Powder Technology 290 (2016) 27–32

Contents lists available at ScienceDirect

Powder Technology

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

Comparison of theory with experiment for single bubbles in charged fluidized particles

Farzaneh Jalalinejad, Xiaotao T. Bi, John R. Grace

Department of Chemical and Biological Engineering, University of British Columbia, Vancouver V6T 1Z3, Canada

ARTICLE INFO

Article history:
Received 7 September 2014
Received in revised form 24 November 2015
Accepted 14 December 2015
Available online 17 December 2015

Keywords:
Electrostatics
Fluidization
Single bubbles
Two fluid model
Computational fluid dynamics

ABSTRACT

Previous numerical studies, focused on single bubbles, predicted that electrostatics can cause bubble elongation in gas-fluidized beds. However, there was a lack of experimental evidence to test the numerical predictions. This study compares experimental bubble size and shape in beds with two levels of charging. The results indicate that single bubbles are smaller and more elongated in a bed with higher charge density. Instability of bubble roofs for particles of high electrostatic charge density was also observed.

The experimental results are in agreement with the previous simulation results, with uniform particle charge density in the lower part of the bed and differences in the upper part. New simulations allowing for spatial variation of charge density show that bubble shape and stability are functions of the particle charge density distribution. Differences between simulation and experimental results are likely due to non-uniform distribution of charge on particles.

1. Introduction

Electrostatic charges are generated inside fluidized beds of dielectric particles. Some of these charges are removed from the reactor through grounded walls, while the remaining charges remain associated with the particles, resulting in an electric field that can influence gas–solid flow. Numerical studies [1–3] have indicated that electrostatic charges can change the velocity and residence time distributions of particles in risers, dense beds and freeboards. A previous numerical study [4] predicted that for single bubbles, electrostatics can cause bubbles to elongate and rise more quickly. Moreover, bubble pair interaction studies [5] indicated that bubble coalescence is unsymmetrical for vertically-aligned bubbles in charged particles, and the resultant bubble volume was predicted to be larger than for uncharged particles. On the other hand, for horizontally aligned bubbles, it was predicted that electrostatics cause a neighboring bubble to migrate towards the axis of the column, with coalescence completed at a lower height, modifying the leading-trailing roles. In addition, bubbling bed simulations [5] predicted a decrease in bubble size and frequency, as well as migration of bubbles towards the axis of the column for uniformly charged particles.

Although the influence of electrostatic charges has been predicted by numerical studies, no previous experimental study has been performed to test the validity of these predictions. We hence compare our previous simulation predictions for single bubbles [4] with experimental data for different levels of electrical charging. This is the first attempt to test the electrostatics theory, and therefore it has the potential to play an important role for applying electrical governing equations in the simulation of gas-fluidized beds containing charged particles.

2. Numerical method

In this work, the two fluid model implemented in MFIX (an open source code, available from the U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL) at https://mfix.netl.doe.gov) was adapted to include electrical governing equations. In this code the gas and solids are treated as interpenetrating continua.

The numerical methods employed for the discretization of temporal and convective terms are the implicit backward Euler method and superbee method, respectively, both of second order accuracy. Details of the numerical implementation of electrical forces are provided in [5].

3. Experimental setup and materials

The equipmental equipment for this work consisted of a "two-dimensional" Plexiglas column, a pressure vessel and a solenoid valve for injection of single bubbles, and a novel Faraday cup device, illustrated schematically in Fig. 1. The column has a cross-section of 280 mm × 12.7 mm × 965 mm tall. It is equipped with a perforated copper distributor, featuring a 12.7 mm central square orifice, as well as 18 circular holes, each of diameter 1 mm, distributed uniformly in a row symmetrically on either side of the central orifice. The distributor and side walls were grounded to have zero potential, matching the electrical boundary conditions applied in the numerical simulations. (See [5] for more details.)

E-mail address: xbi@chbe.ubc.ca (X.T. Bi).

http://dx.doi.org/10.1016/j.powtec.2015.12.014
0032-5910/

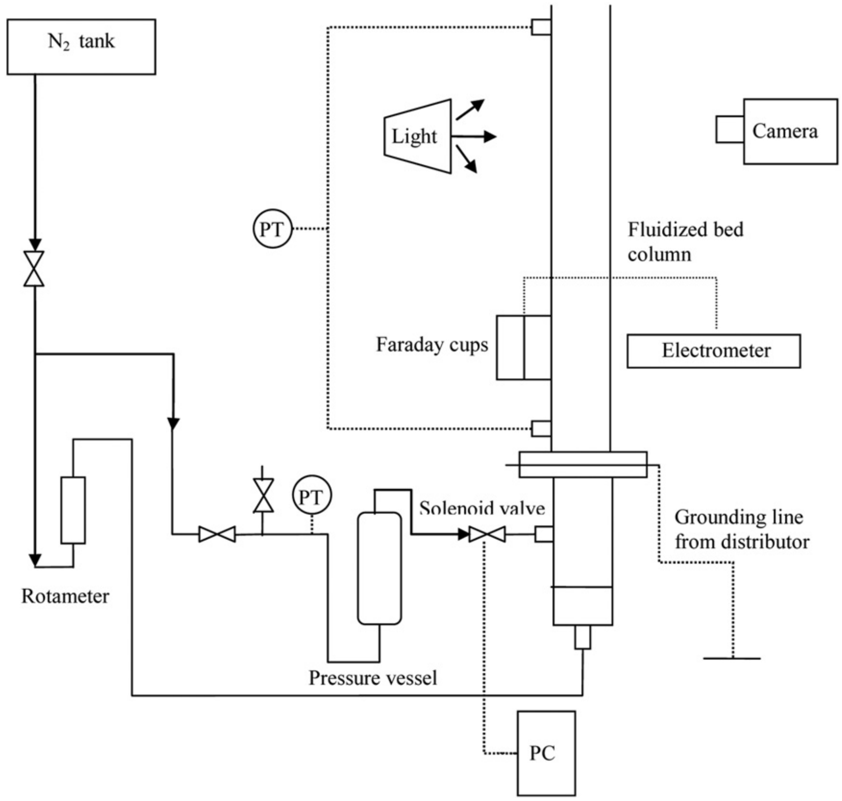

Fig. 1. Schematic of experimental setup.

A custom-made novel Faraday cup device was mounted on the back face of the column, as shown in Fig. 2. This device measured the charge density of particles, increasing the measurement accuracy by reducing the handling effect by allowing particles to flow directly into the inner cup. It consists of inner and outer copper cups separated by a Teflon spacer, acting as an insulator. (See [5] for more details.)

In these experiments nitrogen (99.998% purity) was used as the fluidizing gas to avoid humidity effects. Glass beads (volume-weighted mean diameter = 530 μm, and density = 2250 kg/m^3) were employed as the particles, due to their smooth surfaces and nearly spherical shape [5]. The minimum fluidization velocity of particles U_{mf} was experimentally determined to be ~0.3 m/s by plotting the bed pressure drop versus superficial gas velocity.

4. Experimental method

The initial experimental objective was to inject single bubbles into beds of uncharged and charged particles to compare with the simulation predictions of our previous work [4]. However, the experiments showed that particles always carried non-zero charges, with

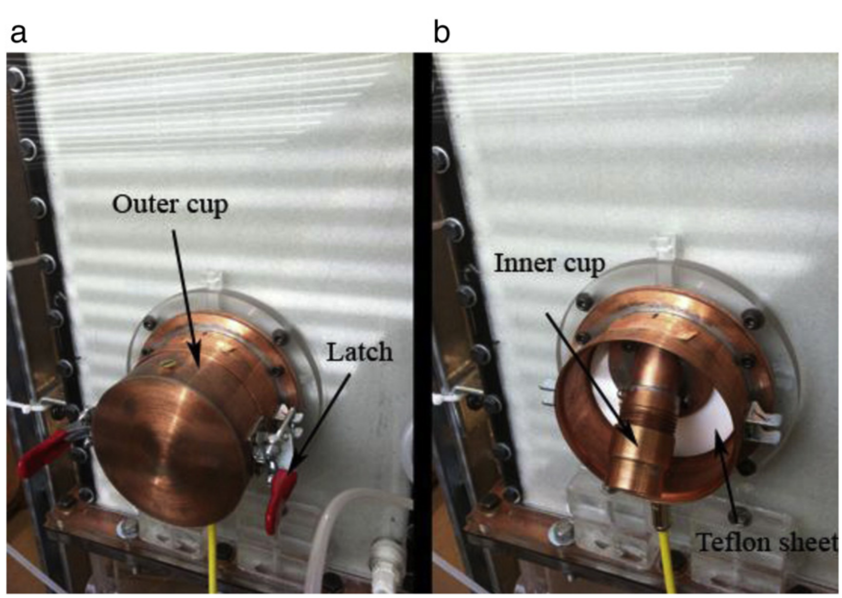

Fig. 2. Faraday cup device mounted at back of column: (a) outer cup closed, (b) outer cup open.