-1.83846
	0.4	0.18793	-0.80983
	0.6	0.07865	-0.34531
	0.8	0.03267	-0.14286
	1.0	0.01385	-0.05766
	1.4	0.00326	-0.00952
	1.8	0.00128	-0.00256
	2.0	0.00086	-0.00179
	2.4	0.00031	-0.00098
	2.8	0.00006	-0.00033
	3	0.00001	-0.00014

Table2: Values of θ (η), θ' (η) with Pr=0.7, Ec=0.02, Mn=1, R=5, when work due to deformation is taken into account

	η	θ(η)	θ'(η)
k1=0.3			
	0.0	1.00000	-3.56656
	0.2	0.50760	-1.62260
	0.4	0.28016	-0.76669
	0.6	0.16971	-0.38944
	0.8	0.11030	-0.22771
	1.0	0.07262	-0.15801
	1.4	0.02443	-0.08662
	1.8	0.00300	-0.02301
	2.0	0.00063	-0.00263
	2.4	0.00229	-0.00446
	2.8	0.00181	-0.00638
	3.0	0.00033	-0.00767
	3.4	-0.00161	-0.00085
	3.8	-0.00069	0.00392
	4.0	0.00000	0.00264
k1=0.5			
	0.0	1.00000	-3.64216
	0.2	0.49270	-1.68618
	0.4	0.25596	-0.79587
	0.6	0.14311	-0.38437
	0.8	0.08795	-0.19121
	1.0	0.05991	-0.10063
	1.4	0.03455	-0.04209
	1.8	0.02037	-0.03101
	2.0	0.01455	-0.02713
	2.4	0.00571	-0.01655
	2.8	0.00129	-0.00614
	3.0	0.00043	-0.00274
	3.4	0.00000	-0.00023
k1=0.7			
	0.0	1.00000	-4.08080
	0.2	0.43416	-1.84978
	0.4	0.18222	-0.80439
	0.6	0.07459	-0.33586
	0.8	0.03030	-0.13598
	1.0	0.01242	-0.05534
	1.4	0.00128	-0.01343
	1.8	-0.00228	-0.00550
	2.0	-0.00308	-0.00250
	2.4	-0.00296	0.00277
	2.8	-0.00136	0.00446
	3.0	-0.00054	0.00359
	3.1	-0.00021	0.00282
	3.2	0.00002	0.00189

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