Towards understanding the interfacial mass transfer during CO2 capture: Basic Flow Forms of Twin-Liquid Films with Counter-current Gas Shear

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Abstract:

With the intensification of the global greenhouse effect and the various environmental problems it brings, it is necessary to forcibly reduce and limit CO_2 emissions, as well as capture and store CO_2 generated in industrial production processes. Chemical absorption carbon capture technology (using packing towers as the main absorption-desorption equipment and complex adsorbent including alcohol amine solutions, ionic liquids, lean organic solvents etc.) is currently the most promising, widely used, and widely recognized technology route for achieving large-scale industrialization. However, the high viscosity of high-performance absorbents and the high energy consumption during the capture process severely limit the large-scale industrial application of current chemical absorption carbon capture technology.

The essence of the absorption and desorption process during CO2 capture is the interfacial mass transfer between gas-liquid phases, which significantly affects the energy consumption of the process. The key to determining the mass transfer efficiency between gas-liquid phases in a packed tower lies in the liquid film flow characteristics on the surface of the packing. Twin-liquid film is a new gas-liquid contact element proposed by our research group in recent years. A twin-liquid film combines wall-bounded film supported by a solid wall and confined free film through the opening window. The interplay between each twin film endows distinct features and has been found to enhance mass transfer performance without additional energy consumption[1-3]. Previous studies have shown that under low viscosity conditions, twin-liquid film can increase mass transfer rates by 100% to 400% due to their unique wave and vortex structures that disturb and curl the interface concentration

boundary layer. And as the liquid viscosity increases, the violent acceleration and thinning of the confined free film cause the concentration boundary layer to stretch, effectively enhancing convective mass transfer and lateral diffusion.

However, the above-mentioned studies on twin-liquid films have ignored the influence of shear effect by the counter-current gas flow, and the film flows under laminar flow conditions. This article uses high speed digital camera to systematically observe the turbulence flow behavior of the twin-liquid film under strong gas shear conditions. Several different shaped windows and five different fluids with Kapitza number ranging from 10 to 3300 have been investigated. As the liquid Reynolds number and gas velocity change, various free surface flow modes such as droplets, liquid columns, liquid films, and bubbles can be observed coexisting and transitioning in the window area. Meanwhile, some interesting free surface flow patterns such as bubble entrainment, formation, and fragmentation caused by gas shear, ligament rupture and bag rupture of liquid film have been observed. Experimental observations show that the gas velocity has almost no effect on the flow pattern of the confined free film inside the window when the gas velocity is less than about 3m/s. Under strong gas shear conditions, as the liquid Reynolds number increases, the confined free film undergoes three states in sequence: non film formation, dynamic film formation, and stable film formation.

Based on experimental data, a dimensionless empirical correlation has been obtained for the critical conditions of flow pattern conversion, which are related to liquid properties (Weber number), operating conditions (gas and liquid velocities), and window geometry. Based on the force balance conditions, the gas-liquid interfacial friction coefficients of twin-liquid films under different operating conditions and window geometry has been obtained. The multiple and dynamic flow structures of twin-liquid films under turbulent and strong shear conditions presented in this present work expand the mass transfer enhancement mechanism of twin-liquid films, broaden the traditional knowledge of liquid flow in packed towers, and clarify the mechanism of mass transfer intensification for the perforated packings.

Keywords: Twin-liquid film; Flow transition; Free surface turbulence; Gas shear

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