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ELECTROSTATIC PHENOMENA IN GAS-SOLIDS FLUIDIZED BEDS

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Abstract Electrostatic charges are generated by particle-wall, particle-particle and particle-gas contacts in gas-solids transport lines and fluidized bed reactors. High particle charge densities can lead to particle agglomeration, particle segregation, fouling of reactor walls and internals, leading to undesirable by-product and premature shut-down of processing equipment. In this paper, the charge generation, dissipation and segregation mechanisms are examined based on literature data and recent experimental findings in our laboratory. The particle-wall contact charging is found to be the dominant charge generation mechanism for gas-solids pneumatic transport lines, while bipolar charging due to intimate particle-particle contact is believed to be the dominant charge generation mechanism in gas fluidized beds. Such a bipolar charging mechanism is also supported by the segregation patterns of charged particles in fluidized beds in which highly charged particles tend to concentrate in the bubble wake and drift region behind rising bubbles.

Keywords electrostatics, charge generation, charge dissipation, charge segregation, gas-solids flow, fluidization

1. Introduction

One of the main problems in gas-solids fluidized beds, such as those used in drying processes and polyolefin production, is particle agglomeration, with electrostatic charges as the key causal factor (Bailey, 1984; Cross, 1987; Astbury & Harper, 1999). Electrostatic forces induced by the charges carried by particles can also change the hydrodynamics of gas-solid fluidized beds. In addition, unintentional accumulation of electrostatic charges could cause hazardous electrical discharges, leading to sparks, fires and even explosions (Jones, 1999). The accumulated electrostatic charges on powder particles or plastic films inside large commercial fluidized bed reactors can interfere with their performance. Despite these negative effects of electrostatic charging, the mechanisms of charge generation and dissipation are still poorly understood.

Electrostatics is a complex phenomenon across multiple scales. The charge generation at a microscale level is generally associated with the surface properties of particles. Tribo-electrification associated with charge separation due to the contact of two dissimilar surfaces has been commonly considered as the main cause for charge generation in gas-solids handling and processing systems. Bi-polar charging associated with charge separation between particles of similar materials but different sizes or surface morphologies was also identified recently in fluidized systems with size distributions (Zhao et al., 2003; Mehrani et al., 2005). Frictional charging due to fluid- particle contact occurs when the gas adjacent to the particle surface is ionized due to friction-induced temperature rises in the near surface region.

Charge dissipation occurs simultaneously with charge generation. In a fluidized bed or transport line with grounded walls, charged particles may lose charges to the wall during their contact with the wall. Particle-particle collision can also result in the transfer of electrons from one particle to the other, with charges dissipated from charged particles by electric conduction. Use of conductive or ionized gases of opposite charges to the bed particles also enables the removal of charges from the particles. The net change in particle charge level in a gas- solids fluidized bed or transport line is thus a result of the balance of charge generation and dissipation, as shown in Fig. 1. When the charge generation rate is much higher than the charge dissipation rate, a net charge could build up in a fluidized bed or solids transport line, creating an electric field which imposes on individual charged particles. Consequently, charged individual particles interact with each other via the Coloumb forces, impacting on hydrodynamics locally via particle-particle interaction and globally via particle-electric field interaction.

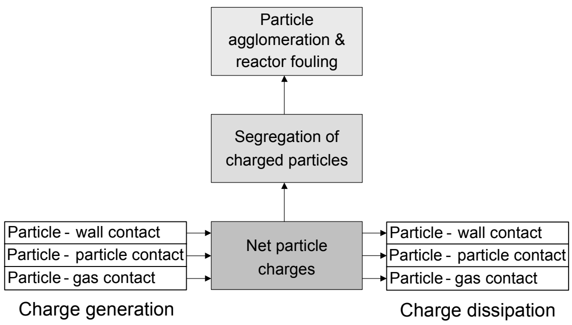

Fig. 1 Multiscale phenomena of electrostatic charging in gas-particle contacting systems.

The electrostatic phenomenon in gas-solids fluidized beds is further complicated by the non-homogeneous flow structure due to the presence of gas bubbles. The electric forces between adjacent particles can no longer be considered as isotropic in the region close to the gas bubbles. Similarly the electric field of the charged particle bed can no longer be treated as in a homogeneous medium. Instead, heterogeneous flow structure at the bubble (meso) scale has to be considered in order to properly understand the electrostatic forces and fields associated with charged particles.

At the unit (macro) scale, the reactor performance is impacted by electrostatics as reflected by particle agglomeration, particle segregation, wall fouling and non-uniform temperature distribution. A multiscale approach in which the proper understanding of charge generation and dissipation mechanisms at the particle scale (or even the molecular or crystal scale) coupled with the distribution of charged particles at the bubble scale is required to properly predict the impact of electrostatic charges on the overall reactor performance and to develop effective tools for mitigating electrostatic charges.

Based on the information in the literature on electrostatic charge generation and dissipation and the charge segregation in gas-solids fluidized beds and transport lines, this paper attempts to elucidate the underlying charge generation and dissipation mechanisms in order to identify the dominant mechanisms under different operating conditions of gas-solids two-phase flow.

2. Charge Generation in Gas-Solids Transport Lines and Fluidized Beds

Triboelectrification due to collision with wall surfaces of transfer lines or reactors has been considered as the primary source for particle charging. Extensive work has been reported in the literature on charge generation via colliding single charged particles with charged surfaces under controlled conditions to investigate the effect of particle pre-charge level, surface pre-charge level, collision angle and collision speed on the degree of particle transfer and separation. The charge generated by collision of a dielectric particle with a metal surface was found (Murata, 1994) to increase with the collision speed and to be at the maximum for a head-on collision with the plate, but to decrease with increasing the pre-charge level of the particle. Applying the results to pneumatic transport lines and fluidized beds, the collision between the surface of the transport lines and the reactor walls and particles is expected to generate electrostatic charges on the particles.

Although charges can be generated on particle surfaces due to the friction between particles and gases, it is not expected to play a significant role under ambient conditions, as shown in the recent experimental data of Mehrani et al. (2005). However, under high temperatures, gas ionization may take place, resulting in charge transfer from ionized gases to particles during the gas-particle contact.

Particle-particle collision in fluidized beds has been recently found to result in charge separation, i.e., bipolar charging, between fine and large particles (Zhao et al., 2003; Mehrani et al., 2005), with fine particles charged opposite to large particles. When fine particles are entrained from the top of the fluidized bed, a net charge could be built up in the fluidized bed. Such a non-uniform charge distribution among particles of different sizes may also explain why fine particle entrainment rate is reduced when the fluidized particles are highly charged, because charged fine particles may establish a strong attractive interaction with coarse particles carrying opposite charges, preventing them from being entrained out of the fluidized bed.

If the particle-wall collision is the dominating mechanism for charge generation, the particle charge level is expected to decrease with increasing the column diameter because the surface area per unit of particle flux, G_s ($kg \cdot m^{-2} \cdot s^{-1}$), is inversely proportional to the column diameter. This appears to be true in pneumatic transport lines (Napier, 1994), suggesting that the particle-wall collision could be the dominant charge generation mechanism in pneumatic transport lines. In the gas-solids fluidized bed where the particle velocity in the near wall region is much lower than in pneumatic transport lines, the charge level appears to be independent of the column diameter (Rojo et al., 1986), suggesting that particle-wall collision is not the dominant charging mechanism. Instead, the bipolar charging due to particle-particle contact could be the dominant mechanism.

3. Charge Segregation in Bubbling Fluidized Beds

Once charges are built up on particles in the transport line or fluidized bed, they may not be uniformly distributed if particles are not charged uniformly or particle segregation occurs. In gas-solids bubbling fluidized beds, charge distribution around a rising gas bubble was first studied by Boland and Geldart (1972) in a two-dimensional fluidized bed using an induction probe. The positive and negative voltage/current signals associated with the passage of the bubble were speculated to be caused by a positively charged nose region in front of the bubble and a negatively charged wake region behind the bubble.

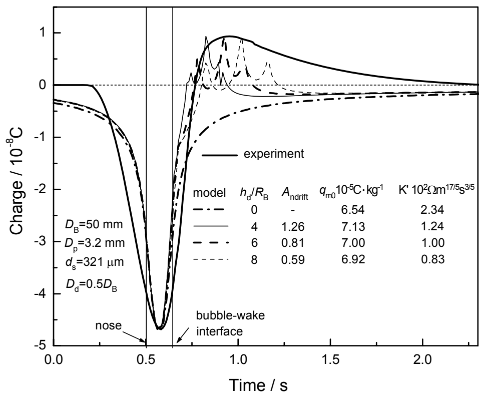

Fig. 2 Electrostatic charges registered by a collision probe during the passage of a single bubble in a two-dimensional fluidized bed, and the comparison with an induction model based on different charge distributions (From Chen et al., 2003).

Similar signals were obtained by Park et al. (2002) using collision probes in two-dimensional fluidized beds. The interpretation of signals using a combined charge induc-

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