Mechanism of particle build-up on gas-solid fluidization column wall due to electrostatic charge generation

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ABSTRACT

Particle build-up on gas-solid fluidization column wall due to electrostatic charging causes significant operational challenges including reactor shutdown in industrial processes such as gas-phase ethylene polymerization to produce polyethylene. It is well acknowledged that in fluidization process electrostatic charges are generated as a result of continuous particle-particle and particle-vessel wall contacts. However, the mechanism of charged particle attraction towards the fluidization column wall and their adhesion has received minimal attention. This work proposes a mechanism for particle build-up on the column wall by experimentally investigating the fouled particles charge distribution using a charged particle separator apparatus. The experiments were carried with two types of linear low-density polyethylene resins in a pressurized pilot-scale gas-solid fluidization system. Experimental results showed that the polyethylene layer built-up on the column wall contained both positively and negatively charged particles. A mechanism was proposed indicating that charged particle migration towards the metallic column wall was due to the image and electrostatic forces. The image forces were attributed to the particle-wall contacts while the electrostatic forces were between the charged particles fouled on the column wall and those oppositely charged within the bulk of the bed. In addition, the net space charge of the bulk particles contributed to the migration of the particles towards the column wall.

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1. Introduction

Gas-solid fluidized beds have been widely employed in many industries such as petrochemical, oil and gas, food, etc. due to their excellent characteristics of providing a high degree of heat and mass transfer, and allowing for good mixing. In such systems, there is a potential for electrostatic charge generation due to continuous contacts between the particles and between the particles and the fluidization column wall. Bed electrification could then give rise to significant problems including fluidizing particle agglomeration and their build-up on the reactor wall and other surfaces. Such occurrences could have undesirable effects on the fluidized bed hydrodynamics or even necessitating reactor shutdown for clean-up. Gas-phase ethylene polymerization in gas-solid fluidized beds to produce polyethylene is an example of an industrial process where electrostatic charge generation is known to result in operational challenges. In this process, charged particles, including catalyst and polyethylene resin, adhere to the reactor wall and dome, and form sheets of fused particles. This phenomenon is referred to as "sheeting" [1]. As the sheets grow thicker, they dislodge from the reactor wall and fall to block the distributor plate, imposing frequent reactor shutdown for clean-up. This in turn causes significant economic losses for the industry.

Although a few works have been reported in literature in relation to detecting the occurrence of electrostatic charge build up within this type of reactors, the problem still persists [1–5]. This is due to the complex nature of gas-solid fluidization process, and more importantly, the lack of a comprehensive understanding of the underlying mechanism of electrostatic charge generation, as well as fouling of charged particles on the fluidized bed walls. The majority of works reported in this area have focused on evaluating the effect of various operating parameters (e.g., fluidization time, particle and gas properties, operating pressure, etc.) on the degree of electrostatic charge generation [6–13]. However, to the author's knowledge, the mechanism of particle migration and wall fouling in gas-solid fluidized beds has not been discussed in literature. Thus, the aim of this work is to suggest a mechanism for particle build-up on the fluidization column wall. The proposed mechanism is supported by experimental work carried out in a pilot-scale gas-solid fluidized bed where the electrostatic charge distribution of particles fouled on the column wall were determined and evaluated at various operating conditions.

2. Experimental setup and method

A pilot plant pressurized gas-solid fluidization system previously designed and commissioned by the same research group was used for this work. The details of the fluidization system are presented elsewhere [6,10]. The system contained a three dimensional stainless steel

fluidization column, 0.15 m in diameter, which housed two online Faraday cups in its top and bottom expanded sections. Both Faraday cups were connected to digital electrometers (Keithley model 6514) and enabled particles charge measurement. A filter bag was placed in the top Faraday cup in order to capture the entrained fines and to allow their cumulative charge measurement. The discharge of the fluidizing particles into the bottom Faraday cup for their charge measurement was enabled by the distributor plate which was a modified knife-gate valve.

Experiments were conducted in the bubbling flow regime and at various operating pressures ranging from atmospheric to 2600 kPa. The highest operating pressure was similar to operating pressure of a commercial gas-phase polyethylene process. Minimum fluidization velocity was measured for each operating pressure, and the fluidizing gas velocity was set at 1.5 times the minimum fluidization velocity for all experiments. Compressed building air and nitrogen gas from a gas cylinder were used as sources of fluidizing gas at atmospheric and high pressure conditions, respectively. The fluidizing gas was at 0 RH% and 25 °C for all trials. For experiments conducted at high pressures, the system was first pressurized to the desired pressure and then a centrifugal compressor with a variable speed drive enabled the circulation of the gas within the system at the desired flow rate.

Two types of linear low density polyethylene (LLDPE) resin, PE_A and PE_B, directly received from commercial reactors, were fluidized in this work. The properties of the two resins are summarized in Table 1. For all experiments, 3.2 kg of particles were placed into the fluidization column. PE_A resin was fluidized at 1600 and 2600 kPa while PE_B resin was fluidized at atmospheric and 400 kPa. Minimum fluidization velocities for each operating condition, which were obtained with bed pressure drop measurements, are presented in Table 2.

In each experiment, as received particles (referred to as "initial" or "initial particles") were placed in the fluidization column after measuring their mass and net charge. During fluidization, the entrained particles were captured by the filter bag and their cumulative charge was measured by the top Faraday cup. Upon the completion of 60 min of fluidization, the system was depressurized, the top of the column was opened, and the filter bag was removed to measure the mass of entrained particles (referred to as "fines" or "fine particles"). The distributor plate was then opened allowing particles in bulk of the bed (referred to as "bulk" or "bulk particles") to drop into the bottom Faraday cup to measure their net charge. The bottom Faraday cup was then removed to measure the mass of the bulk particles. After visually inspecting the inner column wall for any particle fouling, the cleaned bottom Faraday cup was placed back to collect and measure the net charge of these particles (referred to as "wall" or "wall particles"). Compressed building air was passed through a long tube inserted from the top of the column in order to dislodge the wall particles from the column wall into the bottom Faraday cup. For all experiments, samples of initial, bulk, wall, and fines were collected and analyzed for particle size distribution. In this work, fluidization of both polyethylene resins resulted in a negligible amount of entrainment and thus no results have been presented for the fines. All experiments were conducted 3 times to ensure the reproducibility of the results.

In a typical experiment, the wall particles electrostatic charge was measured by the bottom Faraday cup (Fig. 1a). However, such method only enables the measurement of the net charge of particles accumulated on the column wall. In order to investigate the electrostatic charge distribution of these particles, a charged particle separator (CPS),

Table 1
Properties of polyethylene particles used in this work.

	Particle density (kg/m^3)	Particle size and mass distribution			Average particle size (μm)	Geldart group (−)
		<500 μm (wt%)	500–700 μm	>710 μm		
PE_A	915	26.44	28.54	45.02	560	B
PE_B	918	34.03	35.22	30.75	573	B

Table 2
Minimum fluidization velocities under various operating pressures.

Operating pressures (kPa)	Minimum fluidization velocity (m/s)	
	PE_A	PE_B
100	N/A	0.15
400	N/A	0.12
1600	0.1	N/A
2600	0.08	N/A

previously designed and built by the same research group [14], was employed. As presented in Fig. 1b, after removing the bottom Faraday cup containing the bulk particles, the charged particle separator apparatus was placed beneath the fluidization column. The charged particle separator contained two copper plates at the top section and four Faraday cups at the bottom. One of the copper plates was connected to a high voltage power supply (Ultravolt HV Rack Model 1-250-00265) and charged positively. The other plate was grounded and acted as a negatively charged plate. Each Faraday cup was connected to a digital electrometer (Keithley model 6514) to measure the net charge of particles inside. As the particles slowly dislodge from the column wall and drop into the charged particle separator, positively and negatively charged particles are separated and settle in the four Faraday cups at the bottom of the separator. Faraday cups number 1 and 4 (FC1 and FC4) collect the highly negatively and positively charged particles, respectively. The four electrometers were connected to a computer, and LabView® software was used for data collection.

3. Results and discussion

For all experimental trials, the net specific charge (q/m) of initial particles was found to be small with a range of −0.05 to 0.05 μC/kg. After the completion of the fluidization period, >90% of initial particles remained in the bulk of the bed. The net specific charges of bulk particles had a range of 0.12–0.35 μC/kg.

3.1. Wall particles properties

Upon the removal of the bulk particles, the inner column wall was inspected from the bottom for any degree of particle fouling. Fig. 2 presents examples of images obtained from the fluidization vessel inner wall before and after PE resin build up (white layer seen in the image). As can be seen in Fig. 3, <6% of initial particles adhered on the column wall during fluidization. Fig. 4 presents the net specific charges of wall particles out of the initial particles after fluidization. Results show that, after 1 h of fluidization, the particles net charge was positive for both resins tested and at various pressures.

Similar runs were then carried out except that the charge distributions of the wall particles were measured by using the CPS unit. Results are presented in Figs. 5 and 6 for mass percentage ($m\%$), net specific charge (q/m), and the mean size (dp_{50}) of particles collected in the four Faraday cups of the CPS unit. For both types of polyethylene resin, the results indicated that particles fouled on the column wall contained both positively and negatively charged particles, although the majority of particles were positively charged. Negatively charged particles collected in FC1 and FC2 were slightly smaller than the positively charged particles settled in FC3 and FC4. This implied the existence of the size dependence of bipolar charging phenomena in gas-solid fluidization processes. "Bipolar" charging is a unique and important phenomenon observed in granular systems. Researchers have noticed that in contact charging of granules made of identical material, but having different sizes, particles tend to be charged oppositely. A number of authors [15–18] have reported that in bi-polar charging, the smaller particles charge negatively and larger particles charge positively. Although, contradicting results have also been obtained by others [7,9,13,19,20].