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Experimental study of the aerosolization of fine alumina particles from bulk by a vortex shaker

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ABSTRACT

The use of a vortex shaker for particle aerosolization from pseudo-bidisperse micron-sized alumina bulk powders has been studied in view of its application as a dustiness characterization method. A parametric study has been carried out with respect to the bulk mass as well as the vortex speed. A minimum sample size and lower and upper limits for the rotational speed have been identified for this powder. Within these boundaries, the aerosolized particles' mass concentration is found to be proportional to the sample's kinetic energy multiplied by its mass. At too high rotational speeds, the particle size distribution is changed.

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1. Introduction

The aerosolization of particles from bulk solids occurs naturally, e.g. when wind is forming a sandstorm, or by human activities, e.g. when flour or cement is filled into bags. Ninety percent of industrial dust emissions are produced during the storage and transport of bulk materials [1]. The tendency of bulk solids to form an aerosol is directly linked to costs in terms of lost product during handling and contamination of machines and products. The transport of aerosolized particles – and possibly their inhalation – is obviously more difficult to control than particles that form a bulk solid. For this reason, it also has an impact on the possible toxicity risk related to the bulk solid since its dust can be inhaled. In industry, bulk powders have played a very important role for centuries [2], but the recently growing concern about the environment, occupational and public health on the one hand and the emerging use of new nano-particles – whose toxicity is still unknown – in innovative applications on the other hand, today create a new need for methods characterizing the behavior involved in aerosol formation.

First, this behavior is governed by the properties of the primary particles. Their shapes and densities lead to their aerodynamical properties, which may be predetermined by product formulation [3] or product preparation [4], e.g. for inhalation purposes. Their particle density, size distribution and surface properties lead to forces at the (inter)particle level, which are at the origin of the bulk's cohesiveness [5] and its tendency to remain agglomerated [6]. Micron-sized alumina powders have been identified for the work presented here, motivated by demand from the private sector. The dustiness measurement of alumina powders has already been the topic of studies using drop tests or fluidized beds, e.g. [7]. Alumina powder is readily available, has rather 'regular' primary particle shapes and can be handled with existing international chemical safety standards, e.g. [8]. The main challenge of the alumina used here with respect to the evaluation of their dustiness consists in their 'pseudo-bimodality': The primary particles measure less than 10 μm but are cohesive and form almost spherical agglomerates which measure about 100 μm.

Second, the bulk's tendency to form aerosols is governed by the various possible processing or operating conditions, examples of which are already cited above. At laboratory scale, these conditions are approximated by dustiness tests. Yet, no universal dustiness testing method exists [9]. For example, the European Standard 15051 on the 'Measurement of the dustiness of bulk materials' [10] employs with the rotating drum method (EN 15051, part 2) and the continuous drop method (EN 15051, part 3), two different methods with two very different handling processes, possibly yielding totally different results [10]. Both methods have in common that they require bulk solid samples of about 35 cm^3 or 500 g. The Australian and US standards for dustiness measurement of coal investigate about 1 kg of material by means of a rotating drum [11,12]. The continuous drop test has been widely used, e.g. in the field of industrial hygiene for the investigation of e.g. titanium dioxide, limestone, glass beads and lactose, using different moisture contents and particle size distributions [13] or in the field of metallurgical engineering with alumina bulk solids [14,15]. Often, a dustiness index relating the mass of the formed aerosol after the drop of a given

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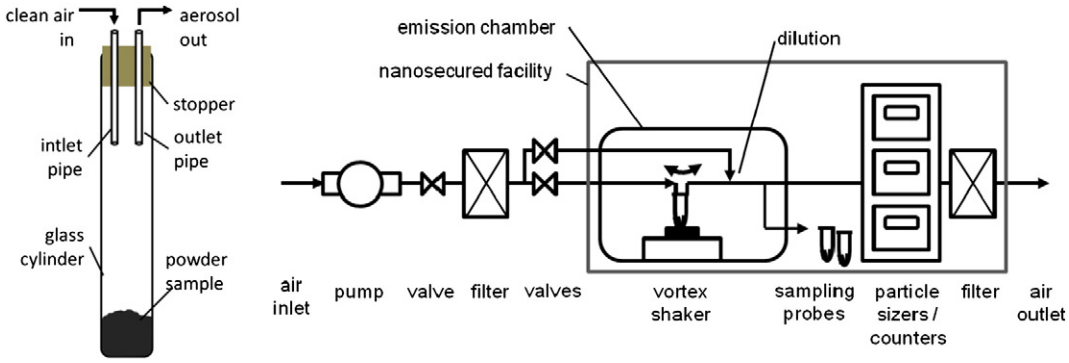

Fig. 1. The experimental setup: the glass cylinder (left) and the equipment placed in an emission chamber (right).

bulk solid's mass to the mass of the sample used is calculated [7,16]. The amounts of bulk solid used in the two mentioned methods might be too great for sectors handling highly expensive bulk solids such as pharmaceuticals or nano-bulk solids. A coupling of both methods has been developed with this in mind by Schneider and Jensen [17], who reduced the amount of powder used to 6 g.

The so-called vortex shaker method has been employed for the characterization of aerosol emission from smaller amounts of bulk solids of carbon nano-tubes [18] and fullerenes, zinc oxide and titanium oxide [19]. The method consists of the mechanical agitation ('shaking') of a small bulk solid sample and requires only about 1 cm^3 of bulk material, which allows for miniaturizing the equipment and for investigating small available amounts of bulk powders. Surprisingly, this method has not yet been fully studied with respect to its potential and its limits.

This paper presents aerosolization results for small amounts of micron-sized alumina bulk solids obtained with a vortex shaker. A focus is put on the identification of appropriate bulk solid masses and vortex rotating velocities.

2. Materials and methods

2.1. Experimental setup

The test setup investigated here is similar to the one used by Ogura et al. [19], i.e. it consists principally of a glass cylinder (diameter 25 mm, height 150 mm), which is mounted on a digital vortex mixer (VWR Signature Digital Vortex Mixer) allowing a uniform vortex action to be applied with rotational velocities ranging between 500 and 2,500 rpm, see Fig. 1. Here, speeds are set to seven speed levels ranging from 1,000 to 2,500 rpm. The glass tube is sealed with a stopper (rubber, depth about 20 mm) through which two stainless steel pipes (inner diameter 3 mm and immersion depth beyond the stopper about 30 mm, i.e. pipe in- or outlets are about 90 mm above the powder's surface) bring purified air into the cylinder and provide a route of escape for the aerosol.

A flow rate of 2 L/min of dehumidified air, purified by a HEPA filter, is set by a valve, controlled by a flow meter and brought into the cylinder. The aerosol is then diluted by purified air (6 L/min) in order to reach the necessary dilutions of the aerosol for the downstream measurements and split to different particle counters, allowing for the detection of particles at different particle size ranges. Since micron-sized alumina particles are studied in the framework of the present work, an aerodynamic particle sizer (APS, allowing for measuring particle sizes between 0.5 and 20 μm, TSI 3321, TSI Inc.) is used. The APS is a time-of-flight particle size spectrometer that measures the velocity of particles in an airflow. For each particle, the time-of-flight is converted into an aerodynamic diameter. The APS also calculates the masses of corresponding spherical particles of the given (and set) solid density [20]. The data are recorded continuously by two personal computers with an acquisition rate of 0.2 samples per minute, during about 1 h of agitation. A sample collector –the Mini-Particle-Sampler® (MPS®) – allows for extracting particle samples on a TEM grid from the aerosol [21]. All equipment is placed in a confined emission chamber in order to prevent the person conducting the experiment from being accidentally exposed to aerosols.

Prior to the tests, the bulk powders have been investigated with respect to their particle shapes and sizes by means of a transmission electron microscope (TEM, FEI CM12®, operated at 120 kV), of a transmission light microscope (Zeiss Axio Imager M1M®) and a particle sizer (Malvern Mastersizer 2000®). For this, bulk samples are dispersed

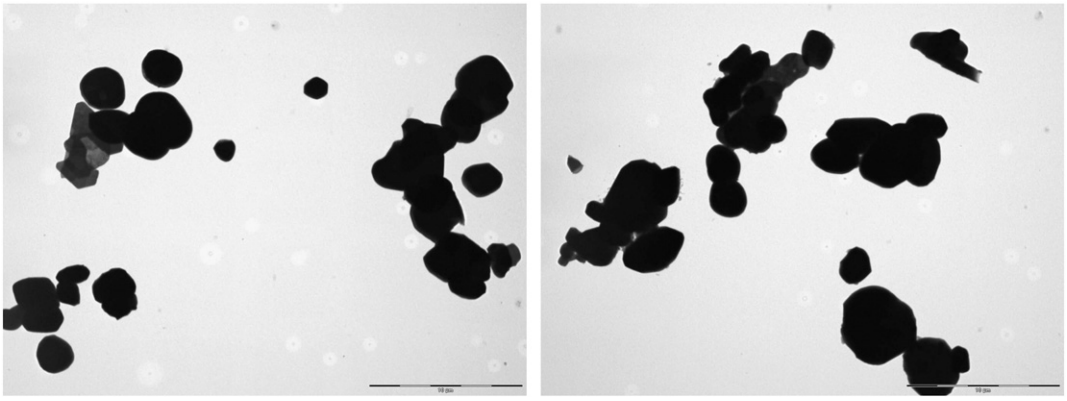

Fig. 2. TEM images of alumina 1 (left) and alumina 2 (right). Image widths are 35 μm.

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