Experimental characterization of triboelectric charging of polyethylene powders

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Abstract. Triboelectric charging causes serious problems in the industrial processing of powders. We focus on the charging of polyethylene (PE) powder particles, whose agglomeration can cause serious economic problems in PE production in fluidized-bed reactors. The ‘cascade method’ apparatus, i.e., a slide followed by the Faraday’s pail, was utilized to observe the particle-wall charging of PE particles in friction contact with various materials (glass, aluminium, PE) and allowed us to characterize the charging dynamics. Our results indicate that the evolution of the charge on the particles follows a saturation curve, where the saturated state is represented by maximum (outcome) charge. Such a trend can be conveniently fitted by a function representing the first-order dynamics. We determine the dependency of charging dynamics on various factors, e.g., the humidity, the slide surface roughness and the slide material. Our measurements imply that air humidity influences the charging process substantially more than the choice of the slide material. Moreover, we observe significant charging even in the case of the same materials being in contact. The work contributes to a better understanding of tribocharging and the estimation of charging-related parameters provides the input for the modelling of this complex process.

1 Introduction

The mechanism of triboelectrification resists our attempts for its full understanding and subsequent accurate description of the charging process. Triboelectrification is in practice often associated with the collisions of industrially important powders (e.g. polymers, drugs, flour). Powder particles undergo the repeated particle-particle and particle-wall friction contacts as they are manufactured and/or transported, which results in undesired charge accumulation. In this work, we focused on the qualitative and quantitative systematic description of the triboelectric charging of polyethylene (PE) particles.

2 Experiments

The granular material used in these experiments was PE (density 0.94 g/cm³, diameter of the particles was 0.8-1 mm). PE particles are rough and porous, representing the nascent material leaving the polymerization reactor. The electrostatic charging of PE particles was characterized using the cascade method apparatus (described below), which was in some cases combined with the corona discharge unit.
The cascade method apparatus was constructed from a plate used as slide. The dimensions (length and width) of the slide were 50x5 cm. The slide inclination was fixed at 30°. Weighted PE sample was poured many times on the top of the slide and the gradual accumulation of the charge on the particle surface was measured in Faraday’s pail after each cycle (Figure 1). Design of the apparatus was inspired by experiments associated with tribocharging of glass [1] and silicon [2], respectively.

Experiments were carried out both in the humid air and in the air mixed with pure nitrogen in order to mimic inert atmosphere of the industrial reactor, respectively. Moreover, the sliding experiments were performed for different slide materials, namely PE, aluminium (Al) and glass.

The procedure of the experiment was the following. First, we measured the weight of the sample, then the sample was poured on the top of the slide. The charge of particles was then measured in the Faraday’s pail. The particles were then extracted from the pail to the Petri dish and again poured on the top of the slide. This procedure was repeated until no significant additional charge on particles was generated.

The effect of corona discharge on the charging dynamics was tested using JCI 155v5 Charge Decay Test unit. Corona discharge was applied on the PE powder only after attaining the saturation charge.

3 Results and Discussion

Example of the charging dynamics is shown in Figure 2, where each point represents the measured value of specific charge accumulated on particle surface after one sliding cycle. Significant charging of the same materials in contact is also observed, which is in contradiction with some published results[3].

Figure 2 shows the significant effect of the relative humidity and of the slide material on the triboelectric charging. Larger saturation charge was observed for lower humidity. The results indicate that the triboelectric charging is not trivially dependent on the choice of slide material. According to
our observations, materials vary in their sensitivity to humidity with respect to charging. These two experimental sets were used to determine the charge of PE particles as the function of a charging period (number of the sliding cycles) for a given slide material and a given humidity.

Since the charge was recorded after each sliding cycle until the saturation value was reached, it is possible to estimate the dynamics of the charging. From Figure 2 it is obvious that the dynamic evolution of specific charge has a saturation character, so that it can be fitted by a combination of elementary functions. We use specifically the following equation

$$Q = A + B \cdot \exp \left( -\frac{x}{C} \right), \quad (1)$$

where $Q$ is the specific electrostatic charge, $x$ is the number of sliding cycles, parameter $A$ represents the saturation charge, $B$ is associated with the initial charge on the particles and $C$ stands for the reciprocal value of the charging rate constant. Parameters $A$, $B$, $C$ of equation (1) depend on the experimental conditions (e.g. humidity, slide material). Figure 3 illustrates that equation (1) fits the experimental data accurately.

Equation (1) is the analytical solution of differential equation (2):

$$\frac{dQ}{dx} = \frac{1}{C} \cdot (A - Q). \quad (2)$$

Since the number of sliding cycles $x$ is only a specific interpretation of charging time, the left-hand side of equation (2) represents the charge accumulation. As the charge accumulation is proportional to the first power of the charge $Q$, we state that the charging process follows the first order charging kinetics.

**Table 1.** Table of parameters of Eq. (1) relevant to Figure 3

|     | A    | B    | C    |
|-----|------|------|------|
|     | -16.99 | 14.79 | 6.45 |

In experiments using the corona discharge unit (Figure 4), the sample was first charged by two corona discharges, and then the sample was slid more than once until the saturation charge was achieved. This procedure was repeated several times.
It is evident from Figure 4 that the sample treated with the corona discharge did repeatedly charge approx. 20% less than the original sample. The value of the saturation charge seems to be independent on the number of the corona discharges if the corona discharge is applied at least once. The corona treated sample was examined by Confocal Raman Microscope and no change of the particle surface in the comparison to the original sample was observed. Even after 20 discharges the Raman spectra remains unchanged. This suggests that the corona discharge might deplete only part of high energy electrons on the particle surface.

Figure 4. The charging curves after repeated corona discharges on the sample (at RH 46%).

4 Conclusions

Polyethylene represents the most commonly produced polymer worldwide. Agglomeration of PE particles during their production caused by the accumulation of the electrostatic charge on their surface can lead to significant economic problems. We measured the triboelectric charge generated by the particle-wall contact using the in-house designed cascade apparatus. Systematic experiments with a good reproducibility were conducted in dependence on the slide material and the air humidity. We demonstrated that evolution of the charge can be fitted by the formal first order kinetics. The air humidity affects the charging process substantially more than the choice of the slide material. However, materials appeared to vary in their sensitivity to humidity with respect to charging. The significant charge accumulation was measured also in the case of the same materials being in the friction contact. The corona discharge applied on the sample reduced the saturation charge approximately about 20%, therefore it might be a fast applicable method for the reduction of the charging during the processing and transportation of powders.

References

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