ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 25, 2017

How tribo-electric charges modify powder flowability

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ABSTRACT

The presence of electrostatic charges inside a powder is known to influence drastically the material flowing properties. The triboelectric charges produced at the contacts between the grains and at the contacts between the grains and the container produces electrostatic forces. On the one hand, the triboelectric effect is useful for many applications, but on the other hand, the triboelectrification causes complications. Unfortunately, the triboelectric effect is still poorly understood, even at the fundamental level. The difficulties are related to the non-equilibrium character of the tribolectetric dynamic and to the variety of mechanisms behind this effect. Moreover, reproducible electrostatic measurements are difficult to perform. We developed an experimental device dedicated to the measurement of powder triboelectric properties. This device measures the ability of a powder to charge electrostatically during a flow in contact with a selected material. This measurement is performed at controlled hygrometric conditions. We present the results of an experimental study involving different powders and granular materials. The relation between the powder electrostatic properties, the hygrometry and the flowing behavior is analyzed.

INTRODUCTION

Granular materials, fine powders and nanopowders are widely used in industrial applications. Therefore, any progress in the understanding of powders behaviors could have huge consequences for numerous industries for the optimization of processes or to avoid technical issues. In order to control and to optimize processing methods, these materials have to be precisely characterized. This characterization methods is related either to the properties of the grains or to the behavior of the assembly of grains. Many advanced methods are available to measure physico-chemical grain characteristics: laser diffraction to obtain the grain size distribution, morphometer to measure grains shape, X-ray diffractometer to characterize crystallinity, ... During the past decades, some interesting techniques have been developed to measure powder flow like powder rheometers inspired by liquid rheometers,[1] shear cells[2] and a variety of improved methods.[3] However, too many techniques used in R&D or control quality laboratories are still based on old measurement techniques.[4] In particular, the powder electrostatic properties are still poorly understood, even at the fundamental point of view.

When two materials are rubbed, electric charges are exchanged at the surfaces.[5,6] Despite the numerous studies dedicated to this subject, the fundamental mechanisms behind this triboelectric effect is not fully understood. In particular, the charging of objects composed by the same material and charging of powders and granular materials are two examples of poorly understood subject. Even the basic question related to the nature of the transferred charges (electrons, ions or material) is still debated. In addition to the fundamental works needed to improve the understanding of the triboelectrification in powders and granular materials, a precise and reproducible measurement method is needed to quantify the ability of a powder to produce electric charges.

When dealing with powder flow and powder electrostatic properties, it is well known empirically that air moisture is an important parameter.[7–9] Indeed, moisture influences surface grains conductivity and capillary bridges formation. For low relative air humidity, the electrical conductivity necessary for charge dissipation is reduced. Therefore, the electric charges created by triboelectric effects induce forces between the grains and/or between the grains and the container. For high relative air humidity, the electrical conductivity increases and liquid bridges may be formed at the contacts between the grains. Therefore, the electrical charges are dissipated more easily. However, the apparition of liquid bridges induces cohesive forces inside the packing. At intermediate relative humidity values the cohesion is expected to decrease.

In this paper, we show how the combined effect of electrostatic charges and capillary bridges affects powder flowability. For that, the powder cohesiveness and the powder compaction dynamics is measured for different relative air humidity conditions. Afterward, we focus on the effect of electrostatic charges on the flow at low humidity. The flow of a charged powder through the aperture of a silo is analyzed.

MEASUREMENT METHODS

Four devices have been used to study the influence of triboelectric charges on powder flow: (i) GranuDrum to measure the powder cohesiveness, (ii) GranuPack to measure the compaction dynamics, (iii) a silo (GranuFlow) to measure the flowability and (iv) a tribocharger (GranuCharge) to measure the ability of a powder to charge during a flow in contact with a selected material. The set-ups used to perform the present study are the prototypes of the instruments presently commercialized by GranuTools company.

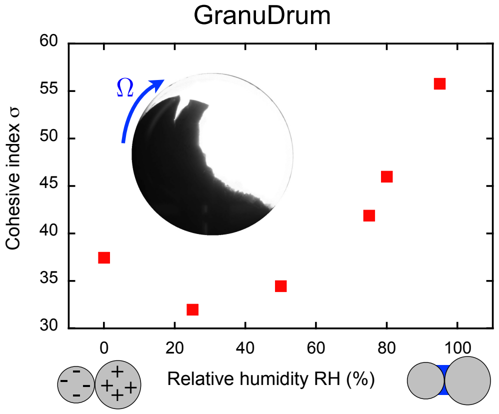

Figure 1. Cohesive index σ measured with GranuDrum at a rotating speed Ω =8 RPM as a function of the relative humidity RH for a residence time in the conditioner fixed to $T = 150$ minutes.

The GranuDrum[3] is an automated powder flowability measurement method based on the rotating drum principle.[10,11] A horizontal cylinder with vertical glass side walls called drum is half filled with the sample of powder (see insert of Figure 1). The drum rotates around its axis at an angular velocity Ω ranging from 2 RPM to 20 RPM. A CCD camera takes snapshots (typically 50 images separated by 0.5s) for each angular velocity. The air/powder interface is detected on each snapshot with an edge detection algorithm. Afterwards, the average interface position and the fluctuations around this average position are computed. Then, for each rotating speed, the flow angle α_f is computed from the average interface position and the dynamic cohesive index σ_f is measured from the interface fluctuations. Indeed, interface fluctuations are induced by the cohesive forces between the grains. Therefore, the dynamic cohesive index σ_f is close to zero for non-cohesive powders and increases when the cohesive forces increase.

Before the measurement in the rotating drum, the powder is conditioned during a time T in a slowly rotating reactor with an air flux of controlled RH. To obtain more information about this method, see.[9]

The GranuPack instrument[3] is an auto-

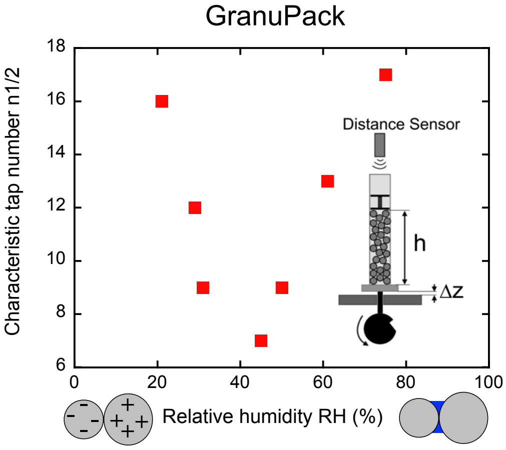

Figure 2. Number of taps $n_{1/2}$ needed to reach one half of the compaction process, *i.e.* needed to reach the density $(\rho_0+\rho_N)/2$, as a function of the relative air humidity RH.

mated and improved tapped density measurement method. The behavior of the powder submitted to successive taps is analyzed with an automated device (see insert of Figure 2). The classical Hausner ratio H_r, the initial density ρ_0 and the final density ρ_N after N taps are measured precisely. Moreover, a dynamical parameter $n_{1/2}$ (the number of taps needed to reach the density $(\rho_0+\rho_N)/2$) can be extracted from compaction curves. The compaction curve is a plot of the bulk density as a function of the tap number. The powder is placed in a metallic tube with a rigorous initialization process. Afterwards, a light hollow cylinder is placed on the top of the pile to keep it flat during compaction. A single tap consists in the tube containing the powder sample moving up to a height of $\Delta Z = 1$mm and then performing a free fall. The height h of the pile is measured automatically after each tap. From the height h, the volume V of the pile is computed. As the powder mass m is known, the bulk density ρ is evaluated and plotted after each tap. The bulk density is the ratio between the mass m and the volume V of the powder. The relative air humidity can be controlled inside the device during the measurement.

A triboelectric charger (see Figure 3 (left)) is used to measure the total electrostatic charge created inside a granular material during a flow in contact with a selected material. The sample is poured manually (the feeding could be automated) in a V-tube and flows to a Faraday cup. The tube material can be selected for each tube. The faraday cup is connected to a customized electrometer able to measure electrostatic charges. At the end of the flow, the total value of the electric charge Q present in the powder is measured and the charge density $q = Q/m$, where m is the sample mass, is computed. The V-tube geometry has been selected to combine the different mechanisms leading to tribo-electrification: (i) friction between the grains, (ii) friction between the grains and the wall and (iii) impacts of the grains on the wall at the connection between the two tubes. The Faraday cup can be replaced by a silo with an aperture D and coupled with an electronic scale (see Figure 3 (right)) to measure the influence of the electrostatic charges on the flow rate. This configuration with the flowmeter (the silo) following directly the tribo-charger is necessary to minimize the charge decay between the tribo-charger and the flow measurement.

RESULTS

Before presenting our very recent results linking directly the total amount of electrostatic charge inside a powder and the flowability, we show how the relative air humidity RH influences the flowability. The RH is expected to modify the amount of electrostatic charge inside the powder, modifying indirectly the flowability.

To measure the influence of RH on powder cohesiveness, a powder conditioning at fixed humidity during $T = 150$ minutes has been done before the measurements in the GranuDrum. Figures 1 shows the influence of RH on powder cohesiveness for a lactose powders (Granulac 140 from the Meggle). The cohesion is found to decrease slightly in the range of RH from 0% to 50%. Afterward, the cohesion increase importantly from RH=50% to RH=100%. For low RH, the cohesion is induced by the apparition of electric charges in the powder. For high humidity condi-

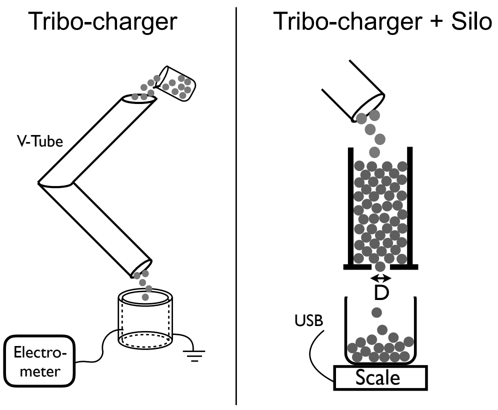

Figure 3. (left) The powder tribocharger used to measure the electrostatic charge created inside the powder after a flow in contact with a selected material. The device used to perform the present study is the prototype of the GranuCharge instrument commercialized by GranuTools company. (right) The tribocharger is used to charge the powder before filling the silo to measure the flow rate. The silo measurement system comes from the GranuFlow instrument from GranuTools.

tions, the condensation of water at the surface of the grains leads presumably to the formation of capillary bridges at the contact between the grains, increasing powder cohesiveness. The same behavior is observed with glass beads during compaction measurements at controlled RH. The glass beads are spherical and monodisperse with a diameter d=1mm. For the present study, the number of taps has been fixed to $N = 2000$ in order to reach the saturation. As shown by Figure 2 the compaction characteristic time $n_{1/2}$ decreases between RH=20% to RH=45% and increases afterward. A low value of the compaction characteristic time $n_{1/2}$, *i.e.* a fast compaction dynamics, is associated to a good flowability.[12]

For low RH, the flowability is decreased due to the apparition of electrostatic charges. For high RH, the flowability is decreased due to capillary interactions. An optimal flowability is obtained around RH=45%. Now, we focus on low RH conditions to link the quantity of electrostatic charges in the powder and the flowability. The flow rate through the aperture of a silo has been measured with a powder previously charged with the tribo-charger (see Figure 3 (right)). The silo aperture size has been fixed to $D = 5$mm and the powder is formed by glass beads of diameter $d = 50\mu$m. The charge density q expressed in μC/kg has been varied by changing the V-tube characteristics. The small glass beads has been selected to obtain a hight charge density. Figure 4 shows the evolution of the flow rate as a function of this charge density q. The flow rate is found to decrease significantly when the absolute value of the charge density increases. Moreover, as shown by the error bars, the fluctuations of the flow rate from one measurement to the other (five repetitions) increases also with the absolute value of the charge density q. Indeed, the cohesive forces related to the electrostatic charges are inducing flow fluctuations.

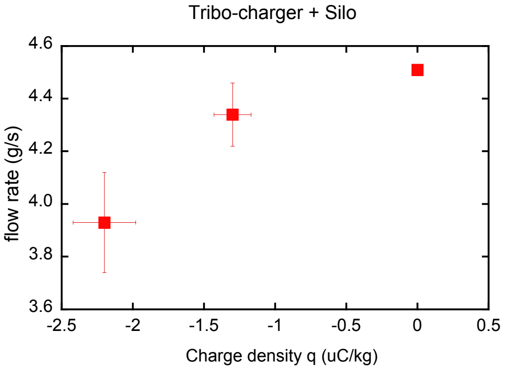

Figure 4. Flow rate through the silo aperture (see Figure 3 (right)) as a function of the charge density inside the powder.

CONCLUSION

We have shown that the relative air humidity affects strongly the flow of powders. The powder cohesiveness increases for both dry and wet conditions. When the relative air humidity is low, grain-grain friction inside the flow induces the appearance of electrical charges in the packing, inducing cohesive forces between the grains. The condensation in high humidity conditions implies the formation of liquid bridges between contacting grains which induce also cohesive forces. Taking both effects (triboelectricity and capillarity) into account, the cohesion is minimized for intermediate values of the relative humidity, i.e. between RH=30% and RH=50%.

The flow rate through the aperture of a silo has been measured with a powder previously charged with a tribo-charger. This flow rate is found to decrease when the absolute value of the charge density q increases. Moreover, the electrostatic charges are inducing flow fluctuations. These first results are opening new perspectives to understand the influence of electrostatic charges on powder flow.

ACKNOWLEDGEMENTS

We Thanks Walloon region (Fonds de maturation - convention 1318086 and BEWARE - convention 1410265) and F.R.S.-FNRS (Grant PDR T.0043.14) for the financial support.

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