Gas Flow Modulation: a suitable approach for axially-resolved measurements of axial gas dispersion in bubble column reactors.

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Highlights

- Gas flow modulation is a tracer-free approach to measure axial gas dispersion in bubble columns.
- Gas flow modulation allows to measure dispersion at different axial positions in the column.
- Obtained experimental data allow refining traditional reactor models for improved reactor design.

1. Introduction

Dispersion phenomena, such as back-mixing, recirculation, and stagnant zones, significantly influence the residence time of the fluid phases in bubble column reactors. Despite some limitations, the axial dispersion model (ADM) is currently the most applied reactor model accounting for axial flow non-idealities [1]. This is mainly due to its simple implementation and to the use of one single parameter, called axial dispersion coefficient.

Traditionally, the axial dispersion coefficient is obtained based on the measured residence-time distribution of an inert tracer substance. While liquid dispersion has been largely investigated in the literature, only very few studies deal with gas dispersion. This is mainly due to the technical challenges connected to gas dispersion measurements, which are summarized in Marchini et al. [2]. As pointed out by Joshi [3], the axial gas dispersion coefficient likely changes along the column height, following, among others, a change in the physical-chemical properties due to progressing chemical reaction or hydrostatic pressure gradients. Technical limitations of traditional tracer methods hardly provide local information on axial gas dispersion. Consequently, the axial gas dispersion coefficient has been assumed axially constant for reactor design.

To overcome these disadvantages of traditional tracer methods, Hampel et al. [4] introduced a novel non-invasive approach for determining the axial gas dispersion coefficient in bubble columns, called Gas Flow Modulation (GFM). Instead of a tracer substance, a marginal sinusoidal modulation is superimposed to the gas inlet flow rate and used as a virtual tracer. This modulation introduces a sinusoidal variation of the gas holdup in time, called gas holdup wave. Along the column, the gas holdup wave is damped in amplitude (A_{ϵ}) and is shifted in phase (ϕ) due to gas dispersion. Amplitude damping and phase shift between two axial positions can be measured and related to the value of the axial dispersion coefficient via the ADM. Using the GFM, the obtained axial gas dispersion coefficient is representative of the flow conditions between the two considered measurement planes.

2. Methods

In the proposed contribution, GFM was applied for measuring the axial gas dispersion coefficient in a bubble column (Ø 50 mm) equipped with a perforated plate gas sparger (2 mm holes , 1% free fractional area) and operated with air-water. Gas was continuously fed at the bottom into a liquid batch. A gas flow modulation with 0.2 Hz frequency and 15% initial amplitude was superimposed to the gas flow. As shown by Marchini et al. [5], such low frequency modulation does not alter the flow conditions. Experiments were performed at several gas superficial velocities (u_{G}).

The gas holdup wave was investigated at three axial positions (z_1, z_2, z_3) using modulation-synchonized gamma-ray densitometry (see Figure 1a). To account for the change in the axial dispersion coefficient (expressed in terms of the Bodenstein number) along the column height, the reactor is conceptually divided into two compartments and described with the classical ADM, changing the Bodenstein number at the compartment interface. To avoid non-physical discontinuities in the obtained concentration profile, the spatial domain is numerically treated as a continuum. Danckwerts and Neumann boundary conditions are considered at reactor inlet and outlet, respectively, which is common standard for the ADM [1].

3. Results and discussion

The calculated Bodenstein numbers for the two column compartments are shown in Figure 1b. It should be noted that the Bodenstein number in each compartment was calculated using the total reactor height ($H_{\text{tot}} = 0.9$ m) and the bubble swarm velocity, estimated as the ratio between gas superficial velocity and holdup.

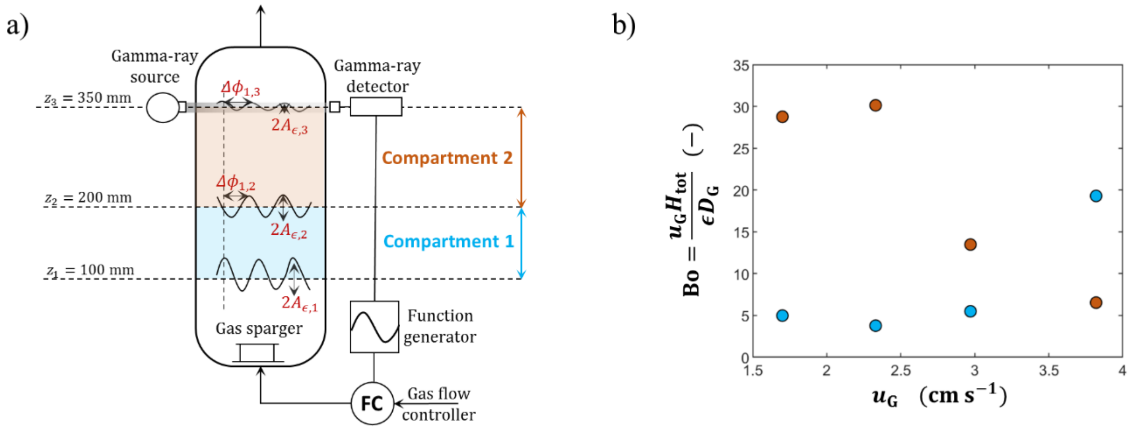

Figure 1. (a) Schematic of the experimental setup, gas flow modulation working principle and selected compartments for applying the refined axial dispersion model; (b) Bodenstein number calculated in the identified compartments (color legend see Figure 1a) as a function of the gas superficial velocity.

To show the effect of an axially changing axial gas dispersion coefficient, the measured Bodenstein numbers were then implemented into the refined ADM for several arbitrarily assumed Damköhler numbers. The results showed that assuming a constant axial gas dispersion coefficient along the reactor can introduce significant deviations in the predicted conversion, depending on the reaction characteristics and on the hydrodynamics of the system.

4. Conclusions

GFM allows quantifying axial gas dispersion in different axial regions of columns, which was impossible with traditional tracer methods. The new approach opens up possibilities for refining existing reactor models and advancing the reliability of performance prediction. Despite dispersion is often regarded as a detrimental phenomenon, it can also prove advantageous, for example, in case of an autocatalytic reaction. Access to local dispersion coefficients opens up possibilities for improved reactor designs.

References

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Keywords
Gas flow modulation, Bubble columns, Axial dispersion model, Axial gas dispersion