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Optimization of a fully air-swept dry grinding cement raw meal ball mill closed circuit capacity with the aid of simulation

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ABSTRACT

Production capacity of a fully air-swept industrial scale two-compartment KHD Humboldt Wedag® cement ball mill was optimized with the aid of simulation. It was proposed to operate the mill as a single compartment by eliminating the pre-drying compartment. In this respect, grinding performance of the air-swept ball mill was evaluated and modelled as a perfectly mixed single tank using the perfect mixing ball mill modelling approach (Whiten, 1974). Static separator was modelled by efficiency curve model (Whiten, 1966). The empirical breakage function required in the estimation of average specific breakage rates was measured by drop-weight technique. The full scale model parameters were used to simulate the raw meal mill grinding circuit with the aid of JKSimMet Steady State Mineral Processing Simulator. Simulation results indicated 23% production capacity increase in cement throughput in case the pre-drying compartment was used in grinding.

1. Introduction

Air-swept raw meal ball mills introduced by the cement mill manufacturers F.L.Smidth® (Smidth, 2002), Polysius® (Polysius, 2002) and KHD Humboldt Wedag® are the most commonly used ones. KHD Humboldt Wedag® manufactured fully air-swept raw meal mills which have two compartments used for drying and grinding processes. In these mills drying and grinding are performed in a single mill as similar to the Polysius® fully air-swept mill (Polysius, 2002). First compartment is used as a pre-drying compartment where it is equipped with lifters and operated without grinding media in order to increase the drying efficiency. In such systems, kiln discharge gases are used as a drying air. Drying compartment consumes more energy as compared to the other systems due to the high level of moisture in the feed. In air-swept mills circulating load is carried pneumatically. Thus, the energy consumption for a fully air-swept grinding circuit is higher by approximately 10–12% as compared to the grinding circuit with bucket elevator (Duda, 1985). Modelling of fully air-swept ball mills used in the cement industry were studied with different approaches in the literature (Austin et al., 1975, 1984; Viswanathan, 1986; Viswanathan and Narang, 1988; Viswanathan and Reddy, 1992; Zhang et al., 1988; Zhang, 1992; Ergin, 1993; Apling and Ergin, 1994; Benzer, 2004). Grinding model parameters are similar except of the material transport function in the related models. The population balance model requires residence time which is difficult to determine for the full-scale mill. Value of residence time distribution is determined experimentally. Perfect mixing model (Whiten, 1974) simplifies the discharge (transport) function by assuming a particle size dependent discharge rate function. The discharge of any particle fraction from the mill can be calculated on the basis of the mass of size fraction in the mill hold-up and mass flow rate of that particle fraction out of the mill as product. Perfect mixing model does not constitute many grinding parameters which needs to be scaled up. The model could be used directly to predict the performance of full-scale mills. The relation between particle size and discharge rate dependent breakage rate parameter which was defined as a ratio of breakage rate to discharge rate function was established to measure the ball milling performance based on perfect mixing modelling approach by Zhang (1992), Benzer (2000) and Hashim (2003).

Breakage function and breakage rate parameters are determined by laboratory experiments in Austin's approach (Austin et al., 1984) and the resulting mathematical equations relating the breakage function and breakage rate to particle size constitute many parameters. Thus, more than one parameter set could be produced in the solution of these equations each of which define different breakage rate-particle size relationships. For this reason, it is difficult to relate the effects of operating variables of ball mills on specific breakage rates. Design and operational parameters were studied on laboratory scale mills which need to be

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Nomenclature

i	particle size fraction i
j	particle size fraction j
f_i	mass flowrate of mill feed (ton/hour)
p_i	mass flowrate of mill discharge (ton/hour)
r_i	specific breakage rate of size fraction i (h^{-1})
d_i	specific discharge rate of size fraction i (h^{-1})
d_i^*	normalized discharge rate of size fraction i
a	single column step triangular breakage function matrix
s_i	mass of size fraction i (ton)
Q	volumetric feed rate (m^3/h)
D	mill diameter (m)
L	mill length (m)
r/d^*	ratio of breakage rate to normalized discharge rate
E_{oa}	fraction of feed reporting to overflow
C	fraction undergoing "real" classification (1-bypass fraction)
B	reduced efficiency curve fish hook parameter
d_{50c}	size of a particle in feed which has equal probability of going to underflow or overflow (cut size)
β^*	model parameter to preserve the definition of d_{50c}
d	particle size
x	ratio of d_i to d_{50c}
α	reduced efficiency curve sharpness parameter

scaled-up. There had been a few attempts to relate their model with air flow through the mill, feed rate, feed size distribution, material filling and ball filling (Viswanathan, 1986; Zhang, 1992). Air swept ball mill model proposed by Austin et al. (1975) was validated by Apling and Ergin (1994) using the industrial scale data from a cement grinding circuit.

In this study, production capacity of a fully air-swept dry grinding raw meal ball mill circuit was evaluated by modelling the mill using the perfect mixing modelling approach (Whiten, 1972). Static separator in the circuit was modelled by efficiency curve model (Whiten, 1966). JKSimMet Steady State Mineral Processing Simulator was used in the simulation stage. Simulation results indicated 23% capacity increase in cement throughput at the steady state condition. However, the static separator is expected to operate with the maximum tonnage that can be handled.

2. Methods

2.1. Sampling survey

The simplified process flowsheet of the sampled circuit with the sampling points is given in Fig. 1. Air-swept ball mill is operating in closed circuit with a static separator. The static fines are collected in product cyclones where the separation of particles from the air is performed. Product of electrofilter is combined with the cyclone products to form final cement. Design specifications of the fully air-swept ball mill and static separator are given in Table 1. Design ball size distribution applied in the ball mill is given in Table 2.

Steady state condition of the circuit was verified by examining the variations in the values of operational variables of the ball mill and the static separator in the process control room system. Sampling was started when the steady state condition was achieved. Representative amount of samples were collected from the shown sampling points in Fig. 1. Samples from the raw meal feed were collected for the determination of moisture content of the mill feed materials. Values of the operational variables were recorded in every 5 min from the process control system to be used in the circuit performance assessment during sampling Control room recordings and related standard deviation values at the steady state condition are tabulated in Table 3.

2.2. Experimental

Samples were prepared by using a riffler for dry sieving from the top size down to 150 μm. Sub-sieve sample (−150 μm) was sized in wet mode in a SYMPATHEC® laser diffractometer. Dry sized material (+150 μm) and wet sized sub-sieve sample (−150 μm) were combined to define the full size distribution from the top size down to 1.8 μm. Raw meal materials were dried at approximately 100 °C before sizing in order to carry out an efficient screening operation. Calculated moisture contents and dry flowrates of mill feed materials are given in Table 4.

3. Results and discussions

3.1. Mass balancing

Measured particle size distributions and operational tonnage flowrates were used to perform mass balance calculations around the circuit with the aid of mass balance module of the JKSimMet simulator to calculate the best fit estimates of the size distributions and tonnage flowrates. Mass balanced flowrates and calculated fineness as 0.045 mm passing % are given in Table 5. Circulating load ratio was defined as the ratio of static separator reject tonnage to static separator fine tonnage and calculated as 75.34%. The results of mass balance calculations were checked out by plotting the experimental and calculated particle size distributions (Fig. 2). Experimental versus mass balanced particle size distributions were found to be fitted satisfactorily which indicated that, sampling was successful and the data could be used for modelling purpose. Experimental size distributions of final cement cyclone collectors were presented in Fig. 3. Particle size distributions indicated no segregation in the cyclones verifying the sufficient level of air flow and balanced air distribution within the cyclones.

3.2. Mill inside sampling and granulometry

The circuit was crash-stopped to collect samples from inside of the mill after completing sampling of the circuit streams. A view of mill inside at the crash-stop condition is given in Fig. 4. Average material height above the ball surface level (18 cm) and free height of the mill (2.27 m) were measured to be used in mill powder load (hold-up) calculation ahead of collecting the samples along the long axis of the mill at the crash-stop condition. Mill filling was calculated to be 32% using the mentioned geometrical measurements. Photograph of the lifter bar design in the drying compartment is presented in Fig. 5. Considerable abrasion and damage on lifters were recognized. Whole length of the grinding compartment was lined with classifying liners. Classifying liner configuration is presented in Fig. 4.

Sample collection dips were formed by digging out the mill charge (mill powder + balls) approximately 40 cm below the charge level. Samples were collected along the long axis of the mill towards the end of the discharge grate in order to demonstrate the size reduction performance using the inside mill size distributions (granulometry). Samples were collected by one meter up to the sixth meter of the grinding length whereas by half meter at the rest of the mill length. Mill inlet and outlet temperatures were recorded