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Simultaneous measurements of particle charge density and bubble properties in gas-solid fluidized beds by dual-tip electrostatic probes

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HIGHLIGHTS

- An *in-situ* dual-tip probe measured particle charge density and bubble properties.
- Signal analysis and decoupling methods were proposed for this probe.
- Decoupled results were in agreement with those from direct measurements.
- Probes with three different configurations were tested in a fluidized bed.
- Glass beads and polyethylene particles were used as bed materials.

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ABSTRACT

The aim of this work was to develop a new dual-tip electrostatic probe for *in-situ* measurements of particle charge density and bubble properties in bubbling fluidized beds. Probes containing two retractable, vertically-aligned tips were tested in a lab-scale two-dimensional fluidized bed operated in both single bubble injection and freely bubbling modes, with glass beads and polyethylene particles of narrow size distributions as bed materials. Different decoupling methods were proposed and employed to analyze the electrostatic signals from the probes. The estimated particle charge density and bubble rise velocity were found to follow the same trends as those measured by a Faraday cup sampling system and obtained from video images respectively, with relative errors depending on the decoupling methods and probe configurations, especially for polyethylene particles.

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1. Introduction

Electrostatic charges in gas-solids fluidized bed reactors, resulting from a balance between charge generation and dissipation, can significantly affect reactor performance. Understanding electrostatic phenomena in fluidized bed has been hampered by the lack of suitable instrumentation. Although the charge density level on fluidized particles can assist on-line process monitoring, reliable, accurate and low-cost charge density measurement sensors are lacking.

A Faraday cup can determine the charge density directly, but as an off-line measurement tool, it is unable to monitor industrial reactors *in-situ*, and only net charge can be measured. Moreover, charge generation or dissipation during particle sampling may affect the measurement accuracy, and the Faraday cup is an open system susceptible to variations in environmental factors (Wong et al., in press). Despite this, the average charge density on bed particles, particles that adhered to the column wall and the particles that were entrained from the column were quantified by a Faraday cup fluidized column equipped with two separately Faraday cups at the top and bottom of the bed (Sowinski et al., 2010, 2012).

Collision probes, one type of electrostatic probe, are widely used by industry, especially in polyolefin processes. In fluidized beds, collision probes made of highly conductive materials can measure the charge or current induced and transferred to the probe by charged particles. Ciborowski and Wlodarski (1962) developed an electrode made of platinum wire (0.5 mm diameter), with a "small" (~5 mm diameter based on a photograph of the experimental setup) ball tip, tethered inside the fluidized bed by a silk thread and connected to an electrometer to measure the electrical potential in a glass fluidization column of 0.06 m inside diameter and 0.555 m height. Fujino et al. (1985) adopted a similar approach by inserting into the fluidized bed a spherical brass

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terminal of 6.0 mm diameter, tethered by a nylon thread and connected to an electrometer, with a grounded brass distributor plate serving as the reference electrode. Park et al. (2002a) and Chen et al. (2003b) mounted collision ball probes to measure charges induced and transferred by particles surrounding rising bubbles in a two-dimensional fluidized bed. Several researchers (Cheng et al., 2012; Moughrabiah et al., 2012; Tiyapiboonchaiya et al., 2012; Zhou et al., 2013) have installed electrostatic probes/sensors at various heights along their columns to measure the charge distribution inside fluidized beds.

Collision probes have rarely been employed for measuring particle charge densities in fluidized beds. A bifunctional electrostatic probe, composed of a bare portion and an insulated portion was claimed (Markel and Timothy, 2013) to be able to provide critical information for characterizing charges in the bed, the mechanism of charge generation, fluidization hydrodynamics, and the state of wall coatings. However, details of signal analysis and experimental results were not included in the patent. He et al. (revision submitted) developed a probe to measure particle charge density and bubble rise velocity from signals of two tips made of different materials. Two equations, representing current peak values from the two tips and depending on the properties of tip materials and particles, were developed to analyze the signals. However, the relative magnitudes of signals from these two tips may change for particles of different properties, causing difficulty in calibration the probe and decoupling the signals in the processes when particle properties, e.g. mean size and size distribution, may change with time. It would be also simpler if the probe tips could be made of a single material, with the bubble rise velocity measured directly from the cross-correlation/time lag between electrostatic signals from the two probe tips.

In pneumatic conveying, charges are mainly generated by collisions between particles and inner pipe walls. Cross-correlation of signals from separate electrostatic rings has been used to measure the solids flow rate and particle velocity (Gajewski, 2008; Yan et al., 1995) based on cross-correlation and calibration methods. Matsusaka et al. (2008) analyzed the electric signals detected from a metal pipe in dilute-phase gas-solids flow system. The current signals contained two sharp pulses corresponding to a cloud of charged particles passing the inlet and outlet of the detection pipe. It was claimed that the average velocity of a particle cloud in dilute phase pipe flow could be obtained from the time interval between the two peaks and the length of the detection pipe.

The hydrodynamics of bubbling fluidized beds are greatly influenced by bubble characteristics. The bubble properties of greatest interest are usually their size and rise velocity (Sobrino et al., 2009). Considerable effort has been dedicated to the measurement and characterization of bubbles. Measurement techniques can be classified as intrusive techniques, such as, optical fiber probes (Glicksman et al., 1987; Liu et al., 2010; Rüdisüli et al., 2012; Zhang and Bi, 2010) and capacitance probes (Werther and Molerus, 1973), and non-intrusive techniques, such as pressure fluctuation measurements (Bi, 2007; van der Schaaf et al., 2002), and X-rays (Rowe and Everett, 1972) or electrical capacitance tomography (McKeen and Pugsley, 2003). Optical fiber probes typically have light emitted by one fiber, reflected by solids particles in the bed and received by the other fiber(s). The bubble rise velocity can be determined by the time lag from vertically aligned probes. This technique has the advantage of providing local voidage information, but cannot withstand harsh reactor conditions (such as high temperature and high abrasion). Pressure fluctuation measurements are cheap and easy to implement, and are thus commonly used in both laboratory and commercial gas-solid fluidized beds. However, interpreting pressure fluctuation signals is challenging (Bi, 2007; Liu et al., 2010). X-ray and electrical capacitance tomography are expensive and difficult to implement in commercial-scale reactors.

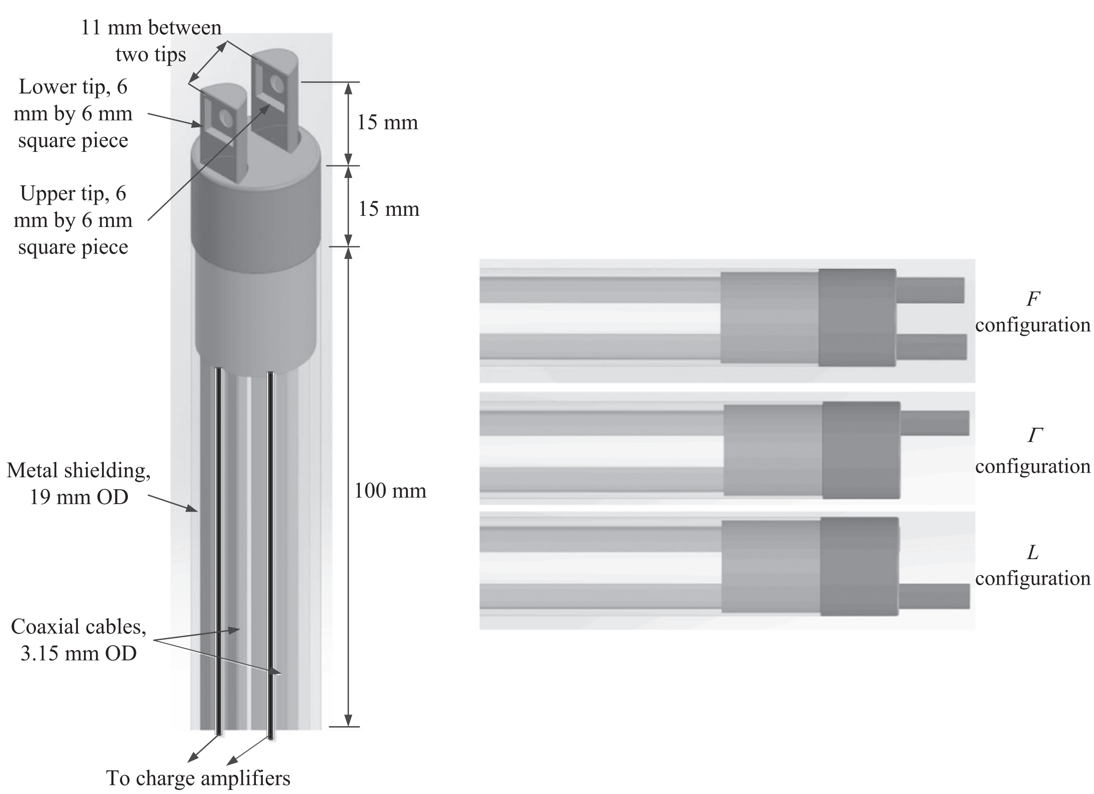

Fig. 1. Schematic of dual-tip electrostatic probe with: *F* configuration (two tips protruding); *Γ* configuration (upper tip protruding, lower tip retracted); *L* configuration (upper tip retracted, lower tip protruding).

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