Impact of column material on electrostatics and entrainment of particles from gas-solid fluidized beds

Farzam Fotovat *, Kareena Gill, John R. Grace, Xiaotao T. Bi

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

HIGHLIGHTS

- Entrainment rate and charge density of the entrained particles were measured simultaneously.
- It was illustrated that how the column wall can influence the electrification of particles.
- The impact of the column wall material on entrainment was depicted.
- The relationship between particle charge density and entrainment was discussed.
- The effect of relative humidity on the entrainment of conductive particles was explored.

ARTICLE INFO

ABSTRACT

To investigate the impact of the column wall material on entrainment and electrification of fines in the freeboard of fluidized beds, fine powders were entrained by air at atmospheric temperature and 205 kPa in columns of diameter 0.15 m made of stainless steel and acrylic. Under equivalent operating conditions, changing the column wall material changed the entrainment flux and charge density of powders sampled from the freeboards of the columns. For all fines tested, the entrainment was lower for a column in which particles had a higher charge density. Depending on the work function of the fine particles and column wall material, increasing the gas velocity in the column could result in an increase or a decrease in the charge density of particles in the freeboard. Regardless of the impact of the column wall material on the particle charge density at different relative humidities (RH), the charge density of the fines decreased for dielectric particles and increased for conductive particles with increasing relative humidity.

1. Introduction

Fluidized beds involving fines or materials prone to attrition usually experience elutriation of fine particles. This can lead to loss of valuable materials, such as catalysts, and potential release of fine particulates into the atmosphere. Successful design and operation of gas-solid separators such as cyclones and filters, which are installed downstream of fluidized beds to reduce the loss of entrained particles, strongly depend on estimating the extent of entrainment. In spite of the numerous attempts to develop predictive correlations estimating the entrainment rate in fluidized beds, there is a serious disagreement, up to 20 orders of magnitude, among the estimates from these correlations (Chew et al., 2015). Furthermore, these approaches lead, in a number of cases, to unphysical predictions and untenable trends (Chew et al., 2015; Matsen, 1979). Complexity of the entrainment phenomena, which has not yet been well understood, is one of the primary causes of the discrepancies between predicted and measured values. The correlations and mechanisms included in the many relationships for predicting entrainment are universally restricted to hydrodynamic properties of the gas (density, viscosity) and particles (diameter, density, shape), as well as operating conditions (superficial gas velocity), column diameter and acceleration of gravity (Fotovat et al., 2016a). Nonetheless, there is growing evidence that, in addition to hydrodynamic factors, inter-particle forces, such as van der Waals and electrostatic forces, influence particle entrainment from fluidized beds (Alsmari et al., 2015a; Baron et al., 1987; Hendrickson, 2006; Yang et al., 2017).

Particle-particle interactions are often considered to be the main cause of electrostatic charge generation because theses interactions outnumber particle-wall interactions (Giffin and Mehrani, 2013; Hendrickson, 2006; Mehrani et al., 2007a; Moughrabiah, 2009; Moughrabiah et al., 2012; Wei and Gu, 2015). However, par-

* Corresponding author.
  E-mail addresses: ffotovat@mail.ubc.ca, farzam.fotovat@gmail.com (F. Fotovat).

Nomenclature

Abbreviations

CGB	coarse glass beads
FGB	fine glass beads
PMMA	poly(methyl methacrylate)
RH	relative humidity
SEM	scanning electronic microscope
SFGB	silver-coated fine glass beads
SS	stainless steel
TDH	transport disengagement height

Symbols

Bo_g	Granular Bond number (–)
C_d	drag coefficient (–)
$d_{3,2}$	Sauter mean diameter (m)
d_p	particle diameter (m)
F_d	drag force (kg m/s^2)
F_e	electrostatic force (kg m/s^2)
F_g	gravity force (kg m/s^2)
g	gravitational constant (m/s^2)
q_e	equilibrium particle charge (C)

q_i	initial particle charge (C)
q_m	mass charge density (C/kg)
q_p	charge of a single particle (C)
R_p	electrical resistivity of a single particle (Ω m)
R_w	electrical resistivity of a water (Ω m)
t	time (min)
U_g	superficial gas velocity (m/s)
U_p	particle velocity (m/s)
W_s	entrainment flux of solid particles (kg/m^2 s)

Greek letters

α, β	parameters in Eq. (A2) (–)
Δq	impact charge (C)
Δq_0	impact charge at zero initial charge (C)
ε_0	vacuum permittivity (F/m)
ε_m	relative permittivity of surrounding medium (–)
ρ_g	gas density (kg/m^3)
ρ_p	particle density (kg/m^3)
Φ_p	particle sphericity (–)

---

ticles in the freeboard are likely to come into frequent contact with the column wall considering the limited solid holdup in this zone. Thus, the properties of the column wall could significantly influence charge generation/dissipation mechanisms, particularly for fine particles, which are subject to elutriation.

A number of studies have been performed on the impact of the equipment wall material on the flow of solid particles in pneumatic conveying systems (Kanazawa et al., 1995; Korevaar et al., 2014; Yao et al., 2004), for which the equipment diameters investigated are usually much smaller than typical diameters of fluidized bed reactors. Few studies have been conducted to shed light on the impact of column material on electrostatic phenomena in fluidized bed reactors. Ciborowski and Wlodarski (1962) reported that the static electrical potential in fluidized beds varied with the humidity and the velocity of the fluidizing gas, the material of construction of the column, and the nature of the fluidized particles. Working with glass beads and polymethyl methacrylate (PMMA) particles in geometrically similar iron and acrylic columns, Fujino et al. (1985) observed that the electrical potential of the bed, arising from triboelectrification of particles and the column wall, was affected to a considerable extent by the material of construction of the column, in addition to the particle size, nature of the particles and humidity of the gas. They indicated that the radial electric field intensity is strongest near the reactor wall and zero at the axis of the column. Particles readily agglomerated in the electric field near the wall, where the electric field was strongest.

Gajewski (1985) fluidized propylene spheres in a glass column whose inner wall was covered with rings of copper sheet. These rings were isolated from each other, but each was connected to ground. The current from each ring, referred to as the "electrification current", was measured. Minor electrostatic charge generation was observed at the walls in the lower portion of the bed. The maximum charge dissipation occurred near the upper part of the fluidized bed, with the height at which the maximum dissipation occurred increasing with increasing gas velocity.

Mehrani et al. (2007a) explored the underlying mechanisms of particle triboelectrification in bubbling gas-solid fluidized beds by means of bench-scale particle-copper plate contacting tests. They found that charge transfer occurred between fine particles

(glass beads, silver-coated glass beads, catalyst and Larostat 519) and the plate, with fines carrying away almost all of the initial charges on the plate, followed by further charge separation for the last three of these fine materials. Due to charge separation, silver-coated glass beads and catalyst fines became negatively charged, whereas Larostat 519 particles became positively charged. Charge separation refers to surfaces in contact gaining opposite charge polarities due to triboelectrification and/or frictional charging. On the other hand, charge transfer refers to one surface gaining the same charge polarity as the other surface when they come into contact with each other.

We have recently shown that electrostatic forces play a key role on controlling the entrainment of fine materials carrying electrostatic charges (Fotovat et al., 2016a, 2016b, 2016c, 2016d). However, it is not yet clear how electrostatic particle-wall interactions affect the entrainment process. This subject is investigated experimentally in the present study by comparing the electrostatic charge density and entrainment flux of a variety of fine materials fluidized in geometrically similar columns made of stainless steel and acrylic.

2. Experimental

2.1. Equipment

To investigate the impact of the material of construction of the column wall on elutriation, similar tests were carried out in two cylindrical columns made of stainless steel and acrylic, both 0.15 m in inner diameter and 2.0 m in height. The wall thicknesses were 3.4 mm and 12.7 mm for the stainless steel and acrylic columns, respectively. The gas distributor, employed in both columns, consisted of a stainless steel perforated-plate containing 50 holes of 4 mm diameter, supported by a second stainless steel perforated-plate containing 50 aligned holes of 5.6 mm diameter. A steel screen with 38 μm openings was sandwiched between the two plates to prevent fine particles from dropping into the windbox. The distributor plates were designed to have an open area ratio of 3.8%. As depicted in Fig. 1, the fluidization column equipped with an external cyclone and a return leg allowed