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# Numerical and Experimental study of electrostatic charge in gas-solid fluidized beds

Youssef Nasro-Allah<sup>1</sup>, Carlos Montilla<sup>1</sup>, Renaud Ansart<sup>1</sup>, Rodney Fox<sup>2</sup> and Olivier Simonin<sup>3</sup>

<sup>1</sup>Laboratoire de Génie Chimique, Université de Toulouse, CNRS. Toulouse, France

<sup>2</sup>Department of Chemical and Biological Engineering, Iowa State University, Ames, IA, USA

<sup>3</sup>Institut de Mécanique des Fluides de Toulouse, Université de Toulouse, CNRS. Toulouse, France

youssef.nasroallah@inp-toulouse.fr

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## Abstract

Electrostatic charges have been one of the major issues in gas-solid fluidized beds, including wall fouling due to particle accumulation on the walls, defluidization, security issues like sparks and dust explosions, etc. At a molecular scale, the particle-wall or particle-particle contact generates electrons transfer, inducing a charge on each particle. As a result, the surrounding gas carries an electromagnetic field which results in an electromagnetic force known as Lorentz force. The aim of this work is to model this force and take its contribution into account in the momentum equation. In this work, a tribocharging model coupled with the multi-fluid model is proposed in an Eulerian approach to model the phenomenon. The numerical simulations will be carried with NEPTUNE\_CFD to test the model. An experimental setup is build to form an accurate database for comparison with simulations. It will also help to adjust the model parameters.

## Introduction

With polymer reactors, electrostatic charge generation can cause the formation of larger granules, as well as reactor wall fouling, which is the formation of layers of the particles on the reactor wall. Hendrickson (2006) reviewed electrostatic effects in polymerization fluidized-bed reactors and the causes of reactor fouling, explained the charge distribution in fluidized beds and compared the effect of electrostatic forces with other forces like drag and, gravity on particle entrainment. Sowinski et al. (2012) studied the effect of particle size of a polyethylene resin received directly from industrial reactors on electrostatic charge generation and reactor wall fouling using a Faraday cup.

Regarding the relative humidity effect, Fotovat et al. (2016) performed experiments at different values of relative humidity using a mixture of glass beads as coarse particles and fine particles of different materials. These experiments aimed to study the relationship between fluidized bed electrostatic and entrainment.

On the numerical side, there was many models proposed to describe the phenomenon. Rokkam et al. (2010) developed an electrostatic model based on basic laws describing electromagnetic phenomena within an Eulerian approach. For tribocharging phenomenon, Lindell et al. (1993) analyzed the interaction of two dielectric spheres to find their reaction to external sources based on a static theory image. On the other hand, some authors proposed models based on the surface state theory (Ali et al. (1998), Laurentie et al. (2013)).

Kolehmainen et al. (2016) built a Lagrangian model on the same works and tested it on a miniaturized fluidized bed in a

DEM simulation. More recently, Kolehmainen et al. (2018) proposed the same model in an Eulerian approach.

## Numerical Methods

Building on the well known Maxwell equations for electromagnetic field, a Poisson equation is solved for the electric potential :

$$\nabla \cdot (\varepsilon_m \nabla \varphi) = - \frac{\sum_{\beta=1}^N q_{p\beta} \alpha_{p\beta}}{\varepsilon_0} \quad (1)$$

where  $\alpha_g$  is the gas volume fraction,  $\alpha_{p\beta}$  is the volume fraction on the  $\beta^{th}$  solid phase, N is the solid phase count in the mixture,  $\varepsilon_m$  and  $\varepsilon_0$  are the dielectric permittivity of the mixture and the vacuum respectively.  $\varphi$  is the electric potential. The walls are assumed to be grounded ( $\varphi = 0$ ). Note that the effect of magnetic field is neglected here.

The gradient of the potential results in an electric field  $\mathbf{E}$ :

$$\mathbf{E} = -\nabla \varphi \quad (2)$$

This electric field induces an electrostatic force  $\mathbf{F}_{qp\beta}$ :

$$\mathbf{F}_{qp\beta} = -q_{p\beta} \alpha_{p\beta} \nabla \varphi \quad (3)$$

Numerical simulations are carried with NEPTUNE\_CFD, an unstructured code using unsteady Eulerian multi-fluid approach for dilute and dense particle-laden reactive flows (Hamidouche et al. (2018)). The coupling between the electrostatic model and the multi-fluid was verified by simulating experimental results of Sowinski et al. (2010). The weakness

of this model is that charges are fixed on particles, which does not take into account the tribocharging phenomenon.

The triboelectric charging mechanism assumes that the charge carried by the solid phase obeys to the following transport equation:

$$\alpha_p \rho_p \frac{\partial \chi_p^c}{\partial t} + \frac{\partial}{\partial x_i} (\alpha_p \rho_p U_{p,i} \chi_p^c) = \frac{\partial}{\partial x_i} \left( \alpha_p \rho_p D_\chi \frac{\partial \chi_p^c}{\partial x_i} \right) + \psi_{p,q} \quad (4)$$

Where  $\chi_p^c = \frac{\langle q_p \rangle}{m_p}$  is the average charge per mass unit.  $\alpha_p$  and  $\rho_p$  are, respectively, the volume fraction and the density of the  $p^{th}$  phase.  $U_{p,i}$  is the  $i^{th}$  component of the  $p^{th}$  phase velocity.  $D_\chi$  is the diffusion coefficient.  $\psi_{p,q}$  is a source term representing the charge generation due to collision between particles of different solid phase. The transfer between particles inside the same solid phase is included in the diffusion coefficient.

The boundary conditions are expressed by a charge flux from the wall towards the particles. This flux represents the charge generation due to the particle-wall collision.

## Experimental setup

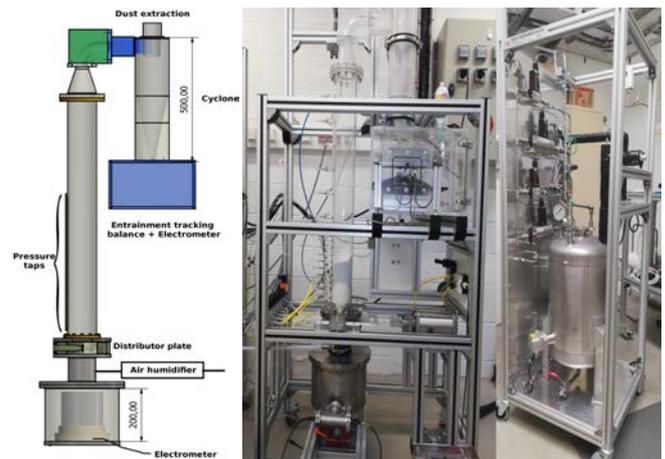
The experiments are performed on a laboratory scale pilot of 0.1 m inner diameter and 1 m height Plexiglass column shown in Fig. 1b. A diagram representing this setup is shown in Fig. 1a. The electrostatic charges are measured by means of two Faraday cups related to an electrometer. The distributor plate was welded in a valve related to an actuator to allow particles to drop into the Faraday cup. Entrainment flux is followed up via a box at the end of the cyclone. The box contains a Faraday cup placed on a balance to follow the evolution of charge and entrainment flux simultaneously. This pilot is made of the same material (Plexiglass) starting from the distributor to the end of the cyclone in order to have the same effect of walls on particles.

The humidity effects is studied by means of a humidity generator presented in Fig. 1b on the right. This generator ensure a constant value of the relative humidity in a range up to 40% without heating the system. It is connected to the compressed air supplier.

The experimental work can be divided in two main parts. The first one is the study of bubbling fluidized bed. The net charge of the particles will be measured after each experiment. This aims to compare to literature findings and to estimate the saturation charge of the particles. The second part is the study of entrainment flux. The entrained mass and charge evolution will be measured at the end of the cyclone. This allows to study the effect of electrostatic charges on entrainment flux. Both parts will be performed at different relative humidity values to highlight its effects. These experiments will provide an accurate database to adjust the tribocharging model parameters depending on relative humidity and particles properties (size, material).

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(a) Diagram of the experimental setup

(b) The experimental setup and the humidity generator

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