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Characterisation of gas mixing in water and pulp-suspension flow based on electrical resistance tomography

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HIGHLIGHTS

- ▶ Gas mixing in horizontal developing flow was examined for 0–3.0 wt.% pulp suspensions.
- ▶ A gas mixing index and scale of segregation characterised gas hydrodynamics.
- ▶ Gas dispersion in turbulent suspension flow was similar to that for water flow.
- ▶ Fibre networks caused bubbles to concentrate near the pipe wall for plug flow.
- ▶ Adding resistor adaptors resolved anomalous ERT data for stratified air–water flow.

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ABSTRACT

Gas dispersion in horizontal developing pipe flow downstream of a 90°-tee mixer and an in-line mechanical mixer was investigated by means of electrical resistance tomography (ERT) for both water and softwood kraft pulp suspensions over a range of fibre mass concentrations (0–3.0%), superficial liquid/pulp velocities (0.5–5.0 m/s) and superficial gas velocities (0.11–0.44 m/s). A gas mixing index, derived from the standard deviation of local gas holdup in each image pixel, quantified the uniformity of gas in cross-sectional planes along the pipe for various flow patterns. The distribution of the gas phase in a cross-section was determined from the vertical gas holdup profiles, and the relative size of gaseous entities for different flow conditions was evaluated based on the scale of segregation. For air–water flow, the gas uniformity and size of gaseous entities depended strongly on the flow pattern. For pulp fibre suspensions, the gas flow varied significantly depending on the flow regime. Mixing was similar to that in water when the flow was turbulent for dilute suspensions, but differed greatly for higher mass concentrations, likely due to robust fibre networks of a plug in the core of the pipe causing bubbles to concentrate near the wall and accelerating coalescence. The impeller disrupted the plug and distributed gas throughout the cross-section, leading to significantly improved gas uniformity in the high-shear zone around the impeller, but decaying turbulence and re-establishment of fibre networks caused bubbles to coalesce at the top of the pipe and worse mixing downstream.

1. Introduction

Effective contacting of a gas phase with pulp and its uniformity in suspension are essential for three-phase (gas–water–fibre) systems in various pulping operations such as oxygen delignification, oxidative extraction and ozone bleaching. Good mixing provides the uniform dispersion of the gas phase and high interfacial area between the phases, promoting mass transfer and hence overall reaction. Pre-distribution of the gas phase in pulp suspensions is usually achieved by in-line mixers ahead of tower reactors. Gas is injected into pulp suspensions, with fibre mass concentration, C_m, from 8% to 14% and void fraction between 0.11 and 0.26 [1,2], ahead of various mixers, including peg and high-shear mixers, and the mixture then flows along the pipes before entering the tower reactors. In spite of its importance, gas-suspension contacting is not well characterised, with literature on gas dispersion in pulp suspension flow in horizontal pipes being rare.

Gas–liquid two-phase horizontal flow also occurs in various industrial applications. The distribution of gas in this flow depends on several factors including gas-to-liquid flow ratio, fluid properties and pipe geometry. Several flow regimes have been identified, e.g. Govier and Aziz [3], Mandhane et al. [4], Taitel and Dukler [5] and Barnea [6]; most authors agree on six flow patterns: stratified flow, wave flow, slug flow, annular flow, elongated bubble (or plug)

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