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A Simple Model of Heat Distribution at Various Rayleigh Number in Silicon Elastomer

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In order to investigate the two-dimensional flow of a non-Newtonian fluid, such as an elastomer liquid over a cylinder, a simplified model is applied. The analysis is carried out to study the thermophysical properties of the melt elastomer flow with Prandtl variable in the presence of internal heat generation. The temperature-dependent physical properties such as velocity, contour temperature, surface temperature as a function of contour velocity, and pressure are considered and discussed. Moreover, the exchange of energy from the surface to the fluids is examined through the variation in the Rayleigh number.

1. Introduction

A gained considerable attention has been raised in the field of elastomer fluid and heat transfer thanks to the application in MRE composites. The role of filler particles within the elastomer fluid plays an important role in the application of shear mechanism in devices such as damper, vibrators, and resonators.[1–3] The raw materials of polymer used in extrusion, filaments during drawing and injection method can significantly change the flow field in terms of friction coefficients and the heat transfer at the surface.[4,5] That is the reason its initially to study of heat transfer and distribution in fixed boundary surface with top and bottom layer with thermal insulation properties and pressure points at the four corners. **Figure 1** portrays the sketch of the square box for the flow of polymer melt with thermal insulation boundary point and temperature distribution sides. The fluid fills a square cavity with impermeable walls so the fluid flows freely within it but without getting out. The right and left edges of the cavity are, respectively, the high and low temperature sources. The upper and lower boundaries are insulated. The temperature differential produces the density variation that drives the buoyant flow.

The laminar flow and heat transfer interfaces in this example are two-way coupled defining a force dependent on the temperature and the fluid velocity transports heat. The incompressible Navier-Stokes equations with a Boussinesq buoyancy term on the right-hand side to account for the lifting force due to the thermal expansion[6,7]

$$\rho_0(u \cdot \nabla)u = \nabla p + \nabla \cdot \mu(\nabla u + (\nabla u)^T) + \rho_0 g \alpha_p (T - T_0) \quad (1)$$

$$\nabla \cdot u = 0 \quad (2)$$

In these expressions, the dependent variables for the flow are u, the vector of fluid velocity, and the pressure, p. T represents temperature, T_0 is a reference temperature, g denotes gravity acceleration, ρ_0 gives the reference density, μ is the dynamic viscosity.

The heat balance comes from the conduction-convection equation

$$\rho_0 C_p u \cdot \nabla T - \nabla \cdot (k \nabla T) = 0 \quad (3)$$

where k denotes the thermal conductivity, and C_p is the specific heat capacity of the fluid.

For the Navier-Stokes equations, impermeable, no-slip boundary conditions apply. The no-slip condition results in zero velocity at the wall, with pressure within the domain remaining undefined.

The boundary conditions for the heat transfer interface are the fixed high and low temperatures on the vertical walls, with insulation conditions elsewhere, as shown in Figure 1.

The physical properties of the elastomer fluid may change with variation in temperature distribution. The heat generated in elastomer fluid increases the temperature significantly by reducing the physical properties across the momentum boundary layer and it may affect near the wall. Therefore, to predict the flow behavior accurately, it is essential to take into consideration the physical properties as a function of the temperature. All the calculations are carried out with thermophysical effects and variable Rayleigh number (R_a).

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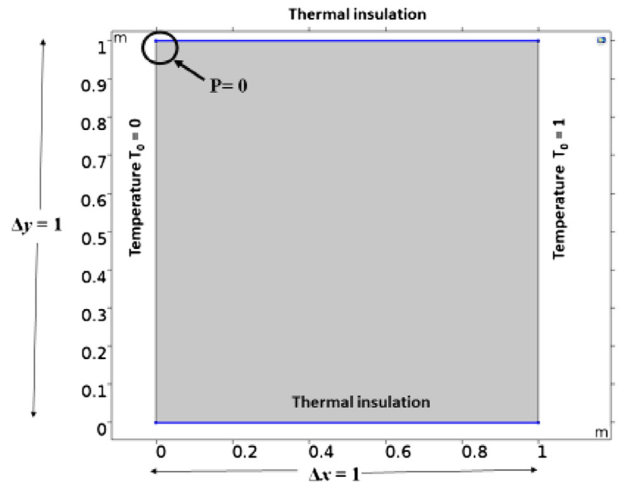

Figure 1. Sketch of square and boundary layer of thermal insulation and temperature distribution side for elastomer fluid at pressure P = 0, from lower boundary T = 0 to upper boundary T = 1.

2. Results of Simulation Models

The adopted model addresses a wide range of cavity sizes, fluid properties, and temperature drops using material properties set up with nondimensional Rayleigh and Prandtl numbers. The Rayleigh number, $R_a = (C_p \rho^2 g \alpha_p T L^3)/(\mu k)$, gives the ratio of buoyant to viscous forces where, L is the length of a side wall. The Prandtl number, $P_r = (\mu C_p/k)$, gives the ratio of kinematic viscosity to thermal diffusivity. Setting the body force in the y-direction for the momentum equation to $F_y = (R_a / P_r)(T - T_c)$, and the fluid properties to $C_p = P_r$, and $\rho = \mu = k = 1$, produces a set of equations with nondimensional variables p, u, and T. The steady state of 2D flow over a square box with length 1 mm is considered in this study. The fluid is assumed to be viscous, incompressible, and nonconducting in nature. It is assumed that elastomer fluid is free pass through the inlet of the chamber. Thermophysical properties such as flow velocity, surface contour temperature, pressure, surface temperature as a function of contour velocity changes as the function of Rayleigh number, displaying the respective as a function of the heat distribution. **Figures 2–5** show velocity, contour temperature, surface temperature, and pressure distribution in the elastomer fluid.

As R_a increases, viscous forces decrease. The element size near temperature boundaries corresponds to the thickness of the boundary layer at $R_a = 10^6$.

3. Conclusion

The results summarize temperatures (surface), velocity fields (arrows), and x-velocities (contours) at different R_a values. The complexity of the convection increases at higher values of R_a. The non-isothermal flow interface provided with the laminar flow interface using the Boussinesq approach, however, demonstrates a well-established method for reducing computational efforts while still representing buoyant flow.[8–11] The outcome result represents the high velocities near the lateral walls due to buoyancy effects that's due to the cavity is closed, the pressure distribution is solely due to gravity.

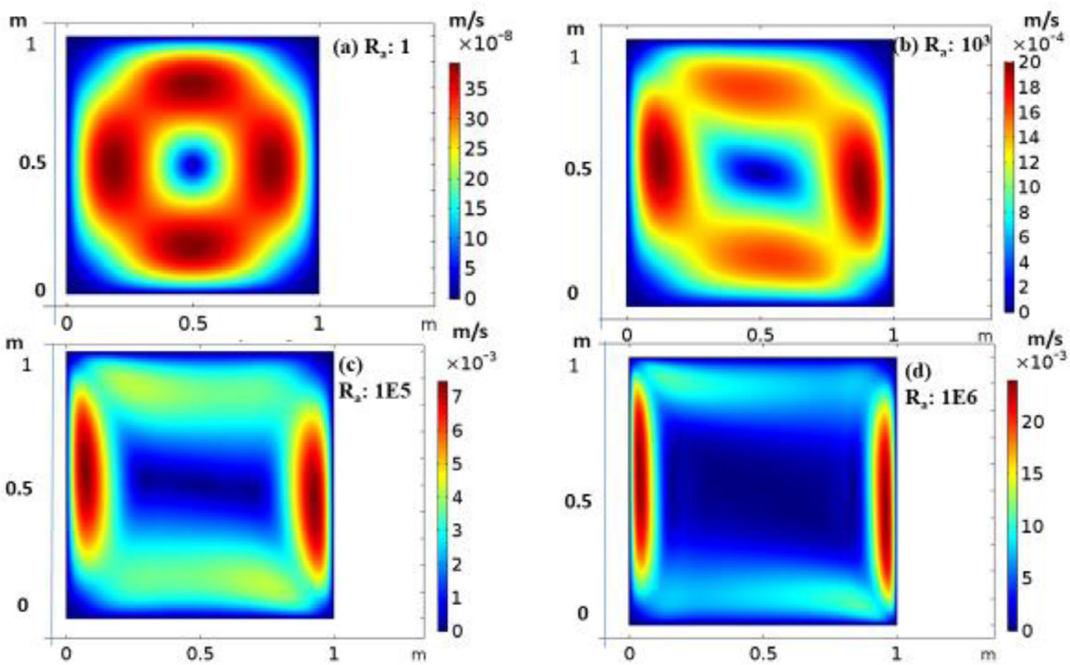

Figure 2. 2D presentation of velocity in magnitude (m s^{-1}) at various Rayleigh number (R_a) a) R_a: 1 b) R_a: 10 000 c) R_a: 1E5 d) R_a: 1E6.

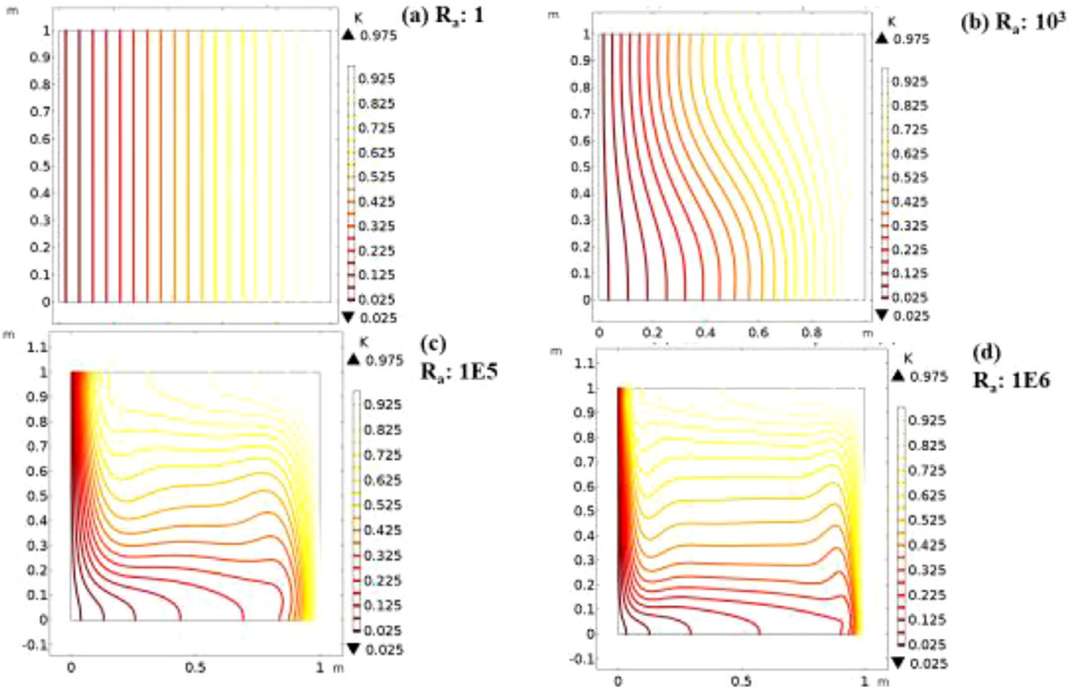

Figure 3. Contour temperature at various R_a a) R_a: 1 b) R_a: 10 000 c) R_a: 1E5 d) R_a: 1E6.

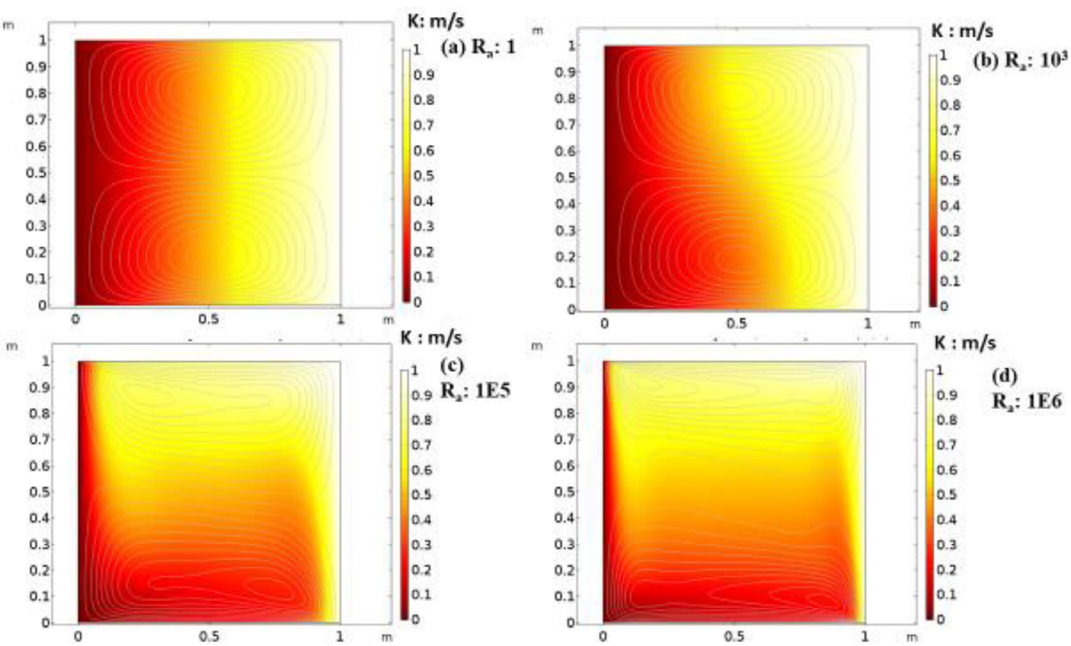

Figure 4. Surface temperature as the representation of contours velocity within the elastomer sample.

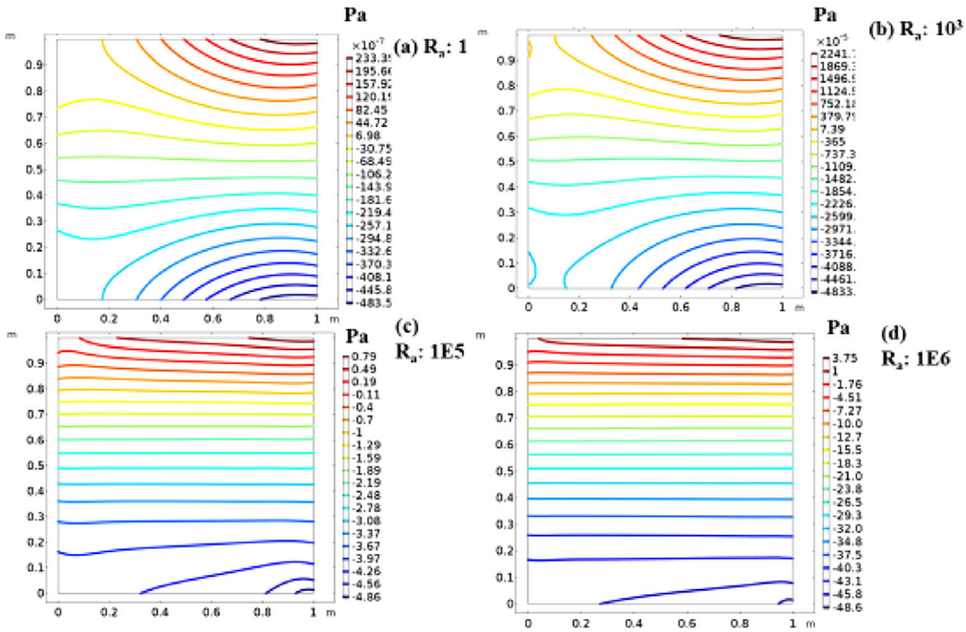

Figure 5. Contour pressure as the function of various R_a in the silicone elastomer.

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Conflict of Interest

The authors declare no conflict of interest.

Keywords

boundary layer, cylinder, elastomer flow, thermophysical properties, variable Rayleigh

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