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An energy based comparison of vertical roller mills and tumbling mills

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ABSTRACT

The Institute of Mineral Processing at the Montanuniversitaet Leoben in cooperation with the company CEMTEC has developed a pilot scale, 200 mm table diameter, vertical roller mill for energy controlled laboratory tests. The mill provides the technical options to vary process parameters like air-flow, mass flow, grinding force and classifier speed in a wide range and is equipped to analyze the internal circulating load. In order to address grinding efficiency (defined as the increase in mass specific surface vs. net specific energy input) the energy consumption of two pilot scale vertical roller mills (200 mm and 670 mm table diameter) was compared to that of a sequence of laboratory comminution equipment covering the same size range. The sequence consisting of a laboratory jaw crusher and three laboratory tumbling mills of differing grinding media was operated following the principles of energy optimized comminution according to the OCS-method. With respect to the grinding energy only all the results for marble, siderite and hematite ore show energy savings when using the vertical roller mill at optimized settings. The methods used are outlined including the special features of the equipment.

1. Introduction

Comminution is one of the most energy intensive mechanical treatments in common mineral processing plants. In consideration of increasing energy prices and the demand for sustainable industrial processes the reduction of energy expense attracts more and more attention. Although the potential of alternative methods such as high voltage treatment or material's pretreatment by ultrasonic or microwaves is intensively investigated, tumbling mills and vertical roller mills still represent the state of the art of comminution in a size range between 10^2 and 10^{-2} mm. The vertical roller mill equipped with an internal classifier is often said to be more energy efficient than tumbling mills working on the same material and the same size step (e.g. Gerold et al., 2012). It is long established in the cement industry and gains more and more importance in the industrial mineral and iron ore sectors. In order to address the energy consumption of the grinding tools a laboratory as well as a pilot scale vertical roller mill were benchmarked by the OCS-method.

The lab scale comminution tools used in this (energy) optimized comminution sequence (OCS) are arranged and operated in a way to reveal the minimum energy expense for a defined size reduction step. The energy input into the grinding chamber of all the lab systems below 10 kW power supply was measured mechanically. The specific energy consumption related to the generated mass of fines and the characterization of the dispersity by the Kozeny surface form the basis of comparison.

2. Methods, equipment and materials

2.1. The OCS method

The concept (Steiner, 1991) of energy optimized comminution (OCS) is based on the idea to establish a comminution process – at least at the laboratory scale – that minimizes the energy expense (Δe) for a given size reduction step i (refer Fig. 1). According to Steiner the general principles of energy optimized comminution (which does not necessarily correspond to cost optimized comminution) are defined as follows:

Subdivide a given total comminution step into a sequence of size reduction steps of low size reduction ratio using comminution tools optimized to the feed size. For an optimum mechanical energy transfer from the comminution tool to the material, keep the amount of fines as small and the retention time of fines after their generation in the comminution chamber as short as possible. The fines cause the absorption of energy due to compaction. A closed circuit design with prescreening and high circulating load result from these requirements. The general setup of an OCS is shown in Fig. 1.

Close to Bond's method the continuous operation is simulated in each step by batch wise comminution with pre- and intermediate

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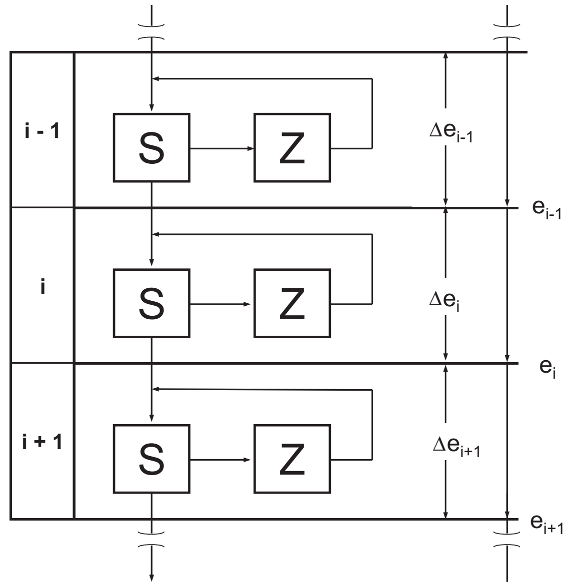

Fig. 1. The optimized comminution sequence (OCS) (Steiner, 1991). Flow sheet of the circuit design of the laboratory comminution (Z) and classification (S) apparatus.

screening and classification respectively. Common laboratory comminution equipment (jaw crushers, rod mills, ball mills) is arranged in the sequence. The circulating load is adjusted to 100% for rod mill operation, to 250% and 300% for mill operations using balls and cylpebs respectively. The energy input into the grinding chamber is controlled by torque measurement. All intermediate classification down to 200 μm is done by manual screening, which can be kept closest to ideal classification at a given separation size. For the −40 μm circuit a laboratory air classifier (Hosokawa, 100MZR) is used. To all experimental evidence at the Institute of Mineral Processing at the Montanuniversitaet Leoben up to now, the method reveals the product size distribution of the lowest variety of particle size classes at a given maximum particle size.

For homogenous materials the size distribution often linearizes in the Gates, Gaudin, and Schuhmann (GGS) plot indicating a potential relation between the particle size and the percentage passing. As no other machinery was found up to now to produce a distribution of steeper inclination it is considered to be material inherent and is called the "natural breakage characteristic" (NBC) according to Steiner.

Plotting the mass specific surfaces of the feed and the products determined by permeametry versus the assigned mass specific energy consumption, the course of measurement results can be fitted best by a straight line. As the experimental findings (down to k_{max} of −40 μm) indicate linear dependence between new generated surface (**Δ**a, cm^2/g) and energy input (**Δ**e, J/g) in the limiting case of energy optimized comminution, the line is called the "Rittinger line" (Eq. (1)). The inclination as the measure of the material's grindability is called the Rittinger coefficient (R, cm^2/J).

$$\Delta a = R \cdot \Delta e \tag{1}$$

Apart from the evaluation of grindability in tumbling mills and benchmarking grinding systems, the method provides reproducible size distributions, characteristic for one type of material, which is needed e.g. for integrated intergrowth investigations. The grindability index R varies between 20 cm^2/J for low grindability (thermally compacted slags) and 150 cm^2/J (unconsolidated limestone).

2.2. Tumbling mills and jaw crushers

The sequence to evaluate the vertical roller mills consisted of a laboratory jaw crusher, a rod mill and two ball mill stages with differing grinding media. The dimensions and settings of the laboratory mills are given in Table 1 and are illustrated in details in (Boehm and Flachberger, 2006). The jaw crusher used is a standard jaw crusher (RETSCH BB 100). The gap width is usually set to obtain a product size of 100% −6.3 mm at a circulating load of 50%. The size reduction ratio should not exceed 1:4. The rod mill is typically operated within the size reduction step 100% α6.3 to 100% −1 mm at a circulating load of 100%. The mass specific energy input Δe_{Rod} [J/kg] is derived from Eq. (2). Details are given in Steiner (1996). Calibration by means of torque measurement revealed a dimensionless power conversion factor for the mechanical power transferred into the material c_p of 1.1. The mass of grinding media (M_K, kg) and the inner diameter (D_i, m) are listed in Table 1. The number of revolutions (U, 1) is adjusted to the desired circulating load, which is defined as the mass of recycled material to the mass of produced fines (M_F, kg). g (m/s^2) corresponds to the gravitational constant.

$$\Delta e_{Rod} = c_p \cdot g \cdot M_K \cdot D_i \cdot \frac{U}{M_F} \tag{2}$$

The tumbling mill used with different types of grinding media is equipped with a torque rod for direct energy measurement. The size reduction steps are set to 100% −1 mm to 100% −0.2 mm for ball milling and 100% −0.2 to 100% −0.04 mm using the cylpebs. The mean torque (M_d, Nm) with time derived from the recorded data together with the number of mill revolutions (U, 1) serves to calculate the specific energy consumption (Δe_{BM}, J/kg) related to the produced fines (M_F, kg) (Eq. (3)).

$$\Delta e_{BM} = \frac{2 \cdot \pi \cdot M_d \cdot U}{M_F} \tag{3}$$

2.3. The vertical roller mills VRM200 and VRM600

The VRM200 is a laboratory scale vertical roller mill with two truncated conical grinding rollers (LOESCHE system) of 133 mm mean diameter, a cross flow rotary cage classifier with a wheel diameter of 160 mm, a bag filter and full sensor configuration. The mill table has a diameter of 200 mm allowing a maximum throughput rate of about 240 kg limestone per hour at a classifier setting of d98 = 200 μm. The mill is described in more detail in Meissner et al. (2012). Fig. 2 gives insight into the grinding chamber. A special feature of this mill is the external classifier drawback that makes the coarse product of the classifier accessible. The experiments however were carried out in common mode with the drawback disabled.

The mill power draw is measured by a torque rod situated in line with the main drive shaft. The specific power consumption ΔeVRM200 in J/kg could be calculated by the control system according to Eq. (3). Details of the VRM600 in the CEMTEC laboratory are published in Gleissenberg and Hofmann (2008). The mill table diameter is around 670 mm forced by three conical grinding rollers of 430 mm

Table 1
Tumbling mills — parameters.

Size or parameter	Rod mill	Ball mill	Cylpeb mill
Inner shell diameter, [m]	0.150	0.200	0.200
Length, [m]	0.3	0.2	0.2
Mass of grinding media, [kg]	70.47.4	9	12
Percentage of critical speed, [%]	70	70	70
Degree of filling, [vol-%]	40	40	40
Circulating load, [%]	100	250	300