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PREDICTION OF THE PERFORMANCE IMPROVEMENT OF A DRY AIR-SWEPT MILL BY A SIMULATION TECHNIQUE

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ABSTRACT: With the objective of process improvement the modelling and simulation of an air-swept mill and a Sepax separator have been undertaken. A grinding model for incorporating the effect of air sweeping has been modified to simulate the Asian Cement plant in Turkey. Sampling, to validate the mill model, was undertaken at three different feed rates and fan settings. Model parameters were determined using a non-linear search technique to produce the best fit of predicted to measured product size over the range of operating conditions sampled. The mill model produced highly satisfactory prediction of the size distribution data and of the calculated specific surface area data Sepax separator was modelled by using size distribution data. Sampling, to represent this separator, was undertaken in the Nuh Cement plant in Turkey. This model curve was combined with the mill model to test the performance of the Asian Cement plant if it were to be converted to a close circuit operation. The simulation studies have produced some encouraging results in terms of achieving the steeper size distribution and higher specific surface area.

1. INTRODUCTION

In the cement industry, in order to achieve uniformity of quality and cost reduction, it is most important that the cement grinding process is optimised as well as the raw meal and burning processes. Grinding of the cement materials consumes about one-third of the power required to produce one ton of cement. It refers to an average specific power consumption of 36 KWh per tonne (Nakaruma et al., 1986). The process is constrained by the two most important properties in the use of cement which are its workability and compressive strength, which depend on the size distribution and the specific surface area of the cement as well as by its material composition. It is also known that for equal specific surface area, cements with a narrow particle size distribution have better quality than those with a wide distribution (Fngione et al., 1976)

Continual improvement in process design and operating efficiency is sought and in this connection mathematical modelling and simulation of the grinding circuits is a useful aid To this end a research programme has been undertaken with an objective of an examination of the feasibility of deriving parameters for a published model of an air-swept dry grinding mill solely from an examination of industrially derived data. It was desired to evaluate whether it would have the ability to represent the response of the mill to changes over the normal operating range. To improve the existing grinding circuit a high efficient separator was thought to install this circuit. Providing the separator model and combining with the parameterized mill model could be the tool to predict this redesigned grinding circuit performance.

2. THE AIR-SWEPT MILL MODEL

The simulation model for continuous grinding for cement tube mill, incorporating the effect of air sweeping suggested by Austin (1980), was used as the basis of the developed model. This model treats the residence time distribution of the mill as equivalent to a number of equal fully mixed reactors in series and in addition incorporates the effect of air sweeping on the operation.

The function of the air flow within a cement mill with the air is primarily to cool the clinker but it also

affects the grinding process by removing fines from the mill hold-up, giving an internal classifying action and reducing the severity of the fines cushioning effect which can diminish the breakage rates of all particles (Austin et al., 1984).

The model assumes that the air flow through the mill picks up particles in the layer of powder and balls rolling down the tumbling mass at a rate dependent on the velocity and particle size. Fine particles will carry forward in the air stream whereas coarse particles will drop back into the bed. It is supposed that at each mill revolution a fraction, r|, of the mill hold-up W, is taken into the air For a rotational speed of v per unit time the mass of particles of size (i) taken per unit time is WJT|VW, where wi is their mass fraction in the hold up. A fraction, Hi, of this material falls back into the bed, by an internal classification action, before the powder leaves the stage considered. The rate of removal in the air flow of particles of size (i), Ri is,

$$R_i = w_i \eta v W (1-\Omega_i) \qquad \text{(D}$$

The values of r|, of hold-up level W, and values of fij can be assumed to be constant along the mill. It is also assumed to be constant along the mill. It is also assumed that airborne particles leaving one stage will mix with those in the next.

The mass-rate balance for the first stage is,

$$(P+R)(1+C)p_i = F f_i + p_i \eta v W \Omega_i - s_i w_i W + \sum_{\substack{j=1 \\ i>1}}^{i-1} b_{ij} S_j W w_j \qquad (2)$$

where P+R (=F), is the external feed rate into the section, powder and airborne flow respectively, 1+C is the circulating load ratio due to a fraction falling back into the bed, and pj is the fraction of material of size (i) in the powder flow. Since a fully mixed stage is considered, pj=wj. The fraction of mill stage powder feed of size (i) is made up of the feed into the stage from the previous stage plus material falling back into the bed from the internal air classification

Finally it may be shown that,

$$p_i(1+C) = p_i^* = \frac{f_i + \tau \cdot \sum_{j=1}^{i-1} b_{ij} S_j p_j^*}{1 - \eta v \tau \cdot \Omega_i \tau''} \qquad (3)$$

Choosing a value of x°, values of p,* can be sequentially calculated starting at i=l Then since.

$$\sum_{i=1}^{n} p_i = 1$$

$$\sum_{i=1}^{n} p_i^* = 1+C \qquad (4)$$

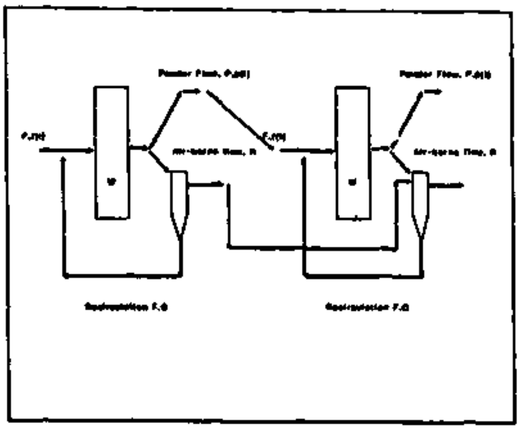

Figure 1 Air swept mill model flow chart

the values of pi and C. The correct value of t°, (and therefore pj* and therefore of p; and C, which are initially unknown) satisfying the relation,

r(1 + C) = r (5)

is found iteratively. The mill nominal residence time, T, can be found from measurement or alternatively from knowledge of mill hold-up and feed rate. The powder flow from the stage is then found by difference between F, the feed rate to the stage, and R, the air borne flow rate. This sequence of calculations for each of the stages allows the simulation of the complete mill, shown in Figure I with the powder flow representing the feed to the next stage and the air-borne flow joining the internal classification stage.

3. THE ASLAN CEMENT AIR-SWEPT MILL AND SAMPLING

For the mill model validation, plant test work was undertaken at the Asian Cement Plant situated in Darıca, Kocaeli, 40 miles from Istanbul. The mill tested was a two compartment 4 2m internal diameter mill with a 5.0 m first and a 10 25 m second compartment, giving a total mill volume of 210 m-*

The mass of balls in the first compartment was 112 t and in the second 169 t

In order to characterise the feed and product streams samples were taken at the points marked in Figure 2 As the sampling points indicate, the combined product was taken as a sample at the mill exit, because it was not possible to take a sample before this point

Samples were taken at 100, 110, 120 th-1 At constant feed rate, in order to observe the effect of airflow on the size distribution of the final mill product, the fan was set to produce output pressures of 80, 100, 120 mm w g

The total sample mass taken was in accordance with British Standards (1984)

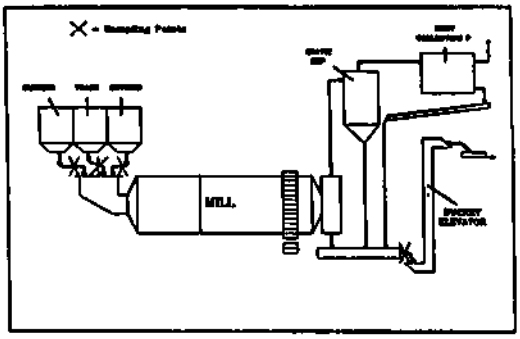

Figure 2 The Asian Cement Plant

4 VALIDATION OF THE MILL MODEL

The model parameters relate to physical conditions within the mill, the material characteristics and the operating conditions of the mill Since these parameters cannot be measured directly, they were found empirically using a Simplex search routine (Neider et al, 1970), to determine the set of model parameter values that result in the closest prediction of the product size distribution compared to the size distribution as actually measured

This required the estimation of the set of parameter values that minimised an objective function defined as the root mean square (RMS) deviation between measured and calculated distribution for all feed rates, that is.

$$RMS = \frac{1}{nsf}\sum_{n=1}^{} \sum_{i=1}^{nsf}\left[pmes_{(i)} - pcal_{(i)}\right]^2 \qquad (6)$$

where, nsf is the number of size fractions, n is the number of test, pmes(,\ is the measured percentage weight of the samples in the air-swept mill product for size fraction i, pcal(,\ is the corresponding calculated value (Aphng et al, 1994)

A number of parameters required estimation Since the hold-up, W, was not known expenmentally, this was calculated using as a starting point a value based on estimated mill filling conditions The air sweeping action is represented by the parameter T], in the model which represents the fraction of material is exposed to the air stream per mill revolution and is essentially dependent on the fan setting

The internal classification function parameters were d5o, the particle size at which half drops back into the powder hold-up and half continues in the air stream out of the stage, and the parameter A. which indicates the sharpness of the classification resulting in values of £2,, the fraction returned to the hold-up for each size and defined by,

$$\Omega_i = \frac{1}{1+\left(\frac{d_{50}}{x_i}\right)^{\lambda}} \qquad (?)$$

The best fit was obtained.by using the form of breakage function (Klimpel et al, 1984),

$$B_{(ij)} = A\left(\frac{x_i}{x_j}\right)^{\alpha} - (1-A)\left(\frac{x_i}{x_j}\right)^{\beta} \qquad A<1 \qquad (8)$$

The fractional form of the function was used, which represents the fraction of the material breaking into size interval j is given by,

$$b_{(ij)} = B_{(i,j)} - B_{i+1,j} \qquad (9)$$

The selection function used had the form of,

$$S_i = K\left(\frac{x_i}{x_j}\right)^{\gamma} \qquad (10)$$

Parameter fitting was achieved by supplying a range of initials estimates of the model parameters and by repeated searching to ensure that a true, rather than local, minimum in the RMS objective function was achieved

-The comparison was also performed between the calculated specific surface area from the experimental and modelled productions size distributions although this was not included as part of the parameter fitting procedure. Specific surface area was calculated from the following formula (Kihlstcid, 1962),

$$S = \frac{6}{\rho}\sum_{i=1}^{n}\frac{\Delta D}{x_{(i)}} + \frac{500}{\rho}\sum_{i=k}^{n}\frac{\Delta D}{\sqrt{d_{50}}} \qquad (11)$$

where, p is the density g/cm^, and AD the relative weight of mean particle size x(j) (cm). S is the specific surface area cm^2/g

The mass flow rates which are the powder flow and the airborne flow could not be measured separately in the sampling campaign at the plant. However, according to the experience of plant engineers and design specifications of the plant airborne product rate was assumed 10 % of the feed in the model fitting.

Simulation with the global set of parameter values derived from the complete data set, allow the prediction of the products at a specific feed rate for a given feed size distribution. The resultant parameter set is indicated in Table II with values of the RMS deviation and the mean absolute difference shown in Table I.

Table 1 Global fit deviations

Feed Rate	100t/h	110t/h	120t/h
RSM	0 3355	0.3459	0 4238
MAD	0.3526	0.3294	0.3771

Tabic II Global fit model parameter values

α	β	φ	A	γ	λ	d_{50}	W	η
0.60	3.44	0.13	IPS	0.70	1.43	1.24	1.41	0.01

The fit of the size distribution in cumulative percentage undersize is shown in Figures 3 for the 110 t/h feed rate and is typical of the results obtained. Full results including in size fraction and the specific surface area are documented elsewhere (Ergin, 1993)

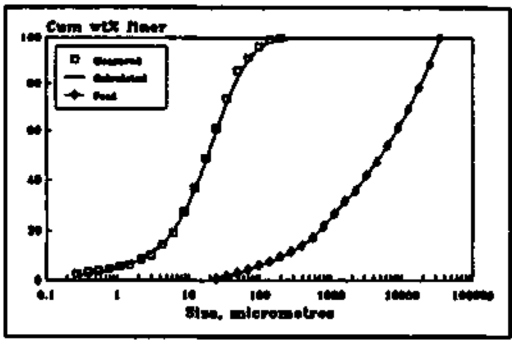

Figure 3 Actual and fitted product size distributions

5. THE SEP AX SEPARATOR MODEL

Although a vast number of types of classifiers have been developed for general industrial use, in the cement industry and particularly for the application in final grinding circuits, only the conventional separators and cyclone separators have so far generally been used (Klumper et al., 1991).

In recent years, the Sepax separator is a widely used centrifugal air separator in the cement industry. For this high efficiency separator the development work concentrated on two areas which were; optimising the performance of the dispersion section and the separation section, respectively (Haese et al., 1992; Onuma et al., 1984). Material from the mill is fed to the dispersion section of the Sepax separator and is carried by the upward air stream. The guide vanes-secure a uniform distribution of air and material from top to the bottom of the rotor. The separation takes place when the air stream and the suspended material pass through the rotor. The rotor is driven by a variable speed monitor. The fineness of the finished product can be adjusted within a wide range by varying the speed of the rotor.

In order to calculate a classification curve, samples were taken from three streams which are at the separator feed, finished product and the rejected material of the Sepax separator in the Nuh Cement plant. The calculation involves determinations of the recovery or yield as the mass flow rates were not known (Luckie et al., 1975; Austin et al., 1981; Apling, 1985). The recovery of a separator is the proportion of the feed that reports to either to overflow or underflow.

Recovery to overflow; .

$$R_o = \frac{\textit{Mass flow of over flow product}}{\textit{Mass flow of feed}} \qquad (12)$$

as the mass flow rates are unknown it is a necessity to calculate a figure for recovery from the size ' analyses of the samples. If R_i represents an estimate of recovery to underflow product that is the rejected matenal to the mill, based on the proportion in each size fraction in each stream, 1, where recovery is defined as above.

A mass balance can be written at each size fraction;

$$R_i = \frac{f_i - u_i}{o_i - u_i} \qquad (13)$$

which leads to.

$$f_i = R_i u_i + (1 - R_i) o_i \qquad (14)$$

where fj, u,, and o; represent the fraction of material of size range i in the feed, underflow and overflow respectively

The recovery to underflow can be calculated from a size analysis of the three streams based on each of the size fractions used in the analysis. Taking the arithmetic mean of all these gives us a figure for the overall average separator mass recovery, that is,

$$R_m = \frac{\sum_{i=1}^{nsf} \frac{f_i - u_i}{o_i - u_i}}{n} = \frac{\sum_{i=1}^{nsf} R_i}{n} \qquad (15)$$

where nsf equals to the number of size fractions used.

The separator performance curve provides such a means of defining the ability of a separator to affect a separation by presenting the probability of particle recovery to the undersize product as a function of its size The performance curve may be calculated in the following manner. Using the values the recovery or probability of a particular size of particle reporting to the underflow product can be calculated, at each size range i,

$$\frac{\textit{Mass flow of size fraction i in UF}}{\textit{Mass flow of size fraction i in feed}} \qquad (16)$$

$$p_i = \frac{Uu_i}{Ff_i} = R\frac{u_i}{f_i}$$

These values are plotted versus particle size to form the separator performance curve. In the case of this study, the recovery to the underflow was $R_m=34.4$ and the result is shown graphically in Figure 5.

The curve depicts the quality of separation being achieved by the Sepax separator under a specific operating conditions. It is, of course, a simplification to use it as a representation of any separator as it might be improved by changing separator setting conditions. But, it can be expected that by using this performance it would indicate how this separator would affect any open circuit if it was converted to closed circuit grinding.

6. DESIGN OF THE CLOSED CIRCUIT AND ITS SIMULATION

As the open circuit grinding mill was converted to the closed circuit, the combined mill product was fed to the air separator. The mill feed rate and its size distributions were recalculated by using fresh feed material and the recirculated material that is actually the air separator underflow.

The approach to the computation was to model the whole circuit, the circuit was considered in three parts (Kuester at al., 1973).

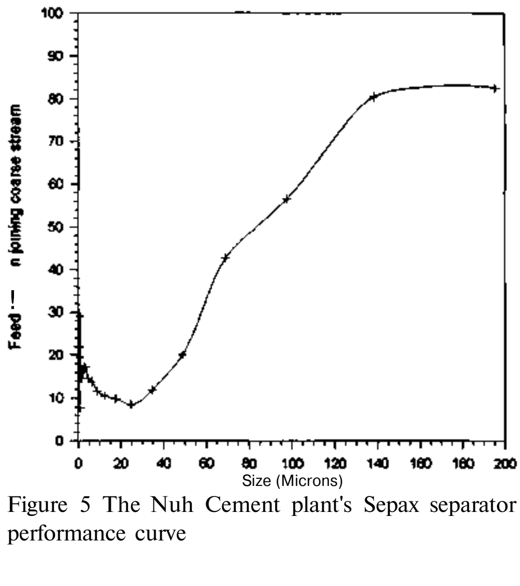

Figure 5 The Nuh Cement plant's Sepax separator performance curve

1-Calculation of the mill feed rate and its size distributions, 2-Calculation of the mill output which are the powder flow and airborne flow,

3-Calculation of the final product.

At the fist iteration, the mill feed was the fresh mill feed rate and its size distribution was that of the original material. The mill products and the air separator underflow and overflow products were calculated by using the designed models. In the second iteration, as was outlined above, the mill feed was recalculated and it was used as a mill feed and mill products were recalculated. By using these, the calculation of the air separator products were carried out and so on. The iterations were continued until the air separator overflow mass rate became equal to the flow rate of the mill fresh feed mass rate.

The model of the whole circuit was tested by using the optimised mill model and its parameters and the model classification curve. At the first step, the open circuit case was compared to its conversion to the closed circuit case at the same feed rate, feed size distribution as for each three testing conditions. Then, the mill feed rate was increased 30% by 10% step size for each test The mill throughput was observed during the simulation as well as the size distributions and its calculated surface area for the final product. These two criteria were important as the mill should be physically capable of handling the material that is ground in the mill and the mill production must be within the acceptable range of quality requirement.

The simulation results are shown for Test-1 in Figure 5,6 and the full result were documented elsewhere (Ergin, 1993).

7. DISCUSSION

It can be seen that the fits of predicted to measured size distributions are very close for three tests. In the range of size fraction of 48.8- 8.6 u,m the fit is particularly good where 50% -55% of the material is present. For 35 size fractions, the sum of absolute errors show that the model produced highly satisfactory predictions to within less than 1%. It can be expected that experimental errors in the size data might have some effect on the quality of the fits obtained.

The size distribution graphs of the open circuit and closed circuit data in cumulative form have shown that it is possible to obtain a steeper size distributions by converting existing Asian Cement plant's open circuit air-swept mill into a closed circuit by installing a Sepax separator according to simulation results

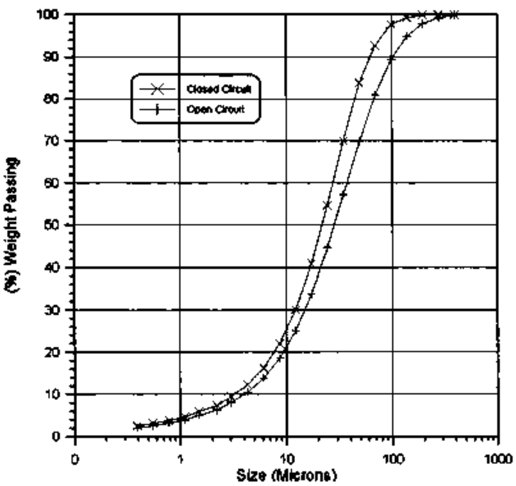

Figure 5. Comparison of the size distribution

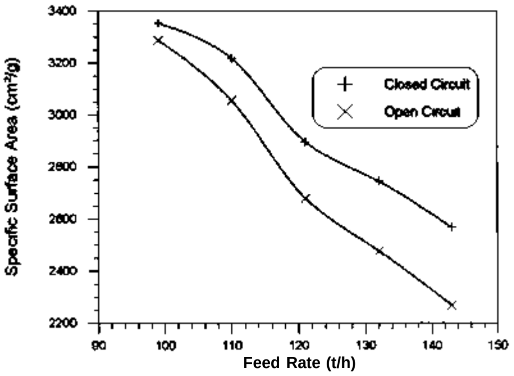

Figure 6 TEST-1, Comparison of the Spesific Surface Area -

The difference in the steepness of the size distributions were very obvious at the high feed rates. For the low feed rates, open and closed circuits behaved very similarly as expected.

Similar results were obtained in the comparison of the calculated specific surface area of the open and closed circuit products. One point that should be made is that the difference in the specific surface areas at the same feed rates and for identical circuits can be explained by the change of the feed material composition and its size distribution.

Constant classifier performance was assumed in the absence of a model of the device. The simulated mass flows through the classifier were always less than mass flow of the Nuh classifier. It would be expected that a real classifier would work equally as well or better and in this case that give a narrower size range and higher surface area.

8. CONCLUSIONS

A model based on a published air swept mill model «an be parameterized using industrially derived data. The model is capable of predicting the size distribution and surface area of products. The mill model generated was to be used to assess the effect of changing the mill to a closed circuit operation with an external classifier. For simplicity, the performance of classifier was assumed to be identical to the performance of an existing separator unit at another cement plant, measured in the form of a separation or partition curve.

Simulation of a closed circuit using the established model parameters together with the separator performance resulted in the prediction of an ability to increase capacity by about 10%, depending on the size required, compared to that of the simple open circuit configuration.

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