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FLOWABILITY OF DUSTS FROM DRY OFF-GAS CLEANING: THE INFLUENCE OF PARTICLE SIZE AND THE SPREAD OF THE SIZE DISTRIBUTION

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Abstract

Considerable amounts of fine granular dusts result from dry off-gas cleaning systems. The flowability of these dusts is an important characteristic for the design of dust-conveying and storage equipment. In this study the relation between the flow-relevant properties unconfined yield strength and flowability and important properties of the dust (Sauter mean diameter, spread of the size distribution) were investigated based on the data of seventy dusts from dry off-gas cleaning systems. The results showed that the Sauter mean diameter of a dust from dry off-gas cleaning can be used as the basis for a rough estimate of the unconfined yield strength and the flowability. As is well-known, for coarser dust the unconfined yield strength is typically lower and the flowability is higher. The influence of the spread of the size distribution is comparatively low. However, to obtain reliable flowability data shear tests are obligatory.

Keywords

Dry Off-Gas Cleaning, Dust, Flowability, Particle Size, Spread of Size Distribution

1. Introduction

In dry off-gas cleaning systems the separated dust remains as residue. Its flowability is an important characteristic for the design of dust-conveying and storage equipment. After separation from the off-gas, the fine granular material has to be conveyed to the storage bin after it has been discharged from the hopper of the dust separator. Later, the material has to be discharged again from the silo for further treatment, utilization or transport to landfill sites.

The flowability of a granular material is especially influenced by the average particle size, by the width of the size distribution and the moisture content. Shear testers are used for investigation of the flow characteristics. In shear tests the yield loci are determined for various normal stress loads at pre-shear (Schwedes 2003). For each yield locus corresponding values of the consolidation stress σ_1 and the unconfined yield strength σ_c (or f_c) can be determined. A granular material stored in silo only flows out through the hopper outlet if the stress acting on the bulk material is greater than its strength. The relevant strength in this situation is σ_c. The higher the ratio of the stress acting on the bulk material to σ_c, the more easily the material will flow. The ratio of σ_1 to σ_c, called ff_c value, provides a quantitative characterization of the flowability of a powder (Schulze 2008). A higher value of ff_c, indicates a better flow of the bulk material. For classification of the flow behavior five categories are used: $10 < ff_c$: free-flowing; $4 < ff_c < 10$: easy-flowing; $2 < ff_c < 4$: cohesive; $1 < ff_c < 2$: very cohesive, and $ff_c < 1$: not flowing (Schulze 1996).

The aim of this study was to investigate the relation of the particle size and the flowability of dusts from dry off-gas cleaning systems of different industries. For this the data of seventy dusts from dry off-gas cleaning in various industrial processes were used.

2. Materials and Methods

The dry dust samples investigated originated from dry off-gas cleaning in various industrial processes (power plants, steelmaking plants, non-ferrous metallurgical plants, mineral processing plants and biomass combustion plants). For these dust samples some data from shear tests and for the particle size distribution are already available in existing literature (Lanzerstorfer 2015a, 2015b, 2016a, 2016b, 2016c; Lanzerstorfer & Feichtinger 2016; Lanzerstorfer & Steiner 2016).

For characterization of the particle size of a dust the Sauter mean diameter d_{32} of the particle size was used. For calculation of the spread of the particle size distributions Eq. 1 was used: as d_{90}/d_{10}.

$$spread = \frac{d_{90}}{d_{10}} \quad \ldots\ldots \quad (1)$$

3. Results and Discussion

3.1 Unconfined Yield Strength

Figure 1 shows σ_c of the dusts at low consolidation stress (vertical stress in the shear cell: 600 Pa). For dusts with a d_{32} of less than approximately 5 µm the values of σ_c are scattered, without a distinct trend. In contrast, for coarser dusts σ_c decreases with the d_{32} of the dust. However, the spread increases with increasing d_{32} too. At higher consolidation stress (vertical stress in the shear cell: 20,000 Pa) the situation is different (Figure 2). For all dusts σ_c decreases with the d_{32}.

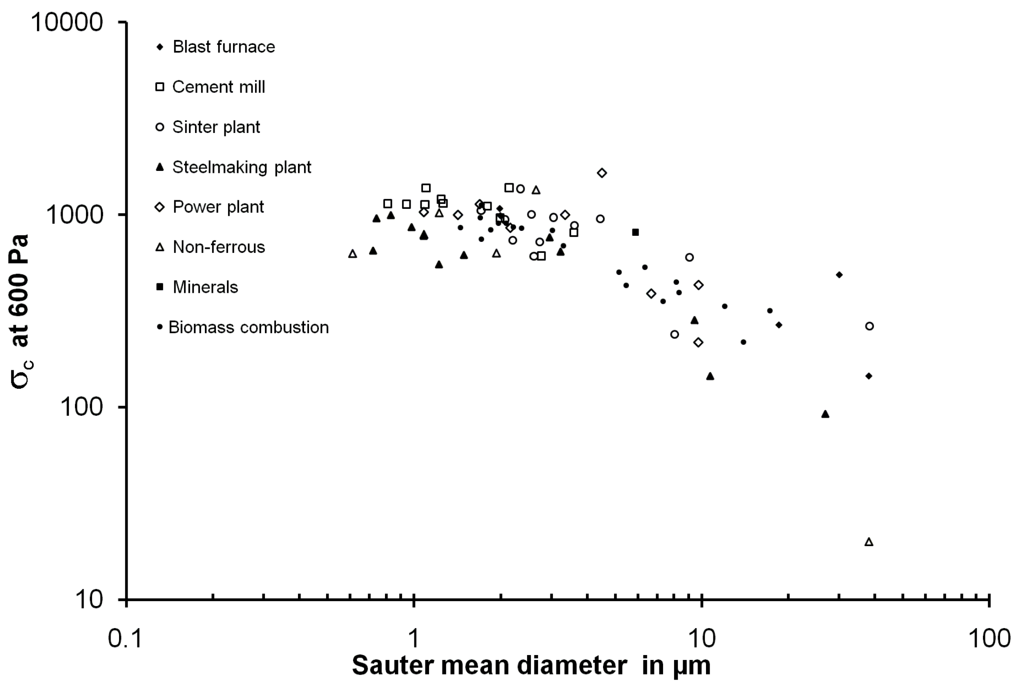

Figure 1: σ_c *as a function of the particle size at low consolidation stress*

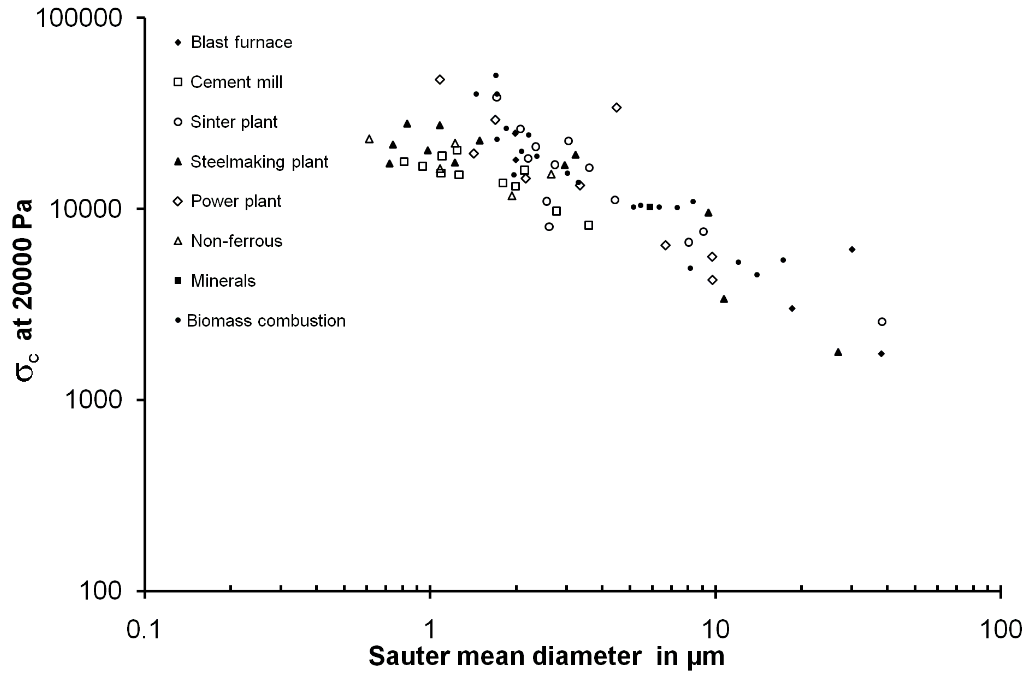

Figure 2: σ_c *as a function of the particle size at higher consolidation stress*

3.2 Flowability

Figure 3 shows the dependence of the flowability ff_c of the various dusts on the particle size at low consolidation stress. The different behavior of the dusts with a d_{32} less than 5 µm and larger than 5 µm observed for σ_c is reflected by the ff_c values. For dusts with a d_{32} of less than approximately 5 µm the flowability is typically in the range of 1 to 2. For coarser dusts the value of ff_c increases with the d_{32}. However, the variation of the flowability increases greatly.

In Figure 4 the dependence of the flowability on the particle size is shown at higher consolidation stress. Generally, the flowability of the dusts is better at higher consolidation stress. The spread of the ff_c value for dusts with the same d_{32} is higher.

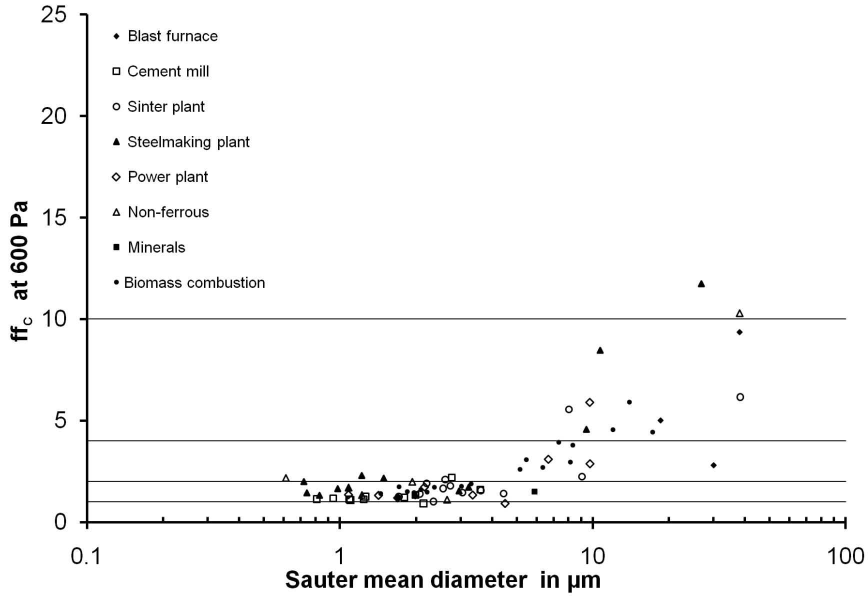

Figure 3: *Flowability as a Function of the Particle Size at Low Consolidation Stress*

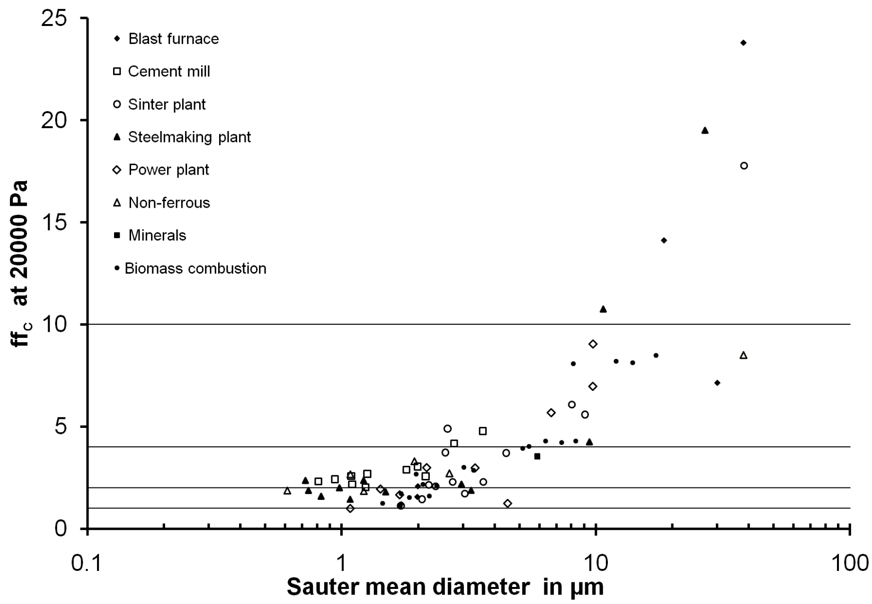

Figure 4: *Flowability as a Function of the Particle Size at Higher Consolidation Stress*

For investigation of the influence of the spread of the particle size distribution the value of the flowability ff_c^* was calculated from the products of powers of the d_{32} and the spread (Eq. 2). The values of the exponents a and b were determined by minimization of the sum of the square of errors.

$$ffc^{*} = d_{32}^{a} \cdot \left(\frac{d_{90}}{d_{10}} \right)^{b} \quad \text{..... (2)}$$

At low consolidation stress the correlation coefficient r^2 increased from 0.68 (ff_c with d_{32}) and improved up to 0.72 when the values for a and b were 0.60 and -0.15, respectively. However, the correlation coefficient increased to 0.70 when exponent a was 0.60 and exponent b was 0.0. The negative value of the exponent for the spread indicates that the flowability is lower for dusts with a broader size distribution. Thus, the spread is not very helpful in explaining the variation of the ff_c. Similar results were found at the higher value of the consolidation stress. The correlation coefficient for ff_c and d_{32} was higher at this stress (0.75). For the values of the coefficients of 0.60 and -0.07 the maximum correlation was reached (0.77). Nearly the same value (0.765) was obtained when a was 0.60 and b was 0.0.

Summarizing the results, the Sauter mean diameter of the particle size distribution of a dust from dry off-gas cleaning can be used for an approximate estimate of σ_c and the flowability. As is well-known, for coarser dust σ_c is typically lower and the flowability is higher. The influence of the spread of the particle size distribution is comparatively low. However, shear tests are essential to obtain reliable flowability data.

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