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A comparative study of electrostatic current and pressure signals in a MSFC gas–solid fluidized bed

Qing Zhang [a], Kezeng Dong [a], Yefeng Zhou [b], Zhengliang Huang [a,*], Zuwei Liao [a], Jingdai Wang [a], Yongrong Yang [a], Fang Wang [a]

[a] State Key Laboratory of Chemical Engineering, College of Chemical and Biological Engineering, Zhejiang University, Hangzhou 310027, China
[b] Department of Chemical Engineering, College of Chemical Engineering, Xiangtan University, Xiangtan 411105, China

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ABSTRACT

Vigorous motion and circulation of insulated particles mostly driven by bubble motions lead to repeated particle–particle and particle–wall frictions in the gas–solid fluidized bed, which result in electrostatic charge generation and accumulation. Variations of electrostatic signals are significantly affected by bubble and particle motions and contain much dynamic information on the characteristics of bubble behaviors and particle movements. It is necessary to explore more information from electrostatic signals to gain a more comprehensive understanding of the relationship between electrostatic charges and hydrodynamics in the fluidized bed. A multistage Faraday cup (MSFC) fluidized bed was constructed in this work to simultaneously measure the electrostatic current and the pressure drop of each Faraday cup. Results indicated that these two signals showed a remarkable similarity in both time domain and frequency domain, especially in the upper part of the bed. In a Faraday cup, the pressure drop is proportional to the value of the average voidage, and meanwhile, the electrostatic current is relevant to the variation of the average voidage. Further analysis demonstrated that the electrostatic current was proportional to the first-order derivative of pressure drop from a Faraday cup when particles possessed the same volume and identical charge. This quantitative relationship provides a possibility for electrostatic signal to be employed to characterize bubble behaviors in a gas–solid fluidized bed.

1. Introduction

Gas–solid fluidized beds are widely applied in numerous industrial processes, such as coal combustion and gasification, drying, olefin polymerization and so on. The bubble flow created by injecting gas via a perforated or porous distributor leads to vigorous motion and circulation of solid particles inside the fluidized bed [1,2]. Consequently, electrostatic charge generation in dielectric particles is almost unavoidable due to repeated particle–particle and particle–wall frictions [3,4]. An excess charge buildup in the fluidized bed can cause problems such as wall sheeting [5], particle agglomeration [6,7], and even spark generation or explosion hazards [8,9]. The generation and variation of electrostatic charges are significantly affected by bubble and particle motions in the fluidized bed [10–14]. In other words, electrostatic signals in the fluidized bed contain much dynamic information on bubble and particle motions [15]. Therefore, it is possible to reveal the characteristics of bubble and particle movements through measurement and analysis of electrostatic signals in the gas–solid fluidized bed.

So far, two general methods have been mainly used to measure electrostatic charges in gas–solid fluidized beds, namely the electrostatic probe method and the Faraday cup method. Boland and Geldart [10] measured the generation of static electricity in a two-dimensional fluidized bed by using an electrostatic probe and found that the static electrification was generated by the motion of particles around gas bubbles, particularly in the bubble wake. Chen et al. [16] reported that the peaks of detected electrostatic charge were caused by the nose or wake of the bubbles contacting the electrostatic probe. Wang et al. [17] identified three zones in the fluidized bed based on the characteristics of axial electrostatic potential profile and particle motions. Mehrani et al. [18] developed a fluidization column functioning as a Faraday cup and concluded that particle–gas contacting had negligible effects on charges generated inside the fluidized bed, and fines entrainment was the main reason causing charge accumulation. Sowinski et al. [19,20] improved the online Faraday cup method and measured the charge-to-mass ratios of bed particles, adhering particles and entrained fines in both bubbling and slugging flow regimes. A mechanism of particle migration and wall sheeting formation was proposed according to the measured electrostatic charge distribution. He et al. [21] developed a dual-tip electrostatic probe to simultaneously measure the particle charge density and bubble properties by decoupling the electrostatic signals in a two-dimensional fluidized bed. To further understand the mechanism of charge generation and the relationship between electrostatic phenomenon and hydrodynamics in the fluidized bed, the

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* Corresponding author.
E-mail address: huangzhengl@zju.edu.cn (Z. Huang).

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influence of fluidization parameters on electrification has also been investigated by many researchers. Guardiola et al. [11] found that the degree of electrification increased with increasing superficial air velocity in a bubbling fluidized bed. Tiyapiboonchaiya et al. [22] measured electrostatic current in a polypropylene fluidized bed and demonstrated that the electrostatic current value rose with increasing gas velocity due to the heightened circulation rate, bubble size and contact frequency between solids. Moughrabiah et al. [23] concluded that an increase in operation pressure led to a higher degree of electrification probably due to an increase in bubble rising velocity, frequency and volume fraction. In a word, fluidization parameters affect the size and rising velocity of bubbles, and meanwhile the variation of bubble motions influences particle motions, which further affect particle electrification in the fluidized bed consequently. Therefore, electrostatic charges are strongly related to bubble motions in fluidized beds.

The most common technique to characterize bubble motions in a fluidized bed is pressure fluctuation [24], which can be used to determine the minimum fluidization velocity [25], the transition velocity from bubbling to turbulent fluidization [26], sizes of bubbles [27] and fluidization regimes [28]. Since both the electrostatic charge and the pressure fluctuation are closely related to bubble motions in the fluidized bed, research has been conducted to compare these two signals. Yao et al. [29] measured the local pressure drop and electrostatic voltage simultaneously in a fluidized bed and confirmed that the power spectra and the probability density distributions of the two signals were similar and the amplitude of voltage signals from a ball probe was mainly induced by passing bubbles. Similarly, Liu et al. [30] compared the power spectrum of the pressure drop signal with that of the cumulative electrostatic charge signal. Their results illustrated that when the superficial gas velocity increased to a certain extent, both signals showed a characteristic frequency of around 1 Hz, because the periodicity of both pressure fluctuation and electrostatic charge was dominated by the large bubbles near the bed surface. The above results show the relevance between electrostatic signal and pressure fluctuation, however, a quantitative relationship has not been established to indicate which parameter leads to the similarity between these two signals. Therefore, interpretation of the similarity between these two signals requires a further systematic experimental investigation and quantitative analysis, which may provide a possibility for electrostatic signal to be employed to characterize bubble behaviors in a gas–solid fluidized bed.

Since the electrification of particles is also affected by particle motions in powder industries [31], many researchers have utilized the electrostatic signal obtained from a pair of axially spaced ring-shape or arc-shape electrodes to measure the velocity of solids in dilute-phase systems, such as pneumatic conveying pipes [32–34] and circulating fluidized beds [35]. However, for the electrostatic signals in the fluidized bed, more information needs to be explored for a more comprehensive understanding of electrostatic phenomena and their connection with hydrodynamic behaviors.

This work is to extend the comparative study of electrostatic signal and pressure drop in the gas–solid fluidized bed and to quantify the electrostatic signals with bubble motions in a bubbling fluidized bed. Electrostatic current and pressure drop were measured simultaneously in a newly-designed multistage Faraday cup (MSFC) fluidized bed. Both time domain and frequency domain analyses of these two signals were employed and further compared. Finally, a quantitative relationship between electrostatic current and pressure drop was established.

2. Experimental apparatus and methods

Fig. 1 shows the schematic diagram of the experimental apparatus. The fluidization column, which is called MSFC fluidized bed below, consists of seven special Faraday cups which are mounted vertically in cascade. An expansion section with an inner diameter of 300 mm and a height of 170 mm is set up at the top. Dimensions of the MSFC fluidized bed are shown in Fig. 2. Each cup is constructed by two co-axial stainless steel cylinders isolated by Teflon. The inner cylinder, 150 mm in diameter and 85 mm in height, is connected directly to the electrometer using a coaxial connector to minimize the distortion of the electric field. The outer cylinder, 210 mm in diameter and 135 mm in height, is grounded to eliminate external electrical interference. The total height of the multistage Faraday cup section is 975 mm. The interval between each cup is 5 mm. A perforated distributor made of stainless steel is installed at the bottom of the column with 146 holes and an open area ratio 2.6%. The distributor is isolated from the bottom Faraday cup. The seven Faraday cups are numbered from 1# to 7# from the distributor to the top, respectively.

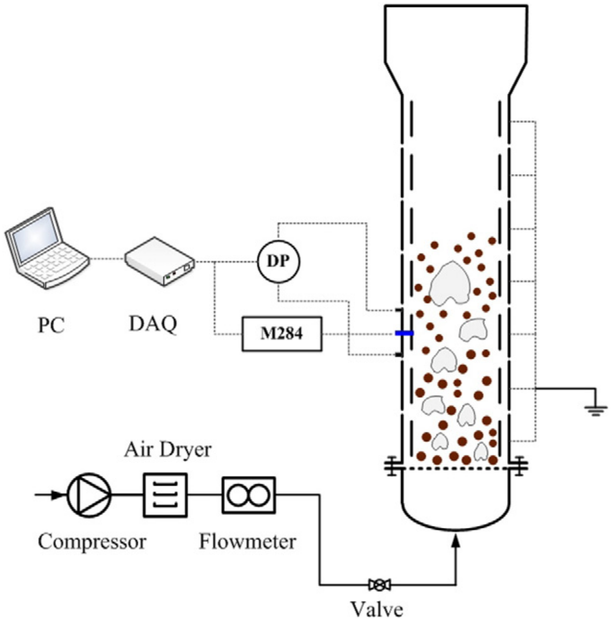

Fig. 1. Schematic diagram of experimental apparatus.

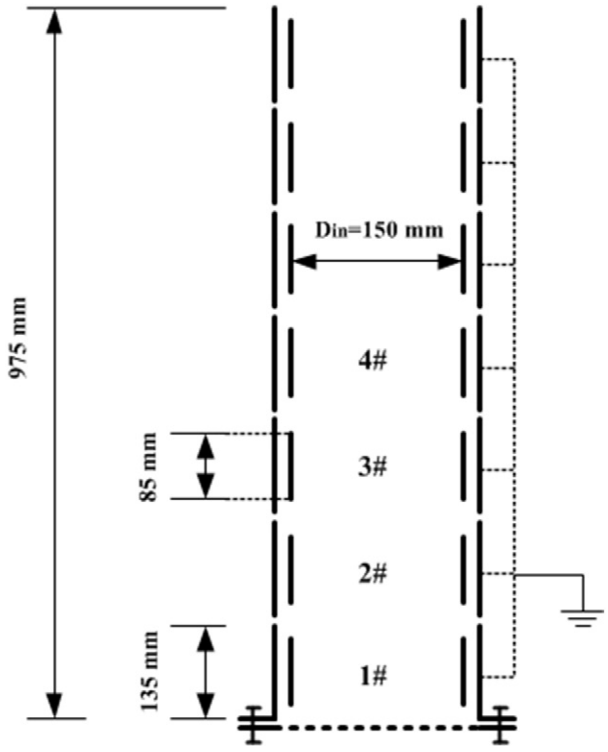

Fig. 2. Dimensions of the MSFC fluidized bed.