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Optimizing Two-Phase Flow Dynamics in Bubble Column Reactors and Airlift Pumps: Insights into Mixing Efficiency and Fluid Density Effects

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Abstract

Bubble Column Reactors (BCRs) and airlift pump systems play a crucial role in various industrial applications that require efficient gas-liquid interaction, heat and mass transfer, and fluid circulation. These systems are widely utilized in chemical processing, CO_2 capture, algae cultivation, aquaculture, and water treatment due to their ability to enhance mixing and circulation while minimizing energy consumption and maintenance requirements. Among these technologies, external loop airlift systems have been identified as highly effective in optimizing flow circulation within BCRs, while airlift pumps demonstrate superior performance in handling multiphase flows with minimal mechanical complexity. Despite their advantages, understanding the complex two-phase flow dynamics governing their operation remains critical for achieving improved system performance and efficiency. This study explores the fluid dynamics and liquid mixing behavior within a bubble column reactor equipped with an external loop airlift system and examines the Taylor bubble behavior in an airlift pump under varying liquid densities. High-resolution Particle Image Velocimetry (PIV) was employed to analyze velocity profiles, turbulence intensity, and vorticity in the BCR system, providing detailed insights into the mixing efficiency. Experiments were conducted with total water flow rates of 10 LPM, a static water head of 43.5 inches, and a reactor diameter of 6 inches. The study investigates the optimal mixing performance and flow structures contributed to enhanced mass transfer. In addition, the performance of airlift pump in the recirculating loop was separately investigated to determine the influence of liquid density on the performance of an airlift pump equipped with an angled axial air injector. Liquid densities were varied from 1000 to 1100 kg/m^3 by adjusting salt concentration, and Taylor bubble characteristics were captured using high-speed imaging. Results demonstrated that as liquid density increased, the airflow required to sustain the lifting effect also increased, leading to a decrease in pump efficiency. Slug lengths were observed to decrease as liquid density increased, with corresponding 10% reduction in slug velocities. These findings emphasize the strong dependence of airlift pump performance on fluid properties, highlighting the need for density-specific design optimizations. The results from this study provide valuable insights for optimizing reactor mixing efficiency and airlift pump performance. This knowledge can contribute to enhanced system design in industries where efficient two-phase flow and mass transfer are essential, such as wastewater treatment, energy production, and bioengineering applications.