EFFECTS OF GRAVITY MODULATION ON DOUBLE DIFFUSIVE CONVECTION IN OLDROYD-B LIQUIDS

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ABSTRACT

Convection in non-Newtonian fluids is quite different from convection in Newtonian fluids. One example of a non-Newtonian fluid is a viscoelastic fluid, which is composed of two components: a viscous component and an elastic component.The main aim of the study is Effects of Gravity Modulation on Double Diffusive Convection in Oldroyd-B Liquids. A horizontally positioned system consists of two walls that confine an infinitely thin layer of Oldroyd-B liquid.The findings derived in this thesis align with the principles of thermodynamics governing the system.

Keywords: Convection, Gravity, Modulation, Thermodynamics, Oldroyd-B

DOI Number: 10.48047/NQ.2022.20.13.NQ88502 Neuroquantology 2022; 20(13): 4134-4141

1. INTRODUCTION

Convection in non-Newtonian fluids is quite different from convection in Newtonian fluids. One example of a non-Newtonian fluid is a viscoelastic fluid, which is composed of two components: a viscous component and an elastic component. Viscoelastic fluids are the sort of fluids in which the connection between stress and strain varies with time. Polymers, human tissues, and metals at high temperatures are some classic examples of this type of fluid. It has recently come to light that viscoelastic liquids are a working medium in many difficulties that are encountered in the chemical and nuclear industries, geophysics, and engineering in biological systems, etc. Convection and the beginning of it in viscoelastic liquids has been the subject of a significant amount of research. Li and Khayat conducted research on stationary and oscillatory instabilities for the Oldroyd-B viscoelastic model. Their findings, which provided much-needed information regarding the development of pattern in viscoelastic fluid convection, may be found in their paper. Green has also looked at the phenomenon of oscillatory convection in these fluids.

When a tiny layer of the fluid was heated from below, researchers discovered that a significant restoring force would set up an oscillating convective motion in the fluid. The linear stability analysis of the Rayleigh–Benard convection issue in a Boussinesquian, viscoelastic fluid was explored by Siddheshwar and Krishna. They concluded that the time required for strain retardation must be less than the time required for stress relaxation for convection to manifest itself in high-porosity medium as oscillatory movements. Siddheshwar did some research not too long ago on the nonlinear stability of thermal convection when it was subjected to g-jitter in a layer of viscoelastic liquid. In contrast to a Maxwell fluid, Sharma discovered that rotation has both a destabilizing and a stabilizing impact on Oldroyd-B liquids. This contradicts the behavior of Maxwell fluids. In the case of these liquids, however, there are much less studies that focus on nonlinear convection in comparison to those that examine linear convection.

1.2 DOUBLE DIFFUSIVE CONVECTION IN OLDROYD B

The processes of fluid flow and heat transfer are widespread in nature as well as engineering. They play an important part in a wide variety of activities, ranging from the climate system of the Earth to industrial applications such as the processing of materials and the creation of energy. For the purposes of maximizing efficiency, forecasting behavior, and resolving environmental problems, having a solid understanding of the underlying mechanics that drive these operations is absolutely necessary.

The phenomena known as convection, in which fluid motion is created by gradients in temperature, concentration, or other qualities, is one of the most fascinating aspects of fluid dynamics. This motion may be caused by a variety of factors. The movement of heat and mass inside fluids is caused by processes known as convection, which also contributes to the creation of complex flow patterns and transport phenomena.

2. LITERATURE REVIEW

P a, Akhila & Mallikarjun B, Patil & Kiran, Palle (2023) This study focuses on the examination of buoyancy-driven convection in a bi-viscous Bingham fluid layer subjected to gravity modulation. The investigation includes both weakly non-linear and linear stability evaluations. The crucial Rayleigh number expression is obtained by linear analysis. The heat and mass transfer parameters, Nu and Sh, are computed by non-linear analysis using the Ginzburg-Landau equation. The numerical values are derived based on the variables of wavenumber and amplitude of modulation. The impact of gravity modulation on the transfer of heat and mass may be quantified using the Nusselt number (Nu) and Sherwood number (Sh) correspondingly. Moreover, several factors have a substantial influence on the processes of heat and mass transmission. Furthermore, this is subjected to analysis and visually shown using graphical means.

Singh, Pervinder& Gupta, Dr. Vinod (2023) Weakly non-linear stability analysis is considered to be a realistic approach for investigating the stability and dynamical behavior of non-linear systems. The presence of time-varying gravitational acceleration and triple-diffusive convection has a notable impact on the generation of acceleration, hence instigating various dynamics within the sector. Further investigation is required to explore the implications of a modified gravitational field on heat and mass transfer in the context of triple convection, specifically concentrating on weakly non-linear stability analysis. This research aims to further our understanding of the natural Rayleigh-Bernard convection and its associated phenomena. The layers of Newtonian fluid were subjected to heating, salting, and saturation from the lower region, resulting in a higher temperature and concentration at the bottom plate compared to the top plate. The present research used the assumption that the acceleration owing to gravity exhibits time-dependence, consisting of a component representing constant gravity and a component representing gravitational oscillation that varies with time. Furthermore, the minuscule nature of the amplitude of the modified gravitational field was taken into consideration. The present study examines the scenario in which a fluid layer is extended endlessly in the x-direction and confined between two parallel plates located at z=0 and z=d. The use of the asymptotic expansion method was employed in order to get the solution of the Ginzburg-Landau differential equation, which consists of a system of non-autonomous partial differential equations. This task was accomplished by using the program MATHEMATICA 12. The initial time does not show any significant impact on the Nusselt number (Nu), Sherwood number for solute 1 (Sh1), and Sherwood number for solute 2 (Sh2) in relation to heat-transfer rates when the amplitude of modulation, Lewis number, Rayleigh number, and frequency of modulation are decreased. The

Rayleigh number, which is of utmost importance, exhibits an increase in magnitude when a third diffusive component is included. The inclusion of the third diffusive component is crucial in effectively prolonging the initiation of convection.

Kaur, Jeevanpreet& Gupta, Urvashi (2022) In this study, the Darcy–Brinkman model is used as an alternative to the Darcy model to examine the linear and nonlinear analysis of thermal convection in porous media that are saturated by Oldroyd-B nanofluids. The use of the two-phase model is employed in the context of a nanofluid, which is based on the theory of the relative velocity between nanoparticles and the fluid. The Galerkin method and normal mode approach were used to generate analytical formulations for the thermal Rayleigh numbers in both oscillatory and stationary states. These formulas were used to investigate the effects of viscoelastic and other non-dimensional characteristics on the stability of the system. Nonlinear analysis is conducted by using a minimum double Fourier series characterized by a weekly periodicity. The study of heat and mass transfer involves the representation of both time-dependent and independent fluctuations of the Nusselt number and Sherwood number for developing factors. The paper's originality stems from the presence of viscoelastic properties in the fluid, which allows for the emergence of an oscillatory mode of convection. This mode is seen only in nanofluids with a top-heavy nanoparticle arrangement, since it is not often observed in nanofluids with Newtonian base fluids. The findings of the mathematical model indicate that heat and mass transmission are augmented when the viscoelastic parameters, namely the stress relaxation and strain retardation numbers, are increased. The stability is significantly influenced by the growing Darcy number, as it hinders the rate of heat and mass transmission. The graphical representations demonstrate that viscoelastic non-Newtonian nanofluids exhibit superior rates of heat and mass transmission compared to Newtonian nanofluids inside the examined system.

Pranesh, Subbarama& Saha, Richa (2022) The objective of this study is to investigate the influence of vertical oscillations, also known as gravity modulation, on triple-diffusive convection in a viscoelastic fluid. The Oldroyd-B model is used to analyze this phenomenon, considering the existence of cross effects. Despite their tiny magnitudes, cross effects may have a considerable influence on three-component convective systems. When the equations controlling heat and species movement include cross factors that account for the linked molecular cross-diffusion of the mixture components, an alteration from the typical three-component convection process becomes apparent. A solution has been derived via the use of both linear and nonlinear analysis techniques. The criteria for the initiation of convection have been derived via the use of linear analysis, which relies on the perturbation approach and the Venezian method. The Nusselt and Sherwood numbers, which measure the rates of heat and mass transfer in nonlinear analysis, are derived from the Lorenz model. The manipulation of parameter values has been seen to exert influence on the initiation of convection, as well as heat and mass movement.

Shankar, B.M. & Naveen, S. &Shivakumara, I. S. (2022) This study examines the stability of double-diffusive buoyant flow in a vertical layer of Darcy porous media, where the borders are maintained at distinct constant temperatures and solute concentrations. The stability of fluid flow is assessed by examining the temporal development of normal mode disturbances superimposed upon the basic condition. The efficacy of Gill's analysis in establishing the stability of fluid flow is deemed inadequate, necessitating the use of numerical techniques such as the Chebyshev collocation method to address the eigenvalue issue. The closed nature of the neutral stability curves is seen, whereby the zone of instability extends as the solute/thermal Darcy-Rayleigh number and the Lewis number increase. The critical thermal/solute Darcy–Rayleigh number and its accompanying wave number are calculated for various values of the governing parameters. The stability of the flow is determined by the Lewis number, with the existence of a certain range of solute/thermal Darcy-Rayleigh numbers. Within this range, the flow stays stable, whereas beyond this range, the flow becomes unstable.

3. EFFECTS OF GRAVITY MODULATION ON DOUBLE DIFFUSIVE CONVECTION IN OLDROYD-B LIQUIDS

3.1 Mathematical Formulation

A horizontally positioned system consists of two walls that confine an infinitely thin layer of Oldroyd-B liquid. The spatial separation between the two entities is denoted as d. The two planes are located at the z-coordinate of zero and d, respectively. The two plates exhibit disparate thermal and compositional conditions. This phenomenon results in the formation of gradients in density and temperature, denoted as ΔT and ΔS, respectively. The density of the fluid exhibits a linear truncation with respect to the solute content, S, and temperature, T. The two limits exhibit a free-free condition. The system is shown in Figure 4.1.

The governing equations pertaining to the issue are presented herein.

Continuity Equation:

$$\nabla.\vec{q} = 0,$$

Conservation of momentum:

$$\rho_0\left(\frac{\partial \vec{q}}{\partial t}\right) = -\nabla p + \rho\vec{g}(t) + \nabla.\tau'$$

Rheological Equation:

$$\left(1+\lambda_1\frac{\partial}{\partial t}\right)\tau' = \left(1+\lambda_2\frac{\partial}{\partial t}\right)(\nabla\vec{q} + \nabla\vec{q}^{tr})$$

Conservation of Energy:

$$\frac{\partial T}{\partial t} + (\vec{q}.\nabla)T = k\nabla^2 T,$$

Conservation of Species:

$$\frac{\partial S}{\partial t} + (\vec{q}.\nabla)S = k_s\nabla^2 S,$$

Equation of State:

$$\rho = \rho_0\big(1-\alpha_t(T_b - T_0) + \alpha_s(S_b - S_0)\big),$$

The variation of gravity with time is given by

$$\vec{g}(t) = -g_0(1+\varepsilon cos\Omega t)\vec{k}$$

3.2 Basic State

In its initial condition, the liquid is in a state of rest. Therefore, $\vec{q} = \vec{q}(b) = 0, p = p_b(z), \rho = \rho_b(z), S = S_b(z), T = T_b(z)$

The pressure, pb, temperature, Tb, and density ρb satisfy

$$\frac{dp}{dz} + \rho g(1+\varepsilon cos\Omega t) = 0$$

$$\frac{\partial \mathrm{T}_b}{\partial t} = k\frac{\partial^2 \mathrm{T}_b}{\partial z^2},$$

3.3 Heat and Mass Transport

The assessment of heat transmission inside a fluid layer has significance in the context of convection-related issues. Once convection starts, the variations in Rayleigh number may be readily seen by the magnitude of heat transfer. In the condition of thermodynamic equilibrium, heat transfer mostly takes place via the process of conduction. If HT is the heat transfer rate per unit area

$H_T = -\chi\langle\frac{\partial T_{total}}{\partial z}\rangle_{z=0}$

The bracket represents horizontal average and $T_{total} = \left[T_0 - \frac{\Delta T}{d}z\right] + zT(x,z,t)$

The first term on the right-hand side represents the temperature distribution in the conduction state. The subsequent word represents the spatial distribution of temperature in the convection regime.

The rate of heat transmission is determined by $Nu = \frac{H_T}{k\Delta T/d}$

In a similar vein, the solute Nusselt number (also known as the Sherwood number) is used to quantify the rate of mass movement. $Nu_s = \frac{H_S}{k_s \Delta S/d}$

The definition of these entities may also be expressed in terms of dimensionless quantities.

$$Nu = \frac{\left[\frac{k_c}{2\pi}\int_0^{2\pi/k_c}(1 - z + T)_z dx\right]}{\left[\frac{k_c}{2\pi}\int_0^{2\pi/k_c}(1 - z)_z dx\right]}$$

The quantification of mass transfer follows a similar approach, whereby the Sherwood number is used as a metric.

$$Sh = \frac{\left[\frac{k_c}{2\pi}\int_0^{2\pi/k_c}(1 - z + S)_z dx\right]}{\left[\frac{k_c}{2\pi}\int_0^{2\pi/k_c}(1 - z)_z dx\right]}$$

The mean Nusselt and mean Sherwood numbers may be determined by evaluating the following integrals.

$$\bar{N}u(t) = \frac{\omega}{2\pi}\int_0^{2\pi/\omega} Nu(t)dt \; and \; \bar{S}h(t) = \frac{\omega}{2\pi}\int_0^{2\pi/\omega} Sh(t)dt$$

4. RESULTS

The issue at hand pertains to the examination of the impacts of gravity modulation on the convection of two components inside Oldroyd-B liquids. The linear problem is solved using the approach proposed by Venezian in 1969. The factors that primarily influence the transport of heat and mass are denoted as Le, Ra, Rs, Pr, Λ1, Λ2, and ω. The variables Le, Ra, Rs, Pr, Λ1, and Λ2 represent fluid parameters, whereas ω represents an external factor that influences convection. The thermal modulation amplitude, denoted as ε, is of a diminutive magnitude. The outcomes are mostly contingent upon the modulation frequency, denoted as ω. If the numerical value of this parameter is less than one, it indicates that the modulation period is quite long. This phenomenon leads to the amplification of disturbances, resulting in the increased significance of finite amplitude effects. When the angular frequency approaches infinity, the impact of modulation on Ra2c tends to be negligible. Therefore, the research considers moderate values of ω. This paper examines the impact of various viscoelastic factors on the value of Ra2c. The paper also addresses the impact of modulation on the transport phenomena of heat and mass. This is accomplished using a condensed depiction of Fourier series.

Table 1: Values of correction Rayleigh number, Ra2c, Nusselt number, Nu, and Sherwood number, Sh, for Le = 100, Pr = 10, Rs = 20, ω=10, ε=0.1.

Newtonianf luid Λ1= Λ2	Λ1	0.1	0.5	0.8
	Ra2c	660.67	655.31	619.21
	Nu	1.8532	1.9815	2.0035
	Sh	2.1091	2.1206	2.8972
Maxwellflui	Λ1	0.1	0.5	0.8

d Λ_2=0	*Ra2c*	182.1	190.34	166.36
	Nu	2.7321	2.6591	2.5531
	Sh	3.0182	3.5655	3.7293
Oldroyd-Bfluid $\Lambda_1 \neq \Lambda_2$	Λ_1	0.1	0.1	0.1
	Λ_2	0.05	0.08	0.09
	Ra2c	203.56	221.98	199.65
	Nu	2.2781	2.381	2.3101
	Sh	2.7619	2.9942	3.5567

We conclude that

1. $Ra_{2c}^{Maxwell\ fluid} < Ra_{2c}^{Oldroyd-B\ fluid} < Ra_{2c}^{Newtonian\ fluid}$,

2. $Nu^{Maxwell\ fluid} > Nu^{Oldroyd-B\ fluid} > Nu^{Newtonian\ fluid}$,

3. $Sh^{Maxwell\ fluid} > Sh^{Oldroyd-B\ fluid} > Sh^{Newtonian\ fluid}$.

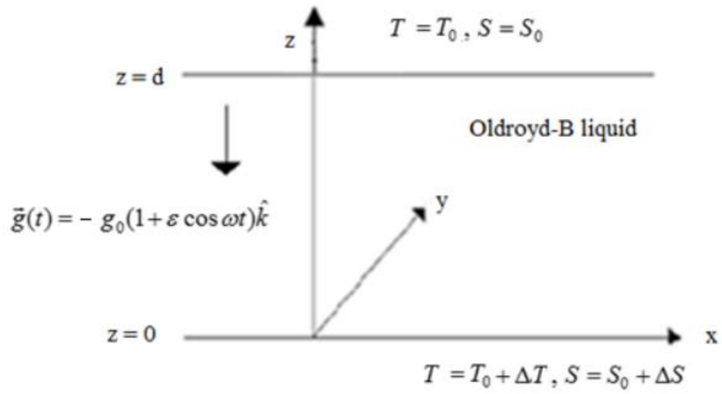

Fig 1 physical configuration

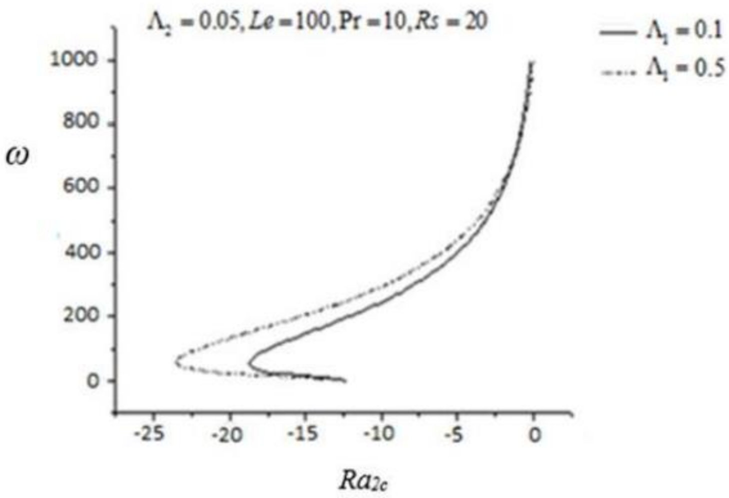

Fig 2 plot of Ra2c versus ω for different values of Λ_1.

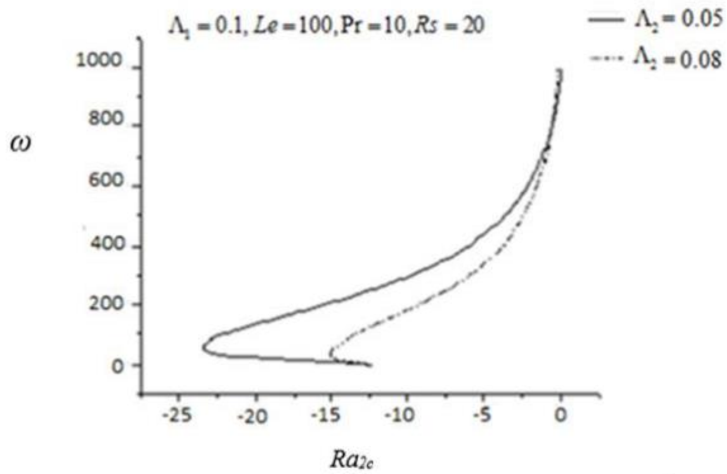

Fig 3 plot of Ra2c versus ω for different values of Λ_2.

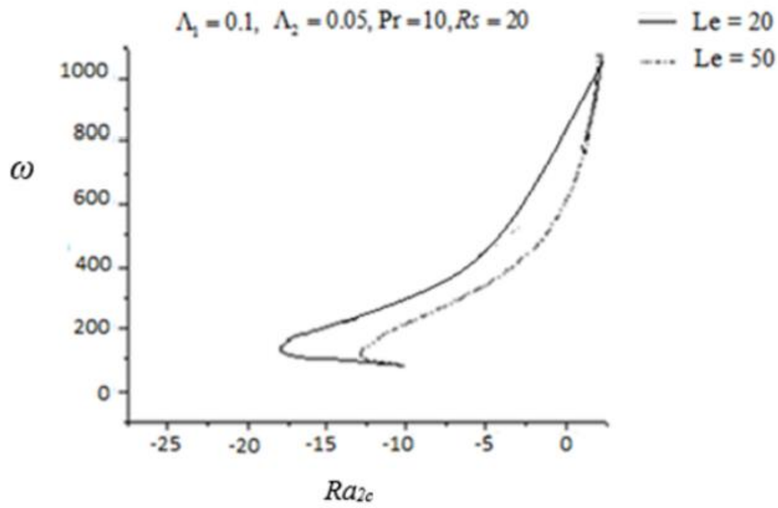

Fig 4 plot of Ra2c versus ω for different values of Le

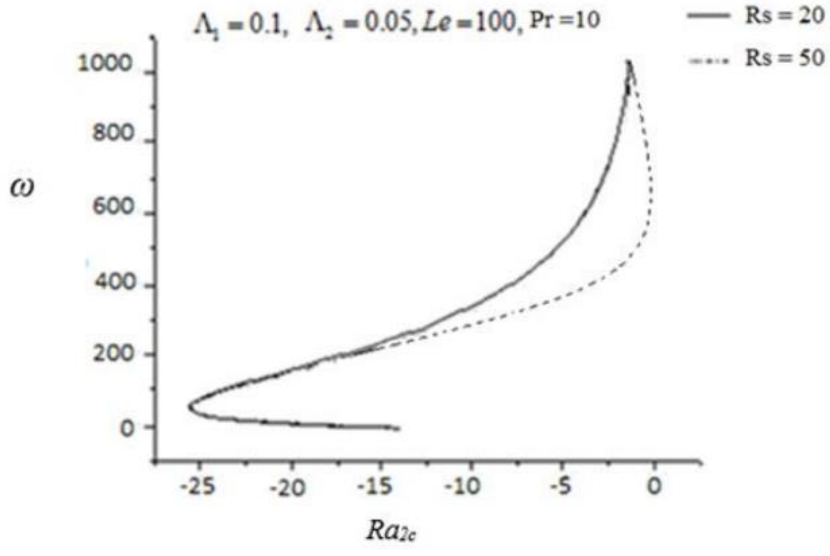

Fig 5 plot of Ra2c versus ω for different values of Rs

5. CONCLUSION

The findings derived in this thesis align with the principles of thermodynamics governing the system. This suggests that the expressions of the several parameters under consideration are accurate. The values obtained for the critical Rayleigh number, as well as the mean Sherwood and Nusselt numbers, are regarded as the most accurate estimations available. The stationary form of convection is considered more favorable compared to the oscillatory mode of convection. The stationary form of convection is preferable, especially when modulation is present. The critical Rayleigh number is seen to grow in the event of synchronous temperature modulation due to the influence of Lewis number and solutal Rayleigh number.

REFERENCES

1. P a, Akhila & Mallikarjun B, Patil & Kiran, Palle. (2023). Nonlinear double diffusive convection in bi-viscous Bingham fluid layer under gravity modulation. 10.22541/au.169045968.85667456/v1.
2. Singh, Pervinder& Gupta, Dr. Vinod &Animasaun, Isaac & Muhammad, Taseer & Al-Mdallal, Qasem. (2023). Dynamics of Newtonian Liquids with Distinct Concentrations Due to Time-Varying Gravitational Acceleration and Triple Diffusive Convection: Weakly Non-Linear Stability of Heat and Mass Transfer. Mathematics. 11. 2907. 10.3390/math11132907.
3. Kaur, Jeevanpreet& Gupta, Urvashi & Sharma, Ram. (2022). Nonlinear stability analysis for the rheology of Oldroyd-B nanofluids embedded by Darcy–Brinkman porous media using a two-phase model. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. 095440892211416. 10.1177/09544089221141600.
4. Pranesh, Subbarama& Saha, Richa. (2022). Three-Component Convection in a Vertically Oscillating Oldroyd-B Fluid With Cross Effects. Microgravity Science and Technology. 34. 10.1007/s12217-022-09935-6.
5. Shankar, B.M. & Naveen, S. &Shivakumara, I. S.. (2022). Stability of Double-Diffusive Natural Convection in a Vertical Porous Layer. Transport in Porous Media. 141. 10.1007/s11242-021-01711-1.
6. Malashetty, M. & Hill, Antony & Swamy, Mahantesh. (2012). Double diffusive convection in a viscoelastic fluid-saturated porous layer using a thermal non-equilibrium model. Acta Mechanica. 223. 967-983. 10.1007/s00707-012-0616-1.
7. Nield, Donald & Kuznetsov, A.V.. (2011). The onset of double-diffusive convection in a nanofluid layer. International Journal of Heat and Fluid Flow. 32. 771-776. 10.1016/j.ijheatfluidflow.2011.03.010.
8. Malashetty, M. & Biradar, Bharati. (2011). The onset of double diffusive convection in a binary Maxwell fluid saturated porous layer with cross-diffusion effects. Physics of Fluids - PHYS FLUIDS. 23. 10.1063/1.3601482.
9. Bhadauria, B.. (2011). Double-Diffusive Convection in a Saturated Anisotropic Porous Layer with Internal Heat Source. Transport in Porous Media. 92. 10.1007/s11242-011-9903-x.
10. Kumar, Anoj &Bhadauria, B.. (2011). Double diffusive convection in a porous layer saturated with viscoelastic fluid using a thermal non-equilibrium model. Physics of Fluids - PHYS FLUIDS. 23. 10.1063/1.3588836.
11.