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RESEARCH ARTICLE

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COMPARTMENTAL MODELLING OF FLOW IN A CLINKER GRINDING MILL

ASBTRACT

This paper reports the results of an investigation of the flow regime in a clinker-grinding mill using the radiotracer residence time distribution (RTD) method. The RTD curve of the mill was obtained through the introduction of 40 mCi liquid gold (Au-198) as radiotracer at the inlet of the mill on-stream and a highly sensitive sodium iodide detector placed at its outlet for signal measurement. The first moment of the curve, the experimental mean residence time was 33.65 minutes which is less than the theoretical mean residence time of 58.15 minutes, an indication of the presence of dead zones within the mill. Of the three models used for the curve fitting and modeling the experimental data, the mixers-in-series with recycle model most adequately represented the flow structure in the mill with a mean residence time of 23.4 minutes.

Keywords: Radiotracer, Residence Time Distribution, clinker-grinding mill, flow structure

INTRODUCTION

Dry grinding circuits for the production of finished cement from cement clinker consist of two-compartment tube mills and air separators. Approximately 95% of the feed to the cement grinding circuit is clinker made up of four basic oxides in the correct proportions: calcium oxide (65%), siliconoxide (20%), alumina oxide (10%) and ironoxide (5%).A small amount of gypsum is added to control the set properties of the produced cement. It is quite typical to add a certain amount of water and small quantities of organic grinding aids to control mill temperature and facilitate the pulverization process(Zhang et al, 1995). The circuit reduces the feed from 80% passing size between 10 and 20 mm to 100% passing 90 microns. The size reduction takes place in a horizontal two-compartment tube mill filled with steel balls: the first compartment being shorter than the second. The coarse clinker is ground in the first compartment where larger steel balls (80, 60, 50 mm) are used whiles the fine grinding is done in the second compartment where smaller steel balls (below 25 mm) are used. A diaphragm separates the two compartments and allows only particles below a certain size to pass to the second compartment. Material fed through the mill is crushed by impact and ground by attrition between the balls. For increased efficiency, closed-circuit systems are widely used in cement grinding, in which the material exiting the mill is directed to a separator. The coarse fraction is sent to the mill's inlet for regrind, whereas the fine fraction becomes the cement which is conveyed by belt or powder pump into silos for storage. However, it is also not uncommon to produce cement in an open circuit where the feed rate of incoming clinker is adjusted to achieve the desired fineness of the product at the mill exit (Benzer et.al, 2001; 2003). Figure 1 shows the internals of a typical mill.

Generally, the design of such process equipment is based on the principle of ideal mixed flow model. However, due to improper reactor design, they deviate considerably from the assumed ideal flow patterns through undesirable phenomena such as bypassing and stagnation.(Levenspiel, 1999; Burrows et al., 1999). Many experimental ways exist to study flow patterns in process vessels as explained by Yapici et al. (2008). However, residence time distribution (RTD) analysis has been identified as the best tool for performance study of non-ideal chemical reactors and industrial circuits. The approach is cost-effective and provides reliable and detailed hydrodynamic information needed to diagnose plant malfunction, check the validity of design data and operational efficiency of process systems (Haakana et al., 2008; Zhang et al., 2005).The RTD is determined experimentally by injecting an inert chemical molecule or atom called tracer, into the reactor at some time t = 0 and then measuring the tracer concentration C, in the effluent stream as a function of time. The tracer usually possesses physical properties similar to those of the reacting mixture, so that its behavior will reflect that of the material flowing through the reactor. The tracer must not disturb the flow pattern of the system. The analysis of the output concentration with time, gives the desired information about the system and helps to determine the residence time distribution function E (t) (Smith et al, 1997; Fogler,1996) which can be used as a diagnostic tool for ascertaining features of flow patterns in reactors.

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The aim of this study is to determine the hydrodynamic characteristics of an industrial clinker grinding mill and consequently model the flow therein. The mean residence time of the mill is measured using radiotracer RTD technique. The RTD curve is then modelled by fitting with compartment models.

Figure 1. The internal view of a ball mill

MATERIALS AND METHODS

Plant Description

The investigation was carried out at GHACEM (Ghana Cement) plant located in Tema in the greater Accra region of Ghana. To obtain a representative tracer, liquid $^{198}AuCl_4$ was mixed and agglomerated with cement powder and a little water in order to obtain a tracer material whose mechanical resistance is similar to the cement clinker. This solid tracer was introduced at the inlet of the mill into the raw material being conveyed by the clinker belt feed transporter and the passage of the radiotracer at the outlet was monitored by an external sodium iodide scintillation detector. The mill has a diameter of 3.6 m, a capacity of 65 ton/hr corresponding to a volumetric flow rate of 50.39 m^3/hr and is 11.4 m long.

Data treatment

DTSPRO V4.2 software produced by PROGEPI (2000) of France was used for the data treatment prior to data analysis. The experimental data was treated for ^{198}Au decay is to ensure that undue weight is not given to measurements taken at the early stages of the experiment due to exponential tracer decay. Thereafter, the data was corrected for background radiation that existed at the experimental site by subtracting the background radiation levels, measured prior to experiment, from the decay corrected data. Finally the experimental data was normalized, by dividing each data point by the area under the curve, to obtain the RTD distribution function, E(t) defined by Eq. (1).

$$E(t) = C(t)/\int_0^\infty C(t)dt \quad such\ that\ \int_0^\infty E(t)dt = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Evaluation of mean residence time

The Mean Residence Time (MRT) is the most important hydrodynamic parameter necessary for the design of any continuous stirred tank reactor. Theoretically, it reflects mass transfer phenomenon in the reactor and defines the relationship between the vessel volume and volumetric feed rate a constant fluid density fluid (Eq. 2). The experimental MRT is usually calculated from the method of moments (Ham and Platzer, 2004; Santos and Dantas, 2004). The first moment (M_1) of the distribution curve represents the experimental MRT ($\bar{t}$)

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and is evaluated using Eq. (3):

$$\bar{t} = V/Q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$M_1 = \int_0^\infty t\, E(t)dt = \bar{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The performance of any industrial reactor is from the theoretically and experimentally determined MRTs. For an ideal system (system without flow abnormalities), the experimental and theoretical MRTs must be the same. If the $MRT_{th} < MRT_{exp}$, then there is the possibility of dead volume (fouling/scaling) in the reactor (Pant and Yelgoankar, 2002, IAEA, 2008). However, if $MRT_{th} > MRT_{exp}$, it follows that the supposed dead volume is not completely dead but stagnant.

Maximum power is drawn by a mill when the charge occupies approximately 50% by volume. As a result, mills are seldom run with charge levels greater than 45%.Therefore, the mill was assumed to be running at 40 % charge by volume and the MRT_{th} calculated based on this assumption was 58 minutes using Eq.2.The MRT_{exp} was 33.65 minutes.

Modeling of Experimental Data

In order to describe the flow structure and quantify the degree of mixing in the processing tanks, three models in the RTD software (provided by the International Atomic Energy Agency(IAEA): Axial dispersion model (ADM), Axial Dispersion with Exchange model (ADMEx) and the Mixers in Series with Recycle (MCR) were used to model the experimental data. The models were selected due to the available information on the physical design of the tanks, the value of the calculated MRTs and the shape of the distribution curve. The two-parameter ADM comprises one main stream in a tube/pipe described by the convection dispersion equation whiles the ADMEx with four parameters comprises the same, plus a no-flow zone exchanging with the main stream. It was first proposed by Van Swaaij et al. (1969) and must bereferred to for all the equations. The MSR model consists of two sets of mixers in series connected by a recycle flow. The details of the equation is given in Leven spiel, 1999.Table 1 gives a summary of the models' parameters and their values used for the modeling. The plots are also shown in the figures 2a-c below.

RESULTS AND DISCUSSION

It can be observed from all the plots that the peaks appear late which is due to the location of the introduction point of the tracer into the mill. One of the challenges in setting up a successful tracer experiment in industry is accessibility to a good point or location for tracer introduction. In this case, the tracer had to be added to the clinker entering the mill on a conveyor belt which obviously could be responsible for the shape of the curve. The curve has two peaks so close to each other with decreasing height and a long tail typical of recycle flows. The narrowness of the curve is also an indication that the clinker travelled through the mill with very little lateral and longitudinal mixing (Taylor, 1954). There is also the appearance of a small peak before the main one. This could be a possible short circuit somewhere in the mill.

The MRT_{exp} of the mill exceeded the MRT_{th}. Practically, this could be due to errors in the volume estimation of the mill affecting the calculation of the theoretical MRT an indication of the presence of dead regions in the mill. This is revealed in the high recycle ratio of the MSR model as shown in table 1. Dead regions or volumes do not take part in the milling and could have implications for mill efficiency which is reported to be very low (Benzer, 2001, Mumuni et al, 2011). The long tail of the curve also corroborates this anomaly(IAEA, 2008,Affum et al, 2013).

From fig. 2c, it is clear that the simplest AD model, which is commonly used for different systems, is not suitable for the accurate prediction of the flow pattern in the mill. The ADMEx and the MSR models are superior in comparison to the AD model as they show

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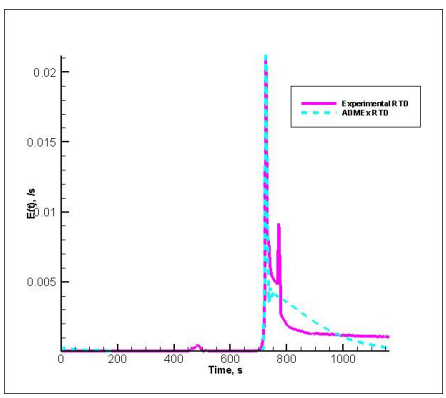
better agreement with the experimental data. However, the ADMEx is limited in its accurate prediction of the complex behavior of mixture particles that are entrapped in dead zones. One the other hand, the MSR model is better able to model dead zones through its recycle component as seen in fig. 2b. Moreover, its estimation of the MRT ($\tau_{1+}\tau_2$), 23.4 minutes approaches the MRT from the method of moments (33.65 minutes) than the ADMEx MRT of 14.16 minutes.

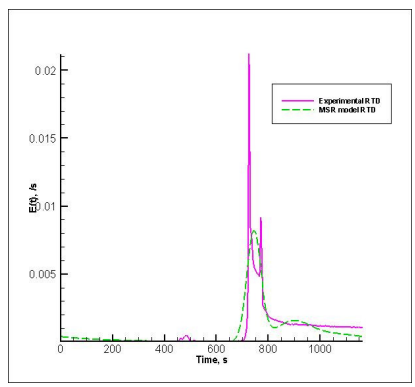
TABLE AND FIGURES

Model		**Parameter**				
1	Axial Dispersion	Mean residence time, τ	Peclet number, Pe			
		772	**227**			
2	Axial dispersion with exchange	Mean Residence time, τ	Peclet Number, Pe	Mass Transfer coefficient, N	Ratio of cross section of the main stream to total cross section, φ	
		850	**227**	**5**	**0.9**	
3	Mixers with recycle	MRT for volume of 1st set of mixers, τ_1	Number of mixers in 1st set of mixers, J_1	MRT for volume of 2nd set of mixers, τ_2	Number of mixers in 2nd set of mixers, J_2	Recycle ratio, Q_r/Q
		735	**881**	**670**	**79**	**0.8**

Table 1. Model Parameters for modelling



a.



b.

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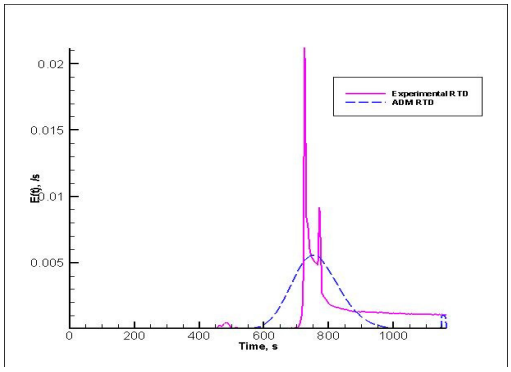

c.

Figures 2a, b, c . Plots of Experimental and Model RTDs

CONCLUSION

The flow regime in a clinker grinding mill has been investigated successfully using the radiotracer residence time distribution technique. The mixers- in series with recycle model best fitted the mill flow structure. The existence of dead volumes or zones in the mill reflected in the low mean residence time could have implications for the efficient running of the milling process.

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