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INVESTIGATION OF THE EFFECT OF FLUIDIZATION TIME ON ELECTROSTATIC CHARGE GENERATION IN GAS-SOLID FLUIDIZED BEDS

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ABSTRACT

This work focused on determining the effect of the fluidization time on particle charging. Charge equilibrium was reached on the bed particles after 60 minutes. The wall particle layer was built with negative and positive charges. Similar sized particles migrated to each region of the bed regardless of fluidization time.

INTRODUCTION

In gas-solid fluidized beds, electrostatic charge generation occurs due to frictional charging, triboelectrification and contact charging from particle-particle and particle-reactor wall interactions. Consequences of electrostatic charges are particle agglomeration, particle build-up on reactor walls, and electrical discharge which could potentially result in fires and explosions. In polyolefin production, formation of a particle layer on the reactor wall due to bed electrification has been reported as a significant problem for many years. If this stagnant layer contains active catalyst, it can overheat, melt and lead to the formation of molten polymer layers (“sheets”) on the reactor wall. Consequently, these sheets dislodge and fall onto the distributor plate requiring reactor shut-down, causing reduction in reactor operation and production. Understanding the contributing factors to charge generation and thus wall fouling is important in determining the charge generation mechanisms potentially leading to the development of methods to reduce or prevent this phenomenon.

Various factors impact charging properties of particles including particle size and shape, composition and work function of contacting surfaces, area and frequency of contacts, and environmental conditions [1] [2]. Of particular interest is the effect that fluidization time has on charge generation. With extended fluidization time, the number of particle-particle and particle-reactor wall interactions increase. However, in the case of sheeting, it is still unknown when particle sheets form following the onset of fluidization, how they change during the fluidization period (e.g., particle layer growth over time), and the charging mechanism behind layer formation.

Only a limited number of studies have been reported in literature in regard to the fluidization period. Murtomaa et al. [3] investigated the effect of fluidization time on electrostatic charge generation using a small acrylic column (outer diameter of 30 mm, height of 240 mm) with glass beads ($dp_{0.5}$ = 1130µm). A ring probe was used to measure the induced charge in the column, 85 mm from the bottom of the bed. It was determined that a charge plateau was reached after 5 minutes. Ciboroswki and Wlodarski [4] measured electrode potential within a Rasotherm glass fluidized bed (inner diameter of 60 mm, height of 555 mm) using particles of three different materials (Vinyl Polyacetate, Polystyrol, and Sand) with size ranges of 49-75µm. The electrode potential was measured with a platinum wire ending in a small ball suspended in the centre of the fluidized bed. After the stabilization of gas velocity and humidity, the electrode potential reached a plateau after approximately 20-30 minutes of fluidization. These works suggest that an “equilibrium” of charge may be reached at some time during fluidization. However, all of these works measure the charge of the particles within the bed during fluidization and do not delve into the effect of time on the charge distribution within different regions of the bed.

The objective of this work was to investigate the effect of the fluidization time on the electrostatic charge generation in key areas of the fluidized bed: elutriated fines, the bulk particles, and particles adhered to the column wall. Additionally, the quantity and size of particles found in each region of the bed was investigated. This work utilized a new measurement technique developed in earlier works of this research group [5] that allows for the simultaneous measurement of charge in different regions of the bed. Additional focus of this work was utilization of a fluidization system which more closely mimicked industrial practices by using a metallic column and industrial polyethylene resins with a wide size distribution.

EXPERIMENTAL SETUP AND METHOD

The experimental apparatus and method described previously [5] were used with two exceptions. The fluidization column was fabricated out of stainless steel (inner diameter 0.1m), and a second Faraday cup with a filter bag inside, was fitted to the top of the column to collect the elutriated fine particles and measure their cumulative charge during fluidization (Figure 1a). This cup was affixed directly to the top of the column to capture the fines immediately following exit from the column, preventing additional charging due to handling of the particles. The filter bag also allowed for the captured particles mass to be measured.

Fluidizing particles were polyethylene resins, produced using a metallocene based catalyst in an industrial gas phase fluidized bed reactor. The resin had particle diameters (d_P) approximately ranging from 20-1500 µm, with a mean d_P of approximately 630 µm, and a density of 918 kg/m^3, giving a Geldart classification of Group B. Bed height to column diameter ratio (L/D) was maintained at 4 for all experimental trials. Fluidizing gas was compressed air supplied from the building at 23 ± 0.6°C, and was dried to 0 ± 0.02% relative humidity by an Atlas Copco dryer (Model CD12). The fluidization was conducted at 1.5 u/u_{mf} gas velocity.

Fluidization times of 15, 30, 60, 120, 180 and 360 minutes were tested. The fluidization column was separated into four different sections where the mass, particle size distribution (PSD) and charge were measured and recorded for each experimental run. The four sections, as shown in Figure 1, were:

- The initial particles used before fluidization **(Initial)**,
- The fines entrained from the column during fluidization period that were caught in the top Faraday cup **(Fines)**,
- The particles that were dropped into the bottom Faraday cup upon the completion of the fluidization period **(Dropped)**, and
- The particles that were adhered to the column wall **(Wall)**.

Two additional sampling locations were evaluated for PSD analysis (Figure 1c). In between the collection of dropped and wall samples some particles dislodged from the wall and fell to the ground (**Intermediate Wall**). Intermediate wall samples were only collected at extended fluidization times. Following the collection of the wall particles, some particles remained adhered to the bottom of the column wall (**Bottom Column**). The charge and mass of these particles were not measured.

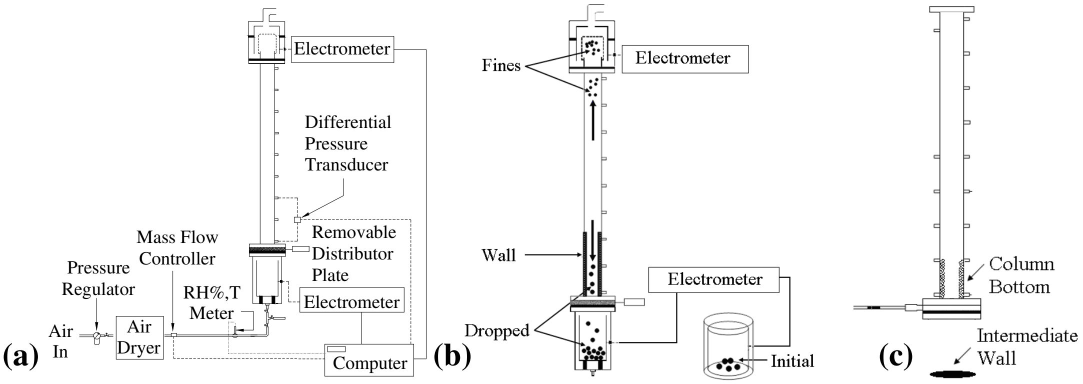

Figure 1: System details a) Schematic, b) Measurement points (charge and PSD), and c) Additional PSD sampling points.

RESULTS AND DISCUSSION

A new batch of particles was used for each run and all experiments were repeated at least three times to confirm their reproducibility. The following sections explain the results obtained for each group of particles with the averages and the standard deviations of repeated runs summarized in Table 1. All experiments displayed similar initial properties. All particles had an initial charge to mass ratio (q/m) within -0.070 to -0.142 µC/kg and had comparable initial particle size distributions (Table 2).

Mass Percent (m%) Collected

Table 1 presents the average mass percent collected in different regions of the fluidized bed. In the dropped region, the m% collected decreased as fluidization time increased. However, the mass levelled out with extended fluidization times. Therefore, the particles from the bulk of the bed were either migrating to the column wall or being elutriated from the column. If the particles migrated to the wall, the cause was probably electrostatic effects; however, if they left the bed it was probably due to their small particles size. In the wall region, m% increased as the fluidization time lengthened. The change in mass collected indicated that as fluidization period increased, the number of particles adhering to the wall also increased. Thus, as the fluidization progressed, a particle layer built on the column wall and grew thicker over time. The mass of fines for all fluidization times was comparable indicating that a minimal amount of fines were leaving the column after 15 minutes.

Table 1: Experimental results.

Fluidization Time min	**# of Runs**	**Initial**		**Fines**	
		m %	**q/m** μC/kg	**m** %	**q/m** μC/kg
15	3	100.0 ± 0.0	-0.103 ± 0.03	0.11 ± 0.00	55.509 ± 16.04
30	3	100.0 ± 0.0	-0.116 ± 0.03	0.11 ± 0.01	93.294 ± 41.16
60	4	100.0 ± 0.0	-0.120 ± 0.02	0.13 ± 0.02	94.933 ± 30.41
120	3	100.0 ± 0.0	-0.089 ± 0.00	0.13 ± 0.01	143.331 ± 65.18
180	3	100.0 ± 0.0	-0.102 ± 0.02	0.11 ± 0.02	246.747 ± 40.09
360	3	100.0 ± 0.0	-0.081 ± 0.01	0.13 ± 0.03	225.632 ± 111.58

Fluidization Time min	**# of Runs**	**Dropped**		**Wall**	
		m %	**q/m** μC/kg	**m** %	**q/m** μC/kg
15	3	97.3 ± 0.4	-0.477 ± 0.07	1.5 ± 0.0	-77.616 ± 14.79
30	3	95.1 ± 2.3	-0.637 ± 0.18	3.1 ± 2.5	-66.238 ± 3.57
60	4	94.3 ± 0.9	-0.709 ± 0.12	3.5 ± 0.8	-58.075 ± 6.98
120	3	92.2 ± 3.1	-0.740 ± 0.23	4.5 ± 1.7	-53.452 ± 11.06
180	3	91.4 ± 1.9	-0.810 ± 0.19	5.3 ± 1.1	-52.042 ± 5.34
360	3	91.0 ± 0.4	-0.795 ± 0.06	6.4 ± 1.0	-57.048 ± 0.98

In each experiment, particles were collected from the three regions of the bed; however, for the wall region, some particles were not able to be collected due to strong electrostatic forces keeping them attached to the wall. The particles close to the wall were those which had more charge and thus more tightly attached to the wall than those in the outer layer of the wall particles.

Charge to Mass Ratio (q/m)

Figure 2 presents q/m results of the fluidizing particles in all measurement regions. Overall, small (entrained fines) and large (dropped and wall) particles were predominately positively and negatively charged, respectively. This supports the bipolar particle charging theory previously reported in literature [6]. Initial particles had the lowest magnitude net q/m (approximately -0.1 ± 0.02 μC/kg), followed by the dropped particles, (-0.4 to -1.0 μC/kg). The wall particles were almost two orders of magnitude larger (-40 to -90 μC/kg). The fine particles had the highest magnitude, but were positively charged (+40 to +320 μC/kg). The bulk is likely comprised of both positively and negatively charged particles, combining together to give a small net q/m, thus explaining the low magnitude of q/m of the dropped particles.

The q/m of the fines elutriated from the column relatively increased with fluidization time until 180 min (Figure 2d). The fines q/m at 360 min was similar to those at 180 min suggesting that a maximum q/m had been reached at this point. Even though the q/m of these particles slightly increased with fluidization time, the mass of particles remained relatively constant. This indicated that the few particles leaving after an extended residence time were more charged than particles initially leaving the bed. This was expected as the particles had higher residence time inside the bed, thus accumulating more charge.

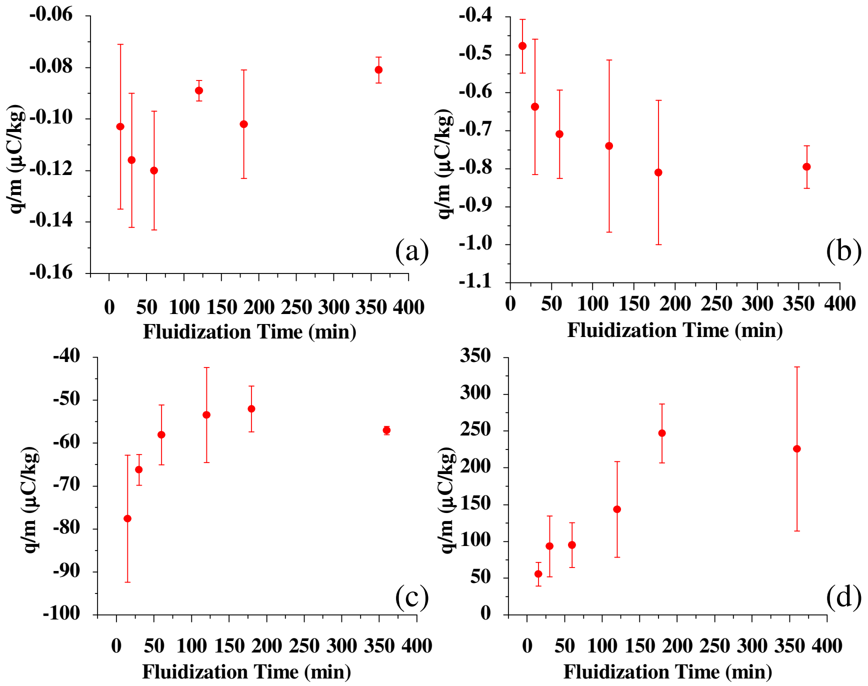

Figure 2: Mean q/m in different regions of the bed for different fluidization times: a) Initial, b) Dropped, c) Wall, and d) Fines.

There was a slight increase in the magnitude of the q/m (i.e., becoming more negative) of dropped particles up to 60 min fluidization times (Figure 2b), while a plateau seemed to be reached for fluidization times of 60 minutes and greater. This showed that with a fluidization time less than 60 minutes, the bulk particles did not have time to generate enough charge to reach saturation. On the other hand, the mass of dropped particles collected continued to decrease as fluidization time increased. This indicated that regardless of collected mass, a similar q/m was obtained with extended fluidization times suggesting that this was the maximum net q/m that could be generated.

The wall particles experienced a decrease in q/m magnitude, becoming less negative up to 60 min, but there seemed to be a q/m plateau at greater fluidization times (Figure 2c). As the work function of polyethylene is greater than that of stainless steel, when particles come into contact with the column wall, the polyethylene is more likely to accept electrons and become more negatively charged [1]. This indicates that the initial particle layers on the wall (i.e., 15 min) must be mainly negatively charged. As fluidization continues, positive charges are required for additional particles to adhere to the wall. Therefore, in shorter fluidization times, the particle layer is comprised mainly of particles with comparatively small positive and larger negative charges. As the fluidization period lengthened to 60 min, the net q/m decreased in magnitude; therefore, as the mass of the wall particles collected increased with time, the positively charged particles adhering to the wall experienced either an increase in magnitude, while the negatively charged particles decreased in magnitude, or an increase in the amount of positively charged particles. The increase in magnitude of positively charged particles is collaborated by the increase in fines q/m with fluidization time. As the mass of fines remained relatively constant, the charge on these particles must have been increasing which is likely true for the fine particles remaining in the bed and eventually adhering to the wall. With particles of a greater positive charge adhering to the wall, the net q/m of the wall would decrease in magnitude (i.e., becoming less negative). For times greater than 60 minutes, since the collected mass increased, both positive and negative charges of similar magnitude must have been adding to the particle layer on the wall to maintain the observed similar overall q/m. Thus, the net q/m was maintained at the same level even with increasing the mass of particles adhered to the wall, resulting in charge saturation and preventing the build-up of additional charge.

Particle Size Distribution (PSD)

Table 2 compares the normalized particle size distributions for all trials. Results demonstrated that particles collected within a single region were similar regardless of fluidization time. Each region had a different PSD, clearly depicted in Figure 3.

Table 2: Normalized particle sizes in different regions of the bed.

Fluidization Time min	# of Runs	Initial $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm		Fines $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm	
15	3	0.46	± 0.01	1.00	± 0.00	2.04	± 0.10	0.05	± 0.01	0.13	± 0.02	0.30	± 0.05
30	3	0.50	± 0.02	1.00	± 0.00	1.94	± 0.07	0.05	± 0.01	0.11	± 0.01	0.24	± 0.03
60	4	0.48	± 0.01	1.00	± 0.00	2.02	± 0.07	0.05	± 0.00	0.12	± 0.01	0.32	± 0.03
120	3	0.49	± 0.00	1.00	± 0.00	1.96	± 0.10	0.05	± 0.01	0.13	± 0.02	0.31	± 0.03
180	3	0.52	± 0.01	1.00	± 0.00	1.86	± 0.05	0.04	± 0.00	0.11	± 0.01	0.27	± 0.02
360	3	0.47	± 0.01	1.00	± 0.00	2.00	± 0.07	0.05	± 0.02	0.13	± 0.02	0.32	± 0.04

Fluidization Time min	# of Runs	Dropped $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm		Wall $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm	
15	3	0.43	± 0.05	0.91	± 0.06	1.87	± 0.10	0.24	± 0.04	0.46	± 0.03	0.84	± 0.02
30	3	0.43	± 0.08	0.88	± 0.09	1.80	± 0.13	0.26	± 0.03	0.40	± 0.02	0.63	± 0.01
60	4	0.47	± 0.04	0.94	± 0.07	1.93	± 0.14	0.28	± 0.03	0.42	± 0.06	0.65	± 0.13
120	3	0.49	± 0.02	0.95	± 0.05	1.88	± 0.07	0.28	± 0.02	0.44	± 0.03	0.66	± 0.05
180	3	0.47	± 0.08	0.87	± 0.11	1.67	± 0.15	0.25	± 0.01	0.37	± 0.02	0.54	± 0.04
360	3	0.51	± 0.03	0.98	± 0.06	1.98	± 0.13	0.29	± 0.01	0.45	± 0.02	0.70	± 0.03

Fluidization Time min	# of Runs	Column Bottom $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm		Intermediate Wall $d_{(0.1)}$ µm		$d_{(0.5)}$ µm		$d_{(0.9)}$ µm	
15	2	0.20	± 0.03	0.38	± 0.03	0.67	± 0.02	-	-	-	-	-	-
30	3	0.17	± 0.01	0.29	± 0.05	0.49	± 0.13	-	-	-	-	-	-
60	1	0.33	-	0.51	-	0.77	-	-	-	-	-	-	-
120	3	0.20	± 0.03	0.34	± 0.05	0.57	± 0.08	0.43	± 0.02	0.61	± 0.04	0.86	± 0.08
180	3	0.19	± 0.02	0.32	± 0.04	0.54	± 0.08	0.41	± 0.02	0.57	± 0.03	0.79	± 0.05
360	3	0.21	± 0.05	0.38	± 0.12	0.67	± 0.25	-	-	-	-	-	-

The sizes of particles collected in the dropped section were comparable to the initial particles. This is expected as the dropped particles comprise the majority of the particles in the bed. The PSD in the wall region was comparable for all fluidization times indicating that the same size particles were adhering to the wall. Therefore, this particle range must be between those particles small enough to be elutriated from the bed by the fluidizing gas and those large enough that the gravitational force exceeds that of the electrostatic force binding them to the wall.

Table 2 also shows the PSD results of the particles in the extra sampling locations, intermediate wall and bottom column (Figure 1c). The intermediate wall particles were slightly smaller than the dropped, and larger than those collected off the wall. These particles formed the outer layer of the wall particles. Thus, it was expected that they were loosely attached to the wall following the collection of the dropped particles, but were too large to remain adhered to the wall for an extended period of time. The bottom column particles varied in size for all trials but there was no obvious trend with fluidization time. The PSDs for this region consisted of particles smaller than those found in the wall region. This indicated that closer to the column wall the size of particles was smaller.

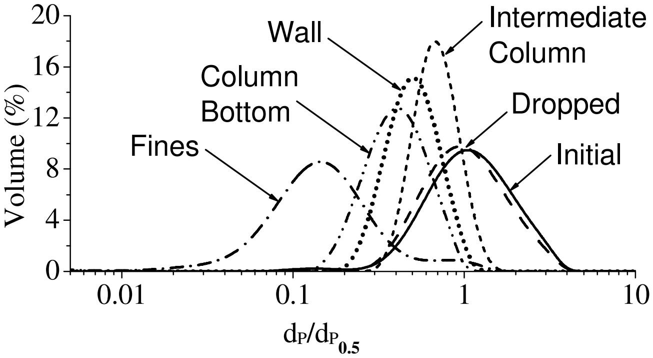

Figure 3: Typical example of comparison of the PSD of different regions of the bed.; Fluidization Time – 120 min; Trial #4.

To compare the size range of particles collected at different sections of the bed, PSDs from all samples were plotted together for each fluidization time. All trials showed similar results. Figure 3 presents typical results from one trial at fluidization time of 120 minutes. Overall, the fines were the smallest, followed by the column bottom, wall, intermediate wall and dropped particles. It can be seen that there is some size overlap between particles of all regions. This supports the previously suggested wall layer effect where particles with positive and negative charges, finer and larger particles, form a layer on the column wall. The fines/wall overlap indicated that some smaller particles were adhering to the wall instead of being expelled from the bed. As these particles were most likely positively charged, based on the sign of the collected fines, they provided the positive aspect of the layering. While larger particles which were more likely negatively charged, provided the opposite sign layer. There was also a large overlap in the wall/dropped PSDs indicating that both regions shared similar size of particles. Two additional PSDs were considered: the particles remaining on the bottom of the column after the wall sample was collected and the particles that dropped off the wall between the collection of wall particles. The particles that fell on the ground were larger than the wall particles, while those that remained on the column were smaller; this suggested that the comparatively smaller particles of predominately negative charge adhered to the wall first followed by the larger particles building-up over time.

CONCLUSION

The particles mass percent, q/m and PSD were studied at a fluidizing gas velocity of 1.5 u/u_{mf} at 15, 30, 60, 120, 180, and 360 min fluidization times. As fluidization time increased, more particles accumulated on the column wall while the amount of particles in the dropped region decreased. For initial fluidization times, the magnitude of q/m of dropped and wall particles decreased and increased, respectively. However, both regions experienced a q/m plateau sometime after 60 minutes of fluidization and showed a negative net q/m. The majority of fines were elutriated by 15 min; however, their net q/m increased, indicating the few particles leaving after an extended residence time, were more charged than particles initially leaving the bed. The fines q/m took much longer to reach a plateau, achieving stabilization after approximately 180 minutes. The PSDs for each region was similar regardless of fluidization time; however, each region had a distinct range of particle sizes.

The results indicated that charge equilibrium was reached on the bulk particles of the bed after a fluidization time of approximately 60 minutes, and the magnitude of charge at equilibrium was not influenced by the amount of particles in the bed. Particles of similar size migrated to each region of the bed regardless of the fluidization time. It was found that both negatively and positively charged particles adhered to the column wall in a layering effect with the net q/m becoming less negative as fluidization progressed. The PSD results confirmed this finding as they showed that wall particle layer consisted of smaller particles closer to the column wall and larger particles towards to the outer layer.

This work focused on one fluidizing gas velocity within the bubbling flow regime. Future work will be conducted to validate these trends with other gas velocities in bubbling regime, in addition to comparing the effects with the slugging flow regime.

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