INVESTIGATION OF FEED DYNAMICS IN CLINKER GRINDING MILL BY RESIDENCE TIME DISTRIBUTION METHOD

Simon Yao Adzaklo[1,*], Christian Priesly Kofi Dagadu[1], Patience Serwaah Adu[1], Hannah Asamoah Affum[1], Bright Jerry Atsu Yao Sogbey[1]

[1]National Nuclear Research Institute, Ghana Atomic Energy Commission,
P. O. Box LG 80, Legon-Accra, *s.yadzaklo@gaecgh.org

Abstract

Residence time distribution (RTD) analysis has been identified as one of the best experimental and classical tools for studying the performance of non-ideal chemical reactors and industrial circuits. In this study, RTD method was used to investigate feed dynamics in clinker grinding mill. The data was collected by introducing 40mCi Au-198 as a tracer in the feed at the mill inlet. The gamma signal was determined with thallium activated NaI detector placed at the mill outlet. RTD curve of the mill was generated from which the mean residence time (MRT) was evaluated using the method of moments. The experimental MRT was 27.1 minutes and the theoretical MRT evaluated from plant parameters was 55.3 minutes. Mathematical models were used to fit the outlet tracer concentration signal of the experimental data. The feed dynamics in the mill was best described by the "perfect mixing cells in series with exchange' model which fitted well with the experimental outlet response curves of the mill.
Keywords: Clinker, dynamics, Feed, mill, residence, time.

1.0 INTRODUCTION

The main raw material for cement production is clinker. Cement clinker is usually grounded using a ball mill. This is essentially a large rotating drum containing grinding media; normally steel balls. As the drum rotates, the balls cascade and crush the clinker. Fig. 1 shows the internals of a typical grinding mill. Approximately 95% of the feed to the cement grinding circuit is clinker made up of four basic oxides: calcium oxide, siliconoxide, aluminium oxide and iron oxide. 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 & Napier-Munn 1995).

Fig. 1. Internal view of clinker grinding mill

A typical grinding circuit feed ranges between 10 and 20 mm and this is reduced to 100% passing 90 microns at the mill outlet.

It is desired to design process equipment on the principle of ideal mixed flow model. These equipment, however, deviate considerably from the assumed ideal flow patterns due to the occurrence of undesirable phenomena such as bypass and stagnation (Burrows et al. 1999 &
Levenspiel 1999). Many experimental methods exist to study flow patterns in process vessels. However, RTD analysis has been identified as an effective tool for performance study of non-ideal chemical reactors and industrial circuits. The experimental RTD curve and its model provide parameters that help in optimizing the performance of the whole clinker grinding system. The idea of RTD concept application to a flow system was described by many authors including Stegowski and Furman (2004). The RTD is obtained experimentally by injecting an inert tracer into the inlet of the reactor and the tracer concentration at the outlet, $C(t)$ is measured as a function of time. The analysis of the output tracer signal, gives information about the feed dynamics through the system. The outlet concentration, $C(t)$ is used to determine the RTD function $E(t)$ which can be used as a diagnostic tool for the reacting system. The $E(t)$function is defined in Eq. (1) (Fogler 1997 and IAEA 2008).

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

2.0 MATERIALS AND METHOD

2.1 Plant Description

The investigation was carried out at GHACEM (Ghana Cement) plant. GHACEM produces cement using three basic raw materials; clinker, limestone and gypsum. Two products, Portland cement and Portland limestone cement, are produced. The production capacity of the plant is 2.4 million tons of cement per annum. The study was conducted on clinker grinding Mill4. The mill has a diameter of 3.66m and it is 11.40m long with grinding capacity of 70 ton/hr corresponding to a volumetric flow rate of 54.27 m^3/hr (GHACEM 2009)

2.2 Data collection

The tracer used was 40mCi liquid $^{198}AuCl_4$. It was first prepared by mixing it with cement powder and a little water to enable it be formed into agglomerate with mechanical resistance similar to the cement clinker. The solid tracer was introduced into the feed at the mill inlet and the tracer concentration at the mill outlet was monitored with sodium iodide scintillation detector as shown in Fig. 2. The detector was connected to data acquisition system which consists of analyzer and laptop with Ludlum software. Fig. 3 shows the data acquisition system.

Fig. 2: NaI detector at mill outlet

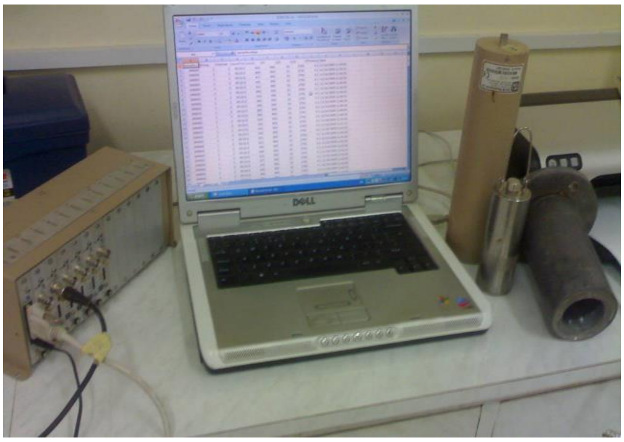


Fig. 3: Data acquisition system

2.3 Data treatment

Construction of RTD function, *E(t)*, requires that the data collected is treated so that the signal represents the tracer in the system monitored (IAEA 2008). The experimental data was therefore treated for decay correction, background correction and starting (zero) point correction. Finally, the data was filtered for electronics noise correction using finite impulse response filter with transfer function defined by Eq. (2) (Kasban et al. 2010).

$$H(z) = \frac{1 + z^{-1} + z^{-2} + z^{-3} + z^{-4}}{5} \qquad (2)$$

2.4 Mean residence time

The experimental mean residence time (MRT) is obtained by evaluating the first moment (M_1) of the *E(t)* function defined by Eq. (3)

$$M_1 = \int_0^{\infty} tE(t)dt = \bar{t} \qquad (3)$$

The theoretical MRT (holding time (τ)) is obtained from the plant parameters and it is defined by Eq. (4).

$$\tau = V/Q \tag{4}$$

V = volume of the system
Q = volumetric feed flow rate

If a system operates without flow abnormalities, then the measured experimental MRT ($\bar{t}$) is the same as the holding time, τ. However, if $\bar{t} < \tau$, it indicates that the mean of the feed exits too early. There is therefore a possibility of fouling/scaling in the reactor (Pant and Yelgoankar 2002). This results in the reduction in the material volume of the reactor signifying the presence of dead space in the system. In a situation where $\bar{t} > \tau$, it may mean that:

I. The holding time of the system is wrongly calculated due to error in flow rate measurement or volume calculation.
II. The tracer used is not inert. It is adsorbed on the walls of the vessel.
III. There is a sluggish area in the system which exchanges its contents with the main flow gradually. This situation can be confirmed from the shape of the experimental curve and subsequent modelling of the data (Dagadu et al. 2010).

2.5 Modeling of Experimental Data

In order to describe the feed dynamics of the studied system, suitable mathematical models were used to simulate the experimentally obtained RTD data. These flow models include perfect-mixers-in-series (PMS), perfect mixers with recycle (PMR), perfect mixers in parallel (PMP) and Perfect mixers in series with exchange (PMSE). PMSE model as illustrated in Fig. 4 gave the best fit.

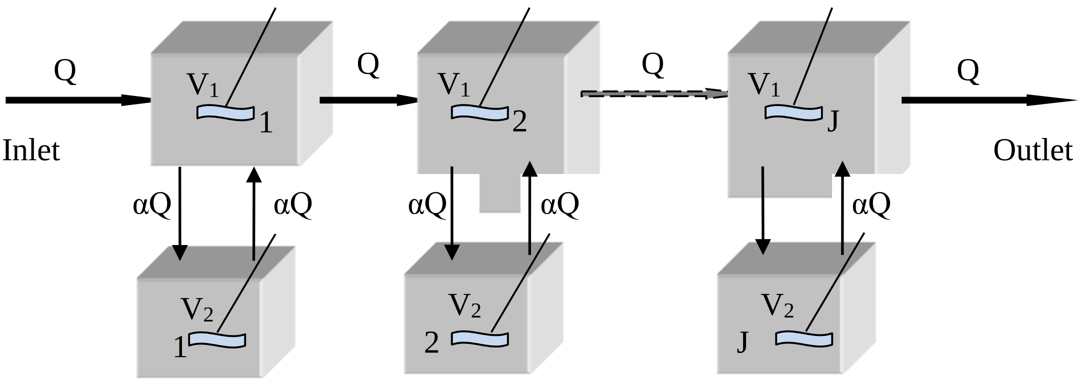


Fig.4: Conceptual representation of perfect mixers-in-series with exchange model.

This model assumes that the main flow rate, Q, goes through a row of J perfect mixers in series of volume V_1 (life volume) each exchanging flow rate αQ with another mixer of volume V_2 (sluggish volume). The mass balance equations for the upper and lower blocks of the model are respectively described by Equations (7) and (8) (Dagadu et al. 2010).

Upper block (active region):

$$\frac{dC_o(t)}{dt} = \frac{1}{t_{act}}[C_i(t) + \alpha C_2(t) - (1-\alpha)C_o(t)] \quad (5)$$

Lower block (sluggish region):

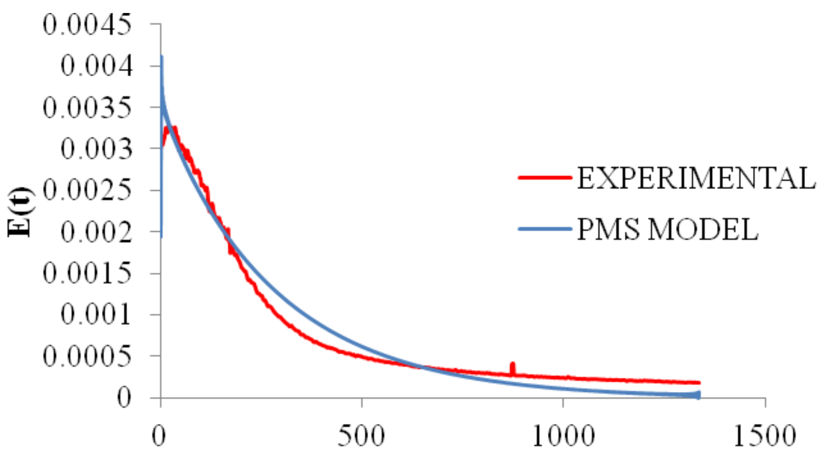
$$\frac{dC_2(t)}{dt} = \frac{1}{t_m}[C_o(t) - C_2(t)] \quad (6)$$

Where $C_i(t)$ and $C_o(t)$ are inlet and outlet tracer concentration functions respectively of the main mixer. $C_2(t)$ is the tracer concentration function in the exchange mixer. The model has four parameters: t_{act}, t_m, J, and k. Here t_{act} is the MRT of the active volume (V_1), and t_m is the time constant for exchange between the two volumes V_1 and V_2. By definition, $t_{act} = JV_1/Q$ and $t_m = V_2/\alpha Q$. If t_m is large, then the exchange is small and vice versa. k is the relative volume of the sluggish zone with respect to the active volume; $k = V_2/V_1$. The total MRT of the model is given by Eq. (7) (IAEA 2008).

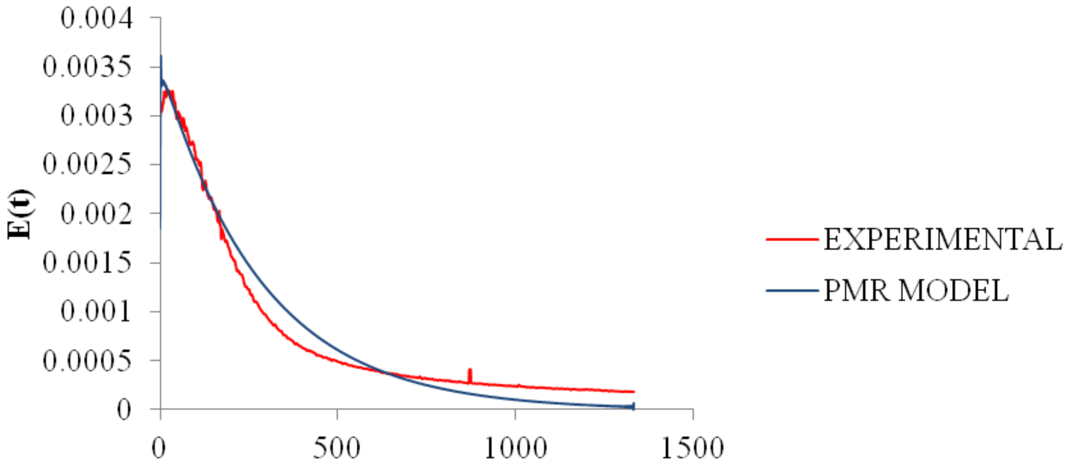
$$\bar{t} = t_{act}(1+k) \quad (7)$$

3.0 RESULTS AND DISCUSSION

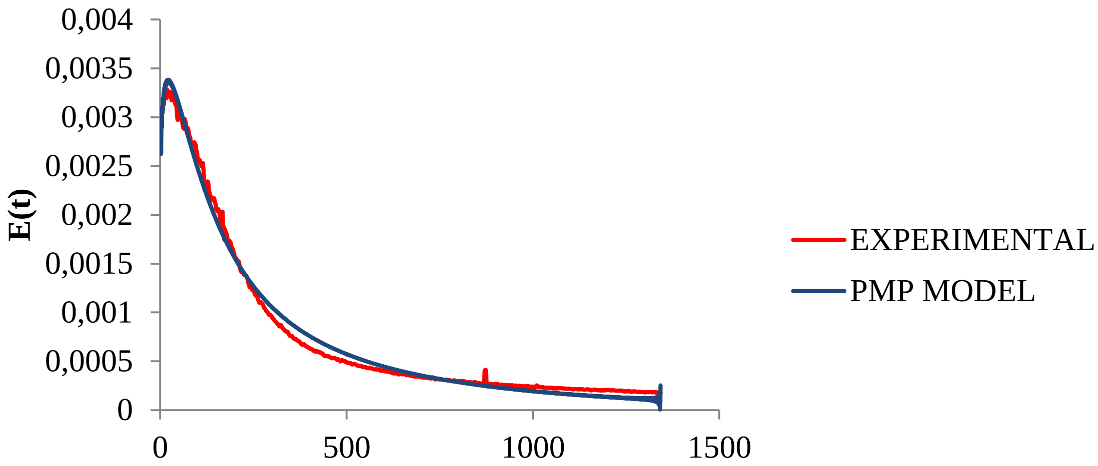
The model fits and the experimental response curves are shown in Fig. 5(a-d). Modeling of the experimental data revealed that the flow of material in the mill was best described by the 'perfect mixing cells in series with exchange' model. This is because this model fitted best with the experimental outlet response curve of the mill as in shown in Fig. 5(d). The model confirmed the long tailing effect of the experimental response curve which is characteristics of reactors with sluggish zones. The long tail nature of the experimental and the PMSE model response curves suggests the existence of sluggish/stagnant zones in the mill. During the investigation the sluggish zones trapped some amount of material in the mill and exchanged their contents with the main flow (active volume) at a very slow rate. This results in the long tail of the experimental RTD curve. The implication is that; materials are being held at some portion of the mill for too long. This situation usually causes over consumption of energy in reactors. The experimental and the PMSE model parameters are presented in Table 1.



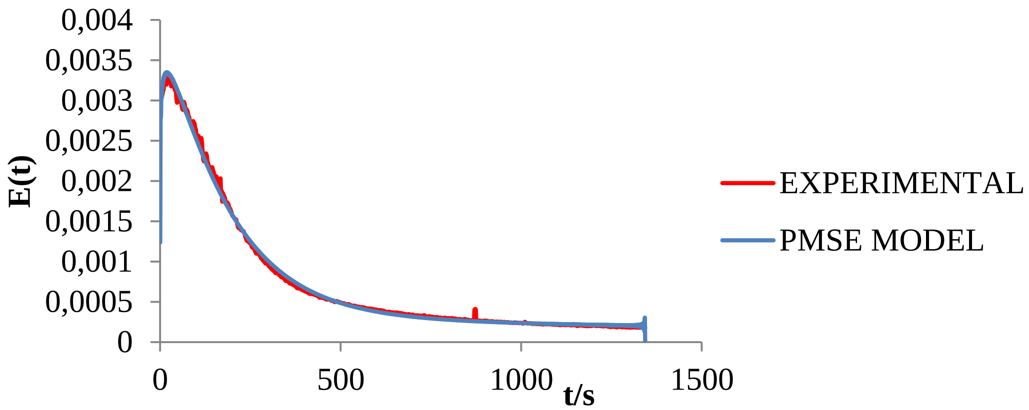
(a) Perfect mixers in series



(**b**) Perfect mixers in series with recycle



(c) Perfect mixers in parallel



(d) Perfect mixers in series with exchange

Fig. 5 (a-d) Experimental response curves and the fit models.

TABLE 1: Experimental and PMSE model parameters

parameter	theoretical	experimental	Model (PMSE)
Feed vol. (m^3)	46.4	-	-
Feed rate (m^3/hr)	54.3	-	-
MRT (min)	51.3	27.1	-
t_{act}(min)	-	-	27.4
t_m(min)	-	-	3
J	-	-	1
k	-	-	0.4
MRT_{total}, $\bar{t}$ (min)	-	-	38.4

4.0 CONCLUSION

Method of residence time distribution was successfully used to investigate the feed dynamics of the mill studied. The mill feed dynamics was best described by perfect mixers –in-series with exchange model. The long tail nature of the response curves suggests feed material stay in some portions (sluggish zones) of the mill for too long before exiting. These zones could decrease productivity as material could be trapped in them. This have implications on the milling efficiency and therefore over consumption of energy. Further investigation needs to be done to ascertain milling effectiveness of the mill.

ACKNOWLEDGMENT

The authors express their profound gratitude to the management of GHACEM for the opportunity granted us to use the plant for the investigation. We also appreciate International Atomic Energy Agency for their technical support.

REFERENCE

1. Burrows L. J., Stokes A.J., West J.R., Forster C.F. and Martin A.D. (1999). “Evaluation of Different Analytical methods for tracer studies in aeration lanes of activated sludge plants”. *Water Research*, (33)2: 367-374
2. Dagadu C.P.K., Amanor E., Coleman A. and Mumuni I. (2010). “Residence-Time-Distribution Measurements At Anglogold Ashanti, Iduapriem Mines, Ghana By Means Of Radioactive Tracer Technology”. *Report to AngloGold Ashanti*
3. Fogler H.S. (1997). “Elements of Chemical Engineering Reaction” *2nd ed. New Delhi, Prentice-Hall of India Private Ltd.*
4. GHACEM (2009). Plant Report Information From Planning Department
5. IAEA (2008). “Radiotracer Residence Time Distribution Method for Industrial and Environmental Applications”. *Training Course Report Series 31, Vienna*

6. Kasban H., Zahran O., Arafa H., El-Kordy M., Elaraby S.M. and Abd El-Samie F.E. (2010). “Laboratory experiments and modeling for industrial radiotracer applications”. *Applied Radiation and Isotopes*, 68: 1049-1056.
7. Levenspiel O. (1999). “Chemical reaction engineering”. *3rd ed. New York, John Wiley and Sons.*
8. Mumuni I. I., Dagadu C.P.K ., Danso K.A., Adu P S., Affum H.A., Lawson I., Appiah G.K., Coleman A. and Addo M.A.(2011). Radiotracer Investigation of Clinker Grinding Mills for Cement Production at Ghacem. *Research Journal of Applied Sciences, Engineering and Technology*, 3(1): 26-31,
9. Pant, H.J. and Yelgoankar, V.N. (2002). “Radiotracer investigations in aniline production reactors”. *Applied Radiation and Isotopes*, 57(3): 319-325
10. Stegowski Z. and Furman L. (2004). “Radioisotope tracer investigation and modeling of copper concentrate dewatering process”. *International Journal of Mineral Processing*, (73)1: 37-43
11. Zhang, Y. M. and Napier-Munn, T. J. (1995). “Effects of particle size distribution, surface area and chemical composition on Portland cement strength. *Powder Technology*,83(3): 245-252