



Stability of Chemically reacting Double diffusive free Convective Flow of Maxwell Fluid Thorough Porous Medium with Internal Heating under Magnetic Effect

Neetu Ram¹, Ashok Kumar², S.Kapoor³, P.Alam⁴

^{1,4}Research Scholar, Dept. of Mathematics, HNB Garhwal University, Srinagar, Uttarakhand, INDIA.

²Assistant Professor, Dept. of Mathematics, HNB Garhwal University, Srinagar, Uttarakhand, INDIA.

³Assistant Professor, Dept. of Mathematics, Regional Institute of Education (NCERT),
Bhubneswar, Odisha, INDIA.

Abstract: The manuscript reports the stability mechanism of chemically reacting Double diffusive free convective flow in a horizontal layer of viscoelastic Maxwell fluid through porous medium with internal linear heating. The flow is also induced by the magnetic effect which gravitational aligned $(0,0,-g)$. Due to magnetic effect the flow is very slow so that the Darcy model is taken into account in the momentum equation. The onset of stabilities at free-free boundaries is calculated analytically. The neutral stability curve between different physical parameter is shows graphically.

Keywords: Porous media, Magnetic effect, Double diffusive, Chemical reacting parameter, Internal heat source.

I. INTRODUCTION

Transport of heat through a porous medium is being extensively studied, as understanding the associated transport processes becomes increasingly important. This interest stems from the variety of cases which can be modeled or approximated as transport through porous media, such as packed sphere beds, high performance insulation for buildings, chemical catalytic reactors, grain storage, and many others. 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.

Magnetoconvection (convection in the presence of a magnetic field) on such processes has been intensively studied by many authors. In recent years, progress has been considerably made in the study of heat and mass transfer in magnetohydrodynamic (MHD) flows due to its application in many devices, like the MHD power generators and Hall accelerators. Philip Oladapo et al [13] evaluated numerically the effects of heat and mass transfer in the hydromagnetic boundary layer flow of the moving plate, and chemical reaction with Dufour and Soret in the presence of suction/injection. Makinde [14-17] have investigated magneto-hydrodynamics (MHD) convection in porous medium. A similar problem, involving natural convection about a vertical impermeable flat plate, was tackled by Sparrow and Cess [18]. Kumar Jha and Prasad [19] studied the heat source characteristics on the free – convection and mass transfer flow past an impulsively started infinite vertical plate bounded a saturated porous medium under the action of magnetic field. Recently Neetu et.al [20-21] has taken an attempt in the direction of stability analysis of double diffusive convective flow in porous media with chemical reaction and linear heating. Keeping in view of the above here we studied the magnetic effect in the porous zone

II. 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_1 at $z = d$. Let ΔT and ΔC be the difference in temperature and concentration across the boundaries.

Let $\mathbf{q}(u, V, w)$, 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.

A. Assumptions: The mathematical equations describing the physical model are based upon the following assumptions.

- Thermo physical properties except for density in the buoyancy force (Boussinesq hypothesis) are constant.
- Darcy's model with time derivative is employed for the momentum equation.
- The porous medium is assumed to be isotropic and homogeneous.
- No chemical reaction takes place in a layer of fluid.
- The fluid and solid matrix are in thermal equilibrium state.
- Radiation heat transfer between the sides of the wall is negligible when compared with other modes of the heat transfer.

B. Governing Equations: The Governing equations for viscoelastic Maxwell fluid through porous medium is governed in form of partial differential equation which may written as

$$\begin{aligned} \nabla \cdot \mathbf{q} &= 0 \\ \left(1 + \lambda \frac{\partial}{\partial t}\right) (-\nabla p + \rho(1 - \alpha(T - T_0) + \alpha'(C - C_0))\mathbf{g}) - \frac{\mu}{k_1} \mathbf{q} - \sigma \frac{B_0^2}{\rho} \mathbf{u} &= 0 \\ \sigma \frac{\partial T}{\partial t} + \mathbf{q} \cdot \nabla T &= k \nabla^2 T + D_{TC} \nabla^2 C + Q_0(T - T_0), \\ \varepsilon \frac{\partial C}{\partial t} + \mathbf{q} \cdot \nabla C &= k' \nabla^2 C + D_{CT} \nabla^2 T - K_r C, \end{aligned} \quad (1)$$

Where D_{TC} and D_{CT} are the dufour and Soret coefficients; $\sigma = (\rho c_p)_m / (\rho c_p)_f$ 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

$$\begin{aligned} w &= 0, T = T_0, C = C_0 \text{ at } z = 0 \\ w &= 0, T = T_1, C = C_1 \text{ at } z = d \end{aligned} \quad (2)$$

C. Steady state and its solutions: The steady state solution can be obtained by assuming

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

The steady state solution is given by

$$T_s = T_0 - \Delta T \left(\frac{z}{d}\right), \quad C_s = C_0 - \Delta C \left(\frac{z}{d}\right) \quad (4)$$

$$p_s = p_0 - \rho_0 g \left(z + \alpha \frac{\Delta T}{2d} z^2 + \alpha' \frac{\Delta C}{2d} z^2\right)$$

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

D. 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 .

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

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

$$\nabla \cdot q' = 0$$

$$\left(1 + \lambda \frac{\partial}{\partial t}\right) (-\nabla p' + \rho_0(\alpha T' + \alpha' C')g) = \frac{\mu}{k_1} q' - \sigma \frac{B_0^2}{\rho} u$$

$$\begin{aligned} \sigma \frac{\partial T'}{\partial t} - \omega' \frac{\Delta T}{d} &= \kappa(\nabla^2 + Q)T' + D_{TC} \nabla^2 C' \\ \varepsilon \frac{\partial C'}{\partial t} - \omega' \frac{\Delta C}{d} &= \kappa'(\nabla^2 - Kr)C' + D_{CT} \nabla^2 T' \end{aligned} \quad (6)$$

the dimensionless parameters are defines as follows.

$$\begin{aligned} (x'', y'', z'') &= \frac{1}{d}(x', y', z'), \quad (u'', v'', w'') = \frac{d}{k}(u', v', w'), \quad t'' = \frac{k}{\sigma d^2} t', \quad T'' = \frac{T'}{\Delta T}, \quad C'' = \frac{C'}{\Delta C}, \quad p'' = \frac{k_1 d^2}{\mu k} p', \\ Q &= \frac{h^2 Q_0}{\alpha_m (\rho c_p)_f}, \quad K_r = \frac{\kappa_r^2 v}{V_0^2}, \quad M = \sigma \frac{B_0^2}{u_0^2} V \end{aligned} \quad (7)$$

Remove asterisk for the simplicity

$$\nabla \cdot q = 0$$

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

$$\begin{aligned} \frac{\partial T}{\partial t} - w &= (\nabla^2 + Q)T + D_f \nabla^2 C, \\ \frac{\varepsilon}{\sigma} \frac{\partial C}{\partial t} - w &= \frac{1}{Le} \nabla^2 C - K_r C + S_r \nabla^2 T \end{aligned} \quad (8)$$

The different non-dimensional parameters are defined as follows.

$Ra = \frac{\alpha dk_1 \Delta T g \rho_0}{\mu K}$ is the thermal Rayleigh number, $Rs = \frac{\alpha' dk_1 \Delta C g \rho_0}{\mu k'}$ is the solutal Rayleigh number, $Le = \frac{k}{k'}$ is the Lewis number, $F = \left(\frac{k}{\sigma d^2}\right) \lambda$ is the stress relaxation parameter and Q is the rate of heat addition per unit mass by internal sources.

$D_f = \frac{D_{TC}}{k} \frac{\Delta C}{\Delta T}$ is the Dufour parameter, and $S_r = \frac{D_{CT}}{k} \frac{\Delta T}{\Delta C}$ is the Soret parameter. The nondimensional boundary conditions are

$$w = T = C = 0 \text{ at } z = 0, z = 1 \quad (9)$$

III. 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).

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

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 equation (10), (8) becomes

$$\begin{aligned} (D^2 - a^2 - M)W + (1 + Fn)(a^2 Ra \Theta + a^2 Rs \Gamma) &= 0 \\ W + (D^2 - a^2 - n - Q) \Theta + D_f (D^2 - a^2) \Gamma &= 0 \\ W + S_r (D^2 - a^2) \Theta + \left(\frac{1}{Le} (D^2 - a^2) - \frac{\varepsilon}{\sigma} n + K_r\right) \Gamma &= 0 \end{aligned}$$

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

$$\begin{aligned} W = 0, D^2 W = 0, \Theta = 0, \Gamma = 0, \text{ at } z = 0 \\ W = 0, D^2 W = 0, \Theta = 0, \Gamma = 0, \text{ at } z = 1 \end{aligned} \quad (12)$$

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

(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

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

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

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

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

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

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

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

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

Her the onset instability is measured in form of stationary 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.

$$\left(\frac{\partial Ra}{\partial a} \right)_{a=a_c} = 0 \quad \text{which gives } a_c = \pi$$

The corresponding critical Rayleigh number Ra_c for the steady onset is

$$Ra_c = 4\pi^2 \left(\frac{S_r D_f Le - 1}{D_f Le - 1} \right) + \frac{(S_r - 1)Le}{1 - D_f Le} Rs \quad (18)$$

$$\text{If } S_r = D_f = Rs = 0 \text{ then } Ra_c = 4\pi^2 \quad (19)$$

IV. RESULT AND DISCUSSION

A linear stability analysis of MHD Chemically reacting double diffusive convection in a horizontal layer of Maxwell viscoelastic fluid in the presence of Soret and Dufour and heating effect 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 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 critical Rayleigh number and critical wave number are independent of viscoelastic parameter because of the absence of base flow in the present case. The neutral stability curves in $Ra_T - \alpha$ a plane, for different values of parameters are shown in Figs. 1–6. In the figures ,we present the variation of Ra_T with respect to α for fixed values of the parameters $S_r = 0.001$, $D_f = 0.2$, $Le = 1.0$, $Ra_s = 10.0$, $M = 0.001$, $Q = 10$ with variation in one of the parameters.

The convection curves for solutal Rayleigh number R_s , Soret parameter S_r , Dufour parameter D_f , Magnetic number M , Heat source Q , chemical reacting parameter K_r and Lewis number Le in the (Ra, a) plane are shown in Figures 1–8.

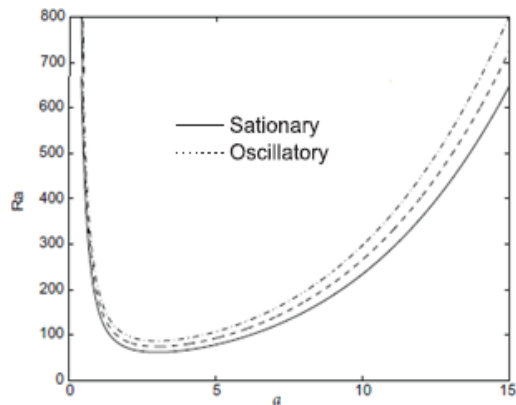


Figure 1: Variation of Rayleigh number Ra and wave number a for different values of Dufour Parameter D_f

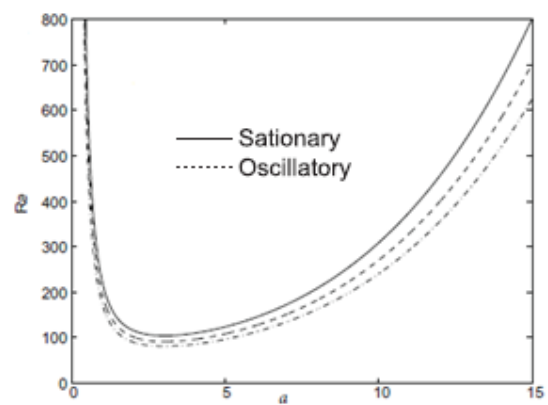


Figure 2: Variation of Rayleigh number Ra and wave number a for different values of Soret Parameter S_r

Figure 1 shows the variation of stationary Rayleigh number with wave number for different values of Dufour parameter and it is found that the Rayleigh number first increases then decreases and finally increases with increase in the value of Dufour parameter; thus for stationary convection Dufour parameter has both the stabilizing and destabilizing effects depending upon certain conditions.

Figure 2 shows the variation of stationary Rayleigh number with wave number for different values of Soret parameter and it is found that the Rayleigh number first decreases then increases and finally decreases with increase in the value of Soret parameter; thus for stationary convection Soret parameter has both the stabilizing and destabilizing effects depending upon certain conditions.

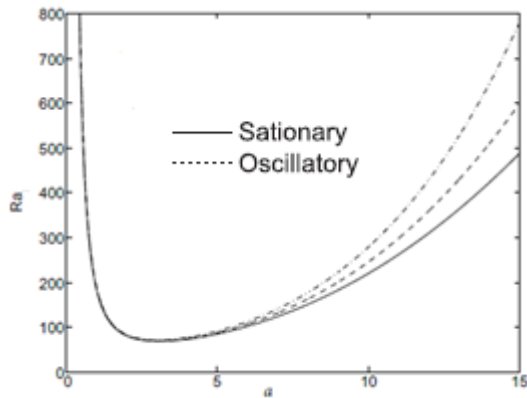


Figure 3: Variation of Rayleigh number Ra and wave number a for different values of Lewis Number Le

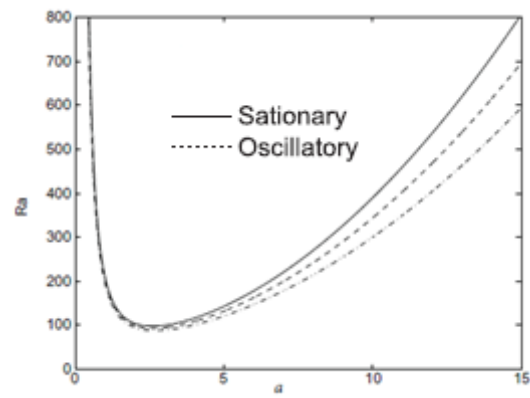


Figure 4: Variation of Rayleigh number Ra and wave number a for different values of Solutal Rayleigh number R_s

Figure 3 shows the variation of stationary Rayleigh number with wave number for different values of Lewis number and it is found that the Rayleigh number first increases then decreases and finally increases with increase in the value of Lewis number; thus for stationary convection Lewis number has both the stabilizing and destabilizing effects depending upon certain conditions.

Figure 4 shows the variation of Rayleigh number with wave number for different value of the solutal Rayleigh number R_s and it is found that the Rayleigh number decreases with increase in the value of solutal Rayleigh number R_s ; thus solutal Rayleigh number R_s has destabilizing effect on the

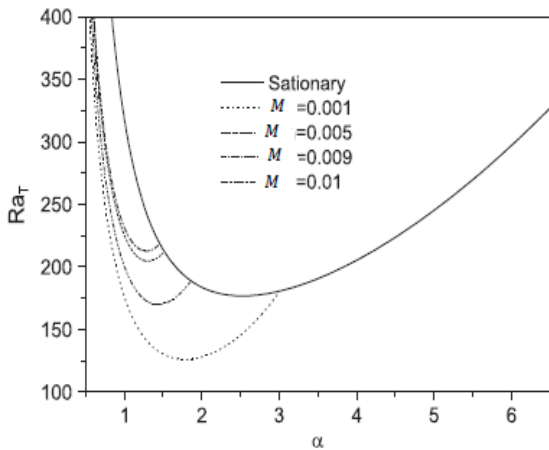


Figure 5 Variation of Ra_T – α for different values of M

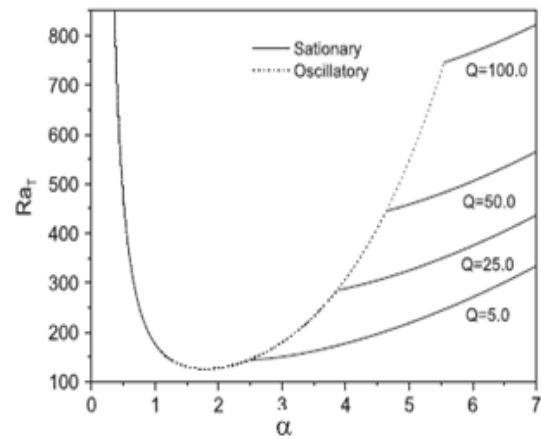


Figure 6 Variation of Ra_T – α for different values of Q

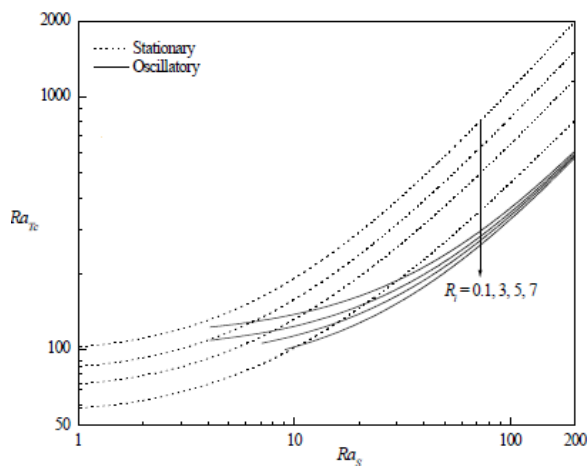


Figure 7 Variation of critical Rayleigh number with solute Rayleigh number for different values of internal Rayleigh number R_{ii}

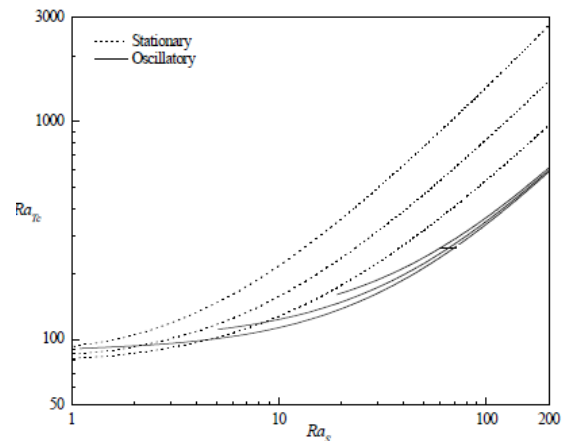


Figure 8: Variation of critical Rayleigh number with solute Rayleigh for different values of chemical reacting parameter.

The Figure 5 shows the variation of Ra_T with respect to α for the different values of Magnetic number (M) while fixing the values of the other physical parameters at $S_r = 0.001$, $D_f = 0.2$, $Le = 1.0$, $Ra_s = 10.0$, $Q = 10$ with variation in one of the parameters. It is clear from these figures that the neutral curves are connected in a topological sense. This connectedness allows the linear stability criteria to be expressed in terms of the critical Rayleigh number, Ra_T , below which the system is stable and unstable above. Although stationary convection does not depend on M , however, oscillatory Rayleigh number decreases on increasing M , thus advancing the onset of convection. In both curve it can be clearly seen that the slope is changing rapidly w.r.t the different parametric values.

Figure. 6 depicts the effect of heat source on the neutral stability curve. We see that the effect of increasing Q is to increase the critical value of Rayleigh number and the corresponding wave number, implying that Q has a stabilizing effect on the double diffusive convection in porous medium. This figure also indicates that for small Q , the instability manifests as stationary convection, while as Q is increased, the instability sets in as oscillatory convection. 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 figure.

Figure 7 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 8 the variation of critical Rayleigh number Ra_{Tc} with solute Rayleigh number Ra_s 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 K_r , 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.

V. CONCLUSIONS

A linear stability analysis of chemically reacting double diffusive convection in a horizontal layer of viscoelastic fluid in the presence magnetic effect in a porous medium is investigated analytically. The expressions for both the stationary and oscillatory stability is obtained.

The major points of conclusions are as follows.

- A. During stationary convection the Maxwell-viscoelastic fluid is shows the effect like a ordinary Newtonian fluid.
- B. During Oscillatory convection the critical Rayleigh number decreases on increasing M , thus its indicate the advancing of the onset of convection
- C. Lewis number, Soret and Dufor parametesr, all shows the stabilizing and destabilizing character during the stationary convection.
- D. Rayleigh solutal number having destabilizes characteristics during the stationary convection.
- E. Internal heat source destabilizes the stationary convection in the small interval of wave number.
- F. The chemical reacting parameter (K_r), indicating that the effect of chemical reaction parameter is to delay the onset of convection in case of oscillatory mode.

REFERENCES

- [1] Ajay Kumar Singh, Numerical solution of unsteady free convection flow of an incompressible micro-polar fluid past in infinite vertical plate with temperature gradient dependent heat source, *Journal of Energy, Heat and Mass Transfer*, 24, (2002), 185–194.
- [2] Ajay .k.Singh, Effects of thermal diffusion on MHD free convection flow through a vertical channel, *Journal of Energy, Heat and Mass Transfer*, 27, 109 – 123.,2005
- [3] M. Acharya, L.P. Singh and G. C.Dash. Heat and mass transfer over an accelerating surface with heat source in presence of suction and injection, *Int. J. Heat Mass Transfer*, 37, (1999), 189 – 211.
- [4] Atul K. Singh, Effects of mass transfer on free convection in MHD flow of a viscous fluid, *Indian Journal of Pure and Applied Physics*,41, 262 – 274,2003
- [5] R. Cortell, 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, *Int. J. Heat Mass Transfer*, 49, (2006), 1851 – 1856.
- [6] S.P. Anjalidevi and R. Kandasamy, Effect of a chemical reaction heat and mass transfer on MHD flow past a semi infinite plate, *ZAMM*, 80, 697-701,2000
- [7] M.A. Mansour, N.F. El-Anssary and A.M. Aly, Effect of chemical reaction and viscous dissipation on MHD natural convection flows saturated in porous media with suction or injection, *Int. J. of Appl. Math and Mech.*, (2008),
- [8] S.Shivaiah , J. Anand Rao ,” Chemical reaction effect on an unsteady MHD free convection flow past a vertical porous plate in the presence of suction or injection”, *Theoret. Appl. Mech.*, Vol.39, No.2, pp. 185–208, Belgrade, 2012.
- [9] B. R. Rout, S. K. Parida, S. Panda, “MHD Heat and Mass Transfer of Chemical Reaction Fluid Flow over a Moving Vertical Plate in Presence of Heat Source with Convective Surface Boundary Condition”, *Hindawi Publishing Corporation International Journal of Chemical Engineering*, Volume 2013
- [10] D. Moalem, “Steady state heat transfer within porous medium with temperature dependent heat generation,” *International Journal of Heat and Mass Transfer*, vol. 19, no. 5, pp. 529–537, 1976.
- [11] M. M. Rahman and M. A. Sattar, “Magnetohydrodynamic convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/ absorption,” *Journal of Heat Transfer*, vol. 128, no. 2, pp. 148–152, 2006.
- [12] U. N. Das, R. Deka, and V. M. Soundalgekar, “Effects of mass transfer on flowpast an impulsively started infinite vertical plate with constant heat flux and chemical reaction,” *Forschung im Ingenieurwesen/Engineering Research*, vol. 60, no. 10, pp. 284–287, 1994.
- [13] Philip Oladapo Olanrewaju · Oluwole Daniel Makinde,” Effects of Thermal Diffusion and Diffusion Thermo on Chemically Reacting MHD Boundary Layer Flow of Heat and Mass Transfer Past a Moving Vertical Plate with Suction/Injection”, *Arab J Sci Eng*, 36:1607–1619, 2011
- [14]. Makinde, O.D.: MHD steady flow and heat transfer on the sliding plate. *A.M.S.E. Model. Meas. Control B.* **70**(1), 61–70 (2001)
- [15] . Makinde, O.D.: Magneto-hydrodynamic stability of plane-Poiseuille flow using multi-deck asymptotic technique. *Math. Comput. Model.* **37**(3–4), 251–259 (2003)
- [16]. Makinde, O.D.: Effect of arbitrary magnetic Reynolds number on MHD flows in convergent-divergent channels. *Int. J. Numer. Methods Heat Fluid Flow* **18**(6), 697–707 ,2008
- [17]. Makinde, O.D.: On MHD boundary-layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux. *Int. J. Num. Methods Heat Fluid Flow* **19**(3/4), 546–554, 2009
- [18]. Sparrow, E.M.; Cess, R.D.: The effect of a magnetic field on free convection heat transfer. *Int. J. Heat Mass Transf.* **4**, 267–274 ,1961
- [19] Kumar Jha, B. and Prasad, R. 1991, MHD free –convection and mass transfer flow through a porous medium with heat source “. *Astrophys, Space Sci*, 8, 117-123
- [20] Neetu Ram., Ashok Kumar., S.Kapoor., R.Bansal and P. Alam., Onset Instability of thermosolutal convective flow of viscoelastic Maxwell fluid through porous medium with linear heat source effect, “ *Int J for Research in Applied Science and Engineering Technology*, vol 3, no3, pp. 493-499, 2015
- [21] Neetu Ram., Ashok Kumar., S.Kapoor., R.Bansal ., V.Dabral and P. Alam., Oscillatory Instability of Chemical Reacting Thermosolutal Convective Flow of Viscoelastic Maxwell Fluid Thorough Porous Medium With Linear Heat Source Effect , “ *Int J of Mathematical Trends and Technology*, vol 20, no1, pp. 55-61, 2015