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Simulation assisted capacity improvement of cement grinding circuit: Case study cement plant

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A R T I C L E I N F O

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A B S T R A C T

Extensive sampling campaign was performed around the cement grinding circuit of a cement plant in Turkey, for different production types of cement, as CEM I 42.5, CEM II 32.5/42.5/52.5, for the modelling and simulation purposes. During the sampling surveys; samples were collected from around the circuit for the steady state condition of the operation and, following a crash stop, from inside the mill. The size distributions of the samples were determined down to 2 μm by the combination of sieving and laser sizing methods. By using the size distributions around the circuit and control room data mass balance studies were performed. Then equipments in the circuit; ball mill, air-classifier and filter, were modelled individually by using the appropriate model structures. After modelling the circuit, simulation studies were performed for capacity improvement, mainly by the ball size optimization. By implementing the proposed optimization, the capacity of the circuit was increased up to 12.7–20.5% for different production types, hence; the overall specific energy consumption of the circuit was reduced, as predicted in simulation studies.

1. Introduction

Cement production is an energy intensive process. It consumes 2% of the global primary energy and 5% of the total global industrial energy. Grinding is a high-cost operation consuming approximately 60% of the total electrical energy expenditure in a typical cement plant. The electrical energy consumed in the conventional cement manufacturing process is in the order of 110 kWh/tonne, of which approximately 30% is used for raw materials preparation and 40% for the finish milling (cement clinker grinding). This is the largest single consumption point of electric power in the process of converting raw materials to finished cement (Bhatty et al., 2004).

The cost of energy as part of the total production costs in the cement industry is significant, warranting the attention for energy efficiency to improve the bottom line. Substantial potential for energy efficient improvements exist in the cement industry and in individual plants. The cement industry is targeting technologies focusing on increasing the mill throughput; energy savings; and minimizing the production costs without negatively affecting product yield or quality.

The increasing demand for "finer cement" products, and the need for reduction in energy consumption and green house gas emissions, necessitate the optimization of grinding circuits. Opportunities exist at cement plants to improve energy efficiency while maintaining or enhancing productivity. Several technologies and measures exist that can reduce the energy consumption of the various process stages of cement production including raw and finish milling. This paper presents the capacity improvement and specific energy reduction in the finish milling stage of a cement plant in Turkey by adjusting the ball size and modifying the intermediate grate design using modelling and simulation tools.

2. Modelling and simulation

Conventional cement grinding ball mills, operated in closed circuit with air separators, have usually two grinding chambers, which are separated from each other by a slotted diaphragm through which the particles finer than the size of the slots pass to the second chamber for further size reduction.

Cement grinding mills are modelled by using the modelling approach described for closed cement grinding circuits (Lynch et al., 2000; Benzer et al., 2001, 2003). According to this approach, each grinding compartment is modelled by the perfect mixing model (Whiten, 1974) which considers a ball mill or a section of it as a perfectly stirred tank. Then the process can be described in terms of transport through the mill and breakage within the mill. Because the mill or section of it is perfectly mixed a discharge rate, d_i, for each size fraction is an important variable in defining the product. The parameter s_i indicates the mill content.

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$$p_i = d_i \cdot s_i \tag{1}$$

The model for steady state operations includes two sets of model parameters, i.e. the breakage function a_{ij} and a combined breakage/discharge rate r_i/d_i function.

$$f_i + \sum_{j=1}^{i} a_{ij} p_j \frac{r_j}{dj} - p_i \frac{r_i}{d_i} - p_i = 0 \tag{2}$$

The breakage function is a material characteristics and defines the size distribution of the product formed after the breakage of the parent size fraction. It is determined by laboratory tests using twin pendulum (Narayanan, 1985), ultra-fast load cell (Höffler and Herbst, 1990) or drop weight apparatus which has been practiced by several researchers for various material characterization purposes (Gross, 1938; Piret, 1953; Fairs, 1954; Schönert, 1972; Rumpf, 1973; Pauw and Marè, 1988). In this study the breakage distributions were determined by drop weight tests. The combined breakage rate/discharge rate function defines the machine characteristics and can be calculated when feed and product size distribution are known and breakage function is available. For the most ball mills *r/d* on particle size is a smooth curve which can be fitted to a spline function with four knots.

The ball mill model is calibrated by determining the *r/d* values using the feed and product size distributions obtained under particular operating conditions. Where the size distribution of the mill contents is available, breakage rates and discharge rates can be calculated separately (Napier-Munn et al., 1996).

The important variable for each mill is *r* which is the tonnes broken per hour/tonne in the mill. This can be calculated from *d* which is the tonnes discharged per hour/tonne in the mill and *r/d* which is calculated from plant data.

Schematical representation of the modelling approach (Benzer, 2000) used for two-compartment ball mills is given in Fig. 1. This modelling approach requires the size distribution data obtained from the mill inside.

In above model structure (Fig. 1), Stream-1 represents the mill feed calculated by mass balancing around the circuit. Stream-2 size distribution depends on the size reduction achieved in the mill usually presented by the size distribution of the sample collected at the last 1 m of the first chamber length. Mill powder rejected from the diaphragm after screening is represented by Stream-5 which is predicted by simulating the diaphragm with its efficiency curve model parameters defined by Whiten (1966). In the modelling of the screening effect of the diaphragm, efficiency curve parameters; *C*, by-pass value; α, sharpness of the screening; β, fish hook effect; *d*50, cut-size are back-calculated.

The efficiency curve model is capable of defining the fish hook and used for separators. The general form of the equation is presented below:

$$E_{oa} = C\left[\frac{(1 + \beta \cdot \beta^* \cdot X)(\exp(\alpha) - 1)}{\exp(\alpha \cdot \beta^* \cdot X) + \exp(\alpha) - 2)}\right] \tag{3}$$

where *C* indicates the by-pass of the separator, α sharpness of the separation, β fish hook behaviour of the classification and $X = d_i/d50_c$.

In cases where the efficiency curve does not exhibit fish hook behaviour, the parameter β is equal to zero and a simplified form of an Eq. (3) is obtained.

$$E_{oa} = C\left[\frac{\exp(\alpha) - 1}{\exp(\alpha \cdot X) + \exp(\alpha) - 2}\right] \tag{4}$$

The calibration of the air-classifier model involves the calculation of the best fit values α, β, $d50_c$ and *C* to the plant data.

3. Sampling and experimental studies

Prior to sampling surveys, steady state conditions are verified from the control room data and then sampling around the circuit is performed. After completing circuit sampling, ball mill is crashed–stopped for mill inside sampling. Mill content sampling

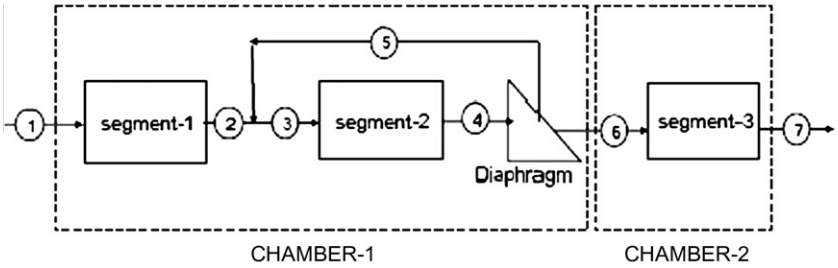

Fig. 1. Ball mill model structure (Benzer, 2000).

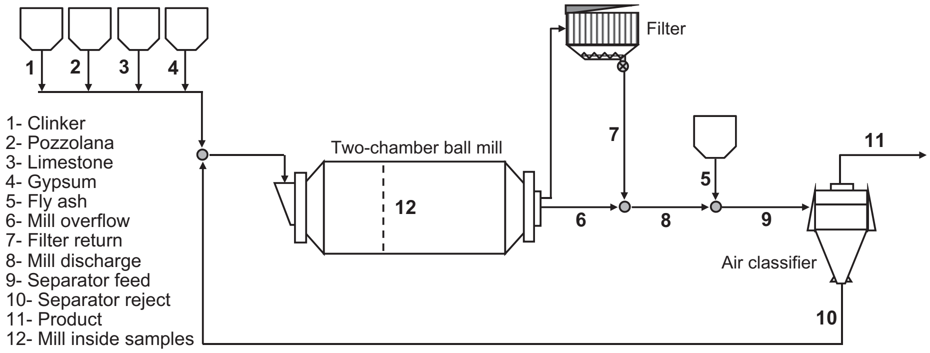

Fig. 2. Simplified flowsheet of the circuit and sampling points.