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# Contribution to the analysis of the flow electrification process of powders in pneumatic conveyers

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In this paper we examine the process of charge development in powders for two different configurations: one is a fluidized bed between two porous electrodes, the other is a flow in a pneumatic conveyer. It is proposed a theoretical approach for both phenomena that is in good agreement with experimental results.

## 1. INTRODUCTION

Transport and storage of loose material in industry often encounters static electricity problems. The research in this area has enabled to obtain systems to measure the particle flow rates [1] but often it has been undertaken for safety reasons [2] or because static electricty leads to a reduction of the industrial process efficiency. The phenomena of charge formation are mainly due to the charge transfer that occurs during the shock of particles on a solid surface and even if important recent advances on contact electrification have been made [3, 4] the process is not yet totally understood. However, for repeated contacts it is generally admitted that the charge of the particles reach a saturation value [5, 6]. In this article we make an analysis of the evolution of these phenomena based on the time dependency of the transfer current. Two different configurations are considered: a fluidized bed where particles impact on a flat electrode and a flow through a pipe where the particles move in a disperse phase and impact on the wall of the pipe.

## 2. FLUIDIZED BED CONFIGURATION

When a thin layer of powder is fluidized between two porous electrodes separated by a given distance, some particles get kinetic energy high enough to reach and hit the upper electrode (see Figure 1). During the collisions the particles get electric charges and then fall down on the top of the bed. This phenomenon leads to the generation of a current $i_g$ and as the process goes on, the particles on the top of the bed become more charged (or more particles are charged) but simultaneously they discharge partly through the electrical resistance of the bed. Finally the system reach a steady state for which the generated current is equal to the leakage current through the resistance of the bed. But even without leakage, the generated current itself would vanish when the charge of particles reach the saturation value. This means that at a given time t, the current due to the charge transfer during the impacts is proportional

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to the difference between the potential V at the top of the bed at the time t and the potential $V_\infty$ for the saturation value at an infinite time.

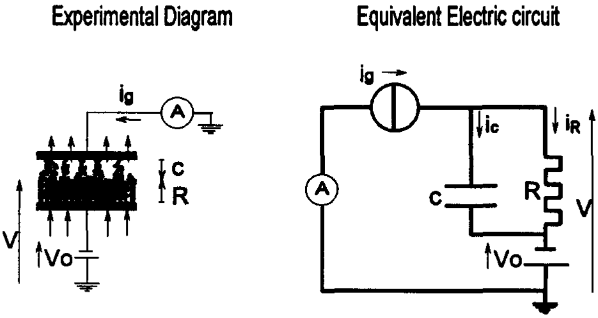


Figure 1. Schematic diagram and equivalent electric circuit diagram.

The phenomenon can thus be formulated as following:

$$i_g = K\left(V_\infty - V_{(t)}\right) \tag{1}$$

after some time the phenomenon reaches an equilibrium for which:

$$i_g = K\left(V_\infty - V_s\right) = \frac{V_s - V_0}{R} \tag{2}$$

where $V_s$ is the steady state voltage, $V_0$ is the applied one, K is a constant and R is the electric resistance of the bed. Being C the capacitance between the upper electrode and the top of the bed, and considering the equivalent electrical circuit of figure 1 we have:

$$i_g = C\frac{dV}{dt} + \frac{V - V_0}{R} \tag{3}$$

Then a simple analysis gives the following solution:

$$V = V_s\left(1 - e^{-t/\tau}\right) + V_0 e^{-t/\tau} \tag{4}$$

where $\tau = \frac{C}{K + 1/R}$. Finally the generated current $i_g$ and the total charge generated $Q_g$ are:

$$i_g = \left(V_s - V_0\right)\left[\frac{1}{R} + K\exp\left(-\frac{K + 1/R}{C}t\right)\right] \tag{5}$$

$$Q_g = C(V_s - V_0)(1 - e^{-t/\tau}) \tag{6}$$

The parameters K, $V_\infty$ and $V_s$ are related to the intensity of the phenomenon and their values increase with the air flow as this is the driving force of the process.

## 3. EXPERIMENTS ON A FLUIDIZED BED

### 3.1. Experimental cell.

The experimental cell is shown in figure 2. The body of the cell (1) is cylindrical and made of PTFE. The two electrodes (2) are of porous brass. Dry air flows through a metallic chamber soldered to the lower electrode (3), then through this electrode, the bed of powder (4), the upper electrode and finally exits the cell. The upper electrode is mobile and fixed to a metallic bar guided by ball bearings (5). A rubber joint around the upper electrode prevents from a powder leakage during fluidization.

### 3.2. General equipment

The general equipment is shown in figure 3. The air flows through the dryer (1) the flow meter (2) and then the cell (3). The humidity is measured at the exit of the cell with a sensor (4) and recorded. The current is measured on the upper electrode with a picoammeter Keithley 642 (5) connected to a Keithley data acquisition board inserted in a PC computer (6). For one set of experiment the lower electrode is grounded, for the other one it is connected to a power supply (7).

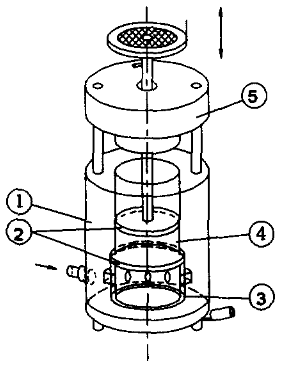


Figure 2. Experimental Cell

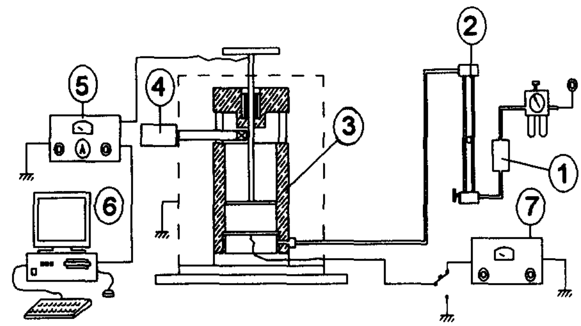


Figure3. General Equipment

### 3.4. Measurements procedure

The powder is introduced in the cell in a layer which is generally a few millimetres thick. The upper electrode is placed at a given distance from the lower electrode. Then the powder is aerated by a dry air during around 30 minutes to have a dry powder (the humidity is controlled by the moisture sensor). Finally, the current is measured for a given potential applied to the lower electrode $V_0$ and a given flow of air $f_l$.

## 4. EXPERIMENTS FOR DIFFERENT VOLTAGE $V_0$

In these experiments, see figure 4, the air flow has been fixed to 1500 l/h and different voltage $V_0$ have been applied to the lower electrode 0, -500 and -1000 V. The parameters found to give a rather good agreement between experiments and predictions (dashed line) are the following: $C = 266$ pF ; $R = 0{,}2\ 10^{12}\ \Omega$ ; $\tau = 11$ s ; $K = 19.2\ 10^{-12}\ \Omega^{-1}$ ; $V_s = 730$ V.

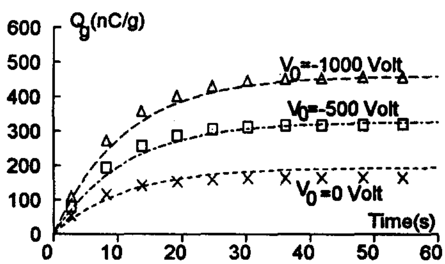


Fig. 4. Charge generated for different voltage

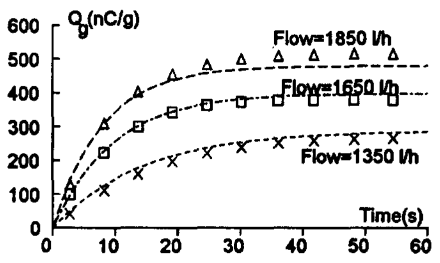


Fig. 5. Charge generated for different flows

## 5. EXPERIMENTS FOR DIFFERENT FLOW VELOCITIES

In these experiments, figure 5, the lower electrode is grounded and we have tested three different flows 1300, 1650 and 1850 l/h. To determine the parameters K and $V_s$ of eq. 5 and 6 we assume the following laws:

$$K = A\,(f_l - f_{l_0}) \tag{7}$$

$$V_s = B\,f_l^{\alpha} \tag{8}$$

A good agreement between experiments and predictions (dashed line) is obtained with the following values for the different parameters $A = 0.04.10^{-12}$ h/ (l $\Omega$), $B = 6\ 10^{-3}$ Volt h/L, $\alpha = 1.6$, $f_{l0} = 900$ l/h, C = 355 pF and $R = 0.15\ 10^{12}\,\Omega$. The parameters K, R, C and $\tau$ are of the same magnitude order in both experiments and the slight differences between them are likely caused by the thickness of the powder layer. Indeed as the thickness of the layer increases for a same flow, the energy of the impact is reduced (more energy is needed to fluidize the bed) and the layer expands more, thus K and C decrease but R increases.

## 6. CHARGE GENERATED IN A PNEUMATIC CONVEYER

From previous experimental work [5] we know that for a flow of electrically neutral particles entering a pipe, a charge built-up occurs which leads to a wall current coming from the wall pipe. This one vanishes when the saturation charge in the powder is attained. As a result, at a certain distance from the inlet, the streaming current as well as the mean space charge convected by the flow attains a saturation value. The length of the pipe corresponding to the saturation value depends on different parameters of the flows of the particles and the pipe. So, the mean charge per unit of mass in a cross section may be expressed by:

$$Q(z) = Q_\infty\left(1 - \exp\left(-z / z_c\right)\right) \tag{9}$$

z being the distance from the entry, $Q_\infty$ the mean charge for an infinite long pipe and $z_c$ is a characteristic length of the charge development phenomenon. As the charging process due to collisions depends on the mean velocity of the flow $\overline{U}$, we propose :

$$Q(z) = A\overline{U}^{\alpha}\left[1 - \exp(-z/z_c)\right] \tag{10}$$

Then, the charge supplied by a part of the pipe of length L and placed at a distance z from the entry is given by:

$$Q_L(z) = L\frac{dQ(z)}{dz} = L\frac{A\overline{U}^{\alpha}}{z_c}\exp\left(-\frac{z}{z_c}\right) \tag{11}$$

We observe that it is maximum for $z = 0$ and then decreases asymptotically to 0 for $z = \infty$.

## 7. EXPERIMENTS IN A PNEUMATIC CONVEYER

A schema of the experimental device is shown in Figure 6. The equipment is composed of three different vessels, upper (1), feeder (2) and lower (3). A set of valves (4) and (5) enable to link vertically the feeder vessel with the upper vessel (when introducing the powder in (2)) or with lower vessel (when making the measurements). The powder is pneumatically conveyed with nitrogen from the lower vessel to the upper one through the pipes. The top of the upper vessel is made of porous brass so that the air exits but not the powder. The particle flow rate is determined by operating the lower valve and if necessary we introduce vibration to help the powder to fall to the lower vessel.

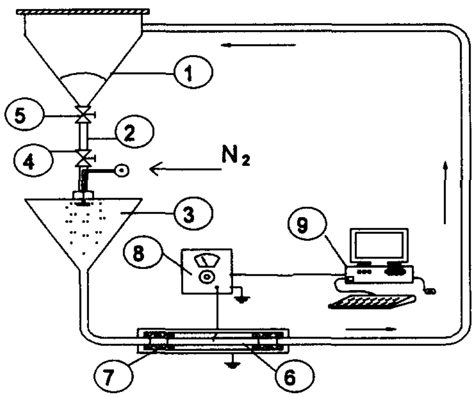


Figure 6 : Pneumatic conveyer experimental equipment.

The development of the process of flow electrification is analysed by measuring the current on a part of pipe (6) made of stainless steel and electrically insulated with PTFE insulators (7) from the rest of the equipment. This section could be placed at different distance from the exit of the lower vessel. All the grid and the Faraday cage surrounding the pipe measuring section are grounded. The current obtained with a picoammeter Keithley 642 (8) connected to a Keithley data acquisition board inserted in a PC computer (9) is integrated in time to obtain the total charge. The same Teflon powder than that of the previous experiments has been used. The powder and the installation are dried with nitrogen before any measurement.

We can see figure 7 and 8 the evolution of the charge transferred by the pipe for different flows and at different distances.

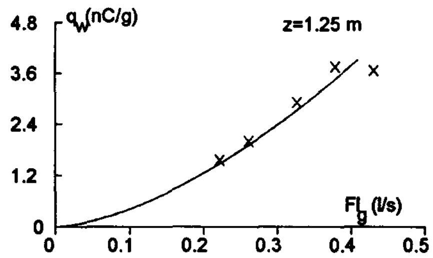


Figure 7 : Charge transferred in terms of flow.

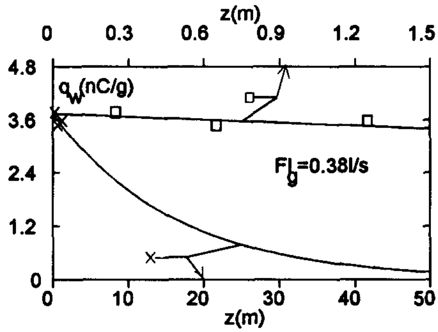


Figure 8 :Charge transferred in terms of z.

From the analysis of the figures 7 and 8 we observe that at small distance from the pipe entrance (z smaller than 1.5m), it is the beginning of the process and the evolution of the wall current in terms of the entry length is very small, that means that the wall current and thus the charge transferred from one portion of the pipe are nearly constant.

From the previous experiment we found that the maximum charge is around 600 nC/g. Thus as a pipe of 10 cm gives around 3.6 nC/g for a maximum velocity we expect a characteristic length $z_c$ = 16 m. The equation (11) is represented in figure 7 and 8 with this value and with $\alpha = 1.6$ we obtain a good agreement of the model with the experimental data.

## 8. CONCLUSION

The experiments and modelling studies on the fluidized bed show that the current decreases with time. This indicates an increase of the particle charge to a steady value, for which the current due to the impact is equal to the leakage one. For the flow electrification process of a disperse phase flow of particles, the process of built-up in the pipe needs several meters to be fully developed and is strongly dependant on the velocity. Its evolution in terms of z seems to be in agreement with the predictions.

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