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A reproducible test to characterise the triboelectric charging of powders during their pneumatic transport

Adoum Traore Ndama, Pierre Guigon, Khashayar Saleh*

Chemical Engineering Dept, Université de Technologie de Compiègne, Laboratoire de Transformations Intégrées de la Matière Renouvelable (EA 4297), B.P. 20529, 60205 Compiègne Cedex, France

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ABSTRACT

Although several investigations had been carried out to explore the triboelectrification of powders, only few data are available on the experimental procedures and set-ups required to obtain reliable data. The present study deals with the development of a pneumatic test to characterise the tribocharging of fine powders. An experimental device was set up allowing on-line monitoring of the charge of both particles and transport pipes. Experiments were carried out using two types of powder (fine sugar and PVC) coupled with two types of pipe materials (Teflon and nylon). Results showed the extreme importance of the control of the relative humidity, the initial charge of particles and the charge dissipation of the walls to obtain pertinent data. Furthermore, the results showed that solids loadings higher than 1 (kg of solids/kg of air) are not proper to achieve reliable measurements. However, at very dilute solids loading (~0.001) the time evolutions of the electrostatic charge and the mass of the powder follow similar trends so that the tribocharging becomes independent of the solids mass flowrate. This allows accurate assessment of the tribocharging of cohesive powders for which a regular flow cannot be guaranteed.

1. Introduction

Handling of particular materials usually leads to the generation of electrostatic charges. Although, electrostatic charging of powders can be constructively exploited in applications such as xerography, electrostatic spraying, painting and separation, the main concerns in this field remain hazard and work safety. Several difficulties encountered during the processing, conveying and storage of powders are attributed to their electrostatic charging. Indeed, charged powders could cause damage ranging from losses in quality and productivity, to more severe accidents like explosions. In addition, the charging of powders could make particles adhere together or to the containers walls and alter their dispersion or flowability. Among all the processes involved in the tribocharging of the powders, pneumatic transport is probably the method that leads more towards the generation of electrostatic charges [1]. Hence, it is of great interest to have consistent tests to characterise the tribocharging of powders due to this process. The aim of this work was to develop a reliable laboratory-scale device and the subsequent experimental procedure to properly characterise the tribocharging of powders during their pneumatic transport.

1.1. Literature survey

Pneumatic transport of bulk materials refers to the moving of particles suspended in, or forced by, a gas stream through a network of horizontal and/or vertical pipes, by compressed air or by vacuum. During this operation, electrostatic charges appear as a result of collision between particles and the wall or between particles of different natures [2–10]. Both materials are then charged oppositely and electrostatic discharges could occur in different scales:

- between particles and the wall;
- from particle to particle in the case of bipolar charges; and
- between the pipe and the earth or the surrounding objects for metallic pipes if not grounded.

When the pipe is made of an insulator material, axial arcs within the duct may also be observed [10,11].

Numerous authors have published results on the tribocharging behaviour of powders during pneumatic conveying [9–52]. Some of them have focussed their attention on issues of hazard and the safe handling of combustible powders (e.g. [13–26]), some on the increase in the pressure drop due to tribocharging and to subsequent energetic impacts (e.g. [27–35]), some on the measuring devices used to characterise the flow characteristics such as particle

* Corresponding author. Tel.: +33 3 44 23 44 23.
E-mail address: khashayar.saleh@utc.fr (K. Saleh).

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concentration or velocity (e.g. [36–46]), and others on the use of the pneumatic transport as a tribocharging test to establish the so-called triboelectric series for powders or to point out the effect of relevant parameters on the tribocharging process (e.g. [47–52]).

1.1.1. Electrostatic discharge and hazard concerns

Although the main cause of explosions and fires remains mechanical sources, electrostatic discharge constitutes a significant source of hazards in powder handling. Electrostatic ignition is thought to be responsible for about 10% of industrial accidents [13,14]. Moreover, about 15% of electrostatic hazards when handling powders take place during their pneumatic transport. Indeed, among those processes reputed to be risky from the point of view of hazard, pneumatic transport is one of those that is most charge generating [1]. It should also be noted that the majority of accidents in silos and separating units should be attributed to tribocharging during pneumatic transport. Indeed, the product's density (and hence space-charge density) in the transport pipe is significantly lower compared to their density under storage conditions. This results in particles acquiring a high degree of electrostatic charge during their pneumatic transport. In the case of non-conductive materials, this can result in high space-charge densities in the storage silos due to the accumulation and compaction of particles and lead to the formation of strong electric fields inside the silo which could be a source of electrostatic discharge and ignition. Examples of this kind of problem have been largely described by [15–24].

1.1.2. Quality, productivity and product losses

Industrial bulk products are most often mixtures of several compounds, each being able to be charged differently. In this case, bipolar charging of particles occurs, leading to their agglomeration due to electrostatic forces. This phenomenon has some negative effects regarding the quality of the products and the hydrodynamics of their transport. Agglomerated particles could undergo segregation during the transport or whilst in storage which is not desired for a consistent quality of production. Note that bipolar charging of particles has been reported even with mono component products when impurities are present in the system or when the particle size distribution is broad [5–8,25,26]. By a rapid approximation using Coulomb's law one can find that for small particles (<100 μm) electrostatic attraction forces become significant for charge quantities as small as 1×10^{-15} C. Taking into account that the maximum charge density of solids is about $2.5 \times 10^{-5}\ \mathrm{C\,m^{-2}}$ [2,6], it becomes evident that even an infinitesimal amount of impurities might generate high electrostatic interactions. Also, some workers (e.g. [5–8,25,26]) pointed out that charge separation can occur due to a difference between the sizes of contacting particles. The phenomenon is not yet fully understood and explanations to describe the reason of this behaviour differ between studies.

It should be noted that even uni-polar charging might affect the quality and the productivity of the units. For example, charged particles can adhere to the surface of plastic bags in the area where the bags must be closed by pressing, sticking or pinching. In this case, the presence of particles disturbs the sealing of packages.

1.1.3. Pressure drop effects

Several workers have reported a variation in pressure drop along the pipe over time until an equilibrium pressure drop is reached. This is of particular importance as in a pneumatic conveyance system, most of the energy is used for the transport of the air itself. Hence, any increase in the pressure drop has a direct impact on energy consumption. The first investigations on this issue were conducted in the 1950s by Clark et al. [27], Culgan [28], Mitlin [29] and Richardson and McLeman [30] who attributed this phenomenon to the electrostatic charge developed on the particles of powder conveyed. Clark et al. [27] showed that if a powder was transported for a long time, the pressure drop required to assure transport would increase by an order of magnitude. Further experiments by other researchers confirmed the increase in the pressure drop due to electrostatic charging. Mitlin [29] observed this effect for the transport of dusts of insulator materials in a metallic pipe. He associated this observation to the deposition of a dust layer on the metal duct due to electrostatic forces which increased the friction factor along the wall. It should be noted that the presence of such a layer had been already reported by Culgan [28]. Other experiments by Mitlin reaffirmed this suggestion and revealed that no pressure drop increase occurred for metallic powders that could lose their charge to the wall. Richardson and McLeman [30] found that once established, the increased pressure drop is maintained even if fresh products are used to be conveyed. Cole et al. [10] conducted experiments with a polystyrene powder transported in both metallic and insulator pipes, brass and Nylon, respectively. These authors found that the charging of particles only had a negligible effect on high-speed gas–solid transport (air velocity in the region of $67\ \mathrm{m\,s^{-1}}$). Indeed, in this case the aerodynamic drag forces seem to have been high enough to overcome the electrostatic forces. In accordance with previous findings, the flow inside metallic pipes remained unaffected during the transport whereas an increase of about 60% in the friction factor of the nylon pipe was observed. However, no evidence of individual particles sticking to the wall was reported, but the presence of a hard layer of polystyrene building up on the nylon pipe wall was shown. Studies of the pressure drop stability became of interest with the attractiveness of dense-phase transport. Ally and Klinzing [31] studied the vertical pneumatic transport of several solids from two aspects, an overall energy consumption level by pressure drop measurements and a micro-level analysis as indicated by charge transfer between particles and tube. These authors postulated that the pressure drop due to the electrostatic contribution was a function of both the number density and the maximum charging ability of the particles. In another work [32], Ally and Klinzing investigated the electrostatic effects in vertical pneumatic transport for a variety of powders with solids loadings up to 100 kg of solids per kg of air. Their results showed that in the dilute phase, or in non-charging dense-phase transport, the pressure drop matched the existing correlations of Yang [53] and Konno-Saito [54] for the friction factors of solids. However for dense-phase transport of electrostatic charging systems an increased energy requirement about 70% was recorded.

Wang et al. [33] studied the vertical pneumatic transport of Group C and Group A glass beads through a plexiglas tube. These authors noted that the influence of the electrostatic charging on the pressure gradients became stronger with increasing air velocity and increasing particle size. The electrostatic charging also slightly affected the transition air velocity between dense-phase and dilute-phase transport as determined by Zenz's diagram [54].

Some workers [32,33] attempted to establish models to take into account the contribution of electrostatic forces in the classic models for solid friction factors and pressure drop predictions. However, further investigations are required to identify the parameters needed to use these models for given materials.

1.1.4. Electrostatic probes for flow measurement of solids during pneumatic transport

The tribocharging of particulate materials during pneumatic transport is so unavoidable that some workers considered the possibility of utilizing this effect to develop solids flow-metering devices. Cole et al. [10] measured the electric current directed to