Oscillatory Instability of Chemical Reacting Thermosolutal Convective Flow of Viscoelastic Maxwell Fluid Thorough Porous Medium With Linear Heat Source Effect

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Abstract-
The present manuscript is extension of published work [18]. In which the Instability mechanism of Thermosolutal convection in a horizontal layer of viscoelastic Maxwell fluid through porous medium with internal linear heating is presented in this manuscript. The chemical reaction is taken into account in the mass transfer equation. Here the chemically reacting fluid flow is affected with temperature and concentration gradient. The Darcy model is introduce in the momentum equation. The onset as well as oscillatory instabilities of the viscolastic Maxwell fluid layer is discussed between free-free boundaries. The chemically reacting parameter is majorly targeted area during the flow study.

Keywords – **Viscoelasic Maxwell fluid, Chemical reaction, Porous media, Linear stability, Rayleigh number,. Oscillatory instability.**

1. INTRODUCTION

The study of convective flow with heat and mass transfer under the influence of chemical reaction with heat source has practical applications in many areas of science and engineering. This phenomenon plays an important role in chemical industry, petroleum industry, cooling of nuclear reactors, and packed-bed catalytic reactors. Natural convection flows occur frequently in nature due to temperature differences, concentration differences, and also due to combined effects. The concentration difference may sometimes produce qualitative changes to the rate of heat transfer. The study of heat generation in many fluids due to exothermic and endothermic chemical reactions and natural convection with heat genereneration can be added to combustion modeling. Heat source and chemical reaction effects are crucial in controlling the heat and mass transfer

The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Possible applications of this type of flow can be found in many industries. Ajay Kumar Singh [1] has studied unsteady free convection flow of an incompressible micro-polar fluid past in infinite vertical plate with temperature gradient dependent heat source. Ajay Kumar Singh [2] who studied the effects of thermal diffusion on MHD free convection flow through a vertical channel . Acharya et al.[3] studied heat and mass transfer over an accelerating surface with heat source in presence of suction and injection. Atul Kumar Singh [4] investigated the effects of mass transfer on free convection in MHD flow of a viscous fluid. Cortell [5] studied flow and heat transfer of an electrically conducting fluid of second grade over a stretching sheet subject to suction and to a transverse magnetic field. Anjalidevi and Kandasamy [6] have examined the effect of a chemical reaction on the flow in the presence of heat transfer and magnetic field. Mansour et al.[7] analyzed the effect of chemical reaction and viscous on MHD natural convection flows saturated in porous media with suction or injection. However, in engineering and technology, there are occasions where a heat source is needed to maintain the desired heat transfer. At the same time, the suction velocity has also to be normal to the porous plate. .

Recently S.Shivaiah et al [8] analyze the effect of chemical reaction on unsteady magneto hydrodynamic free convective fluid flow past a vertical porous plate in the presence of suction or injection. More recently B.R.Rout et al [9] investigate the influence of chemical reaction and the combined effects of internal heat generation and a convective boundary condition on the laminar boundary layer MHD heat and mass transfer flow over a moving vertical flat plate. The lower surface of the plate is in contact with a hot fluid while the stream of cold fluid flows over the upper surface with heat source and chemical reaction.

The flow through porous media is a subject of most common interest and has emerged as a separate intensive research area because heat and mass transfer in porous medium is very much prevalent in nature and can also be encountered in many technological processes. In this context the effect of temperature-dependent heat sources has been studied by Moalem [10] taking into account the steady state heat transfer within porous medium. Rahman and Sattar [11] have investigated the effect of

heat generation or absorption on convective flow of a micropolar fluid past a continuously moving vertical porous plate in presence of a magnetic field. The effect of chemical reaction on different geometry of the problem has been investigated by many authors. Das et al. [12] have studied the effect of mass transfer flow past an impulsively started infinite vertical plate with heat flux and chemical reaction.

The chemical reaction effect on heat and mass transfer flow along a semiinfinite horizontal plate has been studied by Anjalidevi and Kandaswamy [13] and later it was extended for Hiemenz flow by Seddeek et al. [14] and for polar fluid by Patil and Kulkarni [15]. Salem and Abd El-Aziz [16] have reported the effect of hall currents and chemical reaction on hydromagnetic flow of a stretching vertical surface with internal heat generation or absorption . J. Anand Rao et al [17],studied the the chemical reaction effects on an unsteady magneto hydrodynamics free convection fluid flow past a semiinfinite vertical plate embedded in a porous medium with heat absorption.

2. MATHEMATICAL FORMULATIONS OF THE PROBLEM

Let us Consider an infinite horizontal layer of viscoelastic Maxwell fluid with thickness "d," confined between the planes $z = 0$ and $z = d$ in a porous medium of porosity ε and medium permeability $k\,1$ and is acted upon by gravity $\mathbf{g}(0, 0, -g)$. This layer of fluid is heated and soluted in such a way that a constant temperature and concentration distribution is prescribed at the boundaries of the fluid layer. The temperature (T) and concentration (C) are taken to be $T\,0$ and $C\,0$ at $z = 0$ and $T\,1$ and C be the difference in temperature and concentration across the boundaries.

Let $\mathbf{q}(u, \text{V}, w)$, p, ρ, T, C, α, α', μ, κ, and k' , Q_0 be the Darcy velocity vector, hydrostatic pressure, density, temperature, solute concentration, coefficient of thermal expansion, an analogous solvent coefficient of expansion, viscosity, thermal diffusivity, solute diffusivity, and linear heat source of fluid, respectively.

2.1. Assumptions. The mathematical equations describing the physical model are based upon the following assumptions.
(i) Thermo physical properties expect for density in the buoyancy force (Boussinesq hypothesis) are constant.
(ii) Darcy's model with time derivative is employed for the momentum equation.
(iii) The porous medium is assumed to be isotropic and homogeneous.
(iv) No chemical reaction takes place in a layer of fluid.
(v) The fluid and solid matrix are in thermal equilibrium state.
(vi) Radiation heat transfer between the sides of the wall is negligible when compared with other modes of the heat transfer.

*2.2. Governing Equations. The G*overning equations for viscoelastic Maxwell fluid through porous medium is goverened in form of partial differential equation which may written as

$$\nabla.\,q = 0$$

$$\left(1 + \lambda \frac{\partial}{\partial t}\right)\left(-\nabla p + \rho\left(1 - \alpha(T - T_0) + \alpha'(C - C_0)g\right)\right) - \frac{\mu}{k'_1}q = 0$$

$$\sigma \frac{\partial T}{\partial t} + q.\,\nabla T = k\,\nabla^2 T + D_{TC}\nabla^2 C + Q_0(T' - T_0),$$

$$\varepsilon \frac{\partial C}{\partial t} + q.\,\nabla C = k'\nabla^2 C + D_{CT}\nabla^2 T - K'_r C , \qquad\qquad (1)$$

Where $D_{TC}\ and\ D_{CT}$ are the dufour and Soret coefficients ; $\boldsymbol{\sigma = (\rho c_p)_m / = (\rho c_p)_f}$ **is the thermal capacity ,** c_p is specific heat, and the subscript m and f refer to porous medium and fluid, respectively.

Here the wall temperature and concentration assumed to be constant w.r.t the boundaries of the fluid layer. Therefore, the boundary condition are define as follows

$$w = 0, T = T_o , C = C_o \ \ at\ z = 0$$

$$w = 0, T = T_1 , C = C_1 \ \ at\ z = d \qquad\qquad (2)$$

2.3 *Steady state and its solutions.* The steady state solution can be obtained by assuming

$$u = v = w = 0, p = p(z), T = T_s(z), C = C_s(z) \qquad\qquad (3)$$

The steady state solution is given by

$$T_s = T_0 - \Delta T \left(\frac{z}{d}\right),$$

$$C_s = C_0 - \Delta C \left(\frac{z}{d}\right) \qquad (4)$$

$$p_s = p_0 - p_0 g (z + \alpha \frac{\Delta T}{2d} z^2 + \alpha' \frac{\Delta C}{2d} z^2)$$

Where subscript 0 shows the value of the variable at boundary z = 0

2.4 *Disturbance in flow : In order to investigate the stability of the flow dynamic, it necessary to give imposed infinitesimal perturbations on the basic* state which is well documented in the book of Chandershakra rao (1992), The perturbation on the base flow is defined as .

$$q = 0 + q', T = 0 + T', \ C = C_s + C', \ p = p_s + p' \qquad (5)$$

where the parameters q', T', C', p' is known as the perturbed quantities of the mean flow dynamics. Substituting (5) into (1) and neglecting higher order terms of the perturbed quantities, then we get

$$\nabla . q' = 0$$

$$\left(1 + \lambda \frac{\partial}{\partial t}\right)(-\nabla p' + \rho_0(\alpha T' + \alpha' C')g) = \frac{\mu}{k_1} q'$$

$$\sigma \frac{\partial T'}{\partial t} - \omega' \frac{\Delta T}{d} = \kappa(\nabla^2 + Q)T' + D_{TC}\nabla^2 C'$$

$$\varepsilon \frac{\partial C'}{\partial t} - \omega' \frac{\Delta C}{d} = \kappa'(\nabla^2 - Kr)C' + D_{CT}\nabla^2 T' \qquad (6)$$

the dimensionless parameters are defines as follows.

$$(x'', y'', z'') = \frac{1}{d}(x', y', z'), \qquad (u'', v'', w'') = \frac{d}{k}(u', v', w'), \qquad t'' = \frac{k}{\sigma d^2} t', \qquad T'' = \frac{T'}{\Delta T'}, \quad C'' = \frac{C'}{\Delta c'}, \quad p'' = \frac{k_1 d^2}{\mu k} p',$$

$$Q = \frac{h^2 Q_0}{\alpha_m(\rho c_p)_f}, \ K_r = \frac{K_r^2 v}{V_0^2} \quad (7)$$

Remove asterisk for the simplicity

$$\nabla . q = 0$$

$$\left(1 + F \frac{\partial}{\partial t}\right)(-\nabla p + RaT + RaC) - q = 0$$

$$\frac{\partial T}{\partial t} - w == (\nabla^2 + Q)T + D_f \nabla^2 C,$$

$$\frac{\varepsilon}{\sigma} \frac{\partial C}{\partial t} - w = \frac{1}{Le}\nabla^2 C - K_r C + S_r \nabla^2 T \qquad \textbf{(8)}$$

The different non-dimensional parameters are defined as follows.

, $Ra = \frac{\alpha \, d k_1 \, \Delta T g \rho_0}{\mu K}$ is the thermal Rayleigh number , $Rs = \frac{\alpha' \, d k_1 \, \Delta C g \rho_0}{\mu k'}$ is the solutal Rayleigh number, $Le = \frac{k}{k'}$ is the Lewis number, $F = (\frac{k}{\sigma d^2})\lambda$ is the stress relaxation parameter and Q is the rate of heat addition per unit mass by internal sources. $D_f = \frac{D_{TC}}{k} \frac{\Delta C}{\Delta T'}$, s the Dufour parameter, and $Sr = \frac{D_{CT}}{k} \frac{\Delta T}{\Delta C}$ is the Soret parameter.The nondimensional boundary conditions are
The nondimensional boundary conditions are

$$w = T = C = 0 \ at \ z = 0, z = 1 \qquad (9)$$

3. NORMAL MODES AND STABILITY ANALYSIS

The disturbances of the mean flow is taken into account in term of normal modes analysis which is well documented in the book of Drazin (1987).

$$[w, T, C] = [W(z), \Theta(z), \Gamma(z)] \exp (ik_x x + ik_y y + nt) \qquad (10)$$

Where the parameters k_x, k_y are called as wave numbers along with different coordinate axis x and y respectively, and n is defined as growth rate of disturbances. By using eq (10), (8) becomes

$$(D^2 - a^2)W + (1 + Fn)(a^2 Ra\Theta + a^2 Rs\Gamma) = 0$$

$$W + (D^2 - a^2 - n - Q)\Theta + D_f(D^2 - a^2)\Gamma = 0$$
$$W + S_r(D^2 - a^2)\Theta + \left(\frac{1}{Le}(D^2 - a^2) - \frac{\varepsilon}{\sigma}n + \boldsymbol{K_r}\right)\Gamma = 0$$

Where $D = \frac{d}{dz}$ and $a = \sqrt{k_x^2 + k_y^2}$ is define as dimensionless wave number.
The corresponding free – free boundary conditions are
$W = 0, D^2 W = 0, \Theta = 0, \Gamma = 0, at\ z = 0$
$W = 0, D^2 W = 0, \Theta = 0, \Gamma = 0, at\ z = 1$ \hfill (12)

We assume the solution to W, Θ, and Γ is of the form
$W = W_0 \sin \pi z$, $\Theta = \Theta_0 \sin \pi z$, $\Gamma = \Gamma_0 \sin \pi z$, \hfill (13)

Those satisfy the boundary conditions (12).

Substituting solution (13) in (11), integrating each equation from $z = 0$ to $z = 1$ by parts, we obtain the following matrix equation as

$$\begin{bmatrix} J & -a^2(1 + Fn)Ra & -a^2(1 + Fn)Rs \\ -1 & (J + n + Q) & D_f J \\ -1 & S_r J & \left(\frac{J}{Le} - \frac{\varepsilon n}{\sigma} + Kr\right) \end{bmatrix} \begin{bmatrix} W_0 \\ \Theta_0 \\ \Gamma_0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (14)$$

Where $J = \pi^2 + a^2$

The nontrivial solution corresponding to the matrix given in eq (14)

$$Ra = \frac{(J)(J+n+Q)\left(\left(\frac{J}{Le} - \frac{\varepsilon n}{\sigma} + \boldsymbol{K_r}\right) - S_r D_f J^2\right)}{a^2(1+Fn)J\left(\left(\frac{1}{Le}\right) - D_f\right) + \left(\frac{\varepsilon n}{\sigma} + \boldsymbol{K_r}\right)} + \frac{(S_r J - (J+n+Q))}{J\left(\left(\frac{1}{Le}\right) - D_f\right) - \left(\frac{\varepsilon n}{\sigma} + \boldsymbol{K_r}\right)} Rs \quad (15)$$

For neutral instability $n = i\omega$, (where ω is real and dimensionless frequency of oscillation) and equating real and imaginary parts of (15), we have

$$J\left(\left(\frac{J^2}{Le} + \frac{\varepsilon \omega^2}{\sigma} + \frac{QJ}{Le} + QKr\right) - S_r D_f J^2\right) + a^2 Ra\left(J\left(D_f - \frac{1}{Le}\right) + \frac{\varepsilon \omega^2 F}{\sigma} - Kr\right) - a^2 Rs(J + Q - S_r J - \omega^2 F) = 0$$
$$\left(\frac{J^2}{Le} + KrJ\right) + a^2 Ra\left(FJ\left(D_f - \frac{1}{Le}\right) - FKr\right) - a^2 Rs(JF - S_r JF + FQ) = 0 \quad (16)$$

For stationary convection $\omega = 0$ (n=0), we have

$$Ra = \frac{(J)(S_r D_f J^2 - J - Q)\left(\frac{J}{Le} + Kr\right)}{a^2\left(D_f J - \frac{J}{Le} - Kr\right)} + \frac{a^2[J + Q - S_r]}{D_f J - \left(\frac{J}{Le} + Kr\right)a^2} Rs \quad (17)$$

For oscillatory convection $(n = i\omega)$ and equating the imaginary part, we have
$$Ra = \frac{\left(\frac{J^2}{Le} + KrJ\right)}{a^2\left(FJ\left(D_f - \frac{1}{Le}\right) - FKr\right)} - \frac{(JF - S_r JF + FQ)}{\left(FJ\left(D_f - \frac{1}{Le}\right) - FKr\right)} Rs \quad (18)$$

Her the onset instability is measured in form of stationary and oscillatory convection. The different parameter is defined as , the Rayleigh number Ra is a function of dimensionless wave number a, Dufour parameter D_f, Soret parameter S_r, Lewis number Le and solutal Rayleigh number Rs,,chemical reacting parameter Kr and internal heat source Q. Thus for stationary convection of viscoelastic Maxwell fluid is work as an ordinary Newtonian fluid.

The critical cell size at the onset of instability is calculated from.
$\left(\frac{\partial Ra}{\partial a}\right)_{a=a_c} = 0$ which gives $a_c = \pi$

The corresponding critical Rayleigh number Ra_c for the steady onset is

$$Ra_c = 4\pi^2 \left(\left(\frac{S_r D_f Le - 1}{D_f Le - 1} \right) + \frac{(S_r - 1)Le}{1 - D_f Le} Rs \right) \qquad (19)$$

If $S_r = D_f = Rs = 0$ then $Ra_c = 4\pi^2$ $\qquad (20)$

4. RESULT AND DISCUSSION

The Oscillatory instability of double diffusive convection in a horizontal layer of chemically reacting ,maxwell viscoelastic fluid in the presence of heating effect ,Soret and Dufour in a porous medium is investigated analytically and graphically. The expressions for both the stationary and oscillatory Rayleigh numbers, which characterize the stability of the system, are obtained analytically. The stationary as well as oscillatory critical Rayleigh number is found to be independent of the viscoelastic parameter F; thus Maxwell viscoelastic binary fluid behaves like ordinary Newtonian binary fluid. The stationary as well as oscillatory critical Rayleigh number and critical wave number are independent of viscoelastic parameter because of the absence of base flow in the present case. In entire study the following parameters are fixed and having the values $D_f = 0.2, S_r = 0.4 \ Rs = 50, Le = 10, Q = 1, Kr = 2$. The neutral stability curve for wide range of parameters are plotted in the Figures 1-4.

The expressions for the stationary and oscillatory Rayleigh numbers for different values of the parameters such as internal Rayleigh number, chemical reacting parameter are computed and the results are depicted in figures.
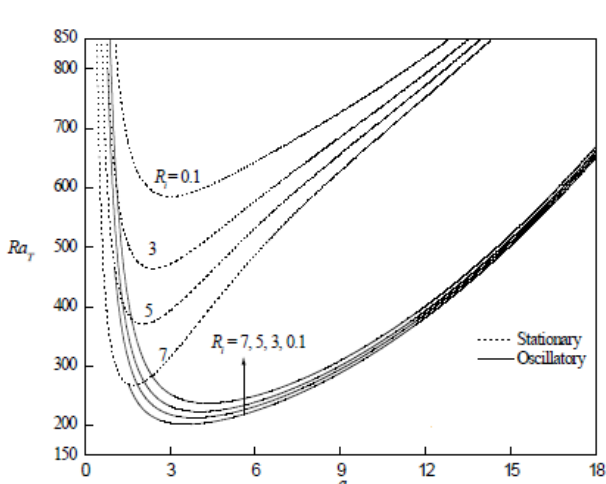

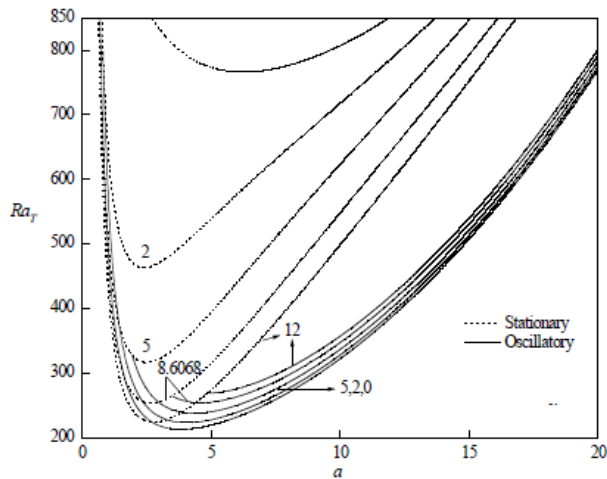Figure1 Neutral stability curves for different values internal Rayleigh number Ra

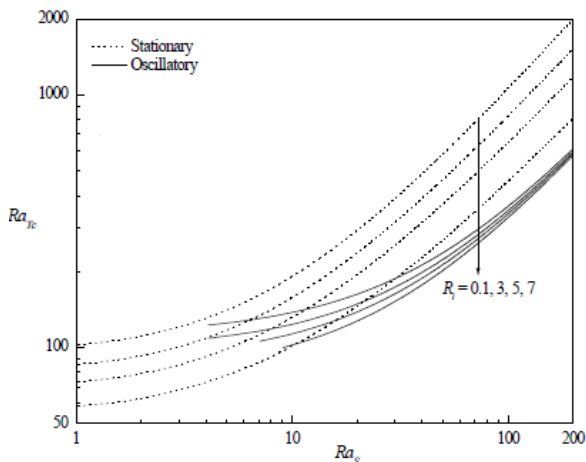Figure 2: Neutral stability curves for different values of chemical reacting parameter

Figure 3:Variation of critical Rayleigh number with solute Rayleigh number for different values of internal Rayleigh number R $_{ii}$
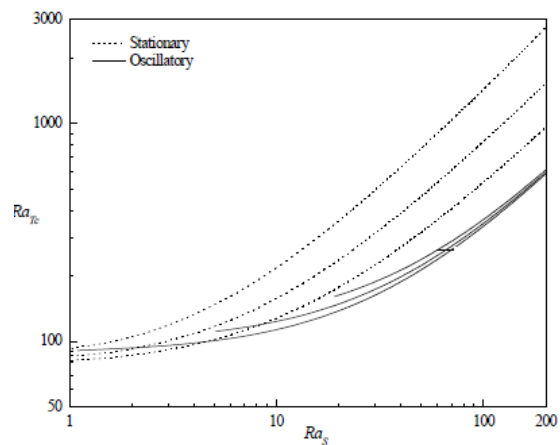

Figure4: Variation of critical Rayleigh number with solute Rayleigh for different values of chemical reacting parameter.

Figure 1 The effect of internal Rayleigh number R_i on the marginal stability curves is depicted for fixed values of other parameters. We find from this figure that with an increase in the value of internal Rayleigh number R_i decreases the minimum of the Rayleigh number for both stationary and oscillatory modes. Therefore, the effect of R_i is to advance the onset of stationary and oscillatory convection. Furthermore, we can observe from this figure that the effect of internal Rayleigh number R_i is more pronounced on the stationary mode than on the oscillatory mode. Also, we find from this figure that the minimum of the Rayleigh number shift towards the smaller values of the wavenumber with increasing internal Rayleigh number.

Figure 2 displays the effect of chemical reacting parameter Kr on the neutral stability curves for stationary and oscillatory modes for fixed values of other parameters. We find that minimum value of the Rayleigh number for oscillatory mode increases with increasing the chemical reacting parameter, indicating that the chemical reacting parameter stabilizes the system in the case of oscillatory mode. On the other hand, increasing the chemical reacting parameter decreases the minimum of the stationary Rayleigh number. This indicates that chemical reaction parameter destabilizes the system in the case of stationary mode. Thus, the chemical reaction parameter has a contrasting effect on stationary and oscillatory modes. It is also interesting to note that there exists critical chemical reacting parameter Kr_c such that when , $Kr > Kr_c$ the convection mode switches to the stationary type, and when $_c Kr < Kr_c$, the convection first sets in through oscillatory mode. Further, when $Kr = Kr_c$, both stationary and oscillatory convection occurs simultaneously but with different wave numbers (we find $Kr_c = 8.6068$, see Fig. 2). Further, we can observe rom this figure that the effect of chemical reacting parameter Kr is more pronounced on the stationary mode than on the oscillatory mode.

Figure 3 shows the variation of the critical Rayleigh number for stationary and oscillatory modes with the solute Rayleigh number for different values of the internal Rayleigh number R_i We find that an increase in R_i decreases the critical Rayleigh number for stationary and oscillatory modes indicating that the effect is destabilizing. Also, we observe from this figure that the threshold value of the solute Rayleigh number below which the oscillatory convection is not possible increases with an increase of the internal Rayleigh number.

Figure 4 the variation of critical Rayleigh number Ra_{Tc} with solute Rayleigh number *Ras* for different values of the chemical reacting parameter Kr is shown. The critical Rayleigh number for the oscillatory mode increases with an increase in the value of Kr , indicating that the effect of chemical reaction parameter is to delay the onset of convection in case of oscillatory mode. This is because the chemical reaction term couples together the temperature and concentration fields to inhibit double diffusive effects. On the other hand, the critical Rayleigh number for the stationary mode decreases with an increase of Kr , indicating that the effect of chemical reaction parameter is to destabilize the system in the stationary mode. Also,we find from this figure that the threshold value of the solute Rayleigh number below which the oscillatory convection is not possible increases with an increase of chemical reacting parameter.

5. CONCLUSIONS

Linear stability analysis of thermoslutal convection with chemical reaction parameter in a horizontal layer of Maxwell viscoelastic fluid in presence of internal heating is performed.
The expressions for both the stationary and oscillatory instability in term of Rayleigh number, which is essential for stability is calculated analytically.
Other concluding remarks are as follows.
 (i)   In stationary convection Maxwell viscoelastic fluid behaves like ordinary Newtonian fluid.
 (ii)   Dufour parameter, Soret parameter, and Lewis parameter have both stabilizing and destabilizing effects on the stationary convection.
 (iii)   Chemical reaction parameter is to destabilize the system in the stationary mode
 (iv)   Chemical reaction parameter is to delay the onset of convection in case of oscillatory mode
 (v)   The chemical reaction parameter has a contrasting effect on stationary and oscillatory modes

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