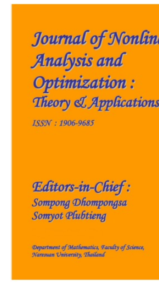
Journal of **N**onlinear **A**nalysis and **O**ptimization
Vol. 16, Issue. 1, No.1 : 2025
ISSN : **1906-9685**



VARIOUS TYPES OF MODULATION ON DUAL DIFFUSION CONVECTION IN OLDROYD-B FLUIDS AND THEIR OUTCOMES IN VARIOUS FIELDS.

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ABSTRACT: -
This study explores different types of adaptation. that applies to coupled diffusive convection in Oldroyd-B fluids, which are characterized by non-Newtonian behavior and thepresence of elastic and viscous properties of the polymer process. They are prominent in many industrial applications. Including the production of food and biomedical equipment. By analyzing the interaction between heat gradients and solutions. This work explains how modulation affects flow behavior. heat transfer and how efficient public transportation is the results indicate that specific modulation strategies can significantly increase or decrease convective events. This affectsoperational efficiency. Moreover, these findings highlight the importance of nonlinear effects and interactions between rheological properties and external modulation. Applications in fields such as materials science, chemical engineering, and environmental engineering are discussed. Emphasis is placed on the practical implications of optimal convection behavior. This is because the field is continually evolving to improve our understanding of non-Newtonian fluid dynamics under varioustuning situations. actually happened -Ongoing research needed to pave the way for innovative solutions in the world.

KEYWORDS:-
- Dual diffusion convection
- Oldroyd-B fluids
- Modulation techniques
- Non-Newtonian fluids
- Thermal gradients
- Solutal gradients
- Flow stability
- Heat transfer efficiency
- Mass transport
- Nonlinear effects
- Rheological properties
- Polymer processing
- Industrial applications
- Chemical engineering
- Environmental engineering
- Convection patterns
- Process optimization
- Fluid dynamics

INTRODUCTION :

Dual-diffusion convection in Oldroyd-B fluid, which exhibits complex rheological behavior due to its viscoelastic properties. It is an interesting area of study of fluid dynamics. Modulation techniques applied to these fluids can have a significant impact on their flow characteristics, stability, and transport phenomena. Various types of adjustment Includes thermal, solute, and magnetic fields. It can change the pattern of convection and diffusion processes. This leads to specific results in applications such as chemical engineering, biomedical devices. and materials science... in chemical engineering Processes such as polymerblending and food production Optimization can be achieved by understanding how adjustmentsaffect mixing and reaction rates. in the biomedical field Manipulating oldroyd-B fluids can improve drug delivery systems and tissue engineering by controlling fluid flow in the microenvironment. Additionally, modulated convection in materials science can help develop composites that It has been optimized to ensure even distribution of components. This introduction explores the mechanism of coupled diffusion convection in various aspects of oldroyd-B fluids. Its relevance and possible applications are highlighted. By examining these interactions Researchers can develop new strategies.The unique properties of these complex fluids for improved technological results.

REVIEW OF LITERATURE :

This study focuses on investigating buoyancy convection in a viscous double Bingham fluid layer under gravity modulation. The search included evaluation of non-linear and slightly linear stability. Important Rayleigh number expressions are obtained using linear analysis. The heat and mass transfer parameters Nu and Sh were calculated by nonlinear analysis using Eq. Ginzburg-Landau Numerical values are obtained from the modulation wavenumber and amplitude variables. The effect of gravitational adjustment on heat and mass transfer can be quantified using the corresponding Nusselt number (Nu) and Sherwood number (Sh). In addition, several factors exist. It has a strong influence on heat and mass transfer processes. Moreover, it is analyzed and visualized using graphical tools. Weak nonlinear stability analysis completed... It is considered a practical method for investigating the stability and dynamic behavior of nonlinear systems. The existence of time-varying gravitational acceleration and triple diffuse convection have a dramatic effect on the generation of acceleration. This creates different dynamics within the field. Understanding natural Rayleigh-Bernard convection and related phenomena. Newton's fluid layer is heated, salty, and saturated from the area below. As a result, the temperature and concentration in the lower plate are higher compared to the upper plate. current research.

MATHEMATICAL FORMULATION:

We consider a Newtonian, incompressible binary fluid, confined between two parallel horizontal walls.Cartesian co-ordinates have been taken with the origin in the middle of the fluid layer and the z-axis vertically upwards, so that the fluid lies between the planes = −d/2 and z = d/2. The walls are infinitely extended in x and y directions, and are rigid. A temperature gradient

ΔT is maintained across the fluid layer by heating from below. Also we maintain a stabilizing uniform concentration gradient ΔS between the walls of the layer. The Soret and Dufour effects on heat and mass diffusion are assumed to be negligible. Then under the Boussinesq approximation the basic governing equations are

$$\frac{\partial V}{\partial t} + V\nabla V = -\frac{1}{\rho_R}\nabla p + \frac{\rho}{\rho_R} g + \nu\nabla^2 V \tag{1.1}$$

$$\frac{\partial T}{\partial t} + V\nabla T = \kappa_T \nabla^2 T \tag{1.2}$$

$$\frac{\partial S}{\partial t} + V\nabla S = k_s \nabla^2 S \quad (1.3)$$

$$\nabla V = 0 \quad (1.4)$$

$$\rho = \rho_R[1 - \alpha(T - T_R) + \beta(S - S_R] \quad (1.5)$$

where ρ_R , T_R and S_R are the constant reference density, temperature and concentration, respectively. V =Temperature Modulation of Double Diffusive Convection (u,v,w) is the velocity,p the pressure, S the solute concentration, T the temperature, g= (0,0,−g) the acceleration due to gravity and t the time; ν is the kine-matic viscosity, k_T the thermal diffusivity, k_s solute diffusivity, and α and β are the coefficients of thermal and solute expansion, respectively. For the temperature modulation of the boundaries we consider the following cases:

(i) When the temperature of the lower and upperboundary is modulated, we have

$$T(t) = T_R \triangle T(1 + \varepsilon \cos \omega t) \qquad atz = -d/2,$$

$$T(t) = T_R + \triangle T \varepsilon \cos(\omega t + \phi)$$
$$atz = d/2$$

(1.6a)
(1.6b)

(ii) When the upper boundary is held at a fixed con-stant temperature, then

$$T(t) = T_R + \triangle T(1 + \varepsilon \cos \omega t)$$
$$atz = -d/2$$

$$T(t) = T_R \qquad atz = d/2 \quad (1.7b)$$

Here ΔT represents the temperature difference, ε is theamplitude of the modulation, φ the phase angle and ω the frequency of the modulation. Since we maintain as tabilizing uniform concentration gradient ΔS betweenthe walls of the porous layer, the imposed boundary conditions on S are

$$S = S_R + \triangle S \qquad atz = -d/2$$

And

$$S = S_R \qquad atz = d/2 \quad (1.8)$$

<u>Basic State</u>

The basic state of the fluid is quiescent and can be given

by $V = (u, v, w) = 0, \qquad T = T_b(z, t), \qquad (1.9)$

$$p = p_b(z, t), \qquad \rho = \rho_b(z, t).$$

The temperature $T_b(z,t)$, concentration $S_b(z)$pressure p_b , and density ρ_b satisfy the equations

$$\frac{\partial T_b}{\partial t} = k_T \frac{\partial^2 T_b}{\partial z^2}, \quad (1.10)$$

$$\frac{\mathrm{d}^2 S_b}{\mathrm{d}z^2} = 0, \quad (1.11)$$

$$\frac{\partial p_b}{\partial z} = -p_b g, \quad (1.12)$$

$$\rho_b = \rho_R[1 - \alpha(T_b - T_R) + \beta(S_b - S_R)] \quad (1.13)$$

Equation (1.10) can be solved for the above cases (i)and (ii). We write

$$T_b(z,t) = T_S(z) + \varepsilon R_e[T_0(z,t)], \quad (1.14)$$

where

$$T_s(z) = T_R + \triangle T(\frac{1}{2} - \frac{z}{d}), \quad (1.15$$

$$T_0(z,t) = \frac{\triangle T}{\sinh\lambda}[e^{i\phi}\sinh\lambda(\frac{1}{2} + \frac{z}{d}) + \sinh\lambda(\frac{1}{2} - \frac{z}{d})]e^{i\omega t} \quad (1.1$$

and

$$\lambda^2 = i\omega\frac{d^2}{k_T} \quad (1.17$$

Solving (1.11) for concentrations with the boundaryconditions (1.8), we get

$$S_b = S_R + \frac{\triangle S}{2}(1 - 2z/d) \quad (1.18$$

LINEAR STABILITY ANALYSIS:

Let the system (1.9) be slightly perturbed. Then, in order to examine the behaviour of infinitesimal thermaldisturbances to the basic state, we write

$$V = V' = (u', v', w') \qquad T = T_b(z,t) + \theta' \qquad p = p_b(z,t) + p\prime$$

$$S' = S_b + S', \quad \rho = \rho_b + \rho'$$

(1.19)

Where V , θ’, S’, p’ and ρ’ represent the perturbed quantities which are assumed to besmall. We substitute (1.19) into (1.1) – (1.4) and linearize with respect to the perturbation quantities V’ , θ’, S’ and p’. In order to non-dimensionalize the variables, we scale thelength,time, temperature, velocity, pressure and modulation frequency according to

$$r' = dr', \qquad t' = \frac{d^2}{k_T}t^*, \qquad T_b = \triangle T T_b^*,$$

$$\theta' = \triangle\theta^*, \qquad V' = \frac{k_T}{d}V^*, \qquad S' = \triangle S S^*,$$

$$P' = \frac{P_R k v}{d^2}p^*, \qquad \omega = \frac{k_T}{d^2}\omega^*, \quad (1.20$$

Then the non-dimensionalized governing equations forthe perturbed variables, namely the vertical compo-

$$w(z,t) = \sum_1^N A_m(t)\psi_m(z)$$

$$\theta(z,t) = \sum_{1}^{N} B_m(t)\varphi_m(z), \tag{2.1}$$

where $S(z,t) = \sum_{1}^{N} C_m(t)\phi_m(z),$ (2.2)

$$\psi_m(z) = [\frac{\cosh \mu_m z}{\cosh \frac{\mu_m}{2}} - \frac{\cosh \mu_m z}{\cos \frac{\mu_m}{2}},$$

$$\frac{\sinh \mu_m z}{\sinh \frac{\mu_m}{2}} - \frac{\sin \mu_m z}{\sin \frac{\mu_m}{2}}],$$

if m is odd if m is even(2.4

$$\varphi_m(z) = \sqrt{2}\sin m\pi(z + \frac{1}{2}), \tag{2.5}$$

$$\phi_m(z) = \sqrt{2}\sin[(m+1)\pi z + (m-1)\frac{\pi}{2}]$$

(m = 1,2,3,...,N). (2.6)

The above functions ψm(z), ϕm(z) and φm(z) are defined such that each forms an orthonormal set in the interval (−1/2 , 1/2)and vanishes at z = ±1/2 . For the derivatives of ψm(z) tovanish at z = ±1/2 , µm must be the

roots of the characteristic equation [28]

$$\tanh\frac{1}{2}\mu_m - (-1)^m tan\frac{1}{2}\mu_m = 0 \tag{2.7}$$

Substituting the expressions (2.1) – (2.3) for w,θ and S in (1.29) – (1.31) and then multiplying by ψ n(z),ϕn(z) and φn(z) (n = 1,2,3,...,N), respectively, the resulting equations are then integrated with respect to
z in the interval (−1/2 , 1/2). The outcome is a system of 3N ordinary differential equations for the unknown coefficients An(t), Bn(t) and Cn(t) as given by

nents of the velocity w, temperature θ and solute con- centration S, in linear form, are

$$P_r^- 1\nabla^2\frac{\partial w}{\partial t} = \nabla^4 w + R_a\nabla_1^2\theta - R_S\nabla_1^2 S, \tag{1.21}$$

$$\frac{\partial\theta}{\partial t} = -(\frac{\partial T_b}{\partial z})w + \nabla^2\theta, \tag{1.22}$$

$$\frac{\partial S}{\partial t} = -(\frac{\mathrm{d}S_b}{\mathrm{d}z})w + \tau\nabla^2 S, \tag{1.23}$$

$$\nabla_1^2 \equiv \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \qquad \nabla^2 = \nabla_1^2 + \frac{\partial^2}{\partial z^2}$$

where and The non dimensionalized numbers which appear in the above equations are: the thermal Rayleigh number

$$R_a = \frac{ag\triangle Td^3}{VkT} \quad R_S = \frac{ag\triangle Sd^3}{Vk_T}$$

the solute Rayleigh number ,the Prandtl number $P_r = v/k_T$, and the diffusivity ratio $\tau = k_s/k_T$. The non- dimensional temperature and $\frac{\mathrm{d}S_b}{\mathrm{d}z}\frac{\partial T_b}{\partial z}$

concentration gradients and which appearin (1.22) and (1.23), respectively, can beobtained from the dimensionless forms of (1.14) and (1.18) as

$$\frac{\partial T_b}{\partial z} = -1 + \varepsilon R_e[g(z),^{i\omega t}]$$

(1.24)

$$\frac{\mathrm{d}S_b}{\mathrm{d}z} = -1$$

(1.25)

where

$$g(z) = \frac{\lambda}{\sinh\lambda}[e^{i\phi}\cosh\lambda(\frac{1}{2}+z) - \cosh\lambda(\frac{1}{2}-z)] \qquad (1.26)$$

and

$$\lambda^2 = i\omega$$

(1.27)

Now we seek the solution for the three unknown fields,
namely velocity, temperature and concentration, using the normal mode technique as

$$[w(x,y,z,t)] = [w(z,t)]$$

$$[\theta(x,y,z,t)] = [\theta(z,t)]exp[i(a_x x + a_y y)]$$

$$[S(x,y,z,t)] = [S(z,t)]$$

(1.28a, b, c)

Substituting the expressions (1.28) in (1.21) – (1.23),we get

$$Pr^{-}1(D^2 - a^2)\frac{\partial w}{\partial t} = (D^2-a^2)^2 w - a^2 R_a\theta + a^2 R_s S$$

(1.29)

$$\frac{\partial\theta}{\partial t} = -(\frac{\partial T_b}{\partial z})w + (D^2 - a^2)\theta$$

(1.30)

$$\frac{\partial S_b}{\partial z} = -(\frac{\mathrm{d}S_b}{\mathrm{d}z})w + \tau(d^2 - a^2)S \qquad (1.31)$$

where $a = \left(a_x^2 + a_y^2\right)^{1/2}$ is the horizontal wave number and
D ≡ ∂/∂z. The boundary conditions for the rigid and conducting walls are given byw = Dw = θ = S = 0 at z = ±1/2. (1.32)

METHOD

Using the Galerkin method, we transform the partial differential equations (1.29) – (1.31) into a system of ordinary differential equations. The ordinary differential equations are then solved numerically. We have

$$Pr^{-}1\sum_{1}^{N}[knm - a^2\delta nm]\frac{dAm}{dr} =$$

$$\sum_{1}^{N}[(\mu_m^4 + a^4)\delta_{nm} - 2a^2k_{nm}]A_m$$

$$-a^2R_a\sum_{1}^{N}P_{nm}B_{nm} + a^2R_s\sum_{1}^{N}U_{nm}C_{nm} \tag{2.8}$$

$$\frac{dB_n}{dt} = \sum_{1}^{N}[P_{mn} - \varepsilon R_e(F_{nm}e^{i\omega t})A_m] - (n^2\pi^2 + a^2)B_n$$

$$\frac{dc_m}{dt} = \sum_{1}^{N}U_{mn}A_m - \tau[(n+1)^2\pi^2 + a^2]C_n(n = 1, 2.\ldots.N) \tag{2.10}$$

where δnm is the Kronecker delta. The other coefficients, which appear in (2.8) – (2.10), are givenby

$$K_{nm} = \int_{-1/2}^{1/2}\psi_n(z)D^2\psi_m(z)d_z$$

(2.11)

$$P_{nm} = \int_{-1/2}^{1/2}\psi_n(z)\phi_m(z)d_z$$

(2.12)

$$U_{nm}\int_{-1/2}^{1/2}\psi_n(z)\phi_m(z)d_z$$

(2.13)

and

$$F_{nm} = \int_{-1/2}^{1/2}\phi_n(z)\psi_m(z)g(z)d_z$$

$\tau = 0.05, \varepsilon = 0.0$			
S. No.	R_S	a_C	R_C
1.1	100.0	3.112	1717.7
1.2	500.0	3.104	1750.3
1.3	1000.0	3.10	1787.6

Table 1. Unmodulated case.

$R_S = 500.0, \varepsilon = 0.0$			
S. No.	τ	a_C	R_C
2.1	0.03	3.10	1775.6
2.2	0.05	3.104	1750.3
2.3	0.5	3.113	1713.4

Table 2. Unmodulated case.

he above coefficients have been evaluated numeri- cally ([29], p. 125). Now, for the computational pur-pose we introduce the notations

X1 = A1, x2 = B1, x3 = C1,
X4 =A2 X5=B2, X6=C2 (2.15)

and rearrange (2.8) – (2.10) in the form

$$\frac{\mathrm{d}x_i}{\mathrm{d}t} = G_{ij}(t)x_j$$

(i, j = 1,2,...,3N), (2.16)

where the coefficients Gi j(t) are periodic in t with the period 2π/ω. The fundamental matrix C =[xi j(2π/ω)] of the solutions has been obtained by integrating the system (2.16), using the Runge- Kutta-Gill procedure ([29], p. 217, 227). Eigenvalues ofthe matrix C are obtained using Rutishauser's method ([30], p. 116), and the stability of the solution of (2.16) is discussed with the

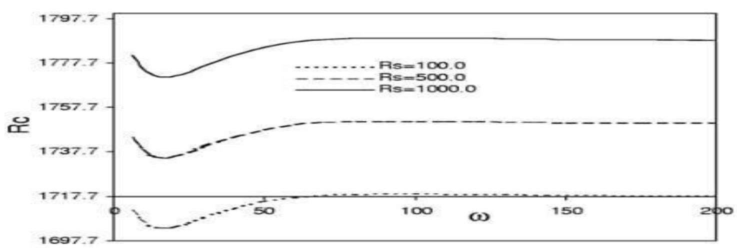
help of the classical Floquet theory ([31], p. 55).4.x

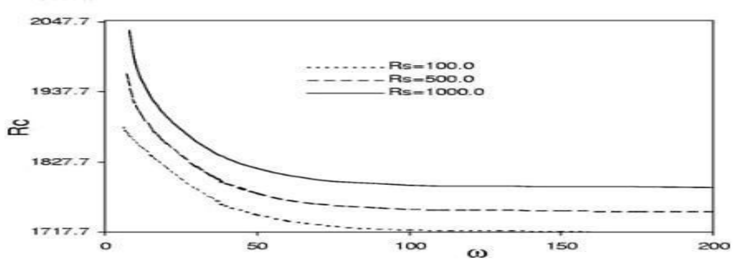
RESULTS AND DISCUSSION:

We did find during the process of numerical solution that it is sufficient to take N = 4 (four Galerkin terms –two even and two odd), therefore all the following results have beenobtained for N = 4. The values of the critical Rayleigh number R_C and corresponding wave number a_C in the absence of modulation (ε = 0) are found as given in Tables 1 and 2.

Now we consider ε $\neq$ 0 and find the effect of the temperature modulation on double diffusive convection in a binary fluid layer. The results have been obtained by solving (3.16) for x1, x2, x3, x4, x5, x6, x7,x8, x9, x10, x11 and x12, i. e., a system of 12 simultaneous ordinary differential equations has been considered. The values of R_C have been calculated for the following three cases:

(a) when the plate temperatures are modulated in phase, i. e., φ = 0; (b) when the plate temperatures are modulated out of phase, i. e.



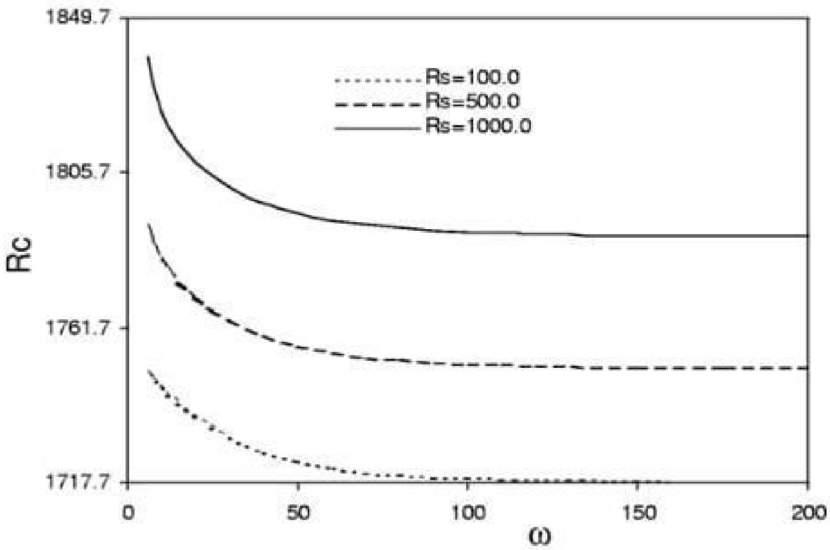


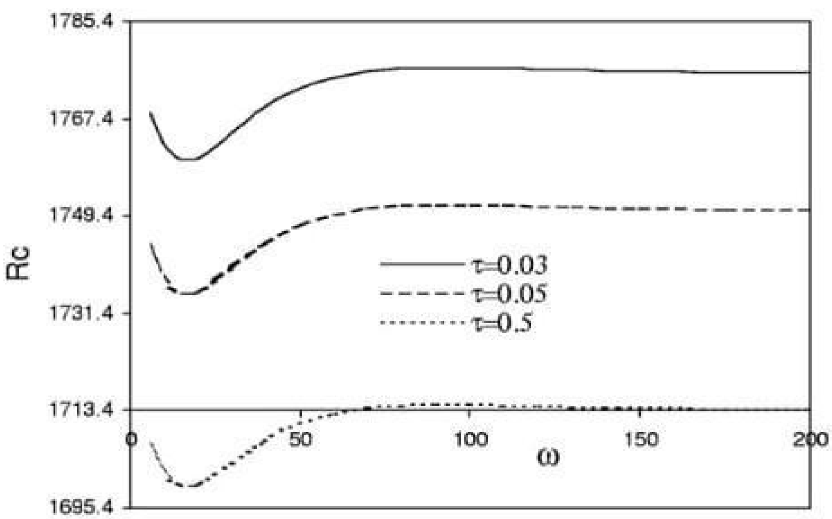
φ = π; and (c) when only the bottom plate temperature is modulated, the upper plate being held at a fixed constant temperature, i. e., φ = i^{∞}. The variation of the critical Rayleigh number R_C with respectto the modulation frequency ω and the amplitude of modulation ε, for different variables, are shown in

Figures 1 – 8.

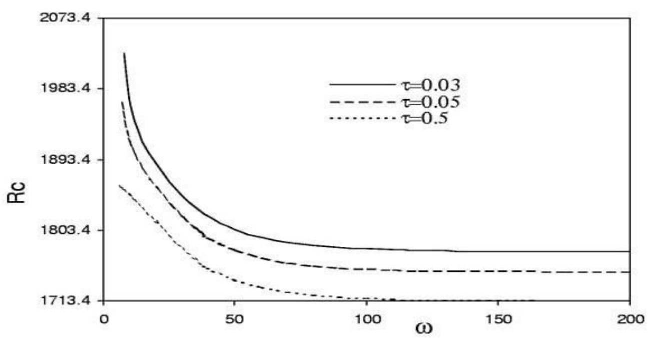
Figures 1 – 3 show the variation of R_C with ω for different values of the solute Rayleigh number R_S the values of the other parameters are ε = 0.4, Pr = 1.0,τ = 0.05. We observe from the figures that the value of the critical Rayleigh number R_C increases with increase of the value of R_S, thus showing that the effect of increasing the solute Rayleigh number R_S is to delay the onset of double diffusive convection, as convection occurs at higher Rayleigh number.

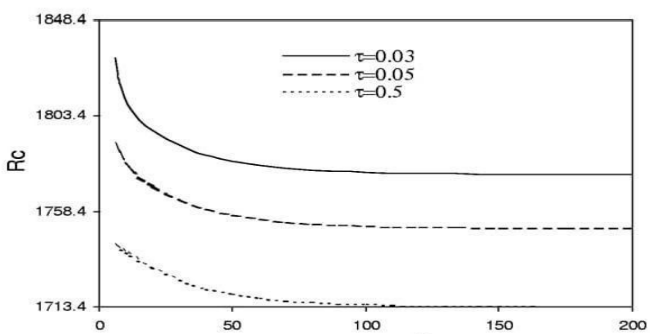
In Figs. 4 – 6 we depict the variation of R_C with ω for different values of the diffusivityratio τ, at ε = 0.4, Pr = 1.0, R_S = 500.0. From the figures we notice that on increasing the value of τ, the value of the critical Rayleigh number $R_C$decreases. Thus, the effect of increasing the value of τ is to advance the onset of convection, as the onset of double diffusive convection takes place at a lower Rayleigh number. Now, to find the effect of temperature modulation on the onset of double diffusive convection, first we con-sider case (a), i. e., in phase modulation. From Figs. 1and 4 we observe that for small values of ω the effect of modulation is small, but destabilizing as convection occurs at a lower Rayleigh number than in the steady temperature gradient case (Tables 1 and 2). For intermediate values of ω the effect of modulation be





comes maximal (destabilizing) near ω = 17, and then decreases with increasing value of ω. It stabilizes the system at around ω = 60, and finally falls off to zero as ω → ∞ (see the Tables 1 and 2). But when the temperature modulation is out of phase (Figs. 2 and 5), or when the upper plate is at constant temperature (Figs. 3 and 6), the effect of modulation is found to be stabilizing. The stabilizing effect is greatest near ω = 0 and disappears altogether when the frequency ω becomes sufficiently large. We know that at high frequency, modulation becomes very fast, therefore the temperature in the fluid layer is unaffected by the modulation except for a thin layer, so that we find almost the same value of R_C as for zero modulation (Tables 1and 2).However, when the frequency of modulation is small, the effect of modulation is felt throughout the fluid layer. Further, the temperature profile consists of a steady straight line section plus a time-dependent parabolic part that oscillates with time. Now when the temperature modulation is in phase, this time dependent parabolic profile becomes more and more significant as the amplitude of modulation increases.Since the parabolic profile is subject to finite amplitude instabilities the convection takes place at an early point thus destabilizing the system at low frequency. Further,when the modulation frequency increases, the effect of parabolic profile decreases, so the system becomes less destabilized and then at some frequency it becomes stabilized on further increasing the value of ω.
But





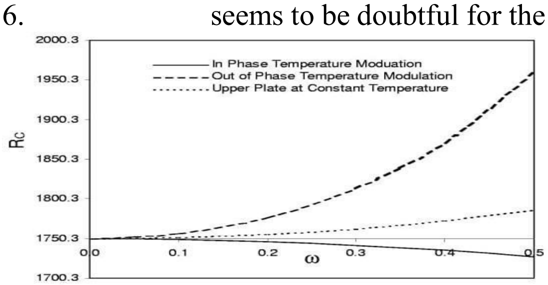
when the temperature modulation is out of phase or the upper wall is at constant temperature, the convective wave propagates across the fluid layer, thereby inhibiting the instability, and so the convection occurs at higher Rayleigh number than that predicted by the linear theory with a steady temperature gradient. This propagation is greatest at low frequency, but decreases with increasing frequency; therefore the stabilizing effect is highest for small frequencies and decreases as the frequency increases. Figure 7 depicts the variation of R_C with the amplitude of modulation ε, for all the three cases, at ω = 17.0, τ = 0.05, RS = 500.0, Pr = 1.0. From the figure we find that forin phase modulation, R_C decreases when the amplitude of modulation ε increases.However for out of phase modulation, or when only the lower wall temperature is modulated, we observe that R_C

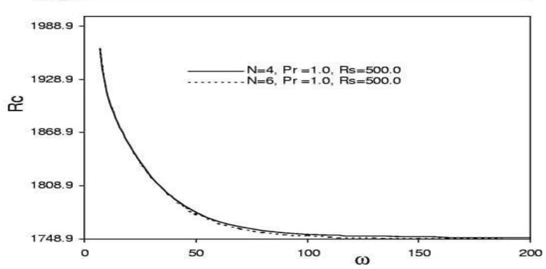
increases as ε increases, thereby showing the stabilization of the system with increasing value of ε. In the last Fig. 8 we have compared the results corresponding to N = 4 and N = 6. It is found that the error in the results for N = 4 and N = 6 is about 0.074%. This justifies our calculations which correspond to N = 4 in this article.

CONCLUSION :

In the present article we consider the effect of temperature modulation on double diffusive convection in a horizontal binary fluid layer with rigid-rigid bound aries, under the assumptions that disturbances are infinitesimal and the amplitude of the applied temperature field is small. The following conclusions are drawn:

1. The value of the critical Rayleigh number R_C increases on increasing the value of the solute Rayleigh number R_S . This shows that the effect of increasing the value of the solute Rayleigh number is to delay the onset of double diffusive convection.
2. The effect of increasing the value of the diffusivity ratio is to decrease the value of the critical Rayleigh number, thus advancing the onset of double diffusive convection.
3. We find that for in phase modulation, the modulation effect is small (destabilizing) when ω is small, becomes maximal (destabilizing) at around ω = 17, decreases for intermediate values of ω, becomes stabilizing on further increasing the value of ω, and finally falls off to zero as ω → ∞.
4. For the out of modulation case, or when only the lower wall temperature is modulated, the effect of modulation is found to be most stabilizing near ω = 0,becomes less stabilizing for intermediate values of ω, and finally disappears as ω becomes very large.
5. The applicability of the present theory, however,
6. seems to be doubtful for the limit ω → 0 [18, 20].





REFERENCE :

1. ***Stommel, H., Arons, A. B., & Blanchard, D. (1956).*** *An oceanographic study of abyssal circulation. Deep-Sea Research, 3(3), 152.*

2. ***Chen, C. F., & Johnson, D. H. (1984).*** *Thermal convection in fluid-saturated porous media.Journal of Fluid Mechanics, 138(2), 405-420.*

3. ***Turner, J. S. (1973).*** *Buoyancy effects in fluids. Cambridge University Press.*

4. ***Turner, J. S. (1974).*** *Buoyancy-driven convection. Annual Review of Fluid Mechanics, 6(1),37-58.*

5. ***Huppert, H. E., & Turner, J. S. (1981).*** *Density stratification and internal waves.*

Journal ofFluid Mechanics, 106(1), 299-329.

6. ***Stern, M. E. (1960).*** *The salt fountain and thermohaline convection. Tellus, 12(2), 172-175.*

7. ***Veronis, G. (1965).*** *On finite amplitude instability in thermohaline convection. Journal ofMarine Research, 23(1), 1-17.*

8. ***Nield, D. A. (1967).*** *Convection in a porous medium with inclined temperature gradient. Journal of Fluid Mechanics, 29(3), 545-558.*

9. ***Baines, P. G., & Gill, A. E. (1969).*** *Thermohaline circulation in a rotating stratified fluid.Journal of Fluid Mechanics, 37(2), 289-306.*

10. ***Chen, C. F. (1974).*** *Stability of thermal convection in a rapidly rotating fluid layer. Journalof Fluid Mechanics, 63(3), 563-576.*

11. ***Proctor, M. R. E. (1981).*** *Steady convective flows in porous media. Journal of Fluid Mechanics, 105(2), 507-523.*

12. ***Thangam, S., Zebib, A., & Chen, C. F. (1982).*** *Convective stability of time-periodic flows ina porous medium. Journal of Fluid Mechanics, 116(1), 363-382.*