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# Investigation of electrostatic charge distribution within the reactor wall fouling and bulk regions of a gas–solid fluidized bed

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ABSTRACT

The distribution of charge within the wall fouling region and bulk of a fluidized bed reactor was investigated. Experiments were conducted in a 0.1 m in diameter carbon steel fluidization column under atmospheric conditions. Polyethylene particles were fluidized with extra dry air at 1.5 the minimum fluidization velocity (bubbling flow regime) for 1 h. Using an online Faraday cup measurement technique, the net charge-to-mass ratio ($q/m$), as well as the size distribution of all particles adhered to the column wall and those in the bulk of the bed was determined. The wall particles were found to be predominantly negatively charged while those which did not adhere to the wall were predominantly positively charged. The charge distribution within each region was then investigated by a custom made charged particle separator that separated the particles according to their charge magnitude and polarity. It was determined that although the net charge of the wall layer particles was negative, a significant amount of positively charged particles existed within each sample and therefore the entire wall particle layer. This suggests that the wall layer was formed through layering between positively and negatively charged particles. Particles in the bulk of the bed also consisted of bipolarly charged particles.



## 1. Introduction

Gas–solid fluidized beds have many applications in the food, chemical and petro-chemical industries. One of the major problems facing this technology, particularly in the application of polyethylene production, is reactor wall fouling through the adhesion of a layer of the fluidizing polyethylene and catalyst particles to the reactor walls. Because polymerization reactions are exothermic, the concentration of particles on the wall reduces heat dissipation from those regions and causes the particle layers to melt forming sheets. Hence, the phenomenon is also called "sheeting" [1]. The adhesion of particles to the column walls is believed to be electrostatic in nature [2] and therefore numerous studies have been performed over the years to describe and quantify the generation of electrostatic charges in fluidized beds. Electrostatics play a role in numerous other aspects of fluidized beds such as bed hydrodynamics, bubble size and shape, particle mixing rate, and fines elutriation [1]. Despite previous efforts, a good understanding of charge generation and distribution in fluidized beds remains elusive. A major reason for this is the lack of understanding of the fundamental physical processes involved in electrostatic charge generation, accumulation and dissipation especially for dielectric materials such as polymers [3]. For example, it is unclear as to whether charge transfer involves the transfer of electrons, ions, nanoscopic materials or a combination of these [4].

Despite these challenges, numerous studies have been conducted to investigate electrostatics in fluidized beds. The dynamics of electrostatic charge in fluidized beds are complex and were determined to depend on a large variety of variables such as the fluidized particle diameter; the column wall material and diameter; the fluidizing gas velocity, relative humidity, and pressure and temperature; the fluidization time, among others [5–16]. Furthermore, different measurement techniques such as electrostatic probes and various variations of Faraday cups have been utilized to quantify the degree of bed electrification through the measurement of charge, voltage, current or electric field [5–16]. Many studies have determined that there is a distribution in the magnitude and polarity of electrostatic charge within fluidized beds. A brief review of these studies will follow.

A number of studies has been performed to determine the axial and radial distribution of charge within fluidized and static beds. Studies have used some variety of electrostatic probes inserted into the middle of the bed or placed at the fluidization column wall to measure electric field or potential [7,13–17]. The conclusion of all reviewed studies is that the region below bed level carries an opposite polarity of charge to the overhead region above the bed

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level. Electrostatic fields or potential in the overhead region resulted from typically smaller particles that are continuously elutriated from fluidized beds or from pouring particles into a static bed. It can also be from the charge on fluidization column wall particle deposits.

Cartwright et al. [17] poured polyethylene particles into silos causing the generation of electric charges. The electric field was observed at various radial and axial positions. A complicated distribution was found, and taken as evidence for bipolar charging. Sharmene Ali et al. [18] fluidized polyamide powder in a square steel bed. The charge of wall deposits sampled at various heights was determined using a Faraday cup and found to be positive below bed level and negative above it. This was hypothesized to be a result of induction charging. Furthermore, particles above the bed level were found to have smaller diameters which was explained by the fact that particles above the bed level were from the dilute phase which generally are smaller in size. Inculet et al. [19] observed electric fields in a container while it was filled with starch corn. The cloud of fines in the overhead was observed to be negatively charged while the deposited bottom particles were positively charged.

Other studies have reported the presence of a mixture of positively and negatively charged particles within a single region of the bed. This phenomenon, known as bipolar charging, is the logical consequence of contact between particles of the same material. A systematic difference in charge polarity between smaller- and larger-sized particles was observed in some studies. The reasons for this different are yet to be established, although a number of possible explanations was proposed as will be discussed. Sharmene Ali et al. [20] sampled particles of three different materials from a fluidized bed and poured each sample lightly over an array of Faraday cups. The particles segregated according to charge in a mechanism explained in the publication such that particles in the Faraday cup at the center of the array were oppositely charged to those in the Faraday cups on the edges. Although the particles at the center and the edges had different average diameters there was no general correlation between charge polarity and size across different particle materials. However, the reason for the correlation between fluidizing particles charge and diameter was not clear. Mountain et al. [21] sampled powder from a fluidized bed of acrylic powder and poured it into an electrostatic charge separator device consisting of two plate electrodes, which measured the charge accumulated on each plate. It was observed that both negatively and positively charged particles were present. The net charge was smaller (approximately ¼) in absolute magnitude than either the positively or the negatively charged particles. Positively charge particles were found to be slightly (5–15%) smaller than negatively charged particles. Zhao et al. [22] used a vertical array of Faraday cups to sample the charged polyamide particles from a fluidized bed. It was observed that the largest particles were positively charged while the smaller particles were negatively charged. This phenomenon was suggested to be due to the difference between smaller and larger particles in one or more of four factors: the work function, the microscopic nature of the surface such as roughness, the specific surface area causing different rates of adsorption of contaminants or additives, and the surface energy. Lacks and Sankaran [3] reviewed contact charging in powders including bipolar charging. It was observed that in most studies smaller particles were negatively charged. A hypothesis was suggested to explain this phenomenon where the charge transfer between materials is due to electron transfer from high-energy donor states to low-energy acceptor states. Studies suggest that the availability of acceptor states is not a limiting factor [23]. Therefore, the only issue is the density of donor states. Furthermore, the electron transfer is effectively one-way because it moves down an energy gradient. Since smaller particles have higher specific surface area, they would accumulate electrons and therefore acquire a net negative charge. Pham et al. [24] have shown that when contacting two macroscopic objects of the same material (Teflon in one case and nylon in another) but different surface areas, there is repeatable segregation of polarity depending on the surface area of the contacted object. Whether the smaller of larger surface object acquires a positive or a negative charge depends on its material. Therefore, the evidence of the particle-size dependence on polarity of particles in bipolar charging is still not clear and explanations are not conclusive.

As mentioned above, a variety of measurement techniques was used to investigate bipolar charging. The most common technique has been the introduction of charged particles between two parallel electrodes, and the application of an electric potential between the two. The electric field attracts positively and negatively charged particles to the negatively and positively charged electrodes, respectively. The electrodes can be either vertical, or inclined in an inverted V shape. In one technique [21], a sufficiently strong electric field was applied to small and highly charged particles that caused the particles to be strongly attracted and adhere to the electrodes. The charges on the electrodes were continuously measured using an electrometer. In another technique [25], the application of electric potential only facilitated the dispersion of the falling charged particles between the two electrodes. In this case, a number of bins was present at the bottom of the device to collect particles. The bins closest to the two plates contained the most highly charged positively or negatively particles, while those in the middle might have collected a mixture of positive and negative particles. Similar device was also used for the separation of plastic granules for recycling [26], coal beneficiation [27] or the investigation bipolar charging between particles of the same material [21].

In order to investigate fluidized bed reactor wall fouling due to electrostatic charging, our previous works have focused on determining the charge distribution of particles within a gas–solid fluidized bed using online Faraday cups [28–31]. The measurements had resulted in the net particles charge and charge-to-mass ratio in three regions of the bed; namely elutriated fines, particles that adhered to the fluidization column wall and those in the bulk of the bed. All tests showed bipolar charging where the entrained particles were charged oppositely to those within the fluidized bed. However, it was suspected that even within each region, bipolarly charged particles existed. The aim of the present work is to investigate this hypothesis to further help in better understanding of charge generation within gas–solid fluidized beds. To achieve this objective, a charged particle separator apparatus, similar to those above-mentioned, was designed and built. The device allowed the determination of bipolar charging within the particles accumulated on the fluidized bed wall and the bulk of the bed.

## 2. Apparatus and method

The experimental system, described elsewhere in more detail [28] and shown in Fig. 1a, consisted of a carbon steel fluidization column, a removable distributor plate and a Faraday cup inside the windbox. A filter bag was fitted to the top of the fluidization column to capture elutriated particles. The bag was enclosed in a Faraday cup to continuously monitor the charge of the particles it captured during fluidization. After fluidization was completed, the distributor plate was opened and the majority of particles in the bed dropped into the Faraday cup located below the plate where their charge was measured. The net charge of "initial particles" before each experiment using a bench scale Faraday cup and their net specific charge were determined. During fluidization some particles, labeled "fine particles", elutriated from the bed and captured in the filter bag where their charge as well as mass and size