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Thermomechanical interactions in nonlocal isotropic homogeneous diffusive solid

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Abstract. This study deals with a nonlocal isotropic thermoelastic solid with diffusion. Mathematical formulation of the problem has been prepared subjected to GN theory of type III. Laplace transform and Fourier transform have been used to solve the problem. The considered solid is under influence of thermomechanical sources. Numerical inversion techniques have been used to find the solution in physical domain. Effect of nonlocal parameter has been depicted on various field variables. Some particular cases have also been considered to validate the results. This research highlights the significant role of nonlocal parameters in understanding the thermomechanical interactions for future developments in material science and engineering.

Keywords: diffusion; fourier transformation; laplace transformation; nonlocal; thermoelastic; stress

1. Introduction

Nonlocal continuum field theories go with the physics of material bodies having properties of material that are influenced by the body's state at all places. According to classical conceptions, material points of a body are considered continuous and assigned specific physically independent objects. Nonlocal theory generalizes classical field theory in two ways. i.e. the energy balancing law is accepted globally (for the entire body) and the response functionals explain the behaviour of the body at a given point in time [1]. In the field of mechanics, how materials respond to various influences such as mechanical forces and heat in relation to their immediate environment rather than considering broader implications across the material as a whole has been examined [2]. However, when materials are reduced in scale or encounter scenarios, like changes or developing microstructures, local theories may fall short in providing a comprehensive understanding of the situation.

Nonlocal effects, which reveal to be a crucial subject in the field of material science when considering material behaviours at the small scale, nanostructures, or complex systems under several physical phenomena has been studied [3]. Ccomplex potentials were used to conceive and solved the fracture issue in all three classical modes [4].

The transient responses in a magneto-thermoelastic medium within the framework of the Lord–Shulman theory, considering a perfectly conducting material was examined [5]. A two-dimensional

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analysis of a generalized thermoelastic diffusion medium incorporating both thermal and diffusion relaxation times was carried out within the framework of the Lord–Shulman theory [6]. The thermal and mechanical interactions in media and examined phenomena such as wave propagation and material behaviour was studied [7]. A mathematical formulation for a two-temperature generalized thermoelastic model incorporating dual relaxation times in an infinite fiber-reinforced anisotropic plate with a circular cavity developed [8].

Thermoelastic interactions in an unbounded fiber-reinforced anisotropic medium containing a cylindrical cavity and using the three-phase-lag thermoelastic theory alongside the Green–Naghdi type III model to evaluate the resulting thermo physical fields has been studied [9]. The transient behavior in a magneto-thermoelastic medium using the generalized thermoelasticity (GL) model with variable thermal conductivity investigated [10].

The two thermoelasticity theories of temperature based on fractional derivative heat transfer and the non dimensional coupled equations with Laplace transform techniques on a half-space subjected to arbitrary time-dependent heating together with free traction has been evaluated [11]. The fundamental equations and governing equation for the theory of micropolar bodies with voids studied [12]. The dynamic response of multi-body elastic systems by the finite element method combined with Lagrange's equations was evaluated [13]. The fundamental theorems in the thermo elastodynamic behavior of microstretch bodies has been investigated [14].

Memory-dependent derivatives (MDD) in a two-dimensional transversely isotropic homogeneous magneto-thermoelastic medium with two temperatures has been derived [15]. The transport of molecules (substance) from high to low concentration is called diffusion. However, Fick's law describes only mass transfer flux with respect to the concentration gradient without explaining the interaction between substances [16].

The nonlocal thermoelastic and phase-lag effects in a modified couple stress thermoelastic (MCT) half-space by considering thermomechanical load was derived [17]. They solved the governing equations using Laplace and Fourier transform techniques. A mathematical model for the nonlocal theory of thermoelastic diffusive materials was developed by incorporating nonlocal heat and mass transport effects based on the Lord–Shulman model. They studied the fluctuation of temperature, stress, displacement, concentration, and chemical potential with nonlocal parameters. They concluded that the material subjected to periodic shock stress exhibits size-dependent constitutive relations [18].

A mathematical model for generalized thermoelastic media with diffusion by considering four lags and incorporating higher-order time-fractional derivatives [19]. A mathematical equation to describe the transient thermodiffusion behavior of a half-space, accounting for variable thermal conductivity and diffusivity has been developed [20]. The surface of this half-space is characterized by zero traction and experiences a time-dependent thermal shock. However, the chemical potentials are already known as a function of time.

The electro-magnetohydrodynamic flow of a hybrid non-Newtonian, electrically conducting and incompressible nanofluid containing nanoparticles moving between two vertical parallel plates was studied [21]. Using a perturbation technique, they found that heat transfer is enhanced in the combination of gold and magnesium oxide nanoparticles.

Functionally graded materials (FGMs), a class of advanced composites characterized by a gradual variation of material properties in a specific direction. Through the combination of different constituent materials, their mechanical and thermal properties such as elasticity, density, thermal conductivity and thermal expansion was studied [22]. A sphere is influenced by electric displacement, elastic deformation, electric potential, magneto-thermoelastic effects and hygrothermal conditions [23].

Investigation of interfacial stresses in a simply supported concrete cantilever beam bonded with a composite plate has been analysed. The analysis incorporates adherend shear deformations by assuming a linear distribution of shear stress across the adherend thickness, which serves as one of the key strengths of the proposed model [24]. The axisymmetric deformation in a Cartesian coordinate system of a nonlocal homogeneous isotropic thick circular plate without energy dissipation by considering two-temperature parameters has been studied [25].

The coupled equations that characterize the pore evolution together with the basic equations describing the elastic deformations of a Cosserat body was analysed. The coupling was achieved using predetermined coefficients. Quantum mechanics, which forms the basis of quantum computing, explains how particles behave at microscopic scales. In contrast to classical physics, which follows deterministic principles, quantum mechanics introduces the concept of probabilistic behavior [26], The deformation of transversely isotropic thermoelastic media with diffusion and found the integrated effect of diffusion and thermal load on transversely isotropic thermoelastic media under an inclined load was studies [27]. The deformation of a homogeneous isotropic thick circular nonlocal thermoelastic plate by varying the angular frequency domain without energy dissipation was investigated [28].

The influence of viscosity on a micropolar thermoelastic solid using the multi-phase-lag model incorporating Eringen's nonlocal thermoelasticity theory was analyzed. They graphical representations of the physical fields for the nonlocal micropolar thermoelastic solid and examined the variations in the presence and absence of viscosity, as well as the effects of the gravity field for different values of the nonlocal parameter was also analized [29]. A higher-order, size-sensitive thermoelastic heat conduction framework that accounts for both spatial and temporal nonlocal interactions within a micropolar visco-thermoelastic medium exposed to a pulsed laser heat source was studied [30].

In the studies mentioned above, nonlocal thermoelastic problems have been investigated extensively. However, the present research focuses on thermomechanical interaction in a nonlocal isotropic thermoelastic medium with diffusion analyzing the combined effects of thermal and mechanical phenomena together with diffusion under concentrated, linearly distributed, and uniformly distributed loads. Specifically, this study examines the influence of varying nonlocal parameters on the behaviour of thermoelastic materials and employs Laplace and Fourier transformation techniques to solve the governing equations.

2. Basic equations

Following [3], the stress tensor at any arbitrary point $x(1)$ within a nanomaterial body is influenced not only by the local stress at that point but also by the stresses throughout the entire body. For a homogeneous and isotropic elastic material without body forces, the nonlocal stress tensor σ_{ij} can be expressed as

$$\sigma_{ij}(x) = \int_{v} \alpha(|x - x'|, \xi) t_{ij}(x) dV(x') \tag{1}$$

By employing Eringen's nonlocal formulation, the stress tensor $t_{ij}(x)$ can be expressed as

$$(1 - \xi^2\nabla^2)\sigma_{ij}(x) = t_{ij}(x). \tag{2}$$

The constitutive equation of coupled nonlocal thermoelastic media with diffusion is given as

$$(1 - \xi^2\nabla^2)\sigma_{ij}(x) = 2\mu e_{ij} + \delta_{ij}(\lambda e_{kk} - \gamma_1 T - \gamma_2 C),$$
$$P = -\gamma_2 e_{kk} - aT + bC. \tag{3}$$

Following [31-33], the basic governing equations for a nonlocal isotropic thermoelastic media with and without energy dissipation are given by

$$(\lambda + \mu)\nabla.\nabla u + \mu\nabla^2 u - \gamma^1\nabla T - \gamma^2\nabla C + \rho(1 - \xi^2\nabla^2)F = \rho(1 - \xi^2\nabla^2)\ddot{u}, \tag{4}$$

$$(K\frac{\partial}{\partial t} + K^*)\nabla^2 T = \rho(1 - \xi^2\nabla^2)\frac{\partial^2}{\partial t^2}(\rho C_e T + \gamma_1 T_0 u_{i,i} + aT_0 C), \tag{5}$$

$$(1 - \xi^2\nabla^2)\dot{C} = d\nabla^2(bC - \gamma_2 e_{kk} - aT). \tag{6}$$

where

$$\gamma_1 = (3\lambda + 2\mu)\alpha_t, \quad \gamma_2 = (3\lambda + 2\mu)\alpha_c. \tag{7}$$

T = temperature change, ρ = density, α_t = coefficient of thermal expansion,
α_c = coefficient of diffusion, K = coefficient of thermal conductivity,
K^* = materialistic constant, a = coefficient of thermoelastic diffusive effects,
b = coefficient of diffusive effects, σ_{ij} = components of the stress tensor,
C = mass concentration, u_i = displacement vector, λ and μ = Lamé's constants,
C_e = specific heat at constant strain, T_0 = temperature of the medium in its natural state,
d = diffusion constant, ξ = nonlocal parameter, $e_{ij} = ½(u_{i,j} + u_{j,i})$, i, j = 1, 2, 3,
∇ = gradient operator, ∇^2 = Laplacian operator.

3. Problem formulation

We consider a two-dimensional homogeneous nonlocal isotropic thermoelastic solid at initial temperature T_0. We take a rectangular cartesian coordinate system (x, y, z) with origin on the surface at $z = 0$ with $z - axis$ pointing vertically downwards. The surface of half space is subjected to thermomechanical loads, i.e normal load F_1 and thermal load F_2 are applied downward at $z = 0$. For two-dimensional problem in $xz - plane$

$$\mathbf{u} = (u, 0, w), u = u(x, z, t), w = w(x, z, t), T = T(x, z, t) \text{ and } C = C(x, z, t) \tag{8}$$

From Eqs. (4-6) using 8 we derive the following equations

$$(\lambda + \mu)\frac{\partial e}{\partial x} + \mu\nabla^2 u - \gamma_1\frac{\partial T}{\partial x} - \gamma_2\frac{\partial C}{\partial x} + \rho(1 - \xi^2\nabla^2)F_1 = \rho(1 - \xi^2\nabla^2)\ddot{u}, \tag{9}$$

$$(\lambda + \mu)\frac{\partial e}{\partial z} + \mu\nabla^2 w - \gamma_1\frac{\partial T}{\partial z} - \gamma_2\frac{\partial C}{\partial z} + \rho(1 - \xi^2\nabla^2)F_3 = \rho(1 - \xi^2\nabla^2)\ddot{w}, \tag{10}$$

$$(K\frac{\partial}{\partial t} + K^*)\nabla^2 T = \rho(1 - \xi^2\nabla^2)\frac{\partial^2}{\partial t^2}(\rho C_E T + \gamma_1 T_0 e + aT_0 C). \tag{11}$$

$$(1 - \xi^2\nabla^2)\frac{\partial C}{\partial t} = d\left(b\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial z^2}\right) - \gamma_2\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial z^2}\right)\left(\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z}\right) - a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2}\right)\right). \tag{12}$$

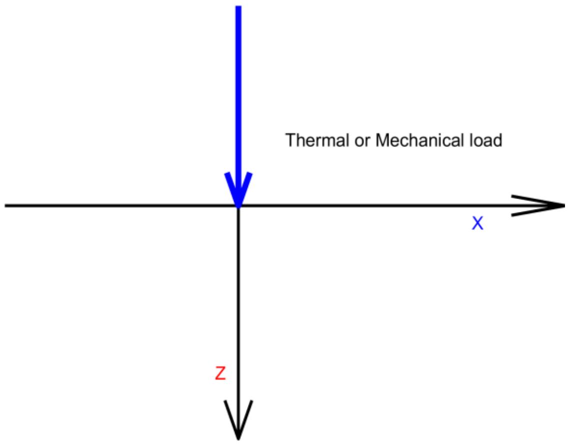

Figure 1. Thermal or mechanical load

The initial and regularity conditions of the above problems are given by the following equations

$$\begin{aligned} u(x,z,0) &= 0 = \dot{u}(x,z,0) \\ w(x,z,0) &= 0 = \dot{w}(x,z,0) \\ T(x,z,0) &= 0 = \dot{T}(x,z,0) \\ C(x,z,0) &= 0 = \dot{C}(x,z,0), for\ z \geq 0, -\infty < x < \infty \\ u(x,z,t) = w(x,z,t) &= T(x,z,t) = C(x,z,t) = 0, for\ t > 0, when\ z \to \infty \end{aligned} \tag{13}$$

We use dimensionless quantities to simplify the solution as

$$\begin{gathered} x' = \frac{\omega_1^*}{c_1}x, \quad z' = \frac{\omega_1^*}{c_1}z, \quad t' = \omega_1^* t, \quad u' = \frac{\omega_1^*}{c_1}u, \quad a' = \frac{\omega_1^*}{c_1}a, \\ w' = \frac{\omega_1^*}{c_1}w, \quad C' = \frac{\gamma_2 C}{\rho {c_1}^2}, \quad T' = \frac{\gamma_1 T}{\rho {c_1}^2}, \quad {F_1}' = \frac{F_1}{\gamma_1 T_0} \\ {F_3}' = \frac{F_3}{\gamma_1 T_0}, \quad e' = e, \\ {c_1}^2 = \frac{(\lambda + 2\mu)}{\rho} \quad \omega_1^* = \frac{\rho C_E {c_1}^2}{K} \end{gathered} \tag{14}$$

For the decoupling of equations, express $u(x,z,t)$ and $w(x,z,t)$ by dimensionless potential functions Ψ_1 and Ψ_2 as follows

$$u = \frac{\partial \Psi_1}{\partial x} - \frac{\partial \Psi_2}{\partial z} \qquad w = \frac{\partial \Psi_1}{\partial z} + \frac{\partial \Psi_2}{\partial x} \tag{15}$$

The Laplace and Fourier transformation are defined as

$$F(x,z,s) = \int_0^\infty f(x,z,t)e^{-ts}\,dt \qquad \text{(Laplace transformation)}$$
$$\hat{f}(\zeta,z,t) = \int_{-\infty}^{\infty} f(x,z,t)e^{-i\zeta x}\,dx\,. \qquad \text{(Fourier transformation)} \tag{16}$$

When we apply the Laplace and Fourier transformation on the equation formed from substituting Eq. (15) in Eqs. (9-12), we get the following equations

$$\left(A_1(D^2-\zeta^2)-s^2(1-\xi^2\nabla^2)\right)\widehat{\Psi_1}-\hat{T}-\hat{C}=0\,, \tag{17}$$

$$(A_2(D^2-\zeta^2)-(1-\xi^2\nabla^2)s^2)\widehat{\Psi_2}=0, \tag{18}$$

$$A_3(1-\xi^2\nabla^2)(D^2-\zeta^2)\widehat{\Psi_1}+A_4(1-\xi^2\nabla^2)-A_5(D^2-\zeta^2)\hat{T}+A_6(1-\xi^2\nabla^2)\hat{C}=0, \tag{19}$$

$$A_9(D^2-\zeta^2)^2\widehat{\Psi_1}+A_{10}(D^2-\zeta^2)\hat{T}+(A_7(1-\xi^2\nabla^2)-A_8(D^2-\zeta^2))\hat{C}=0. \tag{20}$$

where:

$$A_1=\frac{\lambda+2\mu}{\rho {c_1}^2},\qquad A_2=\frac{\mu}{\rho {c_1}^2},\qquad A_3=\rho s^2\gamma_1 T_0,\qquad A_4=s^3\left(\frac{\rho^3 {c_1}^2\omega_1^*}{\gamma_1}\right)C_E,$$

$$A_5=\left(\frac{\rho c_1}{\gamma_1}\right)(K\omega_1^* s+K),\qquad A_6=s^2\left(\frac{\rho^2 C^{13}}{\omega_1^*\gamma_2}\right)T_0 a,\qquad A_7=\left(\frac{\rho\omega_1^* {c_1}^2}{\gamma^2}\right)s,$$

$$A_8=db\left(\frac{\rho{\omega_1}^2}{\gamma^2}\right),\qquad A_9=d\gamma_2\left(\frac{{\omega_1}^2}{{c_1}^2}\right),\qquad A_{10}=ad\left(\frac{\rho{\omega_1}^2}{\gamma_1}\right),$$

$$A_{11}=\frac{{\omega_1^*}^2\xi^2}{c^{12}},\qquad A_{12}=\gamma_1 T_o,\qquad A_{13}=\frac{\rho\omega_1^* c_1}{\gamma_1},\qquad A_{14}=\gamma_1 T_o,$$

$$A_{15}=\frac{\rho\omega_1^* c_1}{\gamma^2},\qquad A_{16}=\frac{A_{12}}{A_{13}},\qquad A_{17}=\frac{A_{14}}{A_{13}}.$$

The system of Eqs. (17-20) possesses a non-trivial solution if the determinant of the coefficients vanishes. We assume it vanishes and derive the following polynomial equations.

$$(D^6R_1+D^4R_2+D^2R_3+R_4)(\widehat{\Psi}_1,\hat{T},\hat{C})=0, \tag{21}$$

$$(D^2+r)\widehat{\Psi}_2=0,\qquad r=R_6/R_5. \tag{22}$$

where:

$$M_1=A_4A_7s^2,\ M_2=(A_1A_4A_7-A_4A_8s^2+A_5A_7s^2+A_6A_{10}s^2+A_3A_7),$$

$$M_3=-A_1A_4A_8-A_5A_8s^2, M_4=A_1A_5A_7+A_1A_6A_{10}+A_3A_8+A_9A_6+A_3A_{10}-A_4A_9,\qquad M_5=A_1A_5A_8-A_5A_9,\quad M_6=M_2{A_{11}}^2-{A_{11}}^3M_1+M_4A_{11}+M_5,$$

$$M_7=M_1A_{11}-2M_2A_{11}-M_3A_{11}-M_4M_8=M_2+M_3-3M_1A_{11},$$

$$\mathrm{M}_9 = \mathrm{M}_1, \quad \mathrm{R}_1 = \mathrm{M}_6, \ \mathrm{R}_2 = -3\mathrm{M}_6\zeta^2 + \mathrm{M}_7, \ \mathrm{R}_3 = 3\mathrm{M}_6\zeta^4 - 2\mathrm{M}_7\zeta^2 + \mathrm{M}_8,$$

$$\mathrm{R}_4 = \mathrm{M}_7\zeta^4 + \mathrm{M}_9 - \mathrm{M}_6\zeta^6 - \mathrm{M}_8\zeta^2, \quad \mathrm{R}_5 = \mathrm{A}_2 + \mathrm{A}_{11}\mathrm{s}^2, \quad \mathrm{R}_6 = \mathrm{A}_{11}\zeta^2\mathrm{s}^2 - \mathrm{A}_2\zeta^2 - 1.$$

By applying the method of solving a polynomial of degree six on Eq. (21), we obtain roots $\pm r_i$, (i = 1,2,3), also roots of (22) are $\pm r_4$ and hence

$$\widehat{\Psi_1} = B_1 e^{-r_1 z} + B_2 e^{-r_2 z} + B_3 e^{-r_3 z}, \tag{23}$$

$$\hat{T} = d_1 B_1 e^{-r_1 z} + d_2 B_2 e^{-r_2 z} + d_3 B_3 e^{-r_3 z}, \tag{24}$$

$$\hat{\mathrm{C}} = l_1 B_1 e^{-r_1 z} + l_2 B_2 e^{-r_2 z} + l_3 B_3 e^{-r_3 z}, \tag{25}$$

$$\widehat{\Psi}_2 = B_4 e^{-r_4 z}. \tag{26}$$

where d_i and l_i are given by

$$d_{\mathrm{i}} = \frac{({r_{\mathrm{i}}}^6 M_{13} + {r_{\mathrm{i}}}^4 M_{14} + {r_{\mathrm{i}}}^2 M_{15} + M_{16})}{({r_{\mathrm{i}}}^4 M_{10} + {r_{\mathrm{i}}}^2 M_{11} + M_{12})}, \qquad i = (1,2,3)$$

$$l_{\mathrm{i}} = \frac{({r_{\mathrm{i}}}^6 M_{17} + {r_{\mathrm{i}}}^4 M_{18} + {r_{\mathrm{i}}}^2 M_{19} + M_{20})}{({r_{\mathrm{i}}}^4 M_{10} + {r_{\mathrm{i}}}^2 M_{11} + M_{12})}. \qquad i = (1,2,3)$$

where:

$$\begin{gathered}
\mathrm{N}_1 = \mathrm{A}_1 + \mathrm{s}^2\mathrm{A}_{11}, \ \mathrm{N}_2 = (\mathrm{A}_1 + \mathrm{s}^2\mathrm{A}_{11})\zeta^2 - \mathrm{s}^2, \ \mathrm{N}_3 \ -\mathrm{A}_3\mathrm{A}_{11}, \\
\mathrm{N}_4 = \mathrm{A}_3 + 2\mathrm{A}_3\mathrm{A}_{11}\zeta^2, \quad \mathrm{N}_5 = -\mathrm{A}_3\mathrm{A}_{11}\zeta^4 + \mathrm{A}_3\zeta^2, \ \mathrm{N}_6 = -\mathrm{A}_4\mathrm{A}_{11} - \mathrm{A}_5, \\
\mathrm{N}_7 = \mathrm{A}_4 + \mathrm{A}_4\mathrm{A}_{11}\zeta^2 + \mathrm{A}_5\zeta^2, \ \mathrm{N}_8 = \mathrm{A}_6\mathrm{A}_{11}, \ \mathrm{N}_9 = \mathrm{A}_6\mathrm{A}_{11}\zeta^2 + \mathrm{A}_6, \\
\mathrm{N}_{10} = \mathrm{A}_9, \ \mathrm{N}_{11} = 2\mathrm{A}_9\zeta^2, \quad \mathrm{N}_{12} = \mathrm{A}_9\zeta^4, \ \mathrm{N}_{13} = \mathrm{A}_{10}, \ \mathrm{N}_{14} = \mathrm{A}_{10}\zeta^2, \\
\mathrm{N}_{15} = (-\mathrm{A}_7\mathrm{A}_{11} - \mathrm{A}_8), \ \mathrm{N}_{16} = (\mathrm{A}_7\mathrm{A}_{11} + \mathrm{A}_8)\zeta^2 + \mathrm{A}_7, \ \mathrm{N}_{17} = (\mathrm{A}_2 - \mathrm{s}^2\mathrm{A}_{11}), \\
\mathrm{N}_{18} = (\mathrm{A}_2 + \mathrm{s}^2\mathrm{A}_{11})\zeta^2 - \mathrm{s}^2, \ \mathrm{M}_{10} = \mathrm{N}_6\mathrm{N}_{15} + \mathrm{N}_8\mathrm{N}_{13}, \\
\mathrm{M}_{11} = \mathrm{N}_6\mathrm{N}_{16} + \mathrm{N}_7\mathrm{N}_{15} - \mathrm{N}_9\mathrm{N}_{13} - \mathrm{N}_8\mathrm{N}_{14}, \\
\mathrm{M}_{12} = \mathrm{N}_7\mathrm{N}_{16} + \mathrm{N}_9\mathrm{N}_{14}, \quad \mathrm{M}_{13} = -\mathrm{N}_3\mathrm{N}_{15} - \mathrm{N}_8\mathrm{N}_{10}, \\
\mathrm{M}_{14} = \mathrm{N}_9\mathrm{N}_{10} - \mathrm{N}_3\mathrm{N}_6 - \mathrm{N}_4\mathrm{N}_{15} + \mathrm{N}_9\mathrm{N}_{10} + \mathrm{N}_8\mathrm{N}_{11}, \\
\mathrm{M}_{15} = N_4 N_{16} - N_5 N_{15} - N_9 N_{11} - N_8 N_{12}, \quad \mathrm{M}^{16} = N_5 N_{16} + N_9 N_{12}, \\
\mathrm{M}_{17} = -\mathrm{N}_3\mathrm{N}_{13} - \mathrm{N}_6\mathrm{N}_{10}, \ \mathrm{M}_{18} = \mathrm{N}_6\mathrm{N}_{11} - \mathrm{N}_7\mathrm{N}_{10} + \mathrm{N}_4\mathrm{N}_{13} - \mathrm{N}_3\mathrm{N}_{14}, \\
\mathrm{M}_{19} = \mathrm{N}_7\mathrm{N}_{11} - \mathrm{N}_6\mathrm{N}_{12} - \mathrm{N}_5\mathrm{N}_{13} - \mathrm{N}_4\mathrm{N}_{14}, \ \mathrm{M}_{20} = \mathrm{N}_5\mathrm{N}_{14} - \mathrm{N}_7\mathrm{N}_{12}.
\end{gathered} \tag{24}$$

4. Boundary conditions

The appropriate boundary conditions at z=0 are considered as

$$(1-\xi^2\nabla^2)\sigma_{zz} = -F_1\Psi_1(x)\delta(t) \tag{28}$$

$$(1-\xi^2\nabla^2)\sigma_{zx} = 0, \tag{29}$$

$$\frac{\partial T}{\partial z}(x,z,t) = F_2\Psi_2(x)\delta(t), \tag{30}$$

$$\frac{\partial C}{\partial z}(x,z,t) = 0. \tag{31}$$

Applying Laplace and Fourier transformations defined by Eq. (16) on the dimensionless form of set of equations Eqs. (28-31) yields

$$M_{21}B_1 + M_{22}B_2 + M_{23}B_3 + M_{24}B_4 = -\widehat{F_1}\,A_{12}\,\widehat{\Psi}_1\,(\zeta)\,. \tag{32}$$

$$M_{25}B_1 + M_{26}B_2 + M_{27}B_3 + M_{28}B_4 = 0. \tag{33}$$

$$M_{29}B_1 + M_{30}B_2 + M_{31}B_3 = A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta), \tag{34}$$

$$M_{32}B_1 + M_{33}B_2 + M_{34}B_3 = 0. \tag{35}$$

where:

$$M_{21} = A_{11}\lambda({r_1}^2-\zeta^2) - {A_{11}}^2\lambda({r_1}^4 - 2\zeta^2{r_1}^2+\zeta^4) - 2\mu r_1 + 2\mu A_{11}{r_1}^3 - 2\mu A_{11}\zeta^2 r_1 -$$

$$A_3d_1 - A_{11}A_3d_1{r_1}^2 + A_{11}A_3\zeta^2 d_1 - A_3l_1 - A_{11}A_3l_1{r_1}^2 + A_{11}A_3\zeta^2 l_1,$$

$$M_{22} = A_{11}\lambda({r_2}^2-\zeta^2) - {A_{11}}^2\lambda({r_2}^4 - 2\zeta^2{r_2}^2+\zeta^4) - 2\mu r_2 + 2\mu A_{11}{r_2}^3 - 2\mu A_{11}\zeta^2 r_2 -$$

$$A_3d_2 - A_{11}A_3d_2{r_2}^2 + A_{11}A_3\zeta^2 d_2 - A_3l_2 - A_{11}A_3l_2{r_2}^2 + A_{11}A_3\zeta^2 l_2,$$

$$M_{23} = A_{11}\lambda({r_3}^2-\zeta^2) - \lambda{A_{11}}^2({r_3}^4 - 2\zeta^2{r_3}^2+\zeta^4) - 2\mu r_3 + 2\mu A_{11} r_3 - 2\mu A_{11}\zeta^2 r_3 -$$

$$A_3d_3 - A_{11}A_3d_3{r_3}^2 + A_{11}A_3\zeta^2 d_3 - A_3l_3 - A_{11}A_3l_3{r_3}^2 + A_{11}A_3\zeta^2 l_3,$$

$$M_{24} = i\zeta - A_{11}i\zeta{r_4}^2 + A_{11}i\zeta^3,\quad M_{25}\quad \mu(-r_1 + A_{11}({r_1}^3 - \zeta^2 r_1)),$$

$$M_{26} = \mu(-r_2 + A_{11}({r_2}^3 - \zeta^2 r_2)),\quad M_{34} = r_3l_3.$$

$$M_{27} = \mu(-r_3 + A_{11}({r_3}^3 - \zeta^2 r_3)),\ M_{28} = \mu(i\zeta - A_{11}(i\zeta{r_4}^2 - i\zeta^3)),\quad M_{29} = -r_1d_1,\ M_{30} = -r_2d_2,\ M_{31} = -r_3d_3,\quad M_{32} = r_1l_1,\quad M_{33} = r_2l_2,$$

By solving the system of Eqs. (32-35), we get the following

$$B_1 = \frac{[-\hat{F}_1\widehat{\Psi}_1(\zeta)\beta_1\Delta_{11} + A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta)\Delta_{12}]}{\Delta} \tag{36}$$

$$B_2 = \frac{[-\hat{F}_1\hat{\Psi}_1(\zeta)\beta_1\Delta_{21} + A_{16}\hat{F}_2\hat{\Psi}_2(\zeta)\Delta_{22}]}{\Delta} \tag{37}$$

$$B_3 = \frac{[-\hat{F}_1\hat{\Psi}_1(\zeta)\beta_1\Delta_{31} + A_{16}\hat{F}_2\hat{\Psi}_2(\zeta)\Delta_{33}]}{\Delta} \tag{38}$$

$$B_4 = \frac{[-A_{12}\hat{F}_1\hat{\Psi}_1(\zeta)\Delta_{41} + A_{16}\hat{F}_2\hat{\Psi}_2(\zeta)\Delta_{42}]}{\Delta} \tag{39}$$

where:

$$\beta_1 = A_{12}M_{28},\ \Delta_{11} = (M_{30}M_{34} - M_{31}M_{33}),$$

$$\Delta_{12} = M_{28}M_{22}M_{34} - M_{28}M_{23}M_{33} + M_{24}M_{27}M_{33} - M_{24}M_{26}M_{34},$$

$$\Delta_{21} = M_{31}M_{32} - M_{29}M_{34},$$

$$\Delta_{22} = M_{24}M_{25}M_{34} - M_{24}M_{27}M_{32} + M_{28}M_{23}M_{32} - M_{21}M_{28}M_{34},$$

$$\Delta_{31} = M_{29}M_{33} - M_{30}M_{32},$$

$$\Delta_{32} = (M_{24}M_{26}M_{32} - M_{24}M_{25}M_{33} + M_{28}M_{21}M_{33} - M_{22}M_{28}M_{32}),$$

$$\Delta_{41} = (M_{27}M_{30}M_{32} - M_{26}M_{31}M_{32} - M_{27}M_{29}M_{33} + M_{25}M_{31}M_{33} + M_{26}M_{29}M_{3} - M_{25}M_{30}M_{34}),$$

$$\Delta_{42} = (-M^{23}M^{26}M^{32} + M^{22}M^{27}M^{32} + M^{23}M^{25}M^{33}{}_{3} - M_{21}M_{27}M_{33} - M_{22}M_{25}M_{34} + M_{21}M_{26}M_{34}).$$

Substitute Eqs. (36-39) and Eqs. (25, 26) in the Eqs. (23-26) and with the aid of Eq. (3), we get the components of displacement, temperature change, mass concentration and stress components as

$$\hat{u} = \left(\frac{\hat{F}_1\hat{\Psi}_1(\zeta)}{\Delta}\right)\left(i\zeta\beta_1 \textstyle\sum_{n=1}^{3}\Delta_{n1}e^{-r_n z} + r_4A_{12}\Delta_{41}e^{-r_4 z}\right) + \left(\frac{A_{16}\hat{F}_2\hat{\Psi}_2(\zeta)}{\Delta}\right)\left(i\zeta\sum_{n=1}^{3}\Delta_{n2}e^{-r_n z} + r_4\Delta_{42}e^{-r_4 z}\right), \tag{40}$$

$$\hat{w} = -\left(\frac{\hat{F}_1\hat{\Psi}_1(\zeta)}{\Delta}\right)\left(\beta_1\sum_{n=1}^{3}r_n\Delta_{n1}e^{-r_n z} - i\zeta A_{12}\Delta_{41}e^{-r_4 z}\right) - \left(\frac{A_{16}\hat{F}_2\hat{\Psi}_2(\zeta)}{\Delta}\right)\left(\sum_{n=1}^{3}r_n\Delta_{n2}e^{-r_n z} - \Delta_{42}e^{-r_4 z}\right), \tag{41}$$

$$\hat{T} = \left(\frac{\hat{F}_1\widehat{\Psi}_1(\zeta)\beta_1}{\Delta}\right)\sum_{n=1}^{3}\Delta_{n1}\, d_n e^{-r_n z} + \left(\frac{A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta)}{\Delta}\right)\sum_{n=1}^{3}\Delta_{n2}\, d_n e^{-r_n z}, \tag{42}$$

$$\hat{C} = \left(\frac{\hat{F}_1\widehat{\Psi}_1(\zeta)\beta_1}{\Delta}\right)\sum_{n=1}^{3}\Delta_{n1}\, l_n e^{-r_n z} + \left(\frac{A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta)}{\Delta}\right)\sum_{n=1}^{3}\Delta_{n2}\, l_n e^{-r_n z}, \tag{43}$$

$$\hat{\sigma}_{zz} = \left(\frac{\hat{F}_1\widehat{\Psi}_1(\zeta)}{\Delta}\right)\left(\beta_1\sum_{n=1}^{3}\Delta_{n1}\,(\lambda r_n^{\,2} - \lambda\zeta^2 - 2\mu r_n - A_3 d_n - A_3 l_n) + A_{12}\Delta_{41}\right) + \left(\frac{A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta)}{\Delta}\right)\left(\sum_{n=1}^{3}\Delta_{n2}\,(\lambda r_n^{\,2} - \lambda\zeta^2 - 2\mu r_n - A_3 d_n - A_3 l_n) + \Delta_{42}\right), \tag{44}$$

$$\sigma_{xz} = \left(\frac{\hat{F}_1\widehat{\Psi}_1(\zeta)\beta_1}{\Delta}\right)\left(-2\beta_1\sum_{n=1}^{3}\Delta_{n1}\, r_n\mu i\zeta - A_{12}\Delta_{41}(\mu r_4^{\,2} + \mu\zeta^2)\right) + \left(\frac{A_{16}\hat{F}_2\widehat{\Psi}_2(\zeta)}{\Delta}\right)\left(-2\sum_{n=1}^{3}\Delta_{n2}\, r_n\mu i\zeta - \Delta_{42}(\mu r_4^{\,2} + \mu\zeta^2)\right). \tag{45}$$

5. Application

5.1 Concentrated load

A concentrated mechanical load is a force or pressure applied at a single point, or over an area that is very small. In mechanical analysis, this kind of load is commonly modeled as a point force (such as a load on the center of a beam or a pin). For concentrated load source distribution function $\phi_1(x)$ & $\phi_2(x)$ are taken as

$$\phi_1(\mathrm{x}) = \delta(x), \qquad \phi_2(\mathrm{x}) = \delta(x). \tag{46}$$

By using Fourier transformation on both of these equations we get

$$\hat{\phi}_1(\zeta) = 1 \quad \hat{\phi}_2(\zeta) = 1. \quad \delta(x) \quad \text{is called Dirac delta function} \tag{47}$$

5.2 Uniformly distributed load

A uniform mechanical load means applying a constant load (force or pressure) uniformly across the surface or length of the structure. Source distribution $\phi_1(x)$ and $\phi_2(x)$ subjected to uniformly distributed load are taken as.

$$[\phi_1(x), \phi_2(x)] = \begin{cases} 1 & |x| \le a \\ 0 & |x| > a \end{cases} \tag{48}$$

The Fourier transformation of Eq. (48) is calculated and equal to

$$(\widehat{\phi_1}(\zeta),\ \widehat{\phi_2}(\zeta)) = \left(\frac{2}{\zeta}sin(\zeta a)\right), \zeta \neq 0 \tag{49}$$

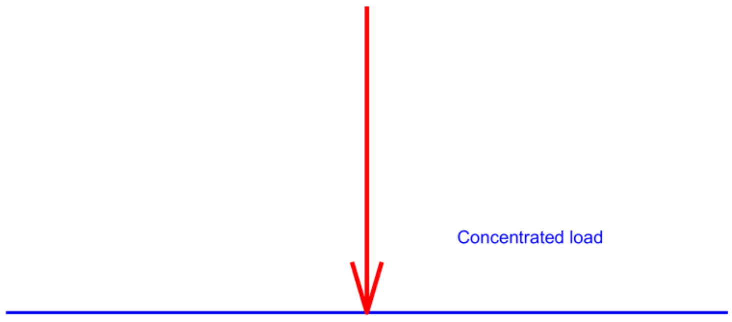

Figure 2. Concentrated load

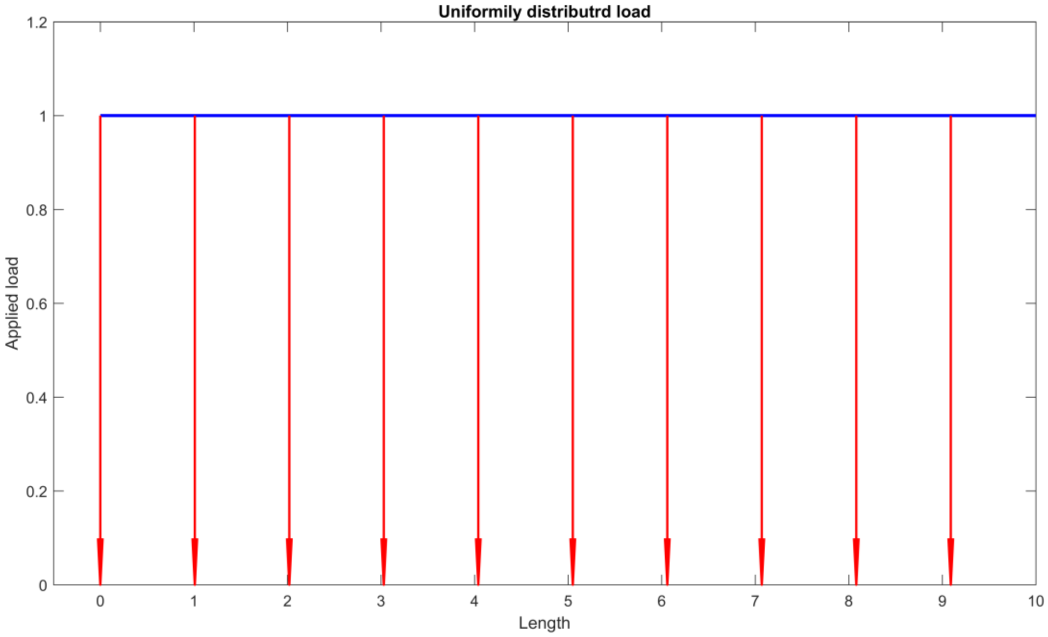

Figure 3. Uniformly distributed load

A load for which the loading intensity varies linearly along a specific direction is referred to as a linearly distributed load. In the thermomechanical analysis, a linear thermal load means that temperature varies linearly in a step-wise manner across the structure, i.e., variation of temperature from one end of a solid to the other. A linear mechanical load could be a force or pressure that varies at a constant rate along the length or area of the structure. The effect of linearly distributed force on nonlocal thermoelastic plate is calculated by assuming $\phi_1(x)$ and $\phi_2(x)$ as

$$[\phi_1(x), \qquad \phi_2(x)] = \begin{cases} 1 - \dfrac{|x|}{a}, if|x| \leq a \\ 0, if|x| > a \end{cases} \tag{50}$$

By taking Fourier transform of Eq. (49) we get

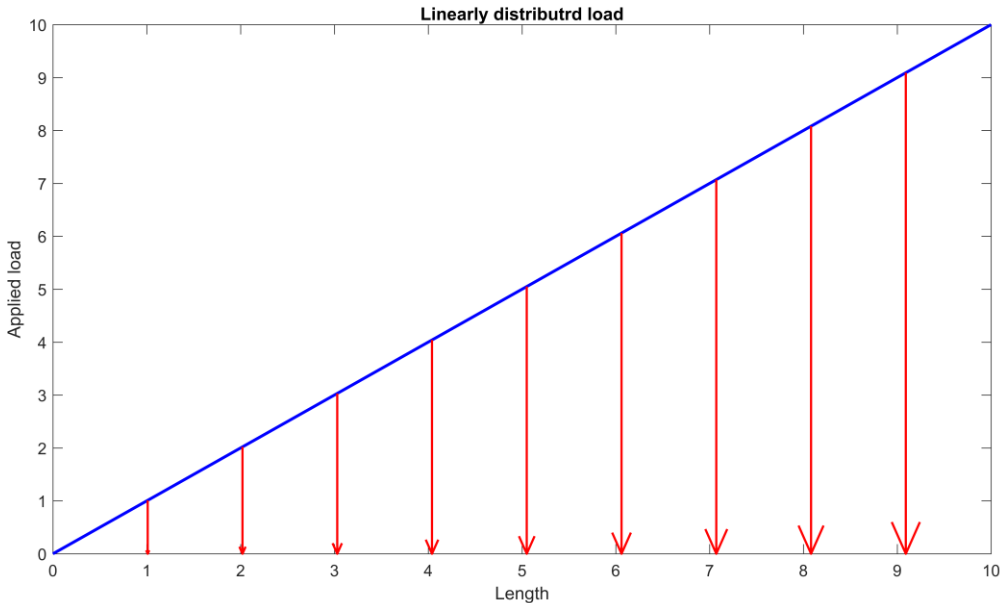

Figure 4. Linearly distributed load

$$[\hat{\phi}_1(\zeta), \qquad \hat{\phi}_2(\zeta)] = \frac{2\big(1 - cos(\zeta a)\big)}{a\zeta^2} \tag{51}$$

In Eqs. (40-45), if we substitute for $\hat{\phi}_1(\zeta)$, $\hat{\phi}_2(\zeta)$ from Eqs. (47, 49, 51), we obtain the expressions due to concentrated load, uniformly distributed load and linearly distributed load respectively.

6. Particular cases

1. When we use $b = 0$, in Eqs. (4-6) we get we get from Eqs. (40-45), results for displacement components temperature change, mass concentration and stress components without diffusion in nonlocal isotropic thermoelastic media.
2. If we take $\xi = 0$ we derive from Eqs. (40-45) the displacement components temperature change, mass concentration and stress components of isotropic thermoelastic diffusive solid.

7. Inversion of the Laplace and Fourier transformations

To get the solution of the problem in a physical domain we should invert the transformed domain from the Laplacian and Fourier domain to the real or physical domain. The inverse Fourier transform is given by

$$\hat{f}(x, z, s) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-ix\zeta}\,\hat{f}(\zeta, z, s)d\zeta = \frac{1}{\pi}\int_{0}^{\infty}(\,cos(\zeta x)f_e - sin(\zeta x)f_o)d\zeta \tag{52}$$

Table 1. Copper parameters and their values

Constant notation	Values	C constant notation	Values
λ	$7.76 \times 10^{10} NM^{-2}$	μ	$3.86 \times 10^{10} NM^{-2}$
α_t	$1.78 \times 10^{-5} K^{-1}$	α_c	$2.65 \times 10^{-4} K^{-1}$
ρ	8954	γ_1	$0.02s$
$\gamma_2 s$	0.2s	K	$386J(msk)^{-1}$
a	$1.2 \times 10^4 m^2 KS^2$	b	$0.9 \times 10^6 Kgm^5 s^2$
T_0	$293K$	C_E	$383.1J(KgK)^{-1}$
d	8.5×10^{-9}	ξ	3.95×10^{-10}
ζ	2×10^{-10}	K^*	1.2
s	1		

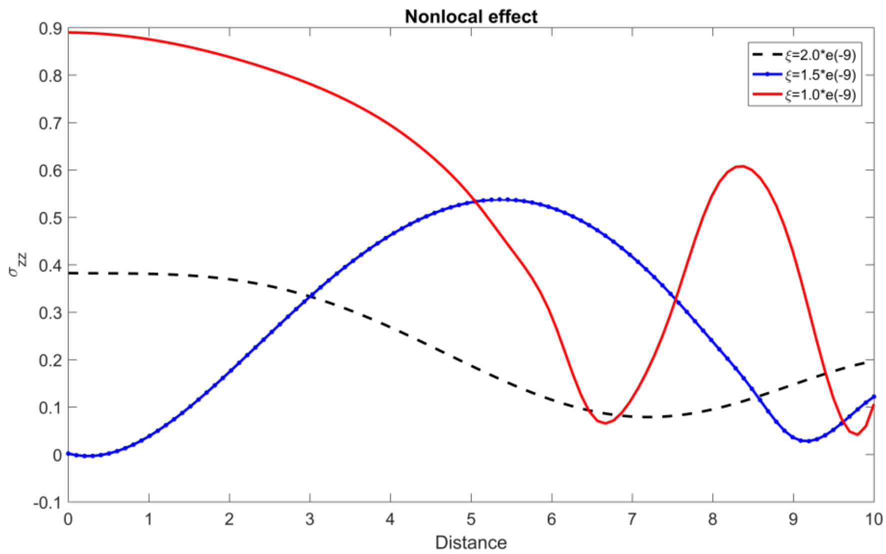

Figure 5. Normal stress under concentrated load with distance *x*

where: f_e and f_o are even and odd function of $f(\zeta, z, s)$ respectively. The inverse Laplace transform is calculated with the use of [34] methods and we get equations in $f(x, z, t)$ form.

8. Numerical results and discussion

In order to depict the effect of nonlocal parameter on normal stress, shear stress, mass concentration and temperature change, we have taken data from [34]. The material constants of copper are given in table below.

8.1 Concentrated load

In the Figs. 5-8
Solid red line (—) represents $\xi = 1.0 * 10^{-9}$

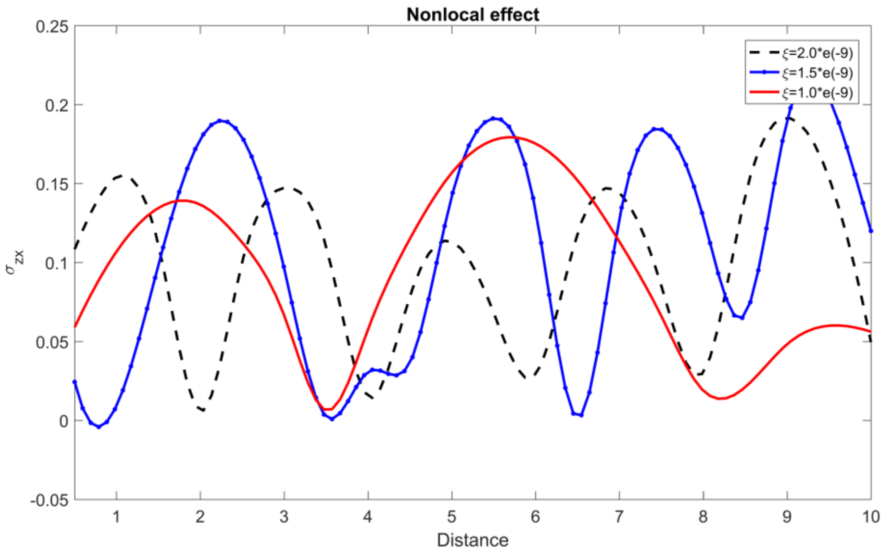

Figure 6. Shear stress under concentrated load with distance x

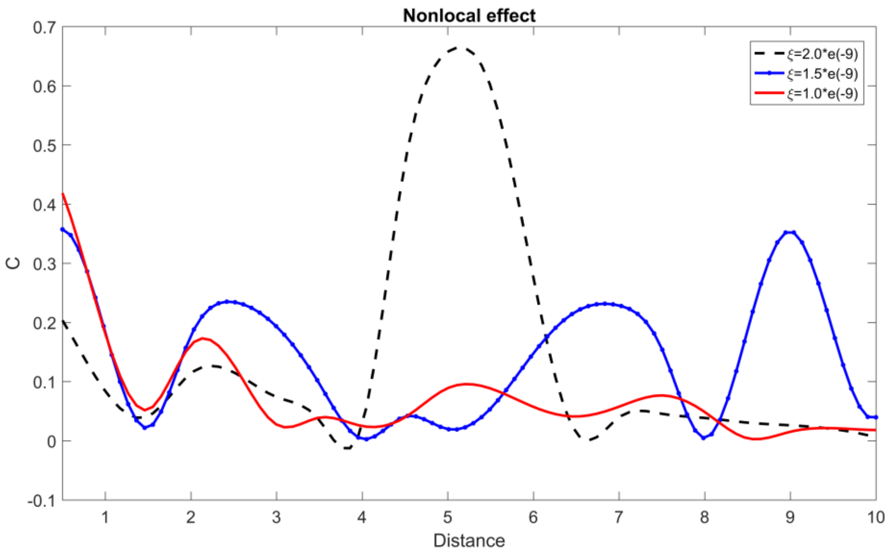

Figure 7. Mass concentration under concentrated load with distance x

Solid blue line with star ($- * -$ represents $\xi = 1.5 * 10^{-9}$

Broken black line ($- -$)represents $\xi = 2.0 * 10^{-9}$

Fig. 5, illustrates the variation of normal stress (σ_{zz}) with distance x due to change of nonlocal parameter in thermoelastic media with diffusion. The graph indicates that for various values of the nonlocal parameter, the normal stress begins at different initial values and exhibits oscillatory behavior. Furthermore, the amplitude of these oscillations gradually decreases with distance, highlighting the damping effect of the nonlocal parameters on the stress distribution over the medium.

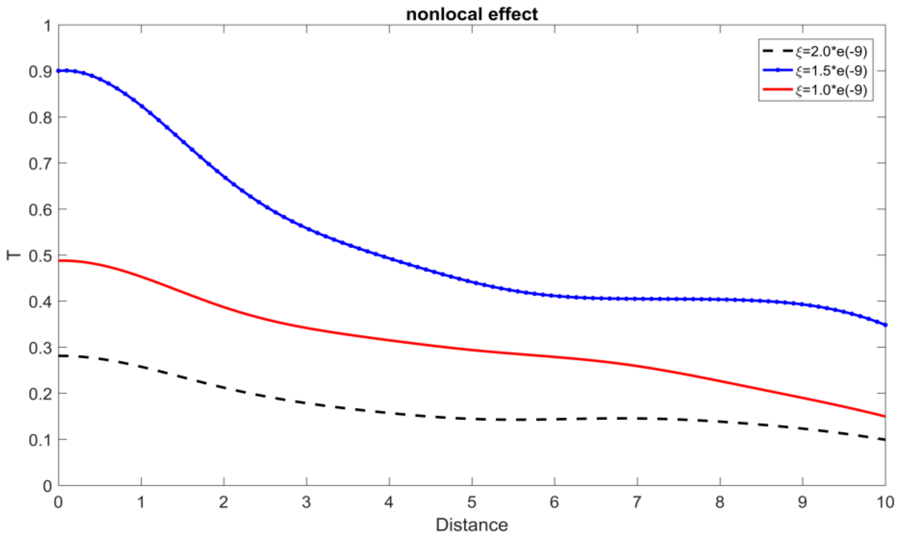

Figure 8. Temperature distribution under concentrated load with distance *x*

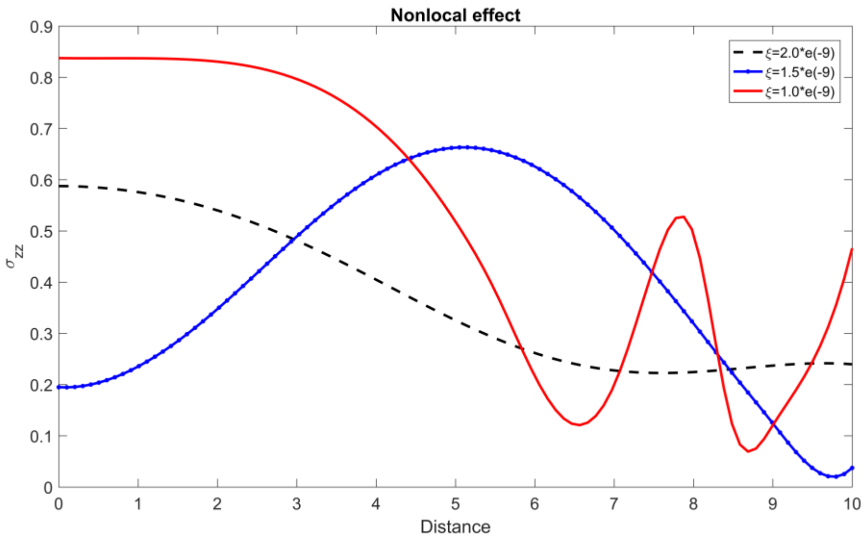

Figure 9. Normal stress under linearly distributed load with distance *x*

From Fig. 6, the graph of shear stress (σ_{xz}) concerning thermoelastic media with diffusion starts from a different point and oscillates. The variation among graphs of different nonlocal parameters are in the same range. This indicates that changes in local parameters affects the properties of concentration.

Fig. 7, illustrates the deviations of mass concentration C with distance x. From the graph, it can be observed that mass concentration (C) initialy decreases and oscillates uniformly for diffferent values of nonlocal parameters. But as the non local parameter increases the oscillations in mass concentration become pronounced, showing a pattern of strict increase followed by strict decrease at the mid point of the graph.

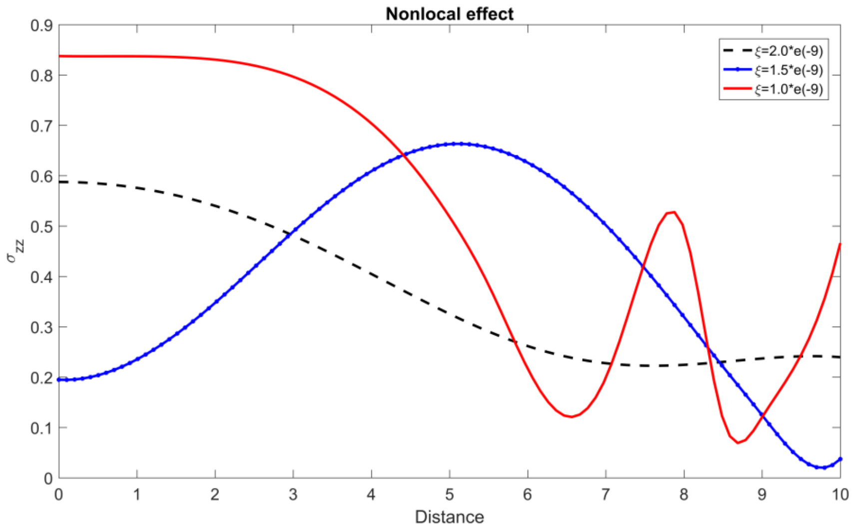

Figure 9. Normal stress under linearly distributed load with distance *x*

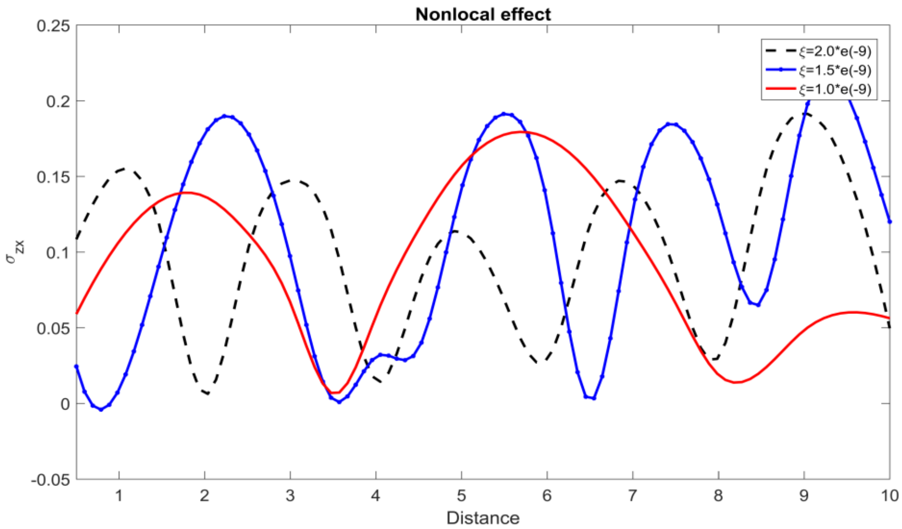

Figure 10. Shear stress under linearly distributed load

From Fig. 8, it is observed that the temperature change T of the material exhibits a slight decrease. Additionally, for different values of the nonlocal parameters, the temperature change of the material varies accordingly. This variation in the temperature profile indicates that the nonlocal parameters significantly influences the conductive temperature behaviour of the termoelastic media with diffusion.

8.2 Linearly distributed load

Fig. 9, shows the influence of nonlocal parameters on the normal stress (σ_{zz}) in thermoelastic

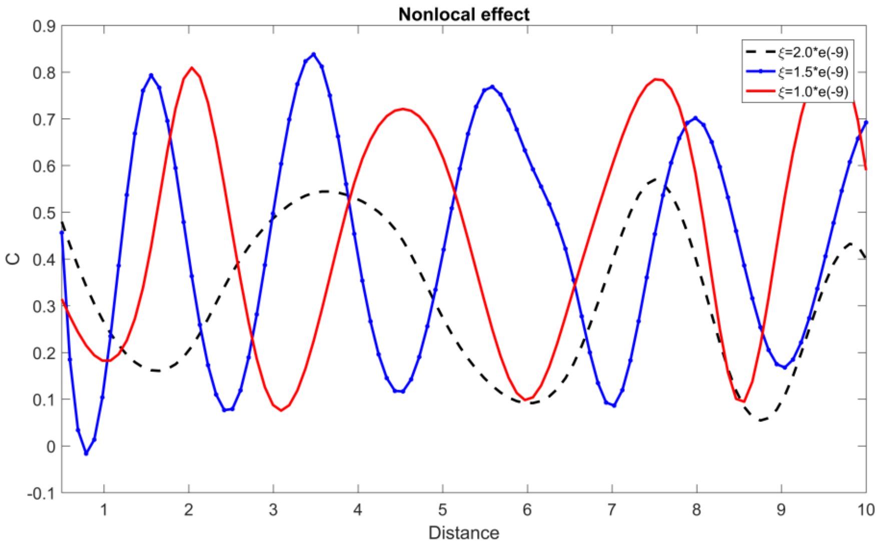

Figure 11. Mass concentration under linearly distributed load with distance *x*

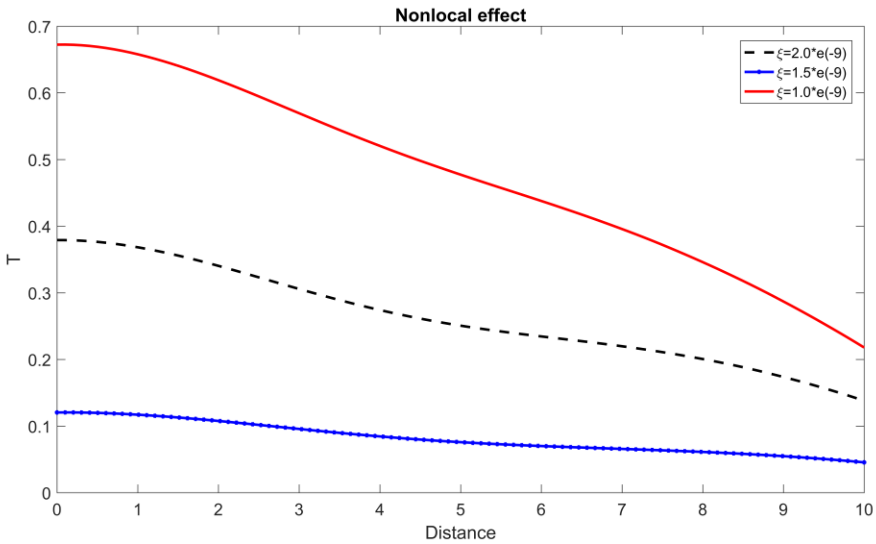

Figure 12. Temperature distribution under linearly distributed load with distance *x*

media with diffusion subjected to linearly distributed load. The effect of nonlocal parameter is very significant here. When nonlocal parameters are min, there are more oscillations From Fig. 10, we observe that the shear stress (σ_{zx}) of thermoelastic media with diffusion has almost equivalent to each other along $x - axis$ subjected to linearlly distributed load. Fig. 11, illustrates the deviations of mass concentration (C) under the frame work of nonlocal thermoelasticity subjected to linearly distribured load. The graph shows that the potential concentration is oscillated uniformly for diffferent values of nonlocal parameters. From Fig. 12, we observed that temperature change (T) of thermoelastic media with diffusion exhibits a slight decrease through x-axis.

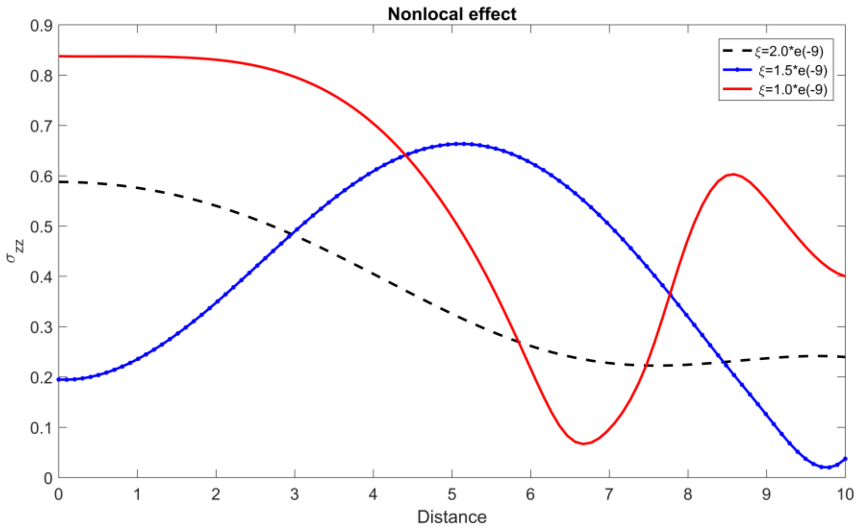

Figure 13. Normal stressσ_{zz} under uniformily distiributed load with distance x

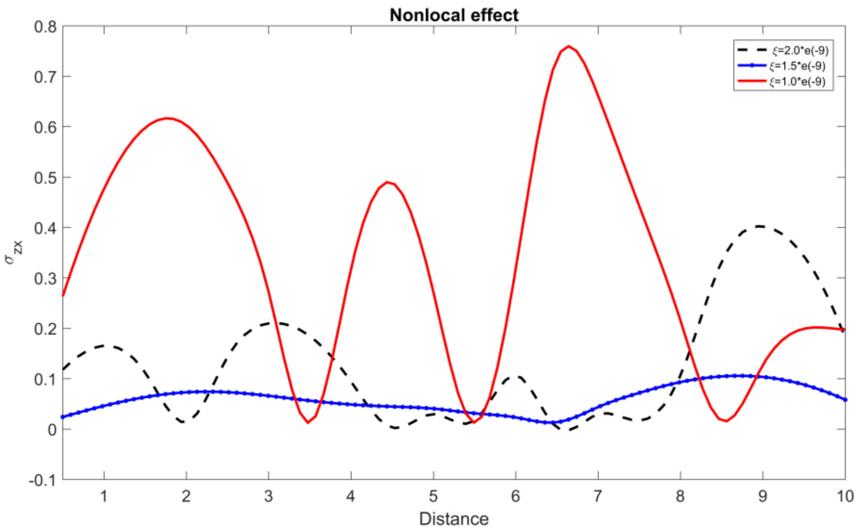

Figure 14. Shear stress σ_{zx} under uniformily distributed load with distance x

8.3 Uniformily distributed load

Fig. 13, is graph of normal stress (σ_{zz}) with change of nonlocal parameters under uniformily distributed load. The graph shows different shapes with different values of nonlocal parameters. From Fig. 14, we observe that the shear stress (σ_{zx}) has oscillated along $x - axis$ subjected to uniformily distributed load. Fig. 15, illustrates the deviations of mass concentration (C) subjected to uniformily distribured load. All the graphs are started by decreasing and then continuous oscillation which is not uniform. From Fig. 16, it is observed that the temperature change (T) of thermoelastic media with diffusion exhibits a slight decrease along $x - axis$.

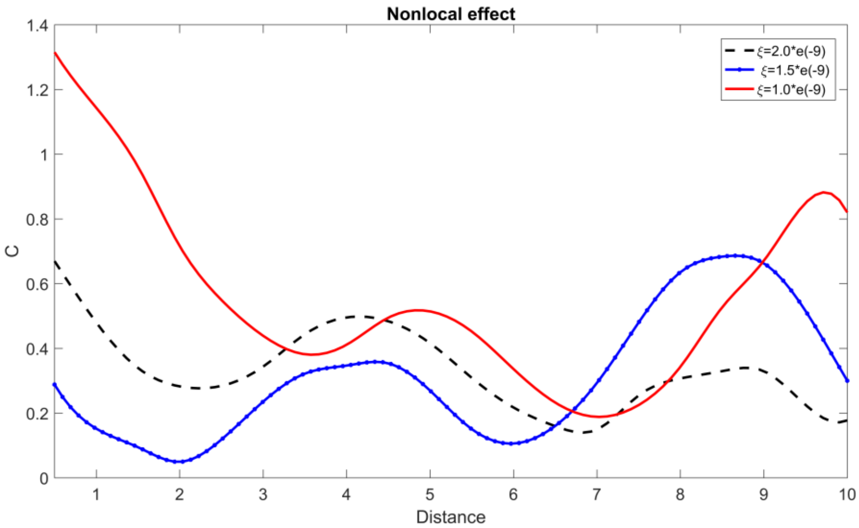

Figure 15. Mass concentration C under uniformly distributed load with distance x

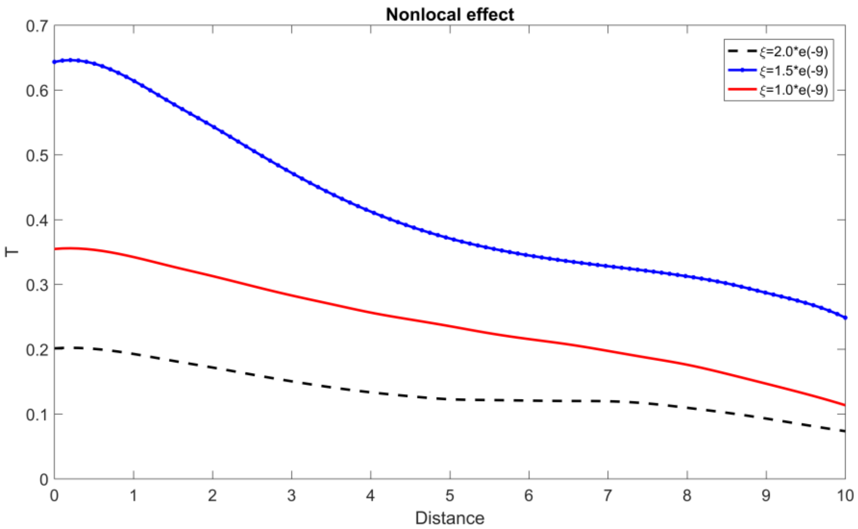

Figure 16. Temperature T distribution under uniformly distributed load with distance x

9. Conclusions

In this paper, we studied the influence of nonlocal parameters on components of stress, mass concentrations and temperature changes on nonlocal thermoelastic media with diffusion under various loading conditions, including concentrated load, linearly distributed load and uniformly distributed load. The study demonstrates that the nonlocal parameters significantly influence all the variables under considerations. Our findings reveal that these parameters play a crucial role in determining the response of the system, leading to notable variations in stress distributions, temperature profiles, and mass concentration fields. The results emphasize the sensitivity of thermoelastic media to nonlocal effects, highlighting the importance of incorporating these parameters in theoretical modeling and practical applications. This research contributes to a deeper understanding of how nonlocal parameters affect the behavior of thermoelastic materials under different loading scenarios, offering valuable insights for the design and analysis of materials and structures in engineering and scientific disciplines.

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