Research article

Effect of maximum density and internal heating on the stability of rotating fluid saturated porous layer using LTNE model

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ABSTRACT

The impact of heat generated inside the porous layer containing a fluid and density maximum when the porous structure is studied analytically subjected to rotation for the case of unlike temperatures of both solid and fluid phases. Two equations each representing solid and fluid phases are used as energy equations. The linear stability theory is used and is based on normal mode technique. Galerkin method is used to find the Eigen values of the problem. The rotation of the porous layer provides extra strength to the system, protecting the structure from instability, however internal heat generation does not support the system in retaining its strength, causing the system to destabilize. Both the conductivity ratio and the density function have a negative impact on system stability. Consequently, the rotation parameter $T_o$ stabilizes the system, whereas internal heat generation, conductivity ratio, and density function destabilizes the onset of convection.

1. Introduction

Convective heat transfer is one of the most influenced and powerful mechanism. The study of convective heat transfer in a porous medium containing fluid has gained much attention in these days, because of its vital importance in extraction of energy from the surface of the earth. It is found that in most of the cases the source of heat is generated by taking itself which leads to setting up of convection by the generation of heat inside the layer. In most of natural and practical context in which convection is managed by internal heat sources. Hence the study of internal heat generation acquired much significance, because its applications include the storage of radioactive materials, geophysics and combustion.

Nield and Bejan [1] have introduced a model of energy which has two equations is called a two-fluid model. Rees [2, 3] in his paper studied through a porous medium when the solid and fluid phases have different temperatures. Govender and Vadasz [4] examined stability of anisotropic rotating, driven convection in the layer. The most important investigation on thermal stability in porous media is well documented by Banu and Rees [5] and Malashetty et al. [6, 7, 8, 9, 10]. Postelnicu [11] has been investigated the stability of convection by using Darcy-Brinkman model. Kuznetsov et al. [12] all have analyzed how the convection in nanofluid saturated in the permeable medium is affected when both fluid and solid phases have different temperature.

Yekasi et al. [13] has explored the characterization of heating inside on Rayleigh-Benard convection driven by suction-injection combination by considering free rigid boundary. Bhaduria et, al [14] investigated how the time periodic gravity modulation with inside heating on Rayleigh-Benard convection in vertically oscillating micro polar fluid. A detailed study on thermal non-equilibrium model has been carried out by Shivakumara et al. [15, 16, 17, 18, 19, 20, 21, 22]. Dhananjay Yadav et al. [23] examined the effect of inner heating and rotating layer using Darcy–Brinkman model and conclude that rotation inhibits the system. Sarvanan [24] has studied the nature of internal heat generation and maximum density function and

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shows that both the parameters enhance the stability of the system. Gaseer et al. [25] studied the effect interior heating for the onset of convection. Chavaraddi et al. [26] gave a conclusion that the couple stress, rotation and thermal anisotropy parameters are stabilizing the onset of convection in a saturated medium. Lotten and Rees [27] studied the anisotropy and heat generated inside in an inclined layer. Israel-Cookey and Omubo-Pepple [28] studied the stability in a low Prandtl number fluid with heating process inside the structure. Srivastava et al. [29] examined the onset of thermal magneto convection in an anisotropic loosely pack medium. Postelnicu [30] studied the effect of inertia on the onset of mixed convection in LTNE medium. Xu et al. [31] focuses on various flow and heat transfer modes of nanofluid, metal foam and the combination of the two, with the physical properties of nanofluid and metal foam summarized. Oumar et al. [32] have been studied the onset of Rayleigh-Benard electro-convection in a micro polar fluid with internally heating particles. A new fractal theoretical model with periodic pore morphology, which idealizes the pore channels of the porous media as gourd-shaped structure, is established to model the transport in complex porous media by Wu et al. [33]. Xu [34] investigated the theoretical study of the fully-developed forced convection heat transfer in a microchannel partially filled with a porous medium core is performed by considering the local thermal non-equilibrium (LTNE) effect between the solid and fluid phases. Anwar Ahmed Yousif et al. [35] investigated the impact of using triple adiabatic obstacles on natural convection inside porous cavity under non-Darcy flow and local thermal non-equilibrium model. Omar Rafea et al. [36, 37, 38] examined the simulation of complete liquid–vapor phase change process inside porous evaporator using local thermal non-equilibrium model.

In most of the situations it is observed that temperature fields of solid and fluid phase of the porous medium are assumed to be identical such a situation is generally known as local thermal equilibrium (LTE). However, in many practical situations involving porous material and also media in which there is a large temperature difference between the fluid and the solid phases, it has been realized that the assumption of LTE model is inadequate for proper understanding of the heat transfer problems. In such circumstances the local thermal non-equilibrium (LTNE) effects are to be taken into consideration in which case the single energy equation has to be replaced by two, one for each phase. The main objective of present paper is to study the effect of maximum density and internal heating on the stability of rotating fluid using LTNE model.

2. Mathematical model

In this paper, we consider a porous media of height ‘h’ which is extended horizontally between two free surfaces and the fluid is subjected to rotation. Let \( T_L \) and \( T_u \) be the temperatures at the lower and upper surfaces. The temperature gradient \( \nabla T = T_L - T_u \) is uniform and \( T_L > T_u \) maintained between the two surfaces. A momentum expression contains the time derivative term and two separate equations are used for temperature. This physical model is shown in Fig. 1.

\[ \nabla \cdot q = 0 \]  
\[ \frac{1}{\varepsilon} \frac{\partial q}{\partial t} + \nabla \times q - \frac{1}{\rho_0} \nabla p + \frac{\rho}{\rho_0} \frac{\partial}{\partial t} \left( \frac{\rho q}{\kappa} \right) \]  
\[ \varepsilon \left( \rho e_f \right) \frac{\partial T_f}{\partial t} + \left( \rho e_f \right) (q \cdot \nabla) T_f = \varepsilon k_f \nabla^2 T_f + h (T_L - T_f) + \varepsilon q_f \]  
\[ (1 - \varepsilon) \left( \rho e_f \right) \frac{\partial T_f}{\partial t} = (1 - \varepsilon) k_f \nabla^2 T_f - h (T_s - T_f) + (1 - \varepsilon) q_s \]  
\[ \rho = \rho_0 \left( 1 - \beta f (T_f - T_u) - \beta_s (T_f - T_u)^2 \right) \]  

To remove the pressure term from the momentum equation (2) and making equations (3) and (4) dimensionless by using eq. (5) and following transformations (6):

\[ (x, y, z) = d \left( x', y', z' \right) \quad (u, v, w) = \frac{e_k f}{\rho_0} \left( u', v', w' \right) \quad p = \frac{e_k f}{\rho_0} R_{p, D} \rho^* \]  
\[ T_f = (T_f - T_u) T_f + T_u \quad T_s = (T_s - T_u) T_s + T_u \quad t = \frac{e_k f}{k_f} R_{p, D} \rho^* \]  
\[ \frac{1}{R_{p, D}} \frac{\partial}{\partial t} \left( \nabla^2 w \right) + (T_f) \frac{\partial^2 w}{\partial z^2} = R_f \nabla^2 T_f + R_w \nabla^2 T_2 - \nabla^2 w - \frac{\partial^2 w}{\partial z^2} \]
\[ \frac{\partial T_f}{\partial t} + u \frac{\partial^2 T_f}{\partial z^2} = \nabla^2 T_f + \frac{\partial^2 T_f}{\partial z^2} + H (T_e - T_f) + Q_f \]  
\[ a \frac{\partial T_f}{\partial t} = \nabla^2 T_f + \frac{\partial^2 T_f}{\partial z^2} - \gamma H (T_e - T_f) + Q_s \]  
\[ R_A = \beta_1 \rho_0 b (\rho_t) f (T_e - T_a) K s f, \quad R_M = \beta_2 \rho_0 b (\rho_t) f (T_e - T_a)^2 K s f k_f \]  
Here Eq. (10) is the Rayleigh number corresponding to the properties of fluid phase. Here \( R_M \) serves as a measure of the density maximum and when to begin property.

\[ H = \kappa d^2 (1 - \epsilon) k_s, \]  
the non-dimensional interphase heat transfer coefficient
\[ T_a = 2 \Omega \rho_s K / \epsilon \mu, \]  
the Taylor number
\[ \gamma = \epsilon k_f / (1 - \epsilon) k_s, \]  
the conductivity ratio
\[ a = (\rho_t) k_f / (\rho_t) k_s, \]  
the diffusivity ratio
\[ Q_f = q_f / (T_e - T_a) k_f, \]  
the fluid phase internal heat generator parameter
\[ Q_s = d^2 q_s / (T_e - T_a) k_s \]  
the solid phase internal heat generator parameters

where Eqs. (11)-(13) are Taylor number, conductivity ratio and diffusivity ratio respectively.

2.1. Quiescent state

The basic state is assumed to be quiescent and is given by
\[ u = v = w = 0 \quad T_f = T_{f b}(z) \quad T_s = T_{s b}(z) \]  
The temperature of fluid phase and solid phase satisfies the equations
\[ \frac{d^2 T_{f b}}{dz^2} = -Q_f, \quad \frac{d^2 T_{s b}}{dz^2} = -Q_s \]  
with the boundary conditions \( T_{f b} = T_{s b} = 1 \) at \( z = 0 \) \( T_{f b} = T_{s b} = 0 \) at \( z = 1 \)

So that the steady state solutions are given by
\[ T_{f b} = -\frac{Q_f}{2} z^2 + \left( \frac{Q_f}{2} - 1 \right) z + 1, \quad T_{s b} = -\frac{Q_s}{2} z^2 + \left( \frac{Q_s}{2} - 1 \right) z + 1 \]  

2.2. Perturbed state

The basic state is perturbed and quantities in the perturbed state are given by
\[ (u, v, w) = (u', v', w'), \quad q = q', \quad T_f = T_{f b} + \theta, \quad T_s = T_{s b} + \varphi \]  
Substituting equation (21) into (7) to (9) and using equation (20) we obtained following linearized equations for perturbed quantities (after neglecting the primes)
\[ \frac{1}{\rho_{f b} \theta} \frac{\partial}{\partial t} \left( \nabla^2 \theta \right) + (T_{f b})^{1/2} \frac{\partial^2 w}{\partial z^2} = R_M \nabla^2 \theta + 2 R_M \left\{ -Q_f z^2 + \left( \frac{Q_f}{2} - 1 \right) z + 1 \right\} \nabla^2 \theta - \nabla^2 w - \frac{\partial^2 w}{\partial z^2} \]  
\[ \frac{\partial \theta}{\partial t} + w \left( -Q_f z + \frac{Q_f}{2} - 1 \right) = \nabla^2 \theta + \frac{\partial \theta}{\partial z^2} + H (\varphi - \theta) \]  
\[ a \frac{\partial \varphi}{\partial t} = \nabla^2 \varphi + \frac{\partial^2 \varphi}{\partial z^2} - H (\varphi - \theta) \]  
Since the fluid and solid phases are not in thermal equilibrium, the use of appropriate thermal boundary condition may pose a difficulty. However, the assumption that the solid and fluid phases have equal temperatures at the boundary surfaces made at the beginning of this section helps in overcoming this difficulty. Accordingly, equations (22) to (24) are solved impermeable isothermal boundaries. Hence the boundary conditions are
\[ \omega = \frac{\partial \omega}{\partial z} = \theta = \varphi = 0 \text{ at } z = 0, 1 \]
2.3. Linear stability analysis

To study the linear stability theory, we use the linearized version of equations (22) to (24). The principle of exchange of stabilities holds in the presence of isotropy and non-LTE effects (there is only one destabilizing agency) so that the onset of convection is stationary (i.e., $\omega = 0$). We seek the solutions to the linearized equations in the form

$$[\omega - (a^2 - D^2) - (Ta)^{1/2} D^2 + (a^2 - D^2)] W - $$$$\left[R_A + 2R_M \left\{ - \frac{Q_f}{2} z^2 + \left( \frac{Q_f}{2} - 1 \right) z + 1 \right\} \right] \phi = 0$$

$$\left(-Q_f z + \frac{Q_f}{2} + 1\right) W + (\omega + a^2 + H - D^2) \Theta - H \Phi = 0$$

$$\gamma H \Theta + (\omega + a^2 + \gamma H - D^2) \Phi = 0$$

The eigenvalue problem associated with the equations (27)–(29) in a horizontal fluid layer bounded by two rigid walls, governing the stability of the basic motion against normal mode perturbations, deduced has the form. We use Galerkin’s technique to solve the Eigen value problem. In the Galerkin approach used here the basis (trial) functions satisfy the boundary conditions. In this case, the simplest choice seems to be write $W$, $\phi$ and $\Theta$ as

$$W_i = z^i(1 - z)^2, \quad \Theta = \Phi = z(1 - z)$$

With this choice (30), the unknown functions $W$, $\phi$ and $\Theta$ satisfy the boundary conditions (25) and integrating the equations, so obtained over the layer from 0 to 1, we get

$$\left[\frac{a^2}{66} + \left(\frac{(Ta)^{1/2}}{2} + 1\right) \frac{2}{9} \right] A_1 - \left[R_A + 2R_M \left\{ - \frac{Q_f}{2} + 14 \frac{14}{36} \right\} \right] \frac{a^2}{6} B_1 = 0$$

$$\left(18 - Q_f\right) A_1 - 168(a^2 + H + 10)B_1 + 168HC_1 = 0$$

$$-\gamma H B_1 + (a^2 + \gamma H + 10)C_1 = 0$$

Now to solve $R_A$ the above equations (31)–(33) can be put in the form of the following matrix, we get

$$\begin{bmatrix} \frac{a^2}{66} + \left(\frac{(Ta)^{1/2}}{2} + 1\right) \frac{2}{9} & - \left(R_A + 2R_M \left\{ - \frac{Q_f}{2} z^2 + \left( \frac{Q_f}{2} - 1 \right) z + 1 \right\} \right) \frac{a^2}{6} & 0 \\ 18 + Q_f & -168(a^2 + H + 10) & 168H \\ 0 & -\gamma H & a^2 + \gamma H + 10 \end{bmatrix} \begin{bmatrix} A_1 \\ B_1 \\ C_1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

By setting the determinant of the coefficient matrix (34) to zero, we get

$$R_A = \frac{448(a^2 + 10)}{a^2(18 + Q_f)} \left[ \frac{a^2}{66} + \left(\frac{(Ta)^{1/2}}{2} + 1\right) \frac{2}{9} \left[ 1 + \frac{H}{a^2 + \gamma H + 10} \right] - \frac{2}{9} R_M(Q_f + 14) \right]$$

3. Result analysis

The impact of internal heating and density maximum in a rotating Darcy-Brinkman porous medium of convection has been investigated using Galerkin method. This study is concentrated to steady state of convection because oscillatory mode seems to be highly implausible. Rayleigh number Eq. (35) is used to determine the stability of the system. If the Rayleigh number is below or above the critical value then the flow is laminar or turbulent. Figs. 2(a) to 2(e) shows that the marginal curves are connected in topological sense and thus the linear stability is calculated in terms of critical Rayleigh number. The system is stable below this critical Rayleigh number and unstable above this number. Figs. 2(a) and 2(e) show the graph of neutral curves for different values of Ta, $N$, $Q_f$, $R_M$, and $\gamma$. We observe that there is no change in the topological connectedness of the curves which shows the neutral nature of these curves. Figs. 3(a) to 3(c) exhibit the effect of $N$ against critical Rayleigh number $R_A$ for distinct values of $\gamma$, Ta and $Q_f$. Figs. 3(a) and 3(c) discloses that $R_A$ is decreasing with increase in $\gamma$, and $Q_f$, as $N$ represents the transfer of heat between the fluid and solid phases. If $N$ is very small indicates that there is almost zero transfer of heat between the two phases on the other hand if $N$ is very large indicates there is a rigorous transfer of heat between the two phases. The behavior of the critical Rayleigh number points out that the effect of conductivity ratio and internal heat generator of fluid phase is to destabilize the onset of convection. This is because when the conductivity ratio increases the fluid part of the medium gains more heat from the solid phase which leads to begin the convection sooner and thereby, the critical Rayleigh number decreases. When the critical Rayleigh number decreases it implies that the system is coming closer to destabilized mode. The same effect is observed for the case of internal heat generation which is shown in Fig. 3(b). The increase in the internal heat generation causes the fluid phase to acquire more heat and thus convection starts early. It is also noted that $R_A$ is independent of $\gamma$ when heat transfer is very less and independent of $N$ when $\gamma$ is very large ($\geq 10$). Fig. 3(b) shows the effect of Ta versus $N$ on Critical Rayleigh number. It is found that when rotation increases, the values of $R_A$ rise, demonstrating that rotation of fluid has the impact of improving the system’s stability. The reason is as the rotation of the porous layer increases there is a slow distribution of heat in the porous layer and fluid particles get heated slowly thus there is a delay in onset of convection which shows that the system is in stable condition.
Figs. 4(a) and 4(b) display the variation of \(a\) against \(N\) for distinct values of \(\gamma\) and \(Ta\). In Fig. 4(a) it is detected that, for small and large value of \(N\), the critical wave number is not depending on the values of \(\gamma\). But for intermediate values the critical wave number increase with decrease in \(\gamma\) and attains a maximum. Fig. 4(b) the critical wave number curves increase with increase in \(Ta\), signifying that the impact of \(Ta\) is to improve the system stability.

Figs. 5(a) to 5(d) demonstrate the variation of \(R_A\) against \(Q_f\) for various values of \(\gamma\), \(Ta\), \(N\) and \(R_M\). In Fig. 5(a) the effect of \(\gamma\) on \(R_A\) is displayed. It is found that \(R_A\) decreases with increase in \(\gamma\), which shows that the conductivity ratio \(\gamma\) destabilizes the system. In Fig. 5(b) the effect of \(Ta\) on the \(R_A\) is revealed. It is detected that the \(R_A\) increases with increase in \(Ta\), representing that the Taylor number has stabilizing effect. In Fig. 5(c) appear that the effect of \(Q_f\) on \(R_A\) is presented for various values of \(N\). It is noted that the growing values in \(Q_f\), the values of \(R_A\) decline and become zero at some finite value of \(Q_f\). This shows that the \(Q_f\) quickens the onset of convection and thus the effect of \(Q_f\) causes the instability of the system. In Fig. 5(d) depicted that the \(R_A\) decreases as the \(R_M\) increases, which indicating that the system turns into unstable mode due to effect of density function.

The comparison presented in Figs. 6(a) and 6(b) is the critical Rayleigh number graphs of present study with the case of Darcy–Benard convection (see Banu and Rees [5]).

Figs. 6(a) and 6(b) are very good comparison of critical Rayleigh numbers with the case Darcy-Benard convection studied by Banu and Rees [5].
Fig. 3. Variation of $R_A$ against $H$ for different values of $\gamma$. (b): Variation of $R_A$ against $H$ for different values of $T_a$. (c): Variation of $R_A$ against $H$ for different values of $Q_f$.

Fig. 4. (a): Variation of ‘a’ against ‘H’ for different values of $\gamma$. (b): Variation of ‘a’ against ‘H’ for different values of $T_a$.

The comparison of critical wavenumber graphs of present study with Darcy–Benard convection done by Banu and Rees [5] is given in Figs. 6(c) and 6(d).

The critical wavenumbers in Figs. 6(c) and 6(d) show the good comparison with the work done by Banu and Rees [5]. Also, the results obtained are presented in Tables 1 and 2, shows a favorable agreement of present work with the results of Banu and Rees [5] in the absence of rotation, internal heat generation and maximum density function thus give confidence that the numerical results obtained are accurate.

4. Conclusion

The stability of a fluid saturated rotating porous layer with internal heat generation and density maximum is studied when both fluid and solid phases have different temperatures. Galerkin method is used to find the Eigen values of the problem. The effect of internal heat generation, rotation and conductivity ratio is determined and demonstrated graphically. The following conclusions have been drawn point by point:
Fig. 5. (a): Plots of $R_A$ versus $Q_f$ for different values of $\gamma$. (b): Plots of $R_A$ versus $Q_f$ for different values of $T_a$. (c): Plots of $R_A$ versus $Q_f$ for different values of $H$. (d): Plots of $R_A$ versus $Q_f$ for different values of $R_M$.

Table 1. Comparison of the critical Rayleigh number of present study with the case of Darcy–Benard convection done by Banu and Rees [5] in the absence of rotation, internal heat generation and maximum density function.

| $H$   | Critical Rayleigh number obtained for the case of present study | Critical Rayleigh number obtained by Banu and Rees [5] |
|-------|---------------------------------------------------------------|-----------------------------------------------------|
|       | $\gamma = 0.1$ | $\gamma = 0.3$ | $\gamma = 0.5$ | $\gamma = 1$ | $\gamma = 0.1$ | $\gamma = 0.3$ | $\gamma = 0.5$ | $\gamma = 1$ |
| -2    | 39.50864        | 39.50863        | 39.50863        | 39.50863        | 39.50871        | 39.50870        | 39.50870         | 39.50870         |
| -1    | 39.69856        | 39.69833        | 39.69755        | 39.69835        | 39.68835        | 39.68815        | 39.68795         | 39.68745         |
| 0     | 41.56690        | 41.54569        | 41.52491        | 41.47464        | 41.45493        | 41.43599        | 41.41741         | 41.37239         |
| 1     | 58.14440        | 56.70393        | 55.43970        | 52.90179        | 57.06386        | 55.79444        | 54.66823         | 52.37010         |
| 2     | 163.2115        | 118.4482        | 96.35335        | 72.67197        | 156.4227        | 116.2631        | 95.3384         | 72.35688         |
| 3     | 370.3745        | 163.3230        | 115.6035        | 78.24936        | 366.9394        | 162.8960        | 115.4474        | 78.21098         |
| 4     | 427.0948        | 170.2972        | 118.1683        | 78.90134        | 426.6959        | 170.2506        | 118.1551        | 78.97663         |
| 5     | 433.6257        | 171.0306        | 118.4596        | 78.97430        | 433.5968        | 171.0312        | 118.4350        | 78.96963         |
| 6     | 434.2889        | 171.1044        | 118.4536        | 78.97430        | 434.2979        | 171.1091        | 118.4630        | 78.97663         |
| 7     | 434.3553        | 171.1118        | 118.4623        | 78.97497        | 434.3680        | 171.1169        | 118.4658        | 78.97733         |
| 8     | 434.3620        | 171.1125        | 118.4625        | 78.97503        | 434.3750        | 171.1176        | 118.4661        | 78.97740         |
| 9     | 434.3627        | 171.1126        | 118.4626        | 78.97504        | 434.3757        | 171.1177        | 118.4661        | 78.97741         |
| 10    | 434.3627        | 171.1126        | 118.4626        | 78.97504        | 434.3758        | 171.1177        | 118.4661        | 78.97741         |

- The rotation of the porous layer if offering extra strength to the system thereby protecting the structure from instability, whereas the internal heat generation does not support the system in maintaining its strength and thus takes the system from a safe zone to a dangerous zone of destabilization.
- The conductivity ratio and density function also have a negative effect on the system stability i.e., both factors oppose the system stability and conductivity ratio is to advance the onset of convection.
- The effect of rotation of porous layer modified conductivity ratio is to enhance the heat transport.
- The overall conclusion is that the rotation parameter $T_a$ stabilizes the system whereas the internal heat generation, conductivity ratio, and density function are having a destabilizing effect on the onset of convection.
Fig. 6. (a): Variation of $R_a$ v/s $H$ for specific values of $\gamma$ in present study. (b): Variation of $R_a$ v/s $H$ for different values of $\gamma$ in DAS Rees et al. result. (c): Variation of $a_c$ v/s $H$ for different value of $\gamma$ in present study. (d): Variation of $a_c$ v/s $H$ for different value of $\gamma$ in Rees et al. result.

Table 2. Comparison of the critical wavenumber of present study with Darcy–Benard convection done by Banu and Rees [5] in the absence of rotation, internal heat generation and maximum density function.

| $H$  | Present study | Banu and Rees [5] |
|------|---------------|--------------------|
|      | $\gamma = 0.1$ | $\gamma = 0.1$     | $\gamma = 0.3$ | $\gamma = 0.3$ | $\gamma = 0.5$ | $\gamma = 0.5$ | $\gamma = 1$ | $\gamma = 1$ |
| -2   | 3.13958       | 3.13958            | 3.13958 | 3.13958       | 3.14643 | 3.14643 | 3.14643 | 3.14643 |
| -1   | 3.14804       | 3.14804            | 3.14804 | 3.14804       | 3.14643 | 3.14643 | 3.14643 | 3.14643 |
| 0    | 3.14804       | 3.20662            | 3.20662 | 3.19832       | 3.21714 | 3.21714 | 3.21714 | 3.20936 |
| 1    | 3.14804       | 3.57378            | 3.50662 | 3.39936       | 3.69459 | 3.61939 | 3.55668 | 3.43511 |
| 2    | 3.14804       | 3.61783            | 3.40714 | 3.24778       | 4.61519 | 3.72156 | 3.46410 | 3.27109 |
| 3    | 3.14804       | 3.19832            | 3.17329 | 3.14804       | 3.42783 | 3.21714 | 3.18591 | 3.15436 |
| 4    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.17017 | 3.14643 | 3.14643 | 3.14643 |
| 5    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.14643 | 3.14643 | 3.13847 | 3.13847 |
| 6    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.13847 | 3.13847 | 3.13847 | 3.13847 |
| 7    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.13847 | 3.13847 | 3.13847 | 3.13847 |
| 8    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.13847 | 3.13847 | 3.13847 | 3.13847 |
| 9    | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.13847 | 3.13847 | 3.13847 | 3.13847 |
| 10   | 3.14804       | 3.13958            | 3.13958 | 3.13958       | 3.13847 | 3.13847 | 3.13847 | 3.13847 |

Declarations

Author contribution statement

N.K. Enagi and Sridhar Kulkarni: Conceived and designed the experiments; Wrote the paper.
Krishna B. Chavaraddi and G.K. Ramesh: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
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Declaration of interests statement

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Additional information

No additional information is available for this paper.

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