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Modelling Thermo-physical Effects of Heat and Mass Transfer in Unsteady MHD Viscoelastic Fluid Flow in inclined Porous Media

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Abstract

This research presents the modelling thermo physical effects of heat and mass transfer in unsteady Magnetohydrodynamics MHDviscoelastic fluid flow in inclined porous media. The resulting governing boundary layer equations were non-linear and coupled form of partial differential equations, and they were solved by using fourth order Runge-Kutta integration scheme with Newton Raphson shooting method. Numerical computations were carried out for the non-dimensional physical parameters. These were carried out to expain the effect of different physical parameters such as they affected viscoelasticity, permeability of the porous media, magnetic field, Grashof number, Schmidt number, heat source parameter and chemical reaction parameter on the flow, heat and mass transfer characteristics.

1. Introduction

The unsteady MHD fluid flow study keeps paving ways for further studies due to its enormous usage in every facets of life. The investigation such as this study can be modelled and solved experimentally, analytically or numerically depending on the nature of the modelled equations. In doing this, the existing models are

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modified or adjusted to reflect the current trends that are germane to the issues being discussed. A great deal of interest has been generated in the area of heat and mass transfer of the boundary layer flow over a stretching porous surface, in view of its numerous and wide-ranging applications in various fields like polymer processing industry in particular in manufacturing process of artificial film and artificial fibers and in some applications of dilute polymer solution, [1] & [2]). In boundary layer phenomena, radiation and chemical effects on unsteady MHD fluid flow, heat and mass transfers in porous media is significant because of its influence exponentially stretching porous surface. In this presentation, efforts are made to reflect the effects of some unsteady MHD parameters in explaining viscoelastic in porous media. MHD fluid flow in porous media has wide and numerous applications in industry and environments [7] & [11]. Some of other areas of applications of this study though not limited are the flow of ground water through soil and rocks (porous media) that are very important for agriculture and pollution control; extraction of oil and natural gas from rocks which are prominent in oil and gas industries; functioning of tissues in body (bone, cartilage and muscle and so on) belong to porous media, flow of blood and treatments through them; understanding various medical conditions (such as tumor growth, a formation of porous media) and their treatment (such as injection, a flow through porous media in medical sciences). In [7], viscous dissipative heat was taken into account under the influence of transverse magnetic field, [8] reported the heat and mass transfer in the boundary layers on an exponentially stretching continuous surface. Also, [6] presented the effects of heat generation and thermal radiation on steady MHD flow near a stagnation point on a stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer, it was discovered that temperature increased with increasing radiation parameter R and concentration decreased with increasing Schmidt number. Unsteady MHD flow of a viscoelastic fluid along vertical porous surface with fluctuating temperature and concentration was presented [9] & [12]. [5] verified the unsteady MHD flow and heat transfer for Newtonian fluids over an exponentially stretching sheet. see [10]. [4] presented thermal radiation effects on heat and mass transfer of MHD flow in porous media over exponentially-stretching surface but neglected unsteady case. In 2018, an adaptive MHD convective fluid in porous media was presented [3]. The authors critically discussed the applications of the adaptive model to environmental issues. In view of the above studies, the present study modelled and explained the thermo-physical effects of some parameters in unsteady MHD viscoelastic fluid flow in inclined porous media over an exponentially stretching porous surface. Specifically, the paper contended that controls of environmental pollution, air and water in porous surface should be our concern.

2. Formulation of the Problem

We consider a free convective, laminar boundary layer flow and heat and mass transfer of viscous incompressible and electrically conducting viscoelastic liquid due to a stretching sheet in inclined surface. The sheet lies in the plane $y = 0$ with the flow being confined to $y > 0$. The coordinate x is being taken along the stretching sheet and y is normal to the surface, two equal and opposite forces are applied along the x-axis, so that the sheet is stretched, keeping the origin fixed. A uniform transverse magnetic field of strength Bo was applied parallel to the y-axis and the chemical reaction is taken place in the flow. The viscous dissipation effect and joule heat are neglected on account of the fluid is finitely conducting it is assumed that the induced magnetic field, external electric field and the electric field due to the polarization of charges are negligible. The density variation and effect of buoyancy are taken into account in the momentum equation (Boussinesq's approximation) and the concentration far from the wall is infinitesimally small and the viscous dissipation term in energy equation is neglected (as fluid velocity is very low). Under this assumption, the governing boundary layer equation of momentum, energy and diffusion under Boussinesq's approximation could be written as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 01 \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} - \gamma_0\left\{u\frac{\partial^3 u}{\partial x\partial y^2} + v\frac{\partial^2 u}{\partial y^2} + \frac{\partial v}{\partial x}\frac{\partial^2 u}{\partial y^2} - \frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial x\partial y}\right\}$$
$$-\frac{\nu}{\varepsilon}u - \frac{\sigma B^2(x)}{\rho}\mu + gB_T(T - T_\infty)\cos\alpha + gB_c(C - C_\infty)\cos\alpha \tag{2}$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{Q}{\rho C_p}(T - T_\infty) - \frac{\partial q_r}{\partial y} \tag{3}$$

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - \gamma(C - C_\infty) \tag{4}$$

where the unsteady parameter is a function of space and time u, v are velocity components, T and C are the temperature and concentration of chemical species in the fluid, υ is the kinematic viscosity, γ_0 is the non-Newtonian viscoelastic parameter, ε is the permeability coefficient, g is the acceleration due to gravity, β_T is the volumetric coefficient of thermal expansion, β_C is the volumetric concentration coefficients, β_0 is the magnetic induction, ρ is the fluid density, δ is the fluid electrical conductivity, k is the thermal conductivity, C_p is the specific heat at constant pressure, Q is the dimensional heat generation/absorption coefficient,

D is the mass diffusivity, q_r is the radiative heat flux in y direction. And λ is the chemical reaction parameter. The boundary condition governing the flow are

(5) $$y = 0, \ \ u = bx, \quad v = 0, \quad C = C_\omega + A\left(\frac{x}{l}\right)$$

(6) $$T = T_\omega + B\left(\frac{x}{l}\right), \quad y \to \infty \ u \to \infty, \quad v_y \to \infty, \ \ T \to T_\infty, \ \ C \to C_\infty$$

To take into account the effect of stretching of the boundary sheet, the effects due to temperature and conditions in the form (5), in order to study the heat transfer analysis, we consider two general cases of non-isothermal temperature boundary conditions, namely (1) boundary with presented power low surface temperature. Now we introduce the following dimensionless variables

(7)
$$u = bxf'(\eta), \quad v = -\sqrt{bv}\, f(\eta), \ \ \eta = y\sqrt{\frac{b}{v}}, \quad \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

where

(8) $$T_w - T_\infty = B\left(\frac{x}{l}\right), \quad C_w - C_\infty = A\left(\frac{x}{l}\right)$$

By using the Rossland approximation ([6], [4]), the radiation heat flux q_r is given by

(9) $$q_r = -\frac{4\sigma_0 \partial T^4}{3\delta \partial y}$$

where σ_0 and δvare the Stefan-Boltzmann and the mean absorption coefficient respectively. Assume temperature difference within the flow is sufficiently small such that T^4 may be express as a linear function of temperature, using Taylor series to expand T^4 about the free stream T_∞ and neglecting higher order terms, this gives the approximation.

(10) $$T^4 = 4T_\infty^3 T - 3T_\infty^4$$

The magnetic field $B(x)$ is assumed to be in the form

(11) $$B(x) = B_0 e^{\frac{x}{2l}},$$

where B_0 is the constants magnetic field. Introducing the stream function $\psi(x, y)$ such that

$$u = \frac{\partial \psi}{\partial y}, v = -\frac{\partial \psi}{\partial x} \tag{12}$$

Substituting (12) into (1), we have Cauchy-Riemann equation, hence identity condition fully satisfied. Therefore, considering (12) in equations (2)-(4) becomes

$$\begin{aligned} \frac{\partial^2 \psi}{\partial t \partial y} + \frac{\partial \psi}{\partial y}\frac{\partial^2 \psi}{\partial y \partial x} - \frac{\partial \psi}{\partial x}\frac{\partial^2 \psi}{\partial y^2} = \frac{\sigma}{\rho} B_0^2 e^{\left(\frac{x}{2l}\right)} \frac{\partial \psi}{\partial y} - \frac{\upsilon}{\varepsilon}\frac{\partial \psi}{\partial y} \\ -\gamma_0 \left\{ \frac{\partial \psi}{\partial y}\frac{\partial^3 u}{\partial x \partial y^2} + \upsilon \frac{\partial^2}{\partial y^2}\frac{\partial \psi}{\partial y} - \frac{\partial^2 \psi}{\partial x^2} - \frac{\partial^4 \psi}{\partial y^4} - \frac{\partial^2 \psi}{\partial y^2}\frac{\partial^2 \psi}{\partial x \partial y^2} \right\} \\ + g B_T (T - T_\infty)\cos\alpha + g B_c (C - C_\infty)\cos\alpha \end{aligned} \tag{13}$$

$$\frac{\partial T}{\partial t} + \frac{\partial \psi}{\partial y}\frac{\partial T}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial T}{\partial y} = \left(\frac{k}{\rho C_p} + \frac{16 \sigma_0 T_\infty^3}{3 \rho C_p \delta} \right) \frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{\rho C_p}(T - T_\infty) \tag{14}$$

$$\frac{\partial C}{\partial t} + \frac{\partial \psi}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial \psi}{\partial x}\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - \gamma (C - C_\infty) \tag{15}$$

Further transforming equation with the dimensionless variable,

$$u = bxf'(\eta), \quad v = -\sqrt{b\upsilon}\, f(\eta), \quad \eta = y\sqrt{\frac{b}{\upsilon}} \tag{16}$$

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}$$

where

$$T_w - T_\infty = B\left(\frac{x}{l}\right), \quad C_w - C_\infty = A\left(\frac{x}{l}\right), \ \frac{\partial u}{\partial t} \neq 0, \frac{\partial T}{\partial t} \neq 0, \ \frac{\partial C}{\partial t} \neq 0 \tag{17}$$

in equations (2)- (4) yield

$$\begin{aligned} f''' + ff'' - 2(f')^2 - U/2(M + Da)f' - \lambda_1 \left\{ 2f'f''' - ff''^2 - f'^2 \right\} \\ + Gr\theta\cos\alpha + Gc\varphi\cos\alpha = 0 \end{aligned} \tag{18}$$

$$\left(1 + \frac{4}{3}R\right)\theta'' + \Pr f\theta' - U/2 \Pr f\theta' + \Pr Q\theta = 0 \tag{19}$$

$$\varphi'' + Scf\varphi' - U/2Scf'\varphi - Sc\lambda\varphi = 0 \tag{20}$$

The corresponding Boundary conditions take the form

$$f = f_w,\ f' = 1\ \ \theta = 1\ \varphi = 1 \quad at\ \eta = 0 \tag{21}$$

$$f' = 0,\ \ \theta = 0,\ \ \varphi = 0(\psi),\ \ as\, \eta \to \infty \tag{22}$$

where superscripts denote the differentiation with respect to η. λ_1 and Da are viscoelastic and Darcy porosity parameters, M is the magnetic parameter or Hartmann number, Gr and Gc are the free convection parameters, Q is the heat generation or absorption parameter. λ is the chemical reaction parameter, Pr, Sc are Prandtl and Schmidt number. These dimensionless parameters are defined as:

$$M = \frac{\sigma B_0^2}{\rho b}$$
$$\frac{Kob}{v},\ \ \lambda_1 = f_w = \frac{v}{\varepsilon b},\ \ Gr = \frac{gB_T(T_\omega - T_\infty)}{b^2 x},\ Gc = \frac{gB_C(C_\omega - C_\infty)'}{b^2 x}$$
$$\Pr = \frac{\mu c_P}{k},\ Sc = \frac{v}{D},\ \ Q_0 = \frac{Q_0}{b\rho c_P},\lambda = \frac{K\gamma}{b},\ R = \frac{4\sigma_0 T_\infty^3}{\delta k}$$

The important physical quantities of our interest are local skin friction, f_w, Nusselt number, Nu and Sherwood number Sh and they are defined

The problem is a boundary value problem, applying a shooting technique (guessing the unknown values) to change the conditions to initial value problem. In order to integrate equations (17), (18) & (19) as IVPs, the values for $f''(0)$, $\theta'(0)$ and $\varphi'(0)$ which were required for solution but no such values were given in the boundary. The suitable values for $f''(0)$, $\theta'(0)$ and $\varphi'(0)$ were chosen and then integration was carried out. The researchers compared the calculated values for $f'(0)$, $\theta'(0)$ and $\varphi(0)$ at $\eta = 3.5$ with the given boundary conditions $f'(3.5) = 0$, $\theta'(3.5) = 0$ and $\varphi(3.5) = 0$. Then adjusted the estimated values for $f''(0)$, $\theta'(0)$ and $\varphi'(0)$, to give a better approximation for the solution. The researchers performed the series of values for $f''(0)$, $\theta'(0)$ and $\varphi'(0)$, and then applied a fourth-order Runge–Kutta method with shooting techniques with step-size $h = 0.01$. The value of η_∞ is noticed to the iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$. The highest value of η_∞ to each parameter is determined when the values of the unknown boundary conditions at $\eta = 0$ does not change after successful loop with error less than 10^{-5}. The computations have been performed using a symbolic program and computational computer language Maple 18.

3. Results and Discussion

From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which were respectively proportional to $f^{''}(0)$, $\theta^{'}(0)$ and $\varphi^{'}(0)$, at the plate were examined for different values of the parameters. The comarison of the present study with the skin friction of the existing works are presented in Table 1 for values of $U = 0$.

Values	Present study	[3]	Devi et al. (2015)
Values	$f''(0)$	$f''(0)$	$f''(0)$
0.0	-0.000000	-0.000000	-1.000480
0.1	-0.876559	-0.876889	-0.872571
0.5	-0.645494	-0.646494	-0.591683

Table 1 shows numerical values of skin friction when compared with the existing literature and were in close agreement. The present study shows improvement over the previous studies. We validated our results by setting all newly introduced parameter $U = 0$ zero and were found to be in excellent agreement with [3]. The computations have been performed using a symbolic program and computational computer language Maple 18. The step size is taken to be $\Delta\eta = 0.001$ to satisfy the convergence requirement of 10-5 in all cases. The value of η_∞ is noticed to the iteration loop by $\eta_\infty = \eta_\infty + \Delta\eta$. The highest value of η_∞ to each parameters are determined when the values of the unknown boundary conditions at $\eta = 0$ not changed to successful loop with error less than 10-5. From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which are respectively proportional to $f''(0)$ and $\varphi'(0)$, at the plate have been examined for different values of the parameters are presented in a tabular form and discussed. The following parameter values were adopted for computation as default number: $M = 1$, $Gr = 1$, $Gc = 0.01$, $SC = 0.35$, $Pr = 0.72$, $R = 0.5$, $Q = 1$, $Da = 0.001$, $U = fw = 1$. All graphs were corresponded to the value except otherwise indicated on the graph.
Table 2 Shows the effect of M, Gr, Gc, α, Q, λ Sc, Pr, Da, fw, U, R on $f''(0)$, $\theta'(0)$, $\varphi^{'}(0)$ (P-Parameters).

P	Values	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$	P	*Values*	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
M	1	-0.26854	0.09333	0.20258	Q	1	-0.56277	-0.26492	0.4525
	2	-0.92028	0.08373	0.19681		2	-1.25506	1.42619	0.41235
	3	-1.069112	0.08805	0.19578		3	-0.96981	0.49564	0.42991
	7	-1.32237	-0.079599	0.19425		4	-0.87312	0.11566	0.43430
G_r	1	-0.05515	0.01906	0.20526	Sc.	0.35	-0.93657	-0.05463	0.30901
	2	0.50653	0.04834	0.21125		0.62	-0.96200	-0.05242	0.44108
	3	1.48767	0.07974	0.21789		1.50	-1.02215	-0.04803	0.88435
	3.2	1.92322	0.087712	0.21968		2.00	-1.04575	-0.04668	1.14009
Gc	0.01	-0.56093	-0.00672	0.19969	A	0.50	-0.96200	0.05242	0.44108
	3.10	0.691002	-0.05058	0.21186		0.80	-1.33805	0.04752	0.50904
	3.80	1.20543	-0.06655	0.21526		0.82	-1.37635	0.04719	0.51317
	4.50	2.34163	-0.08773	0.21994		0.89	-1.5400	0.04607	0.52729

Figure 1: .

fw.	1.00	-0.96200	0.05242	0.44108	Da	0.001	0.69817	0.06025	0.44603
	2.00	-1.66958	0.24653	0.68040		1.000	0.96200	0.05242	0.44108
	3.00	-2.50985	0.48683	0.96140		2.500	-1.25827	0.44313	0.43594
	4.00	-3.39530	0.73617	1.26019		3.500	-1.41819	0.40381	0.43343
Pr	0.72	-0.96200	0.05242	0.44108	α	5	-0.61736	0.08477	0.19764
	0.74	-0.96096	0.04839	0.44113		8	-0.87996	0.07801	0.19375
	0.80	-.095767	0.03554	0.44131		11	-0.79171	0.08035	0.19510
	0.90	-0.95151	0.01131	0.44163		15	-1.21067	0.06857	0.18834
R	0.50	-0.96200	0.05242	0.44107	U	1	-0.96199	0.05242	0.44108
	1.70	-0.97641	0.10738	0.44030		2	-0.92953	0.08946	0.36099
	4.70	-0.98222	0.12889	0.43998		3	-0.91262	-0.19963	0.29347
	7.00	-0.98346	0.13331	0.43992		5	-0.95144	-0.23513	0.21403

Figure 2: .

4. Discussion of Results

The Table 2 represents the numerical results of variation in skin friction, Nusselt and Sherwood numbers at the surface with M, Da, fw, Sc, Pr, R and λ which are of physical and engineering interest. It can be seen from the results that an increase in the values of M, Sc, Pr, Da, fw, decrease the flow boundary layer while increase in values of Gr, Gc, Q, λ and R increase the flow boundary layer. The table depicts that an increase in the values of M, Q, Sc, Da, R thicken the thermal boundary layer by reducing the rate at which heat diffuse out of the system while increase in Gr, Gc, Pr, fw and Pr reduce the thickness of the thermal boundary layer. Also, the results show that increase in Gr, Gc, Q, Sc, fw, R causes thinning in the concentration boundary layer while M, Pr, Da thicken the mass boundary layer.

The following graphical representations further illuminate the research work at hand which describe the velocity (Figures 3 and 4), temperature (Figures 5 and 6) and concentration (Figures 7 and 8) profiles for the variations of parameters explaining the effects of thermo-physical parameters in unsteady MHD viscoelastic fluid flow, heat and mass transfer in inclined porous media.

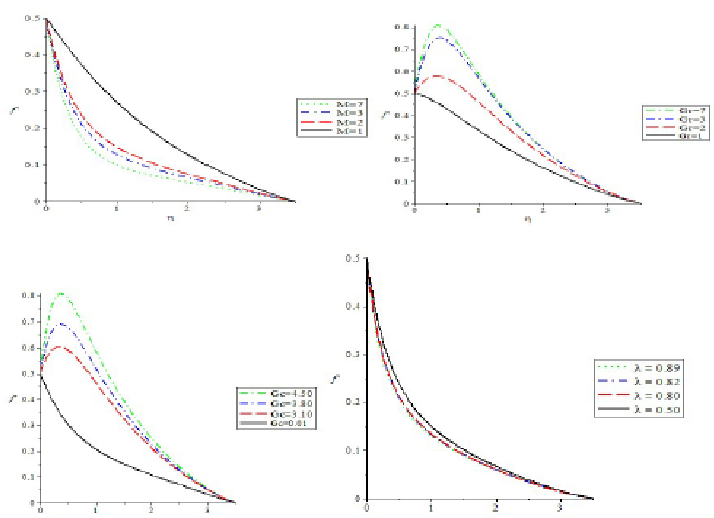

Figure 3: Velocity.

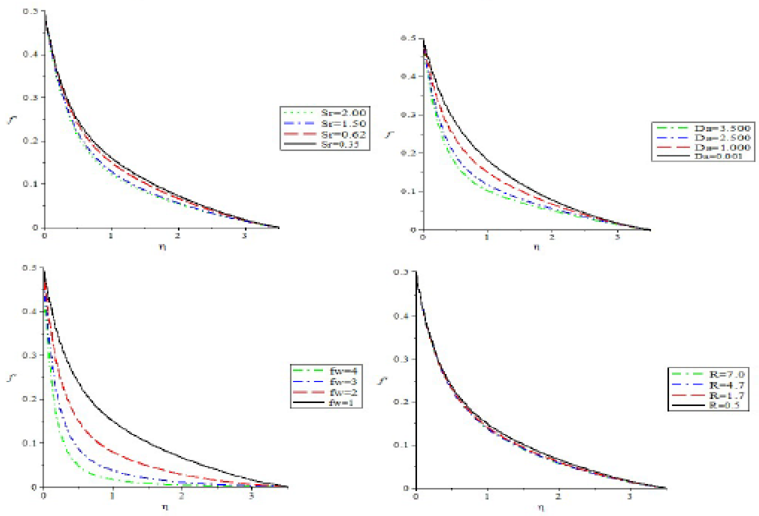

Figure 4: Velocity.

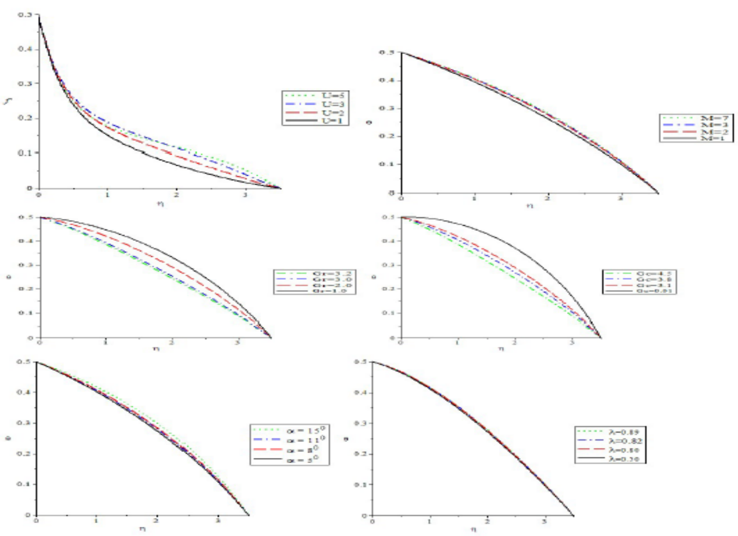

Figure 5: Temperature.

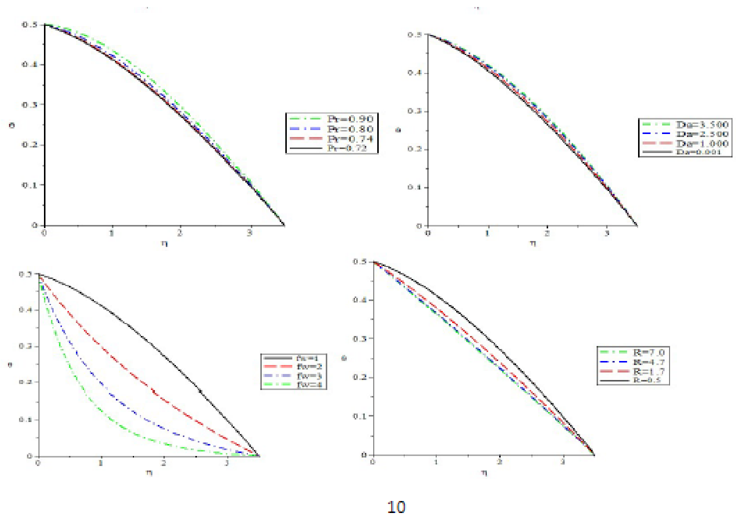

Figure 6: Temperature.

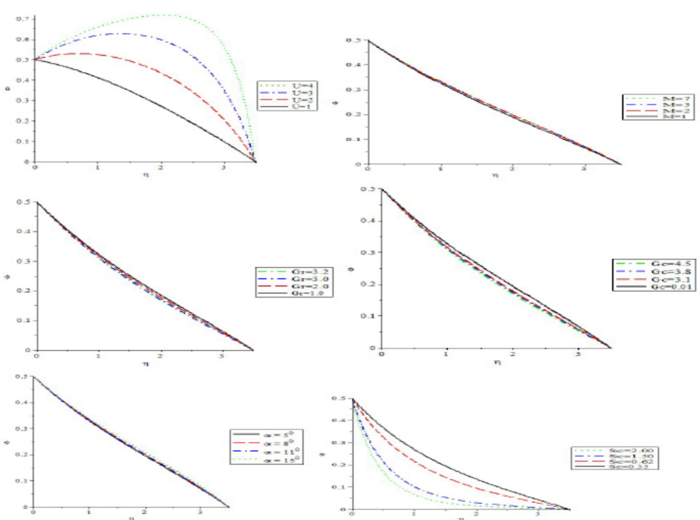

Figure 7: Concentration.

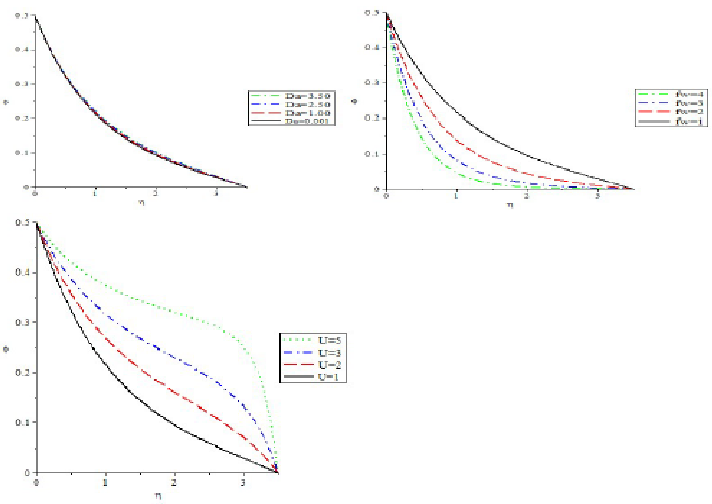

Figure 8: Concentration.

This section presents the summary of the study and these include: Increase in Hartman number (M) led to decrease in the flow boundary layer, increase in both thermal and concentration boundary layer. Increase in thermal Grashof number ($Gr.$) led to increase in flow boundary layer, decrease in both thermal and concentration boundary layer. Increase concentration in solutal ($Gc.$) leads to increase in flow boundary layer, decrease in both thermal and boundary layer. Increase in angle of inclination (α) led to sinusoidal behavior in flow boundary layer, thermal and concentration boundary layer. Increase in heat source (Q) led to corresponding increase in both flow and thermal boundary layer, decrease in concentration boundary layer. Increase in chemical reaction parameter (λ) leads to increase in flow boundary layer, sinusoidal behavior in thermal boundary layer and decrease in concentration boundary layer. Increase in Schmidt number (Sc) leads to decrease in flow and concentration boundary layer, increase thermal boundary layer. Increase in Prandtl number (Pr) leads to decrease in both flow and thermal boundary layer, increase in concentration boundary layer. Increase in porosity (Da) leads to decrease in flow boundary layer, corresponding increase in both thermal and concentration boundary layer. Increase in permeability at the plate (fw) leads to decrease in flow, thermal and concentration boundary layer. Increase in radiation (R) leads to corresponding increase in both flow and thermal boundary layer, decrease in concentration boundary layer.

Conclusion. In conclusion, the study presents the behavior of the dimensionless parameters in analyzing the nonlinear MHD viscoelastic fluid flow in inclined porous media. Using the similarity transformation to arrive at a set of ordinary differential equations was obtained from the governing equations. The momentum equation and equation of concentration were solved numerically using Maple 18.the result show that increase in Gr, Gc, Q, R and λ increase flow boundary layer while increase in M, Sc, Pr, Da, fw decrease the flow boundary layer. Also, M, Q, Sc, Da and R increase thermal boundary layer, while increase Gr, Gc, Pr and fw decrease thermal boundary layer. It can also be seen that increase in M, Pr, Da increase the concentration boundary layer, while increase Gr, Gc, Q, fw, R decrease the concentration boundary layer.

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