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Grinding in an air classifier mill — Part I: Characterisation of the one-phase flow

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ABSTRACT

In this and the related second paper [1], we present an in-depth study of the two-phase flow and the stressing conditions of particles in an air classifier hammer mill. This type of mill belongs to the mostly used mills at all. In order to develop a predictive grinding model not only the material's reaction to the applied stress but also the stressing conditions within the mill, e.g. impact velocity, incidence angle, number of stress events, have to be known. The latter are strongly affected by the interactions between the fluid and the solid phase within the mill. Systematic flow investigations in the vicinity of the impact elements and in the region of the internal classifier have been performed by Particle Image Velocimetry (PIV) and by numerical predictions of the fluid flow in the complete mill using a commercial CFD solver. Different pin geometries have been studied at various peripheral velocities of the grinding disk and the classifier. The classifier velocity does not influence the velocity profiles near the impact elements in the main flow direction and vice versa, the flow in the grinding zone has little influence on the classification. The velocity profile in front of the impact element, where the comminution process takes place, is constant with time and preserves a characteristic form independent of the operational conditions.

1. Introduction

A long-term objective in comminution science and technology is the realistic modelling and design of grinding machines independent of the respective material under consideration. One step in this direction is the development of models which clearly separate the influence of the machine design parameters, the operational conditions and the material behaviour. Impact comminution experiments at well defined and reproducible stressing conditions allow the characterisation of the breakage behaviour of different materials independent of the mill-specific properties [2]. This procedure allows for the separation of the grinding process into a machine and a material function. The machine function depends on the type of the mill and its operational conditions and defines the stress type, the stress intensity and the stress number. The material function includes all material properties relevant to fracture (thermo-mechanical material properties as the Young's modulus in the simplest case, material strength etc.). Fundamental aspects of a generalised model for the flow sheet simulation of the comminution in hammer mills have been already set in the simulation tool for complex solid processes SolidSim [3]. The comminution model clearly separates between material and operational parameters [4]. The size reduction in the mill is modelled by appropriate selection and breakage functions which can be determined in single particle or lab scale tests and are thus being independent from mill specific features [2,5]. Since there is currently not sufficient information on the mixing behaviour in hammer mills, the hold-up in the mill is assumed to be ideally mixed. A constant impact velocity or a theoretically deduced impact velocity distribution function can be assumed for the simulation [4]. The one single free parameter in the model is correlated with the number of stressing events in the mill and shows systematic trends with the operational parameters.

Dodds et al. [6] proposed an overall model of the grinding and classification in an air jet mill with an integrated classifier. The mill is divided into a perfectly mixed grinding zone, a transport zone with prevailing plug flow and a classification zone, characterized by a grade efficiency curve. While the batch grinding kinetics and the grade efficiency curve are determined experimentally, the residence time distribution is obtained using fitting parameters.

In continuous flow systems like in hammer mills particles of different sizes have different residence time distributions (RTD) in the mill and therefore are subjected to different degrees of grinding before reaching the mill outlet. Berthiaux et al. [7] modelled the RTD assuming the flow through the mill as a bundle of flow streams where each stream is independent. Each stream is modelled as plug flow with a specified residence time.

Gommeren et al. [8] proposed a detailed dynamic model for an air jet mill. The model considers three levels. The first level takes the

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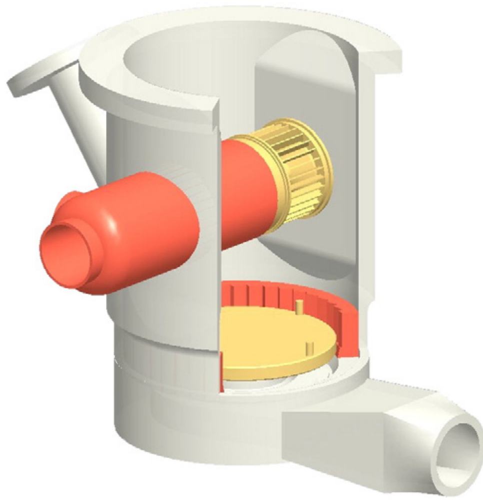

Fig. 1. Air Classifier Mill ZPS 100 (Hosokawa ALPINE GmbH).

interactions between the mill and the classifier into account by describing particle transport and size reduction by empirical probability functions. The second level simulates the fluid flow in 2D and includes the particle motion in the limit of small particle concentrations (one-way coupling) and particle–wall collisions. The third level models the breakage behaviour of the single particle.

The quantification of the particle transport inside hammer mills and the consideration of distributed stress intensity and impact velocity for the simulation of grinding and classification require knowledge of the flow pattern inside the mill. Therefore, the next step for the improvement of hammer mill models is the modelling of the comminution process by taking the full fluid flow into account. The detailed investigation of the flow pattern in the vicinity of the impact elements provides valuable information not only for the impact velocity distribution but also for the relation between stress intensity and residence time distribution in the mill. The present paper deals with experimental and numerical investigations of the single-phase flow in an air classifier mill. In the second part of the paper [1] the particle-laden flow is discussed.

2. Experiments

2.1. Experimental set-up

The flow investigations have been performed using a ZPS 100 air classifier mill (Hosokawa ALPINE GmbH) as shown in Fig. 1. The mill itself consists of a rotating disk with 4 grinding pins at its periphery and an impeller wheel classifier integrated into the top section of the mill chamber. The diameter of the grinding disk is 200 mm and the one of the classifier is 100 mm. Both parts rotate with a variable speed of up to 11,000 rpm. After the particles are fed to the grinding zone of the mill, they are stressed by the rotating grinding pins and then transported by the main air flow to the impeller wheel classifier. The main air is sucked through an inlet positioned under the rotating disk and enters the mill through a gap between the rotating plate and the impact ring. The fine particles leave the mill together with the main air through the classifier, while the coarse material is rejected and transported by the internal circulation back to the grinding zone.

Starting from the air flow visualisation measurements by Particle Image Velocimetry (PIV), the influence of the operating conditions on the flow pattern within the mill is described. To determine the influence of the impact element geometry on the flow field and therefore on the comminution result, cylindrical as well as prismatic impact elements have been investigated. Fig. 2 shows the experimental setup. Tracer particles necessary for the fluid flow measurements are provided by an aerosol generator.

For all experiments performed the overall flow rate through the mill is kept constant at 300 m^3/h (25 °C). The flow rate used for the aerosol generator is 3 m^3/h. Three different peripheral velocities of the grinding disk (80, 100 and 110 m/s) and four classifier peripheral velocities varying from 0 to 50 m/s were investigated. During the experiments special attention has been paid to the flow in the vicinity of the impact elements and in the classification zone.

2.2. Measurement technique

Particle Image Velocimetry (PIV) is a non-invasive method for flow measurements. Using PIV the time-dependent 2D-velocity distributions of the single-phase flow in the regions of the impact element and the classifier have been obtained. For the studies in the mill a thin sheet of light, approximately 0.5–1 mm thick, has been produced with a dual-Nd:YAG-laser (50 mJ/pulse at 532 nm) and a divergent light sheet optics. For the measurement of the air flow the fluid phase has been seeded with tracer particles of di-(2-ethylhexyl)-sebacate (DEHS) with 1 μm in mean diameter. Perpendicular to the light sheet a high-resolution CCD-camera (PCO 1600, 1600 × 1200 pixels) has been positioned and the particle motion in the illuminated plane has been recorded as a function of time. The spacing between two images in the double frame provides a measure of the local flow velocity. The double frames are acquired at 10 Hz and are synchronized with the passage of the impact element and the classifier by precise position type encoders installed at the rotating elements. The pulse delay between the single images in a double frame has been set between 2.48 and 3 μs. The images have been analyzed using the commercial software package VidPIV®. In the experiments instantaneous velocity fields from 450 to 500 pairs of images have been averaged.

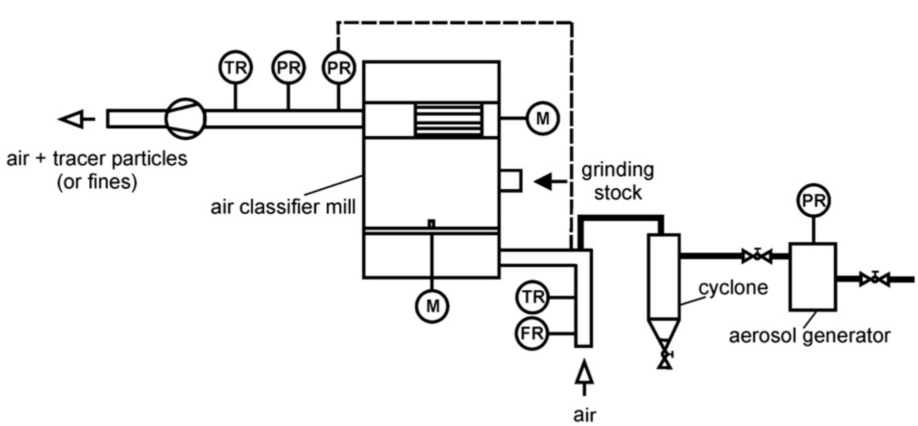

Fig. 2. Schematic view of the experimental setup.