Effect of the milling parameters on the product dispersity and energy consumption in a continuous dry air-transported stirred media mill

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Abstract. Stirred media mills are widely used for the production of ultrafine and nano materials in wet mode, however its application in dry mode is still limited today. The present paper deals with the operation of a continuous dry air-transported stirred media mill. The stirred media mill works in dry continuous mode, and the material is transported inside the mill by air. The mill and the additional systems were designed and built by the research group. The mill was equipped with a measurement and data acquisition system, so the air flow rate and pressure drop in the mill and in the air-solid separation system can be measured continuously. The aim of the research was to investigate the air-transported working principle in case of a horizontal stirred media mill and to install the laboratory scale mill and the additional systems. During the measurements the mill was operated in open circuit mode, the feed model material was limestone. The effect of the feed rate, air flow rate, and tip speed of the rotor on the product particle size was investigated, while the energy consumption of the mill and ventilator was measured as well. As a result of the research work the operation of the mill and the effects of the feed rate, air flow rate and tip speed on the product fineness and specific grinding energy was revealed. The developed laboratory scale dry stirred media milling system can be effectively used for the production of fine ground materials.

Keywords: dry fine grinding, horizontal stirred media mill

INTRODUCTION

The main and biggest problem and the limiting factor in the production of fine and nanomaterials by dry grinding are the adhesion and sticking of the fine particles. Sticking of the particles on the mill liners and on the grinding beads is also associated with this effect. The prevention of these milling efficiency impairing effects can be effectively carried out by utilizing wet grinding (G Mucsi & Bohács, 2016), but in many cases, dry grinding is required. In dry grinding three different processes can be used to prevent these effects: (1) use of surface active chemicals, called grinding aids (2) taking the fine particle out from the grinding chamber and use a closed circuit mill-classifier system, (3) parallel application of the first two processes. The use of grinding aid however in many cases should be avoided (e.g. active ingredients of pharmaceuticals) because of the later application of the ground material. An effective and efficient solution to this dry grinding problem is still a target of research.

Dry grinding in stirred media mill was performed in a prototype continuous horizontal stirred mill to investigate the effect of operating parameters such as stirrer speed, feed rate, media filling and ball size, considering the degree of size reduction and the energy consumption. The test results showed that the stirrer speed, the media size and the media filling are directly proportional and the feed rate is inversely proportional with the specific energy consumption (Altun, Benzer, & Enderle, 2013). The effect of the chamber diameter and stirrer design on cement grinding was investigated in the same type of stirred mill (Altun, Benzer, & Enderle, 2014). Later, 3 types of grinding aids (glycol-based, TEA-based and TIPA-based) were tested in dry stirred milling of cement in the same type of stirred media mill (Altun, Benzer, Toprak, & Enderle, 2015).

In another study (Pilevneli, Kızgut, Toroğlu, Çuhadaroğlu, & Yiğit, 2004), separator rejects of a closed-circuit cement tube mill were dry ground in a 10 1 pilot scale vertical continuous stirred mill. Tests were done in an open and a closed circuit. The results were evaluated by size distributions, Blaine surface area of the products and the specific energy consumed during the tests. Mill capacity and the stirring speeds were the investigated parameters for the open circuit tests, whereas closed circuit tests were carried out at a constant stirring speed but variable discharge rate.

The mechanical activation of cement in a batch stirred media mill was investigated by Mucsi et al. (2013). A large-scale continuous stirred media mill called the MaxxMill system in dry mode was used to investigate the comminution characteristics. The main factors influencing the energy utilization were found to be, in decreasing order of importance, feed rate and rotational speed of the stirrer. The rotation of the stirrer is the most dominant effect on the median size of the ground product. The bead sizes in the range of 4 to 7 mm did not influence the grinding results (Wang, Forssberg, & Sachweh, 2004).

Particle size or specific surface of the product can be related to the operational parameters by the product related stress model, thus creating a basis for control of the stirred media milling in wet mode. Dry batch stirred media milling based on such an approach was investigated by Rácz & Csőke, 2016.

In the present paper the grinding performance of a horizontal continuous dry air-transported stirred media mill are presented. The operation of the mill and the effects of the feed rate, air flow rate and tip speed on the product fineness and specific grinding energy is discussed.

MATERIALS AND METHODS

A continuous dry stirred media mill was developed and built, where the solid material is transported in the mill by air flow. The effective volume of the mill is 520 cm³. Online measurement and data acquisition system was developed fo the grinding system. For the data acquisition a self-written LabWindows program is used. The measuring system is capable to measure the static pressure after the mill (p1), the static pressure after the filter (p2) and the pressure drop in the Venturi tube (Δp). The velocity of the air in the Venturi tube is calculated from the pressure drop and therefore the volumetric flow rate of the air (Q) can be determined as well.

$$Q = A_1 v_1 = A_2 v_2 \qquad (1)$$

The mill currently operates in open circuit mode; the future aim is the development of a closed circuit system with a separator. Parts of the milling system are as follows (Fig 1): 1. computer; 2. electrical control board of the data acquisition system; 3. power supply of the data acquisition system; 4. mill engine; 5. silo and vibration feeder; 6. stirred media mill; 7. filter; 8. Venturi tube; 9. ventilator.
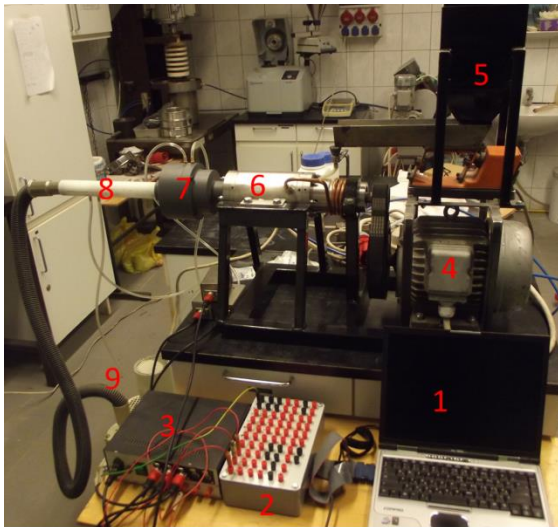

FIGURE 1. Parts of the grinding system

The developed stirred media mill is equipped with six specially shaped triangle discs. The mill is double-walled to cool the grinding chamber. The operation of the motor and the ventilator was regulated by a frequency controller, so the rotor's revolutions per minute and circumferential speed could be adjusted. The stirred media milling was performed at ratio of 70% grinding media fill. During the grinding experiments 0.8-1 mm zirconium silicate grinding media was used. The energy demand of the mill and the ventilator was measured using a Carlo Gavazzi WM1-DIN microcomputer-controlled digital energy meter.

During the experiments limestone was used as model material for the grinding. The limestone powder was obtained from the Felnémet mine site. The limestone powder first was sieved at 106 μm by laboratory sieve and then the material was further separated in an air separator (type NETZSCH CFS 5 HD-S) to separate the most of the fine particles under 10 μm and to receive an appropriate feed for the grinding experiments. Rotor speed of the classifier was set to 3500 RPM, and the air flow rate was 63 m³/h.

During the experiments 0.2, 0.4, 0.6 and 0.8 kg/h feed rate was applied. The effect of the rotor velocity was investigated at 6, 8, 10 and 11 m/s. To measure the effect of the air flow rate, the frequency of the ventilator rotor was set between 20 and 35 Hz. The exact air flow rates were measured during the experiments.

The particle size distribution of the ground material was determined using a HORIBA LA-950V2 type laser particle size analyzer. From the measured data the computer calculated the particle size distribution according to the Mie-theory. During the measurement ultrasonic treatment was used for the dispersion of fine particles.

RESULTS AND DISCUSSION

Before real grinding experiments, experiments without solid material feed had been carried out. In Fig 2, values of p1, p2 and Δp can be seen at 6.6 m/s rotor circumferential velocity and 8.6 m³/h air flow rate. During these measurements at five air flow rates and at five rotor velocities the pressures were measured, however from these results only one combination is presented here. The p1 – pressure after the mill - is relatively low, compared to the p2 (pressure after the filter). That means that the pressure drop on the mill (p1-p0) is significantly lower than the pressure drop on the filter (p2-p1). The results have a slight fluctuation as a function of the time.
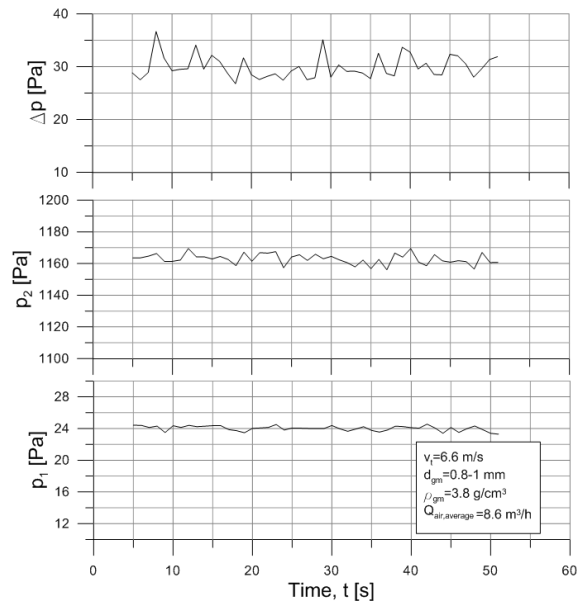
FIGURE 2. The values of the p1, p2, Δp at a certain rotor velocity and air flow rate

Grinding experiments

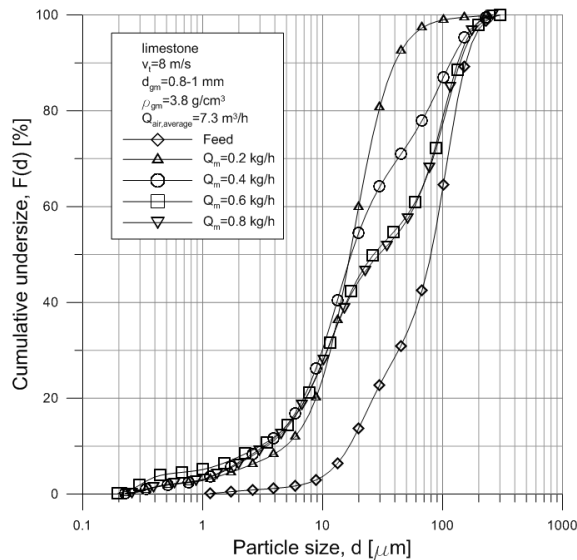The effect of the feed rate on the cumulative undersize of the product can be seen in Fig 3.

FIGURE 3. Effect of the feed rate on the cumulative undersize of the product

Median particle size of the feed material was 89 μm. In the feed material less than 3% were under 10 μm. After grinding at different feed rates the ratio of the fine (<10um) particle fraction significantly grows up to 30%. The finest product was achieved by the 0.2 kg/h feed rate. Higher feed rates resulted in coarser product.
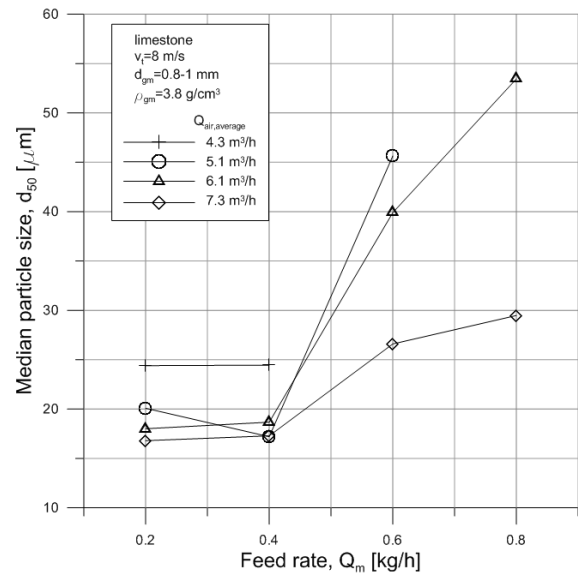
FIGURE 4. Effect of the feed rate on the median particle size at different air flow rates

The effect of the feed rate on the median particle size at different air flow rates can be seen in Fig 4. At a certain air flow rate, the higher the feed rate, the higher the median particle size. At a certain feed rate the higher the air flow rate, the finer the product. The lowest median particle size was achieved at 0.2 kg/h feed rate and 7.3 m³/h average air flow rate, its value was 16.8 μm. At low feed rates (low mill loading) the increasing of the air flow rate did not have significant effect on the median particle size, the grinding was sufficient, the ground material was fine. Increasing the feed rate, at same air flow rates, the product became coarser, because the residence time in these cases was determined by the quantity of feed rate. However, at the same feed rate, the higher air flow rate gives a finer product. The explanation for this is that the grinding efficiency was improved by increasing the air flow rate. The main limiting factor in the production of fine materials by dry grinding is the adhesion of the fine particles and the sticking of the particles on the mill liners and on the grinding beads, which decreases the efficiency of grinding. The higher air flow rate reduced these effects more sufficiently, so the product became finer.
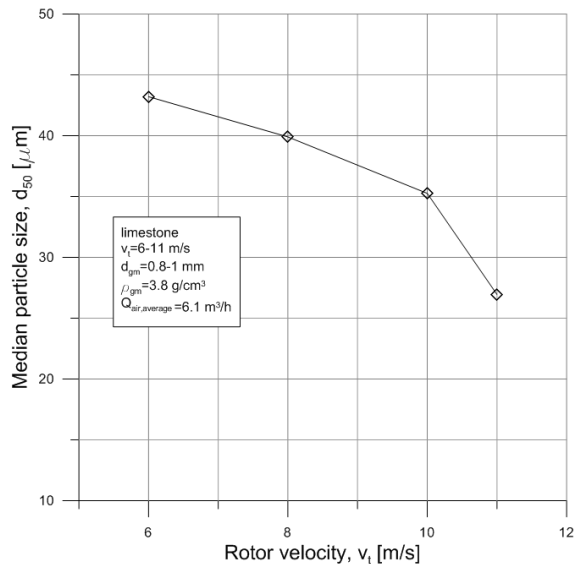
FIGURE 5. Effect of the rotor circumferential velocity on the median particle size of the product

Effect of the rotor circumferential velocity on the median particle size of the product can be seen in Fig 5. The higher the rotor circumferential velocity, the lower the median particle size of the product. The lowest median particle size was achieved at 11 m/s rotor circumferential velocity (average air flow rate 6.1 m³/h) its value was 26.9 μm.
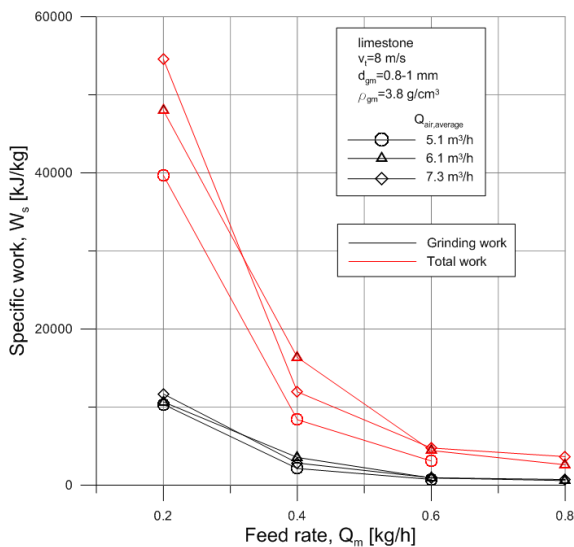

FIGURE 6. Effect of the feed rate on the specific work at different air flow rates

Fig 6 shows the effect of the feed rate on the specific grinding work at different air flow rates. In the graph the specific grinding work and the total work are presented separately. The grinding work means the work of the mills' engine, while the total work means the grinding work plus the work of the ventilator. The total work is significantly higher than the specific grinding work. The higher the feed rate, the lower the specific work.

SUMMARY

A laboratory scale horizontal dry stirred media mill was built, where the solid material was transported by air flow inside the mill. Installation and the results of the first grinding experiments have been presented. The effect of the material feed rate, air flow rate and rotor velocity on the particle size distribution was investigated.

ACKNOWLEDGMENTS

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