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Non-Newtonian fluid flow in a long-distance pipe with circular cross section

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In many chemical and process industries, the fluid should pump through pipes over long distances from a storage to various processing plants. The substantial frictional pressure loss both in the pipeline and in the individual units is a common problem in these applications. Therefore, it is often necessary to calculate the pressure gradient, selection of optimum pipe diameter, and the flow rate. In this work, we develop a mathematical model for the description of the laminar, steady and incompressible fully developed flow of a Non-Newtonian polymer fluid in a circular tube of constant radius. The fluid flow has been studied using the Giesekus fluid model and the radial stress equations. Navier Stokes equations have been used as the governing equations and Giesekus constitutive relation has been used to model the stress tensor. No-slip boundary conditions at the outer wall and non-singularity conditions at the centre have been used to close the system. Non-dimensionalized coupled problem has been solved analytically for the velocity field and volumetric flow rate for optimal flow parameters, namely, the Giesekus parameter, Deborah number and pressure gradient. The maximum constant pressure gradient has been calculated and the behavior of the velocity profiles and the corresponding flow rate of the fluid flow has been computed. The simulation results indicate that for fixed Giesekus parameter and Deborah number, an increase of the ratio of relaxation time of the viscoelastic fluid and the shear viscosity increases the velocity. Furthermore, for a fixed ratio of relaxation time and the shear viscosity and fixed Deborah number, a decrease of the Giesekus parameter increases the velocity. Also, it can be concluded that the negative pressure gradient with the maximum value of the Deborah number provides the maximum velocity field and the maximum fluid flow rate.

Keywords: Deborah Number, Fully developed pipe flow, Giesekus fluid, Non-Newtonian fluid, Pressure gradient