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Radiotracer Investigation of Clinker Grinding Mills for Cement Production at Ghacem

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Abstract: Radiotracer Residence Time Distribution (RTD) method was used to investigate the process of clinker grinding in Ghana Cement Plant (GHACEM) at Tema with the objective of determining hold-up and grinding efficiencies of two ball mills operating in close circuit regime. The experiment was conducted using 40Ci Au-198 radiotracer in liquid state and highly sensitive NaI detectors for radiation measurement. The experimental RTD data revealed that the Mean Residence Times (MRT) of the material in the milling and separator sections of both mills were the same. It was also observed from the estimated mill efficiencies that mill 4 operated with optimal performance while the efficiency of mill 3 was far below the expected value.

Key words: Cement, efficiency, hold-up, modelling, RTD

INTRODUCTION

Ghana Cement (GHACEM) Plant in Tema is one of Ghana's largest manufacturing establishments for production of cement with a total capacity of 2.4 million tons per annum.

GHACEM produces cement using three basic raw materials; clinker, limestone and gypsum. Clinker and gypsum are imported whilst limestone is obtained locally. Two products are currently obtained; Portland cement CEM1 class 42.5N (90% clinker, 5% limestone and 5% of gypsum) and Portland limestone cement CEMII/B-L (LL) 32.5 R (70% clinker, 25% limestone and 5% gypsum) (GHACEM plant report, 2009).

Cement manufacturing requires the use of mills that operate with large power consumption. In addition, their capacity and operation must be optimized in order to obtain efficient performance. The performance optimization of such mills will be possible if the technological parameters of the milling process are known.

Grinding systems are either 'open circuit' or 'closed circuit'. In an open circuit system, the feed rate of incoming clinker is adjusted to achieve the desired fineness of the product at the mill exit. In a closed circuit system, coarse particles are separated from the finer product and returned for further grinding. In a closed circuit mill, the total throughput is higher and hence the mill exit material is coarser. Unlike the open circuit mill, material coming from the mill goes to an air separator from where the finer materials are the product and the rejects are returned to the mill.

Figure 1 presents the design of the clinker grinding system (closed circuit), which consists of a two-chamber ball mill and the separator (Plasari and Theraska, 1981).

Cement clinker is usually grounded using a ball mill. This is essentially a large rotating drum (Fig. 2), containing grinding media; normally steel balls (Fig. 3). As the drum rotates, the motion of the balls crushes the clinker. The drum which is divided into two chambers with different sizes of grinding balls rotates at a speed of approximately 16 rpm. As the clinker particles are crushed, smaller balls are used for more effective reduction of particle size. In cement and other mineral processing plants, grinding process requires a considerable amount of power. Grinding of the clinker consumes about 1/3 of the power required to produce 1 ton of cement. This refers to an average specific power consumption of 57 kWh/ton (Worrel *et al.*, 2002).

This makes the application of radiotracer Residence Time Distribution (RTD) technique very important in the optimisation of the grinding process.

The experimental RTD curve and its model provide parameters that help in optimizing the performance of the whole clinker grinding system. The RTD estimates the grinding probability while the MRT gives the hold-up. The mass balance of material between the exit of the mill and recirculation to the mill gives the grinding efficiency of the system.

The time of residence of materials in the mill is an important factor to predict the distribution of particle size in the product. Therefore the RTD concept, which is fundamental for reactor design, is equally important in the design of a mill. Any success in this direction, improving

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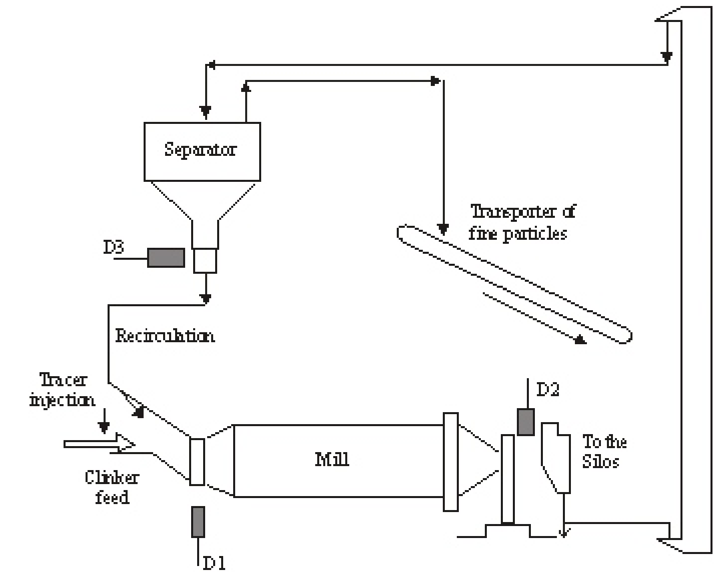

Fig. 1: Design of clinker grinding system; mill and separator

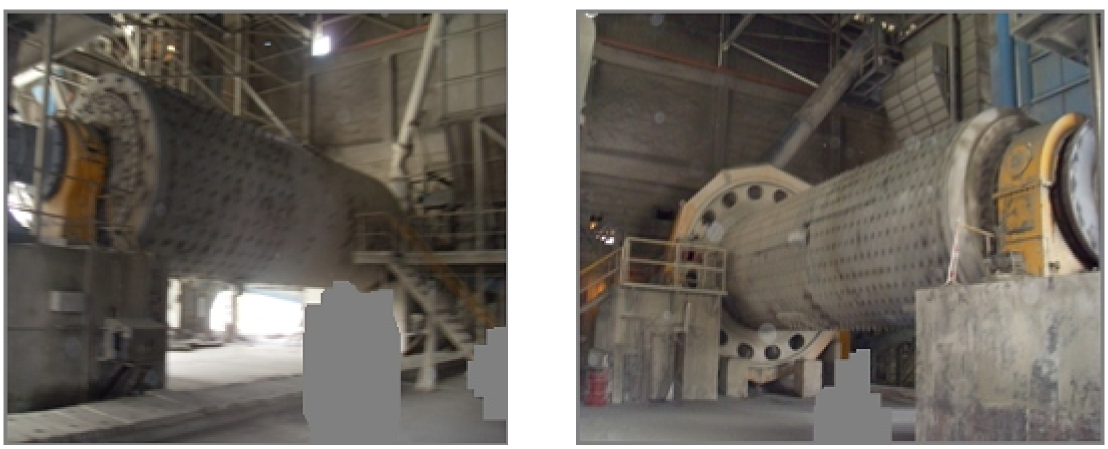

Fig. 2: External view of Mill 4 (left) and mill 3 (right) at GHACEM

machine design and/or choosing optimal operating and environmental conditions could possibly lead to the development of new approaches toward energy saving in cement production (Fuersteneau and Abouzeid, 2002).

Investigation has been done on the effects of feed rate, feed percent solids, mill speed and discharge trunnion diameter on the slurry hold-up, mean residence time and particle size distribution in a 41.6×64.1 cm pilot mill whose hold-up can be measured while in operation. It was observed that hold-up increases with increasing solids feed rate, solids ratio in the feed and decreasing discharge trunnion diameter (Songfack and Rajamani, 1999). Two equations relating the hold-up in the grinding media and pool zone with flow rate, grate design and mill diameter whose sum gives the total hold-up for the data obtained from a laboratory scale 30×15 cm mill at three different grate designs for three different rotational speeds and a variety of flow rates was proposed (Morrell and Stephenson, 1996). It was found that hold-up is directly proportional to flow rate, mill rotational speed, open area of the grate and inversely proportional to the radial positions of the holes on the grate. All of these valuable studies are very important guidelines for investigating the effects of discharge mechanisms on material hold-up and discharged material. However, these studies that have been carried out in relatively small scale mills need to be validated with industrial scale data as has been done (Morrell and Stephenson, 1996; Rogovin and Hogg, 1988; Zhang, 1992).

Fig. 3: Internal view of a two-chamber ball mill.

Earlier studies on industrial scale multi-chamber cement mills have shown that diaphragms in multi-chamber ball mills can be considered as a kind of classifier which is fed by the product of the first grinding chamber and produces a fine product as the feed of the second grinding chamber in conventional cement mills. A coarse product arises from this classification which returns to the first grinding chamber for further size reduction (Benzer, 2000, 2005; Lynch *et al.*, 2000; Benzer *et al.*, 2001b)

Material grinding in a mill depends on many factors including mill geometry, speed, ball size distribution, hold-up, material grindability and granulometry. In addition, partial recirculation of material to the mill inlet introduces a nonlinear positive feedback in the process (Zhang, 1992).

The present radiotracer work was carried out in two mills (mills 3 and 4) both operating in closed circuit regime. The exit material consists of fine cement product (powder of fine grains 0-13 μm) and rejects (coarse grains more than 13 μm) that are returned to the mill. The drum of each mill is made of two chambers. The first chamber, which is equipped with a coarse grinding media, is separated from the second chamber (has a fine grinding media) by an intermediate diaphragm as shown in Fig. 3.

The designed characteristics of the ball mill are presented in Table 1. During the experimental period, the capacity of mill 3 was 64 tons/h whilst mill 4 was 70 tons/h.

The objectives of this work were to determine the RTD, MRT and grinding efficiency of the clinker mill using radioactive tracer. The RTD is used for reactor troubleshooting like parallel flows, dead space, bypass or hold-up. The MRT (holdup) is evaluated from the experimental RTD, while the grinding efficiency is evaluated from mass balance of tracer between the exit of the mill and recirculation to the mill.

Table 1: Operational parameters of Mill 3 and 4

Mill	Mill 3	Mill 4
Diameter	3.6 m	3.66 m
Length	12.22 m	11.40 m
Grinding capacity	65 ton/h	70 ton/h
Average production	75 ton/h	78 ton/h
Mill speed	16.6 RPM	16.0 RPM
Rated motor power	2000 KW	2000 KW

Basic theory of residence time distribution (RTD): The time of residence of a particle in a system at a particular instance is the age of that particle. The age of a particle which is just leaving the system is known as the residence time of that particle. It is the time required for a fluid element to pass through a system from the entrance to the exit.

The RTD, also known as the frequency of the distribution of ages of flow elements leaving a vessel (reactor) at a particular time (t) is usually denoted by the function E(t), which in its standardized form is expressed by the relation (IAEA, 1997-2000):

$$\int_0^\infty E(t)dt = 1 \tag{1}$$

The theoretical MRT (τ) is given by the equation:

$$\tau = V/Q, \tag{2}$$

where,
V is volume of the unit
Q is mass flow rate (or feed rate)

Fig. 4: (a) Inlet detector (b) Recycle detector (c) Outlet detector

The experimental MRT $\bar{t}$ is given:

$$\bar{t} = \int_0^\infty t.E(t)dt \tag{3}$$

Practically, the experimental MRT, $\bar{t}$ is calculated by measuring the tracer concentration c(t) at the reactor outlet with time, t (or by measuring count rate r(t) of radiotracer):

$$\bar{t} = \frac{\int_0^\infty t.c(t)dt}{\int_0^\infty c(t)dt} \quad or \quad \bar{t} = \frac{\int_0^\infty t.r(t)dt}{\int_0^\infty r(t)dt} \tag{4}$$

Where c(t) is the tracer concentration, which is proportional to the count rate r(t).

Retention (Hold-up) of the mill: Only a portion of energy supplied to the mill is used in the reduction of particle sizes. A considerable percentage of energy is used to maintain particles in motion. These particles form the so-called Retention (Hold-up) of the Mill.

If the count rate is r(t) and the mass flow of the material through the unit is Q, then the Holdup is given by equation:

$$H_{up} = \frac{Q\int_0^\infty t.r(t)dt}{\int_0^\infty r(t)dt} \tag{5}$$

where, t = 0, the time of entry of tracer into the system.

Efficiency of the grinding mill: The efficiency of a grinding mill is determined by the separation coefficient (η)

$$\eta = \frac{\Delta M}{M_{entry}} = K\frac{\left[\bar{v}\int_0^\infty r_j(t)dt\right]}{\left[\bar{v}\int_0^\infty r_i(t)dt\right]} \tag{6}$$

where,

ΔM : The mass of the separated material, which is the difference of the material entering the separator and the material that is recycled back to the mill.

M_{entry} : The total mass of the material leaving the mill into the separator.

$\bar{v}$: The average velocity in the separator j and at the inlet i.

K : The detection calibration factor, which depends on the detection efficiency of detectors in different positions.

$r_{i,j}(t)$: The concentration of radiotracer (or net count rate) at points j and i, in time t after injection.

MATERIALS AND METHODS

This investigation was conducted at GHACEM in Tema on October 2009, which is a city located on the coast of Atlantic Ocean, in the Greater Accra region of Ghana

To obtain a representative tracer, liquid $H^{198}AuCl_4$ was mixed and agglomerated with cement powder obtained from GHACEM (2009) and a little water in order to obtain a tracer material with mechanical resistance similar to the cement clinker.

This solid tracer was introduced at entrance to the mills into the raw material being conveyed by the clinker belt feed transporter. The passage of the radiotracer at predetermined points was monitored by external scintillation detectors as shown in Fig. 4. Three detectors were installed in mill 3 (detectors 1, 2 and 3) whilst 2 were installed in mill 4 (detectors 5 and 6) and positioned as follows:

- **Detector 1 (D1):** at the mill inlet for recording the time of entry of tracer into the mill (i.e., time zero)
- **Detector 2 (5) [D2 or D5]:** at the mill outlet
- **Detector 3 (6) [D3 or D6]:** on the recycle loop for recording tracer concentration in the material that returns to the mill entry for regrinding

The NaI detectors as shown in Fig. 4, were connected by five-metre cables to a Data Acquisition System (DAS) consisting of Ludlum model 4606 rate metre of ten channels and laptop computer. The signals (count rates) recorded by the detectors were transmitted through the cables to the rate metre and then stored on the computer for further processing. The counts rates were plotted against time to represent the RTD.

The two radiotracer tests were performed in parallel, injecting the same amount of radiotracer (40 Ci Au-198) into each mill. The injection was instantaneous (Dirac).

EXPERIMENTAL DATA AND DISCUSSION

The experimental RTD curves are presented in Fig. 5 for mill 3 and Fig. 6 for mill 4. Figure 5 shows three experimental response curves measured by D1 (red), D2 (blue) and by D3 (green). Detectors D1 and D3 were placed near to each other due to the mill-separator configuration and as a result of their high sensitivity they received signals from the radiotracer just before it was injected (they 'saw' the tracer just as it approached the injection point). This resulted in two parasite peaks at the very beginning of the two curves (red and green small peaks) are ignored. The very high peak (18000 cp/10s) recorded by D1 represents the injection peak which arrived at a measuring time of 750s corresponding to "time zero" when the radiotracers entered the mill, D1 was therefore used only for recording "time zero" during the entire investigation. Further treatment of the experimental responses was done for curves obtained by D2 and D3.

Similarly, the first sharp peak recorded by D6 in Fig. 6 corresponds to a parasite peak whilst the second represents the injection peak with a measuring time of 715 s for "time zero".

The experimental responses curves for mill 3 (D2, D3) and mill 4 (D5, D6) were treated for background and electronic noise. The most important correction of radiotracer experimental data is background subtraction. In most radiotracer field investigations, the initial background (real background of environment around the probe) is not the same as final background which is normally higher due to radiotracer dust and absorption effect. The backgrounds shown by the detectors were around 70 cps at the beginning and 150 cps at the end of the tests. The background value was taken as the average of these two values.

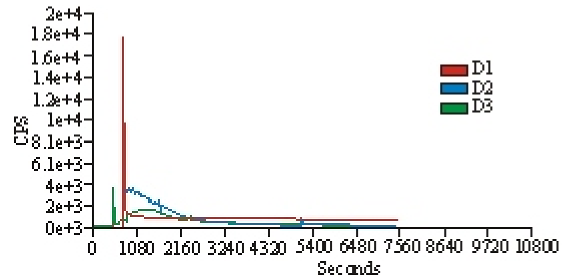

Fig. 5: Experimental response curves of 3 detectors in mill 3

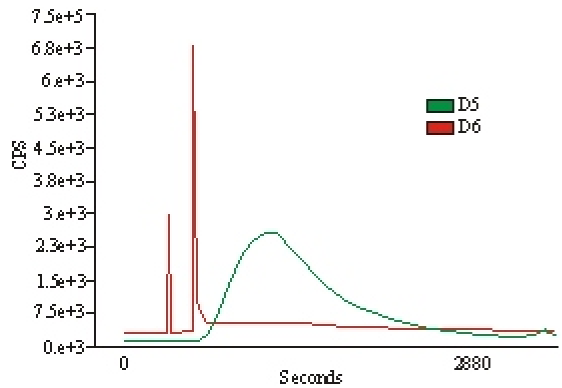

Fig. 6: Experimental response curves of 2 detectors in mill 4

Table 2 showing efficiency of the two mill

Parameters	Mill 3	Mill 4
MRT of Mill (min)	16.70	3.33
MRT of Separator (min)	16.13	3.50
η (%)	42.00	84.00

Electronic noise (sharp and short signal fluctuation) was registered during the experiment. Almost all detection systems (especially Ludlum) show up some sudden abnormal fluctuations, time after time coming from unknown factors that are consider as noise because they are not in the logic of a normal data recording. These isolated points are interpolated into the normal values measured.

Experimental results: From the corrected data, the MRT and efficiency of the two mills were evaluated using Eq. (4) and (6) and the results shown in Table 2.

Both mills have nearly the same MRT of material within the mill and in the separator. This implies that the time of residence of materials in the milling and separator sections of the two mills are almost the same at the time of the investigation. It was also observed from the calculated mill efficiencies that material recycle at the exit of mill 3 and mill 4 is about 50 and 20%, respectively.

The calculation of the efficiency of the mill-separator system was made based on the assumption that the detection efficiency of two detectors (in the outlet of the mill and separator) is nearly the same. In fact, the same types of detectors were used with the same collimation, so this assumption is quite realistic.

CONCLUSION

The results obtained during the investigations revealed that the residence time of material at the exit of the milling and separator sections of both mills are almost the same. This observation suggests that power consumption of both mills were almost the same during the time of the investigation. However, the estimated efficiency of mill 3 of 42% (with an error of nearly 15-20%) did not justify its optimal performance. The expected performance of the mill is >60% for hard clinker (60% fines and 40% returns), and >80% for soft clinker (80% fines and 20% returns). During the time of the experiment, both mills were fed with soft clinker, so the expected efficiency should have been >80%.

It could therefore be concluded that, during the time of the investigations, the performance of mill 4 was optimal while mill 3 was operating far below the expected performance level. Mill 3 has to be stopped for maintenance.

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REFERENCES

Benzer, A.H., 2000. Mathematical modeling of clinker grinding process. Ph.D. Thesis, Hacettepe University Institute of Pure and Applied Sciences, University of Queensland, JKMRC, Ankara, Turkish.

Benzer, H., L. Ergun, A.J. Lynch, M. Oner, A. Gunlu, I.B. Celik and N. Aydogan, 2001. Modeling cement grinding circuits. Miner. Eng., 14(11): 1469-1482.

Benzer, H., 2005. Modeling and simulation of a fully air swept ball mill in a raw material grinding circuit. Powder Technol., 150: 145-154.

Fuersteneau, D.W. and A.Z.M. Abouzeid, 2002. The energy efficiency of ball milling in commsinution. Int. J. Miner. Process, 67: 161-185.

GHACEM plant report, 2009. Information From Planning Department.

IAEA, 1997-2000. Radiotracer technology as applied to industries. Final report of a coordinated Research project.

Lynch, A.J., M. Öner and H. Benzer, 2000. Simulation of a closed cement grinding circuit. ZKG Int., 10: 560-567.

Morrell, S. and I. Stephenson, 1996. Slurry discharge capacity of autogeneous and semi-autogeneous mills and the effect of grate design. Int. J. Miner. Process., 46: 53-72.

Plasari, E. and J. Thereska, 1981. Radiotracer technique aiding the modelling of an industrial air-swept ball mill grinding phosphate rock. Institute of Nuclear Physics, Tirana-Albania.

Rogovin, Z. and R. Hogg, 1988. Internal classification in tumbling grinding mills. Powder Technol., 56: 179-189.

Songfack, P. and R. Rajamani, 1999. Hold-up studies in a pilot scale continuous ball mill: Dynamic variations due to changes in operating variables. Int. J. Miner. Process., 57: 105-123.

Worrel, E., N. Martin and L. Price, 2000. Potentials for energy efficiency improvement in the US cement industry. Energy, 25: 1189-1214.

Zhang, Y., 1992. Simulation of comminution and classification in cement manufacture. Ph.D. Thesis, Department of Mining and Metallurgical Engineering.