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Decoupling electrostatic signals from gas–solid bubbling fluidized beds

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ABSTRACT

Electrostatic signals registered by collision probes in gas–solid fluidized beds contain useful information. However, the signal has been poorly understood, with questions, such as what the signal means and how to extract useful information, being unanswered. In this study, different decoupling methods based on a simple charge transfer and induction model are proposed and applied to obtain both the particle charge density and the bubble rise velocity by decoupling electrostatic charge/current signals from a previously developed dual-material probe in both two- and three-dimensional freely bubbling fluidized beds. A signal processing procedure including a bubble selection algorithm is proposed and applied to screen electrostatic signals from the probe in bubbling fluidized beds. Decoupled results from two selected methods showed consistent trends and had the same order of magnitudes as those obtained from the analysis of video images and Faraday cup measurements. The effects of the bubble selection algorithm criteria on interpreted results are also investigated.

1. Introduction

Electrostatic charges build up in gas-fluidized beds due to an imbalance between charge generation and dissipation. These charges can significantly upset reactor operation, e.g. by causing reactor wall fouling in commercial gas phase polyethylene production reactors [1,2].

Electrostatic charge signals registered by collision probes, a common measurement tool in industry, are poorly understood. Several statistical values can be used to represent the measured current signals, including simple averaging, root mean square, standard deviation and average of the absolute value of the base current signals. The periods of signal acquisition and processing also vary, ranging from 10 ms to 10 h[2]. Some studies show that the electrostatic signals can provide useful information on local fluidization characteristics [3], moisture content [4], proportion of fines in the bed [5] and bed level [6].

From statistical analysis, the electrostatic signals measured by the probe are related to bed hydrodynamics. Boland et al. [7] observed that the voltage signals from a shielded ball probe are similar in trend to pressure signals from the bed. The mean current/charge generally represents the net transferred part, while the standard deviation of current/charge is related to the net induction part [8]. Liu et al.[9] found standard deviations of both pressure drop and cumulative charges on polyethylene particles in a pressurized gas–solid fluidized column increased when the superficial gas velocity increased, and the characteristic frequency of cumulative charges changed consistently with the pressure drop signals. Tiyapiboonchaiya et al. [10] used several copper strips to measure the average current in a Plexiglas column when fluidizing polypropylene particles. It was found that the average current reached a maximum in the lower part of the bed and decreased with increasing height, because of more collisions and friction with higher inlet gas velocity. Park and Fan [11] studied electrostatic phenomena of high density polyethylene (HDPE) particles in a gas–liquid–solid fluidized bed, with liquid as the continuum phase. Their work indicated that the mean voltage signal measured by a commercial electrostatic probe did not change significantly with superficial gas velocity, whereas the standard deviation of the voltage output increased as the superficial gas velocity increased. As the superficial liquid velocity increased, the magnitude of both mean and standard deviation of the voltage output increased. Cheng et al. [12,13] investigated the electrostatics of sand particles by placing insulated copper rings outside the walls in the developed regions of the riser, downer and gas-sealing bed of a triple-bed circulating fluidized bed. With increasing superficial velocity in the gas-sealing bed, the average induced currents first increased and then approached a constant, consistent with the variation of solid flux and average solids holdup. With increasing superficial gas velocity in the riser, the average induced current in the riser increased, whereas the average induced current decreased in the downer with increasing superficial air velocity.

Electrostatic signals have been also examined by time-frequency analysis [9,13,14] and by chaotic analysis [15]. Both options again show that the signals are influenced by local hydrodynamics. The signals contain useful information on charge levels in fluidized beds coupled with hydrodynamics. Chen et al. [16] tried to deduce particle charge density from charge signal by a ball probe in the single bubble injection experiments. Bubble size was estimated from the known bubble volume, and charge density was estimated by inserting bubble diameter into the induced charge equation. Bi [8] proposed that the standard

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deviation be normalized by the average value to cancel out the particle charge density term, thereby exposing the local hydrodynamics. He et al. [17] recently developed a dual-material probe consisting of two tips of different materials and, for the first time, used it to extract charge density and bubble rise velocity from two different signals of the dual-material probe. The decoupling of signals from the tips is based on inserting two peak values from the two tips of the probe into two calibration equations obtained for each tip of the probe to solve the two equations for two unknowns. Because the decoupling heavily relied on the accuracy of the calibration of the two tips of different materials, which are assumed to remain unchanged during the tests, any slight change, either physical or mechanical, in one probe tip may potentially induce substantial errors on the decoupled charge density when the probe is installed in the commercial fluidized bed reactors for monitoring electrostatics. Different decoupling methods or procedures should be developed to improve the accuracy, reliability and reproducibility of the dual-material probe.

This paper reports our latest work on developing a novel collision probe system to extract the particle charge density and bubble rise velocity from electrostatic signals. Several signal decoupling methods are proposed based on a charge transfer and induction model [18,19], and signal selection criteria and processing procedures are developed to improve the data quality and stability of analysis. As a demonstration, signals from the dual-material probe were analyzed and the results from each method are compared with direct measurements in both two- and three-dimensional freely bubbling fluidized beds.

2. Signal processing

Charge/current signals measured by the dual-material probe in current study are processed by first selecting appropriate bubbles, followed by calculations using those selected bubbles. Also, raw electrostatic signals, especially those from large-scale reactors, need to be pre-treated to eliminate noise. The raw signal may also exhibit baseline drift, usually due to weak conductive isolation of the probe. Therefore, a proper signal conditioning may be needed to pre-treat the signals from larger-scale reactors. Two approaches can be taken to avoid or remove noise from signals: better grounding and shielding during signal acquisition, and applying filtration to the recorded data [20].

2.1. Peak (bubble) detection

The electrostatic signal responds to bubble movement inside a fluidized bed. Selecting the appropriate bubbles is important to eliminate irregular signals linked to bubble splitting, coalescence, rising obliquely or missing one of the two sensors. Bubble movement is related to peaks in electrostatic signal. Therefore to select bubbles, a bubble selection algorithm was developed in Matlab® as described in Fig. 2.

After the optional signal conditioning (de-noise and/or baseline correction), average current ($\bar{I}$) and its standard deviation (I_{sd}) can be calculated from the raw signal from the probe. A sudden increase or decrease of the current signal indicates passage of a bubble. All maximum and minimum peaks (I_{max} and I_{min}) are identified in the signals from the two tips, and two thresholds based on the average and standard deviation are defined to identify where the bubble passage starts (bubble nose) and where the bubble ends (bubble wake). Drops in current signals which do not cross the threshold may be due to signal changes not directly linked to bubble passage, or to irregular bubbles reaching the probe.

$$I_{\max,1}(i) > \bar{I}_1 + \varphi I_{sd,1} \quad I_{\min,1}(i) < \bar{I}_1 - \varphi I_{sd,1} \tag{1}$$

$$I_{\max,2}(i) > \bar{I}_2 + \varphi I_{sd,2} \quad I_{\min,2}(i) < \bar{I}_2 - \varphi I_{sd,2} \tag{2}$$

where φ is a coefficient to be chosen.

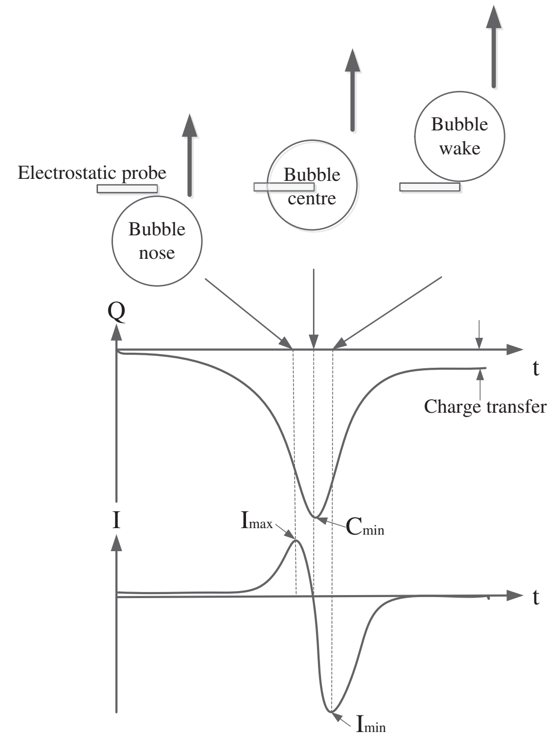

Fig. 1. Illustration of theoretical charge and current signals received from a collision probe when passed by a single bubble in a fluidized bed.

The extremes among the minima and maxima are obtained to ensure that only one minimum peak and one maximum peak exist within each signal segment, representing a single bubble. The time difference between adjacent maximum and minimum peaks from one tip represents the time for a single bubble to pass the probe, and is thus related to bubble size.

$$\Delta\tau_{B\max} \geq |t_{\max,1}(j) - t_{\min,1}(j)| \geq \Delta\tau_{B\min} \tag{3}$$

$$\Delta\tau_{B\max} \geq |t_{\max,2}(j) - t_{\min,2}(j)| \geq \Delta\tau_{B\min} \tag{4}$$

where the $\Delta\tau_{Bmax}$ and $\Delta\tau_{Bmin}$ represents time for maximum and minimum allowable bubbles to pass the probe. Above two criteria (Eqs. (1)–(4)) defines the peaks caused by passing bubbles for two tips separately.

2.2. Peak (bubble) selection

Signals from a second tip (electrode) of the probe were then used together with the first tip signals to select appropriate bubbles. These criteria are depending on how the two tips are configured. For example, for a dual-material probe with two tips side by side, the current peaks, from the two different materials should appear at the same time to ensure that the bubble contacted the two tips simultaneously, so that:

$$|t_{peak,1}(j) - t_{peak,2}(j)| \leq \lambda \tag{5}$$

where λ is the maximum tolerable time difference between current peaks from the two materials, and subscripts 1 and 2 represent the two materials.

Also the ratio of the current peaks from two materials represents the difference between the two materials. A smaller ratio means a larger difference between currents from two materials.