Abstract

The present thesis investigates unsteady solute dispersion in pulsatile, non-Newtonian fluid flow through a circular tube, emphasizing its relevance to physiological and biomedical transport processes such as blood flow and targeted drug delivery. The primary objective of this work is to analyze how complex rheological properties, body acceleration and deceleration, wall absorption, and pulsatile pressure gradient influences solute transport behavior, considering higher order statistics.

Earlier studies on solute dispersion were largely confined to steady-state or long-time Gaussian and non-Gaussian approximations in Newtonian and non-Newtonian flows. In this thesis, several non-Newtonian fluid models are employed to represent the rheological behavior of blood and similar complex fluids, including the Ellis, Casson, Herschel–Bulkley, Bingham, and power-law models. These models account for shear-thinning and yield-stress effects that play a crucial role in microcirculatory and physiological environments.

This investigation considers both steady and unsteady flow conditions, with and without wall absorption. The unsteady flow incorporates the pulsatile nature of blood and the effects of periodic body acceleration and deceleration. Three flow and dispersion regimes are examined viscous diffusive, viscous unsteady, and fully unsteady regimes characterized by the interaction between the Péclet number (Pe), Womersley frequency parameter (α), and oscillatory Péclet number ($\mathcal{P}^2$), which includes the Schmidt number (Sc). A new nondimensional time scaling, $t = t'\omega$ (where ω is the frequency of body acceleration), is adopted to more effectively represent unsteady effects, in contrast to the traditional $t_1 = D_m t'/R^2$ scaling used in earlier dispersion studies. This new formulation simplifies the governing equations by preserving the sinusoidal form of the pressure gradient and establishes a relationship between the old and new scalings through $t = \alpha^2 \times Sc \times t_1$. Analytical and numerical techniques are employed to solve the convection–diffusion equation governing solute transport. The Aris' method of moments is used to compute higher-order statistical moments—namely, the exchange ($K_0(t)$), convection (K_1), dispersion (K_2), skewness (K_3), and kurtosis (K_4) coefficients allowing a detailed characterization of non-Gaussian behavior. For low Womersley parameters ($\alpha < 1$), analytical solutions are derived using perturbation techniques, while for higher frequencies, numerical simulations are performed using a computationally explicit Runge–Kutta (CERK) method. The results obtained from these different approaches show strong agreement, validating the adopted models and methods.

The findings reveal that parameters such as yield stress, wall absorption, body acceleration, pulsation amplitude, and rheological indices significantly affect solute transport. Yield stress and wall absorption tend to suppress dispersion and reduce solute spreading, whereas body acceleration and pulsatile pressure enhance mixing and transport rates. The oscillatory Péclet number plays a dominant role in separating dispersion regimes and determining whether the solute distribution exhibits Gaussian or non-Gaussian characteristics. Higher-order effects, reflected through skewness and kurtosis, illustrate asymmetry and sharpness in concentration profiles, which gradually decay toward Gaussian behavior at long times.

Overall, this study provides a unified framework to understand solute dispersion in pulsatile non-Newtonian flows. It emphasizes that unsteady effects, non-Newtonian rheology, and physiological forces significantly control solute transport. The findings have direct relevance to biomedical and engineering applications, including drug delivery, nutrient transport, microfluidic design, and pulsatile flow systems in medical devices.

Keywords : Pulsatile flow, Solute dispersion, Body acceleration, Non-Newtonian fluid, Blood rheology, Wall absorption, Skewness, Kurtosis, Non-Gaussianity, Axial mean concentration, Method of moments.