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Fluid mechanics of mixing in a two-dimensional stirred: regimes and mechanisms

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DATE

Abstract

Mixing involves blending fluids to reduce heterogeneities in, e.g., solute concentration, temperature, density, viscosity, or other rheological characteristics. This essential process is ubiquitous, occurring naturally and across various industries, including wastewater management, food processing, cosmetics production, pharmaceutical development, and oil extraction. This study investigates mixing mechanisms and regimes in an infinite, two-dimensional domain. The domain is initially filled with a quiescent Newtonian fluid, where the bottom half of the domain is marked with a passive dye. Stirring is promoted by moving a stirrer on a circular path. We explore the flow and mixing development when the flow is laminar. We identify three distinct mixing regimes, depending on the rate of stirring: (i) Regime I, where a central well-mixed region forms rapidly after the onset of mixing and then grows monotonically, and the normalized variance of dye concentration follows an exponential decay; (ii) Regime II, distinguished by the azimuthal and radial movement of the well-mixed region away from the domain center; and (iii) Regime III, characterized by extensive stretching and deformation of the interface beyond the central region. The mixing mechanism observed in the different regimes and the connection with momentum transfer is explained using the development of the vorticity field. We further classify the mixing regimes using Fourier analysis of hydrodynamic forces on the stirrer, identifying distinct spectral features associated with each regime. Mixing efficiencies are quantified in terms of time and energy, showing that mixing at higher stirring rates is time-efficient, while mixing at lower stirring rates maybe more energy-efficient overall.

Keywords-component

Mixing; Laminar; Stirred tanks; Flow regimes

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