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A numerical investigation on rheological turbulent flow through a 90° mixing elbow

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Abstract

Mixing elbows are widely used in various industrial processes to mix two different Newtonian or non-Newtonian fluids under turbulent flow conditions. This study numerically investigates the fluid flow and mixing characteristics in 90-degree elbows with different bend curvatures (curvature ratios of 3, 6, and 9) and Reynolds numbers ranging from 1×10^4 to 5×10^5 for both fluid types. The Reynolds-Averaged Navier–Stokes equations are solved using the turbulent k-epsilon model in ANSYS Fluent. Results show that the bend curvature creates an adverse pressure gradient that drives secondary flows, which become more pronounced with higher Reynolds numbers and lower curvature ratios. Higher Reynolds numbers improve mixing quality, as indicated by velocity and temperature variations quantified using standard deviations. For Reynolds numbers in the range of 10^4, velocity fluctuations initially increase, but at higher values ($\sim 10^5$), they decrease, even by up to 64% as the Reynolds number rises from 1×10^5 to 5×10^5. Similarly, increasing the curvature ratio enhances mixing efficiency, with a 32% reduction in velocity fluctuations when the curvature ratio increases from 6 to 9. Furthermore, shear-thinning fluids ($n = 0.6$) exhibit superior mixing performance, with a standard deviation of velocity fluctuations at the outlet of 0.32, compared to 0.54 for shear-thickening fluids ($n = 1.4$). In terms of temperature fluctuations also, a similar trend is observed. These findings are valuable for optimizing mixing and fluid transport in industries such as chemical processing and food production, where effective mixing of complex fluids is critical. This study provides insights for improving the design of mixing systems that handle fluids with various rheological characteristics.

Keywords: Mixing efficiency, Non-Newtonian fluid, Computational fluid dynamics (CFD), $k-\varepsilon$ model, Secondary flow

Introduction

The mixing elbow, which is typically a component of piping system, is essential in several industries like water treatment, polymer, food processing, chemical, and nuclear power plants as it is commonly employed in mixing and transfer of fluids with two different sets of flowing parameters. When it is necessary to successfully mix two or more liquids or gasses, an industrial setting frequently utilizes a mixing elbow as a pipe fitting. When reactions or downstream performance depend on the fluid mixture's homogeneity, this feature is especially helpful. In the food (yogurt, ketchup, mayonnaise), pharmaceutical