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An overview of advances in understanding electrostatic charge buildup in gas-solid fluidized beds

Poupak Mehrani [a], Matti Murtomaa [b,*], Daniel J. Lacks [c]

[a] Department of Chemical and Biological Engineering, University of Ottawa, 161 Louis Pasteur Ottawa, ON K1N 6N5, Canada
[b] Department of Physics and Astronomy, University of Turku, Turku, FIN-20014, Finland
[c] Department of Chemical and Biomolecular Engineering, Case Western Reserve University Cleveland, OH 44106, USA

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ABSTRACT

Electrostatic charging of particles in gas-solid fluidized beds often results in operational complications in commercial processes. This paper provides a comprehensive review of the advances from the last decade in three key areas, namely the fundamental understanding of triboelectric charging, methods to measure particle charge, and experiments to elucidate particle charging processes in fluidized beds. This review underscores the need for better understanding the mechanisms of triboelectric charging in granular systems, effective online charge monitoring techniques, and experiments under industrially relevant conditions to better comprehend the problems in commercial reactors that can enable strategies to mitigate charging.

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* Corresponding author.
E-mail addresses: poupak.mehrani@uottawa.ca (P. Mehrani), matti.murtomaa@utu.fi (M. Murtomaa), daniel.lacks@case.edu (D.J. Lacks).

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1. Introduction

Gas-solid fluidization technology is widely employed in many industries such as oil and gas, mining, chemical, food and agriculture, etc., for various applications including catalytic reactions, drying, mixing, just to name a few. The widespread usage of the technology is due to its high heat and mass transfer capability. Such characteristics are provided by the high levels of contact between the fluidizing gas and solids which also result in frequent collisions between the fluidizing particles as well as the particles and the fluidization column wall. A major nuisance resulting from such continuous particle contacts is the generation of electrostatic charge. The generated charges might cause particle agglomeration causing deviation from the desired bed hydrodynamic behavior, electrostatic discharge endangering operators and equipment, and the adhesion of particles to the fluidization column wall and other surfaces necessitating regular shutdown for clean-up. The extent of charging would vary from one system to another depending on the physical and chemical properties of the surfaces in contact (i.e., fluidizing particles and fluidization column wall) as well as the hydrodynamic conditions of the fluidized bed.

One industry which has faced operational challenges due to the generation of electrostatic charges is the polyolefin industry. For example, in the catalytic polymerization of ethylene to produce polyethylene, the accumulation of electrostatic charges in the fluidized bed reactor is a major nuisance primarily due to occurrence of a problem known as “sheeting”. In such reactors the charge buildup on the fluidizing polyethylene and catalyst particles results in their adhesion to the reactor wall where the heat of exothermic polymerization reaction may not be removed as much and thus resulting in the particles to melt and form sheets along the reactor wall. Industrially, a reactor might operate for only a few hours before sheeting necessitates its shutdown for clean-up [1]. Hendrickson provided a comprehensive review of polymer reactor electrification resulting in sheeting, as well as the academic works reported in the literature pertaining to understanding of the fluid bed electrification [2]. Hendrickson concluded that further research was still necessary in relation to wall sheeting formation in polymer reactors as well as its detection since it was shown that most of the research reported was carried out at conditions that were not typical of commercial polymerization reactors. They included, the usage of humid air, usage of particles that had properties far from polymers such as polyethylene and usage of small scale equipment.

The existence of electrostatic charges in gas-solid fluidized beds have been reported for many decades [3] and there have been studies attempting to study this phenomenon for almost as long [4]. But although there has been some progress in the understanding of electrostatic charging in fluidized beds and a number of proposed solutions, the problem still persists. This is partly due to complex nature of the fluidization process as well as the complex nature of the electrostatic phenomenon. Thus there is still a great need to better understand the fundamental mechanisms of charge generation and dissipation in gas-solid fluidized beds. Over the past ten years much research has been carried in an attempt to advance the understanding of electrostatic charging in fluid beds. The specific areas of research include: advances in charge measurement techniques applied in gas phase fluid beds; mechanisms of surface charging including better understanding of triboelectrification in insulators; and describing the effects of bed hydrodynamics and operating conditions on electrostatic charge generation and distribution within a fluidized bed. This paper reviews the advances made over the years from the fundamental understanding of triboelectrification to measurement methods developed to better quantify the degree of charging, and experimental works carried out to better understand fluid bed electrification.

2. Triboelectrification

When two neutral surfaces are brought into contact and then separated, transfer of charge generally occurs such that one surface becomes charged positively and the other surface becomes charged negatively if at least one of the materials is insulating. This phenomenon, which is called “triboelectric charging” or “contact electrification”, has been written about since antiquity. It is a surprise to most people that our scientific understanding of triboelectric charging has not progressed significantly over this time. Triboelectric charging is a very complex and difficult-to-study process, both theoretically and experimentally. We briefly describe below what we feel are the most important open questions in the area, why the answers to these questions are difficult, and the state of current understanding.

2.1. The charge carriers

It is not known what species act as charge carriers in the charging process – the species could be electrons, ions, or pieces of material. The identity of the charge carriers is difficult to determine because the charge carriers represent a very small fraction of surface atoms. A typical value of the surface charge density on a highly charged surface is 10^{-5} C/m^2. As one elementary charge is 1.6×10^{-19} C and there are 10^{+18} nm^2 per m^2, this charge density corresponds to or 10^{-4} elementary charges per nm^2. Since the diameter of an atom is approximately 0.3 nm, there are approximately 10 surface atoms per nm^2. Thus, on a highly charged surface there is only about one excess elementary charge per approximately 100,000 surface atoms. Such a small concentration is very difficult to detect experimentally or to analyze with theoretical models.

2.1.1. Electron transfer

On first glance there seems to be no mechanism for electron transfer between surfaces of insulator materials. In the standard picture of electrical insulators, the valence bands are filled and there is a very large energy gap between the valence band and the conduction band. Such a large energy gap would make it unlikely for an electron to transfer from a valence state on one surface to a