Powder Technology 317 (2017) 471–480

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Online measurement of particle charge density in a gas-solid bubbling fluidized bed through electrostatic and pressure sensing

Jingyuan Sun [a,b], Yao Yang [a], Qing Zhang [a,c], Zhengliang Huang [a], Jingdai Wang [a,*], Zuwei Liao [a], Yongrong Yang [a]

[a] *State Key Laboratory of Chemical Engineering, College of Chemical and Biological Engineering, Zhejiang University, Hangzhou 310027, PR China*
[b] *School of Engineering and Digital Arts, University of Kent, Canterbury, CT2 7NT, UK*
[c] *Patent Examination Cooperation Hubei Center of The Patent Office, SIPO, Wuhan 430205, PR China*

ARTICLE INFO

Article history:
Received 4 September 2016
Received in revised form 23 March 2017
Accepted 5 April 2017
Available online 7 April 2017

Keywords:
Induced electrostatic current
Pressure drop
Particle charge density
Ring-shaped sensing electrode
Gas-solid fluidized bed

ABSTRACT

Electrostatic phenomena widely exist in various olefin polymerization fluidized bed reactors, due to the continuous collision and friction of dielectric particles and the low-humidity reaction environment. The measurement of particle charge density is essential for monitoring and controlling the electrostatic level as well as probing the hydrodynamic characteristics in a fluidized bed. In this work, a non-intrusive online measurement system, employing ring-shaped sensing electrodes and a pressure transducer, is designed and implemented on a fluidized bed test rig. A modified model considering the influence of spatial sensitivity of the electrodes is proposed to predict the particle charge density in the fluidized bed, based on the measured induced electrostatic current and pressure drop signals. Experimental results have demonstrated that the induced electrostatic current and pressure drop signals show remarkable similarity, with the two PSDs both mainly distributed within 0.5–5 Hz, which indicates close relationship between the two signals. The predicted particle charge density increases with the superficial gas velocity and decreases with the injection content of liquid anti-static agent (LAA), showing the same variation tendencies as that measured through a Faraday cup. When the electrode width is 20 mm, the mean absolute relative errors for the direct method, area method and envelope method are 12.7%, 14.7% and 13.5%, respectively, indicating that the direct method is the most reliable signal processing approach proposed in this work.

1. Introduction

Gas-solid fluidized beds are widely applied in numerous industrial processes, such as coal combustion and gasification, drying, olefin polymerization, to name but a few. Bubble flow, originated from the injection gas through the perforated or porous distributor, always leads to fierce gas motion and particles circulation in a fluidized bed [1,2]. Due to the continuous collision and friction between the dielectric particles as well as the dielectric particles and walls, the generation and accumulation of electrostatic charges are almost unavoidable [3–5]. As the charge accumulation significantly affects the fluidization operation and can cause particle agglomeration, electrostatic discharge and even reactor shutdown [3,6,7], it is of significant importance to quantify the particle charge density (charge-to-mass ratio) online for the purpose of monitoring and controlling. Although extensive work has been undertaken to measure the particle electrostatic levels in gas-solid fluidized beds [8–13], a reliable online and non-intrusive approach to measuring the particle charge density is still lacking.

Until now, two instruments mainly employed to measure the electrostatic charges in fluidized beds are named collision electrostatic probes and Faraday cups. Collision electrostatic probes allow the online monitoring of electrostatic voltage, potential and current, indicating relative charge levels in the fluidized beds under investigation [6,14]. However, these probes cannot directly provide the value of particle charge density, and are rarely used for the measurement of particle charge density. He et al. [15–17] made the first attempt to use dual-material or dual-tip collision probes to simultaneously measure the particle charge density and bubble velocity, which show same variation tendencies as those obtained from a Faraday cup and video images, respectively. However, such collision probes are intrinsically intrusive and interfere with the flow field under test to some extent. Faraday cups are commonly used for the offline measurement of particle charge density [11,18,19]. During the measurement, fluidized particles go through the sampling ports into the Faraday cup due to the pressure difference between the internal and external of the fluidized bed. The main limitation of this offline method is the strong interference to the flow field and the generation of extra charges when transferring particles. Despite such drawback, Faraday cups are still the only well-developed method for the quantification of particle charge density in fluidized beds [20]. The measurement results from Faraday cups also serve as a reference for

---

* Corresponding author.
E-mail address: wangjd@zju.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.powtec.2017.04.026
0032-5910/© 2017 Published by Elsevier B.V.

the comparison with other electrostatic measurement methods. To allow the online measurement of particle charge density, Sowinski et al. [11] developed a unique Faraday cup system, with the fluidized bed itself employed as the inner cup and a second column as the outer cup. However, this method only allows the measurement of total net charges in a fluidized bed without any information about the local particle charge density.

In our previous work [21], a quantitative relationship between the electrostatic signal and pressure signal was proposed. It was found that the induced current was proportional to the first-order derivative of the pressure drop versus time, when the fluidized particles were assumed to have the same size and identical quantity of charges. Moreover, the proportional coefficient was related to particle charge density. This provides us a potential method to measure the particle charge density online through the simultaneous measurement of induced current and pressure drop. In this work, a non-intrusive online measurement system, employing ring-shaped sensing electrodes and a pressure transducer, is designed and implemented on a fluidized bed test rig. A modified model considering the influence of spatial sensitivity of the electrodes is proposed to predict the particle charge density in the fluidized bed, based on the measured induced electrostatic current and pressure drop signals. The predicted results are compared with those obtained from a Faraday cup, further demonstrating the reliability of the measurement approach developed in this work.

2. Experimental setup

Experiments were carried out on a gas-solid fluidized bed test rig as shown in Fig. 1. The fluidized bed column made of transparent Plexiglas has an inner diameter of 140 mm and an outer diameter of 150 mm, a height of 1000 mm, and a thickness of 5 mm. The expanded section at the top of the bed has a height of 300 mm and a width of 250 mm. An iron perforated distributor with 226 holes and an open area ratio 2.6% is installed at the bottom of the bed, along with a gas-mixing chamber. In the experiments, pre-dried compressed air with a relative humidity of 8–15% and temperature of 20–25 °C was introduced as the fluidizing gas. Linear low density polyethylene (LLDPE) particles (SINOPEC, Geldart B group) with a sieved size range of 450–900 μm and density of 918 kg/m^3 were used as bed materials. The minimum fluidization velocity (u_{mf}), experimentally determined through the conventional pressure drop method [22], was 0.2 m/s. The fluidization numbers (u/u_{mf}) employed were 2.0, 2.5, 3.0, and 3.5 to ensure that the fluidized bed was operated in the bubbling flow regime. The weight of the particles was 1.5 kg and the static bed height was 265 mm. To adjust the electrostatic charging level inside the fluidized bed, a trace of LAA was injected into the bed. LAA used in this work was Atmer™ 163, the same as that in our previous work [13,23]. The mass ratio of LAA was calculated based on the weight of particles and listed in Table 1.

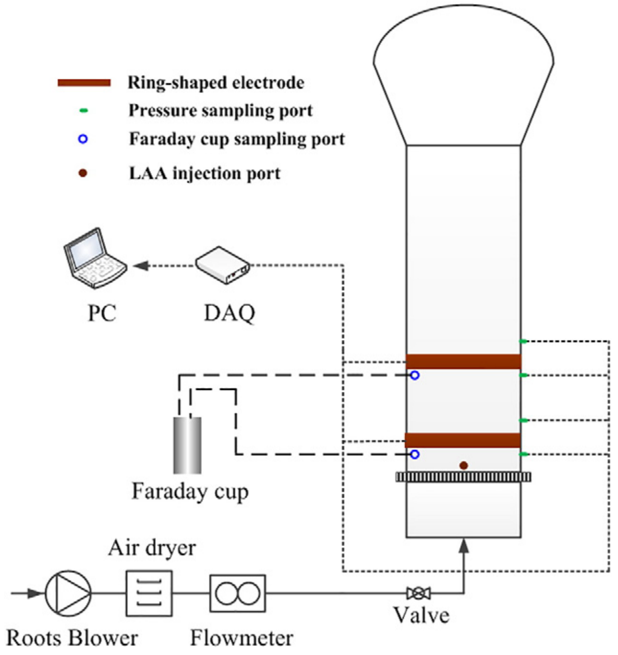

Fig. 1. Layout of the gas-solid fluidized bed test rig and measurement system.

Fig. 1 also shows the measurement system composed of two ring-shaped sensing electrodes, an electrometer (Monroe Electronics, NanoCoulomb Meter 284), a differential pressure transducer (CTG121P, China), a Faraday cup (Monroe Electronics, 284/22A), and a data acquisition card (National Instruments, USB-6351). To eliminate the effects of charge transfer between the particles and the wall on the measurement results, the ring-shaped electrodes were mounted outside the fluidized bed with their inner surfaces attached closely to the outer wall of the bed. Therefore, charges sensed by the non-intrusive measurement system were dominantly dependent on electrostatic induction, and the influence of any sheeting layers inside the bed was neglected. In addition, grounded metal boxes were installed outside the electrodes to eliminate external electrical interferences and enhance the signal-to-noise ratio. The accumulation of electrostatic charges was measured through the electrometer with a standard range of 0–200 nC, a resolution of 0.1 nC, and an accuracy of 2%. The induced electrostatic current signals were derived from the first-order differential of the charge signals [21]. The measuring range of the pressure transducer is −2–2 kPa with a relative accuracy of −0.25%–0.25%. After the particles were fluidized for over 30 min to achieve a saturated charged level, the electrostatic signal and pressure signal were measured simultaneously with a sampling frequency of 400 Hz and a duration of 240 s. The pre fluidization duration of 30 min was determined through our preliminary observation of the electrostatic signal variations, and consistent with that adopted in our previous work [9,21,24], in which highly similar or even the same PE particles, fluidized bed geometries, and operation conditions were employed as for this study. The Faraday cup was used to measure the average charge-to-mass ratio of the charged particles, which were transferred through the sampling port directly into the Faraday cup under the effects of the pressure difference. During the measurement, the Faraday cup was covered by a metal lid to eliminate the effects of any charged-air flow. In consideration of the possible influence of the sampling process on the measurement, all the experiments were repeated at least three times to ensure the reproducibility of the results.

Fig. 2 further shows the local layout of the electrodes, Faraday cup sampling ports and LAA injection port. As the electrodes are attached closely to the outer wall of the bed, the inner diameter (D) of each sensing electrode is 150 mm, the same as the outer diameter of the fluidized bed. The axial widths (W) of two sets of sensing electrodes are 20 mm and 40 mm, respectively, corresponding to the measuring heights (L) of pressure drop of 30 mm and 60 mm. The two sampling ports for the Faraday cup are at 90 mm and 230 mm from the distributor, respectively.

3. Results and discussion

3.1. Analysis of induced current signals

Fig. 3 shows the typical variation of an induced current signal with time. The current fluctuates considerably from positive to negative periodically. Fig. 4 compares the induced current signals from the electrodes with different widths and at different heights. In the lower region of the fluidized bed, the fluctuation amplitudes at $W = 40$ mm are larger than

Table 1
LAA injection content for LLDPE particles.

Mass ratio (ppm)	25	50	75	125	225
Volume (mL)	0.045	0.090	0.135	0.225	0.405