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MHD Viscoelastic Fluid Flow over a Vertical Stretching sheet with n^{th} order of chemical reaction

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Abstract:

we have investigated heat and mass transfer in a steady two-dimensional magneto hydrodynamic viscoelastic fluid flow over a stretching vertical surface with nth order chemical reaction. The two-dimensional boundary-layer governing partial differential equations are reduced to ordinary differential equations by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta iteration Method. e ordinary differential forms of momentum, energy and concentration equations obtained by local similarity transformation are highly nonlinear. The effects of different flow parameters like magnetic field parameter, Prandtl number, buoyancy parameter, Soret number, Dufour number on velocity, temperature and concentration profiles are plotted and discussed numerically and graphically.

Keywords — **MHD, Viscoelastic fluid, stretching sheet, Boussinesq approximation, Buoyancy force.**

I. INTRODUCTION

The heat transfer investigation due to a continuously moving stretching surface through an ambient fluid is one of the thrust areas of present research. This finds its application over a broad spectrum of Science and Engineering disciplines, particularly in the field of chemical engineering. Numerous chemical engineering processes like metallurgical process, polymer extrusion process involves cooling of a molten liquid being stretched into a cooling system [1,2]. In such processes the fluid mechanical properties of the penultimate product would mainly depend on two possessions, one is the cooling liquid used and other is the rate of stretching. Few of the polymer fluids such as Polyethylene oxide, polyisobutylene solution in cetane having better electromagnetic properties are recommended as their flow can be regulated by

taken to control the rate at which in place of cooling liquids the extrudate is stretched; rapid stretching results in sudden solidification thereby destroying the properties expected for the outcome.

The Dufour and Soret effects on heat and mass transfer according to Fourier's and Fick's laws [3] are neglected by some researchers; however, when density differences exist in the flow regime, these effects are significant and cannot be neglected[4]. Afify [5] has demonstrated that when heat and mass transfer occurred in a stirring fluid, the energy flux can be generated by a composition gradient, namely, the Dufour or diffusion thermo effects, and the mass fluxes developed by the temperature gradients are called the Soret or thermal diffusion effect. The Soret and Dufour effects of a steady flow due to a rotating disk in the presence of viscous dissipation and ohmic heating were investigated in their numerical study. Heat and mass transfer with hydrodynamic slip over a moving plate in porous media was reported by Hamed et al.[6] via Runge-kutta-Fehlberg fourth-fifth order method. The mixed convection of vertically moving surface in stagnant fluid using heat transfer was examined by Ali and Al-Yousef[7,8].The effect of variable viscosity of mixed convection was presented by Ali[9].

Das et al [10] considered the effect of heat and mass transfer on a free convective flow of an incompressible electrically conducting fluid past a vertical porous plate. Chen [11] applied finite difference method in order to study the heat and mass transfer in MHD free convective flow with ohmic heating and viscous dissipation. Noor et al.[12] explained the Effect of MHD flow over an inclined surface with heat source/sink using shooting method. Abreu et al.[13] derived the boundary- layer flow with Dufour and soret effects in both forced and first order chemical reaction. An unsteady MHD convective flow past a semi infinite vertical plate under oscillatory suction and heat source in slip – flow regime were taken into account by pal and Talukdar [14]. Heat and mass transfer of a mixed convection boundary – layer flow considering porous medium over a stretching vertical surface was reported by Gbadeyan et al.[15]. Using the keller-box method the thermo diffusion and diffusion- thermo effects are discussed by Prasad et al[16]. Pal et al [17-20] analyzed the effects of thermal diffusion and diffusion thermo on steady and unsteady MHD non-darcy flow over a stretching sheet in a porous medium considering soret and dufour effects with thermal radiation, nonuniform heat source or sink, variable viscosity, viscous dissipation and first order chemical reaction using runge-kutta-fehlberg integrated method. Beg et al [21] have reported the heat and mass transfer micro polar fluid flow from an isothermal sphere with Soret and Dufour effects used Keller-box implicit method. Furthermore, Alam et al [22], Tai and Char [23], Mahdy [24,25], Pal and Sewli [26] and also Tsai and Huang [27] have examined the influence of Soret and Dufour effects in their analyses for different aspects of heat and mass transfer flows.

One of the most effective and reliable methods in order to solve the high nonlinear problems is the homotopy analysis method. Homotopy analysis method (HAM) was initially employed by Liao to offer a general analytic method for non- linear problems [28, 29]. Rashidi et al. [30] reported the effect of MHD fluid flow in a rotating disk with partial slip, diffusion thermo and thermal diffusion via HAM and discussed the effects of various slip parameters, magnetic field parameter, Prandtl number, Schmidt number and other important variables, Mustafa et al. [31] taken in to account the effects of Brownian motion and thermophoresis in stagnation point flow of a nanofluid towards a stretching sheet. Rashidi and pour [32] engaged HAM for unsteady boundary-layer flow and heat transfer on a stretching sheet. Abbas et al. [33] analyzed the mixed convective of an incompressible Maxwell fluid flow over a vertical stretching surface by HAM. Dinarvand et al. [34] applied HAM to investigate unsteady laminar MHD flow near forward stagnation point of a rotating and translating sphere. Hayat et al. [35] discussed the thermal-diffusion and diffusion thermo effects on two – dimensional MHD axisymmetric flow of a second grade fluid in the presence of Joule heating and first order chemical reaction. Brinkman equation for the non-linear stagnation – point flow was studied via HAM by Ziabakhsh et al. [36]. An analytical and numerical solution of a radial stagnation flow over a stretching cylinder has been recently reported by Weidman and Ali [37] where aligned and nonaligned flow was studied. Rashidi et al.[38] employed HAM to obtain the analytical solutions over stretching and shrinking sheets in the presence of buoyancy parameter.

The objective of this analysis is to study the steady two dimensional MHD viscoelastic fluid flows over a vertical stretching surface in the presence of the Soret and Dufour effects with nth order chemical reaction. The governing partial differential equations are converted into nonlinear ordinary differential equations and then solved numerically by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta Method. The effects of non dimensional parameters such as

Prandtl number, magnetic field parameter on the fluid velocity, temperature and concentration distributions are plotted and explained.

II. MATHEMATICAL FORMULATION

Let us consider a steady two-dimensional heat and mass transfer flow of an incompressible electrically conducting viscoelastic fluid over a stretching vertical surface with a variable magnetic field $B(x)=B_0x^{(n-1)/2}$ normally applied to the surface. Two equal and opposite forces are applied along the x-axis by keeping the origin fixed. Let us assume that the stretching velocity is in the form of $u_w(x)=ax^n$, where a and n are constants. The induced magnetic field is neglected by comparison of applied magnetic field and the viscous dissipation. Under these assumptions along with boundary layer approximations, the system of governing equations are

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+k_0\left(u\frac{\partial^3 u}{\partial x\partial y^2}+\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial y^2}+\frac{\partial u}{\partial y}\frac{\partial^2 v}{\partial y^2}+v\frac{\partial^3 u}{\partial y^3}\right)$$
$$-\frac{\sigma B^2(x)u}{\rho}+g\left(\beta_T\left(T-T_\infty\right)+\beta_c\left(C-C_\infty\right)\right), \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_ek_T}{c_sc_p}\frac{\partial^2 C}{\partial y^2}, \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_e\frac{\partial^2 C}{\partial y^2}+\frac{D_ek_T}{T_m}\frac{\partial^2 T}{\partial y^2}-\mathrm{K}^*(\mathrm{C}-\mathrm{C}_\infty)^n, \tag{4}$$

In this study, velocity components u and v are taken in the directions of x and y and normal to the surface, respectively. ν is the kinematic viscosity, k_0 is the viscoelasticity parameter, σ is the electrical conductivity, ρ is the fluid density, g is the acceleration due to gravity, β_T is the coefficient of thermal expansion, β_c is the coefficient of thermal expansion with concentration, α is the thermal diffusivity, k_T is the thermal diffusion ratio, c_s is the concentration susceptibility, c_p is the specific heat at constant pressure, D_e is the coefficient of mass diffusivity, T is the fluid temperature, C is the fluid concentration, and T_m is the mean fluid temperature.

And the boundary conditions are :

$$u=u_w(x),v=v_w,T=T_w(x),C=C_w(x)\,at\;\;y=0,$$
$$u\to 0,\frac{\partial u}{\partial y}\to 0,T\to T_\infty,C\to C_\infty,as\;\;y\to\infty. \tag{5}$$

wheret $T_w(x)=T_\infty+bx$ and $C_w(x)=C_\infty+cx$;b and c are constants. The equations (2) to (4) are transformed into ordinary differential equations by using similarity transformations.

$$\eta=\sqrt{\frac{u_w}{\upsilon x}}y,\psi=\sqrt{u_w\upsilon x}f(\eta),\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\varphi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}, \tag{6}$$

Sub (6) into the equations (2) to (4), the non dimensional, non linear, coupled equations (7) to (9) are obtained as follows:

$$f'^2-ff''-f'''-k_1\left\{2ff'''-\frac{1}{2}f''^2-ff^{(4)}\right\}+Mf'-\lambda(\theta+N\varphi)=0 \tag{7}$$

$$\theta''+\Pr\left(f\theta'-f'\theta+Du\varphi''\right)=0 \tag{8}$$

$$\varphi''+Le\left\{\Pr\left(f\varphi'-f'\varphi\right)+Sr\theta''\right\}-K_r\varphi^n=0, \tag{9}$$

Where $k_1=k_0a/v$ is the viscoelasticity parameter $M=\sigma B_0{}^2/a\rho$ is the magnetic field parameter, $\lambda=g\beta_T\left(T_w-T_\infty\right)x/a^2x^2=Gr_x/\mathrm{Re}_x^2$ is the buoyancy parameter, $Gr_x=g\beta_T\left(T_w-T_\infty\right)x^3/v^2$ is the Grashof number, $\mathrm{Re}_x=u_wx/v$ is the Reynolds number, $N=\beta_c\left(C_w-C_\infty\right)/\beta_T\left(T_w-T_\infty\right)$ is the constant dimensionless concentration buoyancy parameter, $\Pr=v/\alpha$ is the Prandtl number, $Le=\alpha/D_e$ is the Lewis number, $Sr=D_ek_T\left(T_w-T_\infty\right)/T_m\alpha\left(C_w-C_\infty\right)$ is the Soret number, and $Du = D_e k_T \left(C_w - C_\infty\right) / c_s c_p \left(T_w - T_\infty\right) v$ is the Dufour number.

The corresponding boundary conditions reduced to:

$$f(\eta) = f_w, f'(\eta) = 1, \theta(\eta) = 1, \varphi(\eta) = 1, at\ \eta = 0,$$
$$f'(\eta) = 0, f''(\eta) = 0, \theta(\eta) = 0, \varphi(\eta) = 0 as\ \eta \to \infty \qquad (10)$$

III. RESULTS AND DISCUSSION

The coupled non-linear ordinary differential Equations (7) - (9) subjected to the boundary conditions (10) are solved numerically by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta Method. The effects of non dimensional parameters such as Prandtl number, magnetic field parameter on the fluid velocity, temperature and concentration distributions are plotted and explained.

Fig.1, Fig.2 & Fig.3 illustrates the effects of Magnetic parameter (M) on velocity, temperature and concentration profiles. From this figures we can see that, the velocity field decreases with an increasing values of Magnetic parameter (M) but the temperature and concentration field's increases with an increasing values of Magnetic parameter (M).

Fig.4, Fig.5 & Fig.6 illustrates the effects of Buoyancy parameter (λ) on velocity, temperature and concentration profiles. From this figures we can see that, the velocity field increases with an increasing values of Buoyancy parameter (λ) but the temperature and concentration field's decreases with an increasing values of Buoyancy parameter (λ).

Fig.7, Fig.8 & Fig.9 illustrates the effects of Prandtl number (Pr) on velocity, temperature and concentration profiles. From this figures we can see that, all fields are decreases with an increasing values of prandtl number (Pr).

Fig.10, Fig.11 & Fig.12 illustrates the effects of Soret (Sr) and Dufour number (Du) on velocity, temperature and concentration profiles. From this figures we can see that, the velocity and temperature field's decreases with an increasing values of Soret (Sr) and Dufour number (Du) but the concentration field increases with an increasing values of Soret (Sr) and Dufour number (Du).

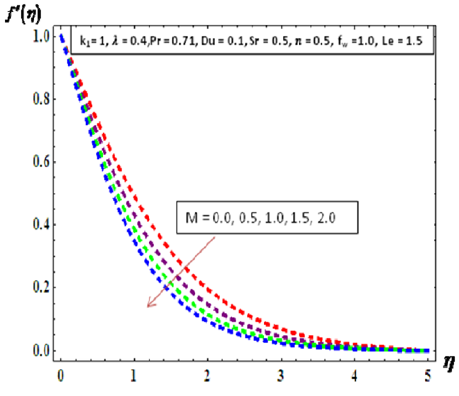

Fig 1 : Effect of M on velocity profile

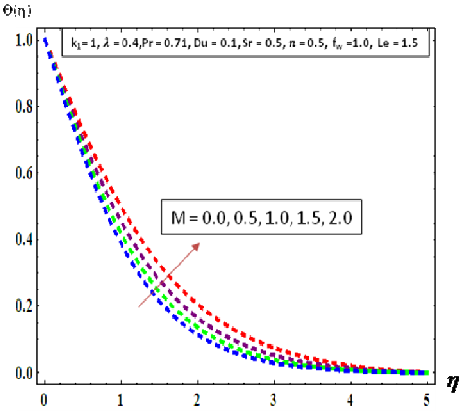

Fig 2 : Effect of M on temperature profile

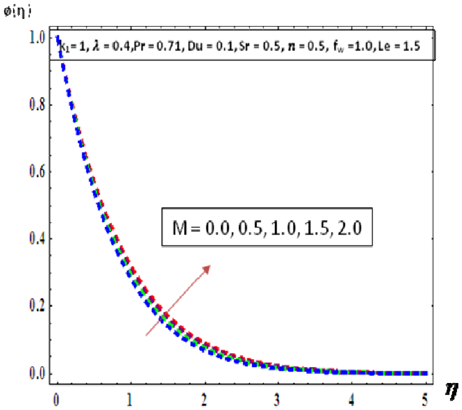

Fig 3 : Effect of M on concentration profile

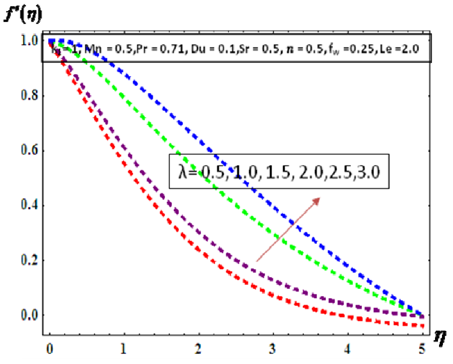

Fig 4 : Effect of λ on velocity profile

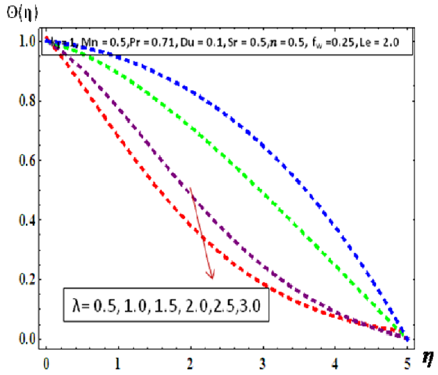

Fig 5 : Effect of λ on temperature profile

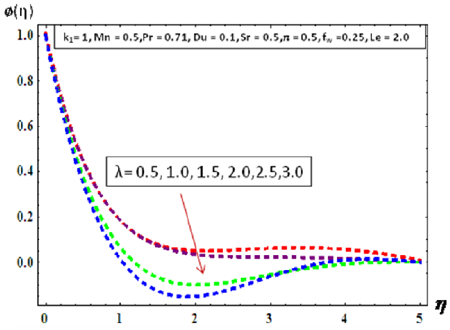

Fig 6 : Effect of λ on concentration profile

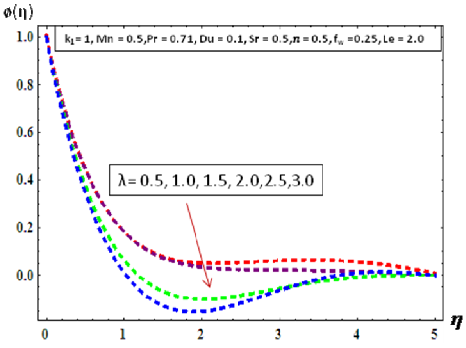

Fig 6 : Effect of λ on concentration profile

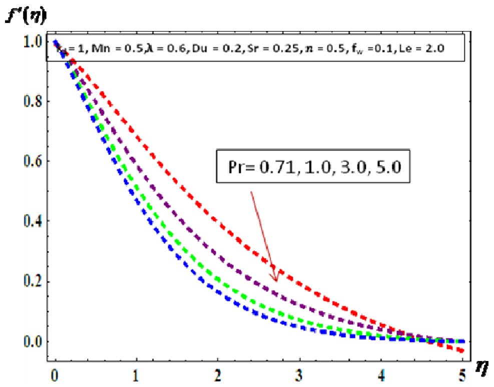

Fig 7 : Effect of Pr on velocity profile

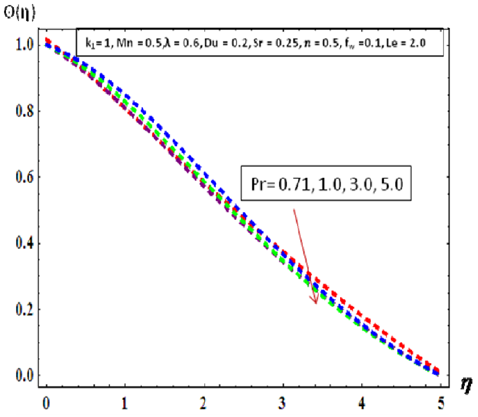

Fig 8 : Effect of Pr on temperature profile

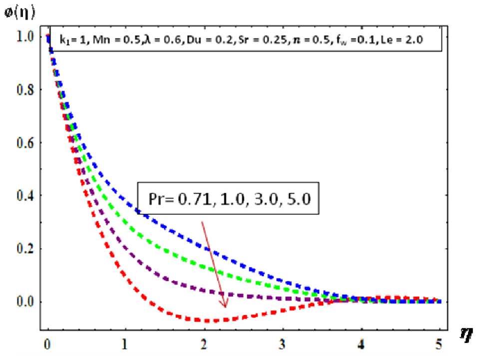

Fig 9 : Effect of Pr on concentration profile

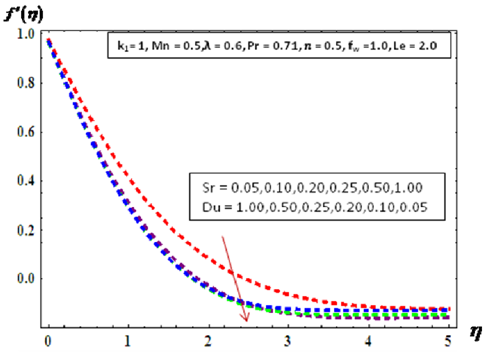

Fig 10 : Effect of Du,Sr on velocity profile

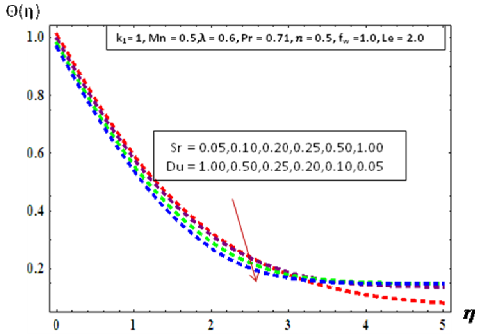

Fig 11 : Effect of Du,Sr on temperature profile

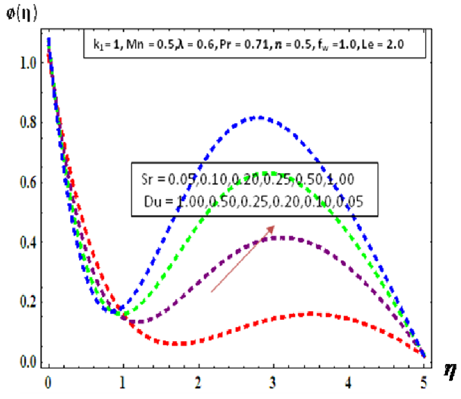

Fig 12 : Effect of Du,Sr on concentration profile

IV. CONCLUSIONS

The coupled non-linear ordinary differential Equations are solved numerically by using Nactsheim-Swigert shooting technique with sixth order Runge-Kutta Method. The non dimensional parameters are analysed graphically. The conclusions are as follows:

- Velocity field decreases with an increasing values of Magnetic parameter(M) but the temperature and concentration field's increase with an increasing with an increasing values of Magnetic parameter(M)

- Velocity field increases with an increasing values of Buoyancy parameter(λ) but the temperature and concentration field's decreases with an increasing Buoyancy parameter(λ)
- All fields decreases with an increasing values of Prandtl number (Pr)
- Velocity and temperature field decreases with an increasing values of Soret number(Sr) and Dufour number (Du) concentration field enhances with an increasing Soret number(Sr) and Dufour number (Du).

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