



Effect of fluidizing particle size on electrostatic charge generation and reactor wall fouling in gas–solid fluidized beds

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ABSTRACT

Electrostatic charge generation from particle–particle and particle–wall contacts in gas–solid fluidized beds is virtually unavoidable and generally undesired. Charged particles are known to cause problems including particle agglomeration and particle–reactor wall adhesion. The polymerization industry has been plagued by reactor wall fouling for many years, but the actual mechanism behind this problem is not well understood. The wide particle size distribution present in polyolefin fluidized bed reactors is believed to play an important role. This work studied the effect of particle size of a polyethylene resin received directly from industrial reactors on electrostatic charge generation and reactor wall fouling. The resin was sieved into five different narrowed particle size fractions and fluidized at two different gas velocities; 1.5 and 4 times the minimum fluidization velocity (u_{mf}) representing the bubbling and the slugging flow regimes. The fluidization was performed in a 0.1 m carbon steel fluidization column with the charge measurement technique described by Sowinski et al. (2010). In the bubbling flow regime significant particle wall adhesion was found for particles sizes up to 600 μm , after which very little reactor wall fouling was observed. In the slugging flow regime, there was significant particle wall adhesion for all particle size fractions tested with the exception of the 600–710 μm range, which at times resulted in significant particle–wall adhesion and in other times none was obtained. Overall, it was found that the smaller particles had a higher charge and resulted in more reactor wall fouling. With the non-sieved resin, the particles that adhered to the column wall were approximately of the same size as the smallest size fraction tested (300–425 μm). This study found that the measurement of the net charge-to-mass ratio inside a fluidized bed is not an indication of the amount of reactor wall fouling.

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1. Introduction

Gas–solid fluidization is a unique process found in numerous chemical industries with applications such as gas–solid catalytic reactions, coating, drying, and mixing, to name a few. One major problem observed in some gas–solid fluidization processes is the occurrence of electrostatic charging of particles. Charge generation occurs through the significant number of particle–particle and particle–reactor wall contacts and separations, creating triboelectrification (Cross, 1987), as well as frictional charging. In many incidences the generation of electrostatic charges in gas–solid fluidized beds is not desired and uncontrollable as it ultimately leads to challenges such as particle agglomeration, particle–reactor wall fouling, process equipment disruption, and electrostatic discharge.

Polyolefin production is one industry that has suffered significantly from the negative effects of electrostatic charge

generation within gas–solid fluidized bed reactors. In such process, an electrified bed has been reported to be the cause of particle agglomeration (undesired large polymer chunks), and reactor wall fouling (known as “sheeting”) (Hendrickson, 2006). Polymer sheets can range from a few square centimeters to a few square meters and are generally formed where the drag forces along the column wall are at a minimum (Hendrickson, 2006). This occurs at approximately half the diameter of the fluidization column above the distributor plate (Goode et al., 1989). Sheetting is a major problem in the polyethylene industry as these large chunks of fused particles can break off the reactor wall and clog the distributor plate, creating a costly downtime required for clean-up. Numerous claims were made to measure and reduce electrostatic charges within gas–solid fluidized beds (Fulks et al., 1985; Goode et al., 1989; Hagerty et al., 2005; Newton et al., 1999; Song et al., 1995; Yu et al., 2007).

Particle wall adhesion has been observed by many researchers, but it has never been fully quantified. Ciborowski and Wlodarski (1962) found that vinyl polyacetate, polystyrol, and sand particles at first adhered to the Rasotherm glass column wall non-uniformly. However, over time the layer built up and created a more uniform

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layer of particles. This was also observed using polypropylene particles in a glass column (Gajewski, 1985), as well as in an Altuglass column (Revel et al., 2003). Fujino et al. (1985) found that the static electricity to be strongest near the column wall using an acrylic column, and glass beads, neobeds, and polymethyl methacrylate (PMMA) as the fluidizing particles. This large amount of electrostatic charge near the wall could lead to particle–wall adhesion, which has been found to also occur in dry systems (Guardiola et al., 1992; Ham et al., 1992). Valverde et al. (2008) indicated that when the particles adhere to the column, they can remain bound to the column and do not move during the entire fluidization process. Revel et al. (2003) also concluded that the bound particle–wall layer would lead to a decrease in the amount of particle–wall contact as fluidization continues.

Overall, the mechanism of the particle–wall adhesion in gas–solid fluidized beds is not very well understood, nor fully researched; however, one possible factor that may contribute to the formation of these sheets is the size of the particles present within the fluidization column. Within a commercial polyethylene gas–solid fluidized bed reactor, two types of particles exist, the catalyst and the polyethylene resin. The catalyst particles are very small in size whereas the polyethylene resin can range from the size of the catalyst to a few millimeters in diameter, depending on the length of the reaction time. The wide size range of the resin makes it extremely complicated to study the electrostatic charge generation within fluidized beds. Sowinski et al. (2010), while using industrial polyethylene resin with a wide particle size distribution in a carbon steel fluidization column, found that particles of a certain narrow size range were adhering to the column wall after a period of fluidization, indicating that particle size might have an effect on the particle–reactor wall fouling.

In order to understand as why certain sized particles adhere to the reactor wall, it is important to be able to adequately measure the electrostatic charge of these particles. There have only been a few researchers who have reported on the effect particle size on bed electrification but not specifically on reactor wall fouling. Boland and Geldart (1971/72) used a two dimensional Perspex glass fluidization column and glass ballotini beads of size ranges between 100 μm and 800 μm . Using an electrostatic probe they concluded that as the particle size increased, the degree of electrification also increased. Similar results were obtained by Fasso et al. (1982) using a 0.09525 m inner diameter column constructed of Plexiglas. This work used a Faraday cup method to trap some entrained particles and measure their charge. Again it was concluded that the increase in the particle size results in a rise in the particles charge. Gajewski (1985) took a different approach by placing copper bands into a 0.25 m diameter organic glass column and measuring the charge distribution within the fluidized bed. The work focused on large polypropylene particles of size ranges between 0.5 and 4 mm in diameter. It was found that bed electrification increased with increasing particle size until 2.5 mm, before starting to decrease. As well, a layer of particles coated the copper rings when the particle were smaller than 2.5 mm. Guardiola et al. (1996) used an electrostatic probe in a 0.044 m Perspex fluidization column and glass beads of size ranges of 250–297 μm , 297–350 μm , and 350–420 μm . Again, as the particle size increased, the level of bed electrification increased. Zhao et al. (2002) used a system of seven vertical Faraday cups located below a 25 cm \times 25 cm electrically grounded steel fluidization column with polydisperse polymer particles of a mean volume diameter less than 100 μm . It was found that as the size of the particles increased, the particles charge varied from negative to positive. The dependence of charge polarity on particle size is known as bipolarity and has also been observed by other researchers (Ali et al., 1999; Sowinski et al., 2010). Bipolar charging has also been observed in other granular systems. Forward et al. (2009a) studied bi-polar charging nature of bimodal

distributions of both clear soda lime glass and polyethylene in a spouted bed. They concluded that for the same material, smaller particles charged negatively and larger particles positively when subjected to only particle–particle interactions. This has also been theoretically explained by other works (Duff and Lacks, 2008; Forward et al., 2009b; Pähz et al., 2010). From the handful of studies previously performed, very few have investigated or commented on the actual effect of fluidizing particle size on reactor wall fouling, which is a significant challenge in some industries. The fluidization system previously developed by Sowinski et al. (2009), which houses a unique Faraday cup electrostatic charge measurement technique, is able to provide a wealth of information regarding the charge distribution inside the fluidization column, and specifically the particles adhered to the column wall. Thus, the focus of this work was to utilize this system and investigate the role that the fluidizing particle size plays on electrostatic charge generation, and in particular, its contribution to the particle–reactor wall fouling in gas–solid fluidized beds.

2. Experimental setup and procedure

The overall experimental setup and procedure are described elsewhere (Sowinski et al., 2009, 2010). The system consisted of a metallic fluidization column, 0.1 m in diameter and 1.3 m tall that housed two Faraday cups, and was used to determine the charge, mass, and size distribution of the bed particles, those attached to the column wall, and those entrained.

The fluidizing particles utilized in this study were polyethylene resin produced using a metallocene based catalyst in an industrial gas-phase fluidized bed reactor. The resin had a particle density of 918 kg/m^3 and a wide size distribution, ranging approximately from 20 to 1500 μm . To study the effect of only particle size, this resin was separated into narrow size ranges by sieving. The particle size fractions of sieved resin were 300–425 μm , 425–500 μm , 500–600 μm , 600–710 μm , and 710–1000 μm . The bed height to column diameter ratio (L/D) was held constant at 4 for all particle sizes. For each particle size fraction (non-sieved and sieved particle size fractions), experiments were carried out with dry air at 1.5 and 4 times of their respective minimum fluidization velocity (u_{mf}). The u_{mf} for each particle size fraction was determined experimentally using the bed pressure fluctuations. The test was performed at least twice using a new batch of particles, once by increasing the gas velocity, and once by decreasing the gas velocity. These factors were used to attempt to maintain the same hydrodynamic conditions for each particle size fraction. For all experimental runs, the fluidization gas temperature was 23 $^{\circ}\text{C} \pm 0.6$ $^{\circ}\text{C}$, and the room temperature and relative humidity were 23 $^{\circ}\text{C} \pm 0.5$ $^{\circ}\text{C}$ and 10–20%, respectively. All experimental runs were conducted for a period of 60 min and repeated at least three times to ensure the reproducibility of the results.

The polyethylene particles were divided into different categories depending on their location inside the fluidization system. First, before placing the particles inside the fluidized bed, their mass and charge were determined (*Initial*). Next, during fluidization, some particles were entrained from the fluidized bed where their charge was continuously measured (*Fines*). However, since the particle size fractions were narrow, the amount of fines collected was negligible and thus not discussed in this work. After fluidization was completed, the particles remaining inside the bed were divided into three different groups as follows.

1. *Dropped Particles*: The gravitational force on these particles dominated any attractive forces pushing them towards the column wall (e.g., electrostatics and van der Waals forces). Thus, upon completion of the fluidization period, when the

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