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Determination of Malfunctions in Gold Processing Tanks by RTD Modelling

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Abstract: Radiotracer technique was used to measure the Residence Time Distribution (RTD) of material in 4 leach tanks at AngloGold Ashanti, Iduapriem gold processing plant. The investigation was conducted to determine the mean residence time and possible flow malfunctions in the tanks. The liquid phase of gold ore slurry was traced using ^{131}I radiotracer which was instantaneously injected into the feed stream of the first tank. RTD curves were generated using sampling data collection method to monitor the radiotracer at tank outlets. The measured RTD data were treated and the Mean Residence Times (MRTs) of material in the tanks determined. For each tank, the experimental MRT calculated from the method of moments exceeded the corresponding theoretical MRT. The experimental curves were simulated using perfect mixers-in-series with exchange model. Results of the simulation indicate exchange of flow between life and stagnant volumes at a very slow rate leading to increase in the MRTs.

Key words: ^{131}I, mean residence time, radiation detector, residence time distribution, stagnant volume, tanks-in-series model

INTRODUCTION

Gold processing tanks are typical continuous slurry mixing vessels (solid-liquid contactors) where the suspension of floating solids is of particular interest. In gold leaching tanks the solid ore particles are incorporated into a continuous liquid phase consisting mostly of cyanide and water.In order to aid reaction performance, in these types of reactors, it is necessary to ensure maximum interfacial contact between the solids and liquid phase and avoid the accumulation of solids at any part of the contactor. (Kuzmanic *et al*., 2008; Nocentini *et al*., 2002; Raghav and Joshi, 1988). Generally, the design of these reactors is based on the principle of ideally mixed flow model. However, due to improper reactor design they deviate considerably from the assumed ideal flow patterns and exhibit different flow structures consisting of parallel flows such as bypassing and existence of dead or stagnant regions. These regions hamper the mixing and cause several adverse effects that lower the performance of the unit and should be avoided in all types of process equipment (Levenspiel, 1999; Burrows *et al*., 1999; Yao *et al*., 1998; Himmelblau and Bischoff, 1968). In order to assess the performance of industrial reactors and diagnose possible malfunctions, systematic studies leading to the flow dynamic characterization of these reactors must be conducted. This could address the problems associated with reactor design and scale-up by establishing suitable models that represent the real flow patterns in the reactors.

There are many experimental ways to study flow patterns in stirred tank reactors as explained by Yapici *et al*. (2008). However, Residence Time Distribution (RTD) analysis has been identified as the best experimental and classical tool to study the performance 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. It allows an accurate kinetic modelling of flow systems and help reactor design to achieve or preserve a desired flow pattern (Haakana *et al*., 2008; Zhang *et al*., 2005).

The RTD method is based on the injection of a tracer material at the inlet of the system and as it flows through the system its concentration in the outlet stream is measured as a function of time. The material balance of tracer at the influent and effluent of the studied system provides a characteristic relationship between corresponding concentrations. The relations are then analysed by statistical methods and flow model simulations to obtain vital information on the hydrodynamic characteristics of the system.

The aim of this study is to determine the hydrodynamic characteristics of industrial gold leaching tanks in order to assess their performance. This would be done by measuring the retention time and determining the pattern of flow in the tanks using radiotracer RTD technique. The results are needed for plant upgarde.

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Fig. 1: Picture of leach tank

a b

c d e

Fig. 2: Picture summary of sampling data collection method: (a) inlet feed stream, (b) sampling at tank exits, (c) settling of samples, (d) 1 L clear liquid sample, (e) sample counting

EXPERIMENTAL

Plant description: The investigation was carried out at the Iduapriem gold processing plant located in the Western region of Ghana. The processing facility includes pure leach and Carbon-in–pulp (CIP) circuits which are used for treating concentrates of milled gold ore. The treatment process begins with ore leaching with cyanide and oxygen (main leaching agents) in four tanks connected in series. After leaching, the pulp containing the dissolved gold flows by gravity into a cascade of seven CIP tanks where dissolved gold adsorbs onto carbon granules present in the tanks. The carbon granules, loaded with gold, are separated from the pulp and then treated to remove the pure gold (de Andrade Lima and Hodouin, 2005).

The leach tanks are cylindrical flat bottom vessels each with pulp holdup of about of 1980 m^3. Each tank is equipped with four baffles uniformly spaced at 90^0 around the vessel periphery. The tanks are mechanically agitated by two hydrofoil impellers mounted on a shaft concentric with the axis of the tank. A picture of a typical leach tank is shown in Fig. 1.

Radiotracer: The suitability of a radiotracer for a particular investigation is a crucial aspect of radiotracer studies. In general the selection criteria are based on the nuclear characteristics of the radiotracer. These include physicochemical behaviour, type and energy of emitted radiation, half-life and radiotoxicity (IAEA, 1990). Radiotracers that are used for hydrodynamic studies of industrial process systems should have similar physical properties as the traced medium. It should emit gamma radiation(s) with sufficient energy which can be detected. The half life of the tracer should be comparable to the duration of the experiment. It should be long enough to allow for transportation of tracer from the nuclear reactor to the experimental site and effective detection till the end of the experiment. However, it should be short enough in order to reduce the level of residual tracer in the exit streams for minimum radiotoxicity. Based on these criteria, ^{131}I radiotracer in the Chemical form of sodium iodide (Na ^{131}I) was selected to tracer the aqueous of the are slurry.

Radiation measurement: An impulse of ^{131}I radiotracer was introduced into the inlet stream of the first leach tank and the movement of tracer in the tanks monitored using the sampling data collection method. Fifty slurry samples were taken at tanks outlets at regular time intervals. Thereafter, about one liter of filtered liquid samples were counted in a marinelli beaker mounted on a calibrated sodium iodide NaI(Tl) scintillation detector. ^{131}I concentration in each sample was measured using Ludlum model 16 electronic counting system which was connected to the detector. The counts rates were recorded against sampling time in a table for further data processing. A picture summary of sampling data collection method is shown in Fig. 2.

DATA ANALYSIS AND RESULTS

Data treatment: Prior to data analysis the experimental data was treated for ^{131}I decay. This 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):

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

such that:

$$\int_0^\infty E(t)dt = 1 \tag{2}$$

Plots of the normalized residence time distribution function E(t), versus sampling time (t)] for the tanks are shown in Fig. 4.

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. It is the main reason why the evaluation of the RTD is performed. Theoretically, the MRT 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. 3). The experimental MRT is usually calculated from the method of moments (Ham and Platzer, 2004; Santos and Dantas, 2004; Thyn *et al*., 2000; Naumann and Buffham, 1983). The first moment (M_1) of the distribution curve represents the experimental MRT ($\bar{\tau}$) and is evaluated from Eq. (4):

$$\tau = V / Q \tag{3}$$

$$M_1 = \int_0^\infty tE(t)dt = \bar{t} \tag{4}$$

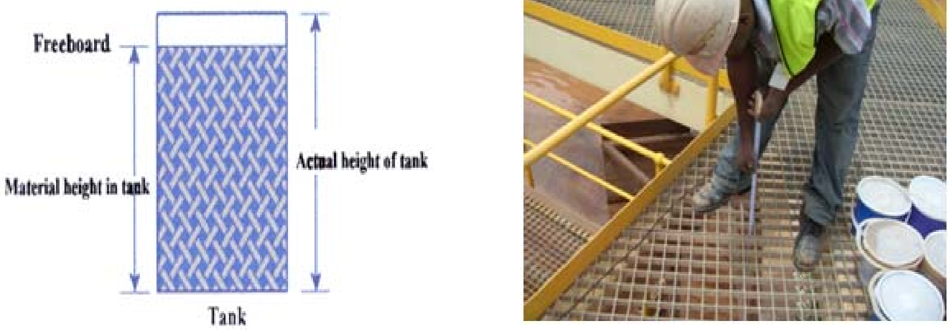

Fig. 3: Measurement of freeboard height

Table 1: Summary of results

Parameters	Tank 1	Tank 2	Tank 3	Tank 4
Flow rate, $Q(m^3/h)$	725	725	725	725
Required capacity, $V(m^3)$	1980	1980	1980	1980
Active capacity, $V(m^3)$	1950	1936	1903	1855
Theoretical MRT, τ(min)	161	160	157	154
Experimental cumulative MRT, τ(min)	174	360	546	720
Experimental MRT per tank, τ(min)	174	186	186	174

The performance of any industrial reactor is determined from the values of the theoretically and experimental MRTs. For an ideal system (system without flow abnormalities) the values of τ and $\bar{\tau}$ are the same. If $\bar{\tau} < \tau$ then there is the possibility of dead volume (fouling/scaling) in the reactor (Pant and Yelgoankar, 2002). However, if $\bar{\tau} > \tau$ it follows that the supposed dead volume is not completely dead but stagnant. In this situation it is assumed that τ is accurately calculated and the tracer used is inert and does not adsorb at the walls of the vessel.

In order to obtain accurate values of the theoretical MRT the actual volume of slurry in each tank was calculated with respect to the freeboard height which was measured at regular time intervals during the experiment as shown in Fig. 3. Flow rate values were recorded hourly by control room staff and an average value of 725 m^3/h was obtained. The theoretical and experimental MRTs calculated from Eq. (3) and (4), respectively are listed in Table 1.

Modeling of experimental data: In order to describe the flow structure and quantify the degree of mixing in the processing tanks, the tanks-in-series (TIS) model and the Tanks-in-Series with Exchange (TISEx) model were used to simulate the experimental RTD data. The TIS model was selected due to the conventional in-series arrangement (de Andrade Lima, 2006) of the tanks while the TISEx model was chosen due to the available information on the physical design of the tanks, the value of the calculated MRTs and the long tails of the distribution curves. The two models are described in detail by IAEA, (2008). The analytical solution of the TIS model for impulse tracer injection is given by:

$$E(t) = \left(\frac{J}{\tau_m}\right)^j \frac{t^{J-1}\exp\left(-\frac{Jt}{\tau}\right)}{(J-1)!} \tag{5}$$

The model has two parameters; the mean residence time (τ_m) and the number of mixers (J).

The TISEx model is based on flow exchange between life and stagnant zones of volume sV_1 and V_2 respectively. The material balance equations representing the zones are given by:

Active zone:

$$\frac{dC_1(t)}{dt} = \frac{1}{t_{act}}\begin{bmatrix} C_{in}(t) + aC_2(t) \\ -(1-a)C_1(t) \end{bmatrix} \tag{6}$$

Stagnant zone:

$$\frac{dC_2(t)}{dt} = \frac{1}{t_m}\left[C_1(t) - C_2(t)\right] \tag{7}$$

The model has four independent 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, respectively. By definition: $t_{act} = JV_1/Q$ and $t_m = V_2/aQ$. If t_m is large, then the exchange is small and vice versa. k is the relative volume of the M stagnant zone with respect to the active volume; $k = V_2/V_1$. The total MRT of the model is given by:

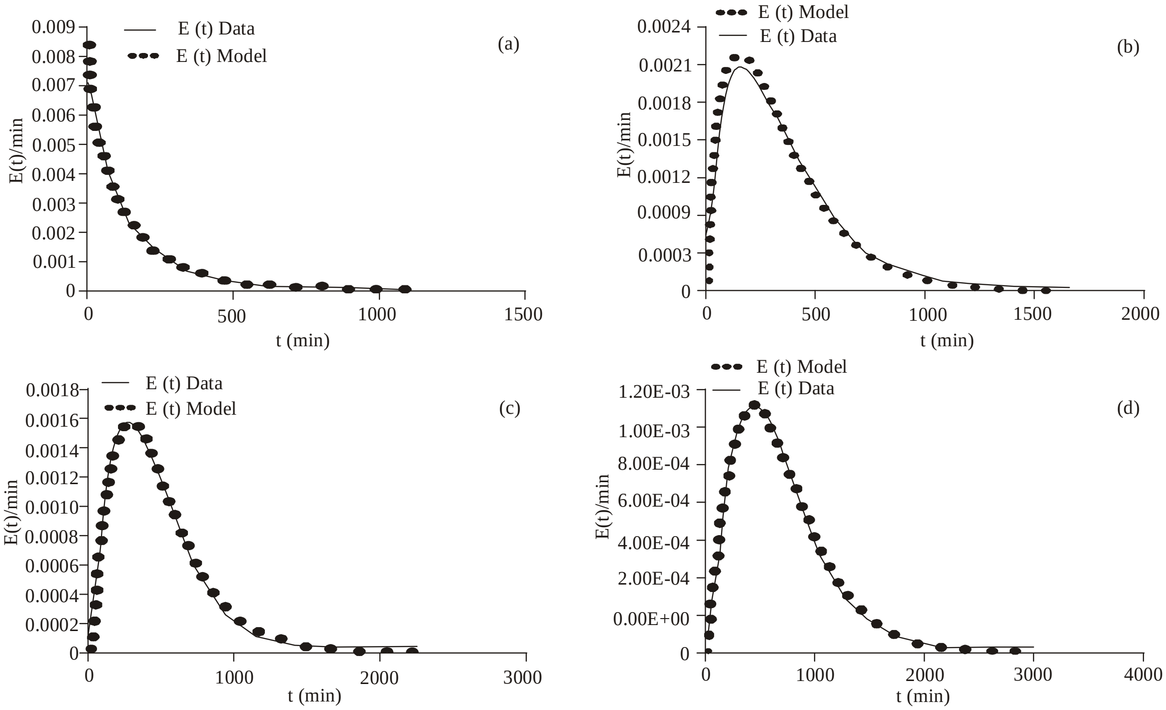

Fig. 4: Tanks-in-series model simulation, (a) tank 1, (b) tank 2, (c) tank 3, (d) tank 4

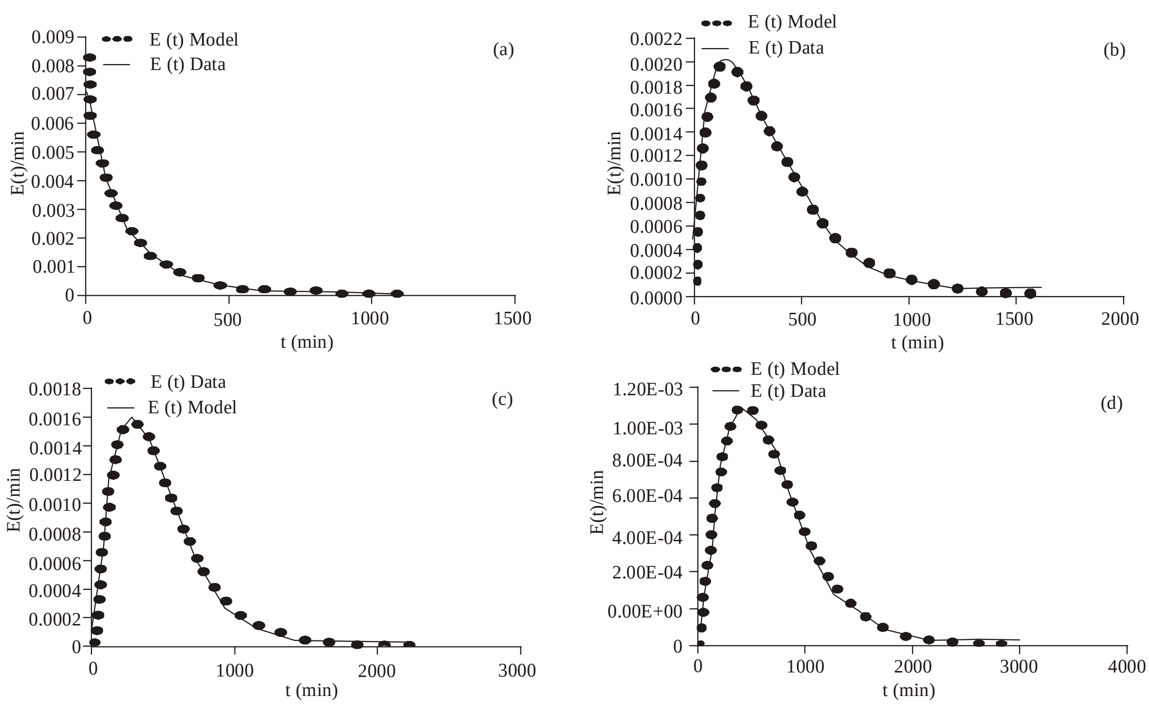

Fig. 5: Tanks-in-series with exchange model simulation, (a) tank 1, (b) tank 2, (c) tank 3, (d) tank 4

Table 2: Model parameters: TIS model

Model parameters	Tank 1	Tank 2	Tank 3	Tank 4
MRT, τ_m (min)	159	335	485	717
Number of mixers, J	0.8	1.8	2.6	2.7

Table 3: Model parameters: TISEx model

Model Parameters	Tank 1	Tank 2	Tank 3	Tank 4
MRT of active volume, t_{act} (min)	150	360	477	689
Time constant for exchange, t_m (min)	227	415	795	991
Number of mixers, J	0.84	1.75	2.6	2.7
Relative volume, k	0.01	0.01	0.08	0.06
Total MRT, τ_m (min)	152	364	515	730

$$\bar{t}_m = t_{act}(1 + k) \tag{8}$$

The DTSPRO V4.2 software produced by PROGEPI (2000) of France was used to simulate experimental and model curves. The software uses least square curve-fitting method to obtain the best fit and optimum values of model parameters. Plots showing the comparison of experimental and model simulated curves for the TIS and TISEx models are shown in Fig. 4 and 5, respectively. The corresponding model parameters are shown in Table 2 and 3.

DISCUSSION

Plots of the experimental curves represented in Fig. 4 and 5 show signs of deviation from ideal mixing conditions. The curves exhibit long tails at the final stages of tracer exit. The long tails could be the result of tracer washout at very slow rate towards the end of data collection.

The experimental MRT of each tank obtained during the investigation exceeded the corresponding theoretical value. Practically this could be due to errors in flow rate measurement or volume calculation leading to wrong calculation of the theoretical MRT. It could also be the result of tracer adsorption at the walls of the tank if the tracer is not inert. Finally it could be the result of parallel flows in the tanks. However, as explained in section 3 free-board heights of the tanks were constantly measured (Fig. 3) and the actual volume of material in each tank was accurately determined. Moreover, ^{131}I radiotracer is a suitable aqueous tracer and was found to be inert in similar investigations. Therefore, barring faulty flow meter readings (readings reordered hourly by control room personnel), the interpretation of the observed increase in residence time is due to slow release of tracer trapped within the system as a result of parallel flow. Economically this observation could increase production cost due to addition use of energy during ore leaching.

Modeling of the experimental data revealed that the simulation results are better for the TISEx model than the TIS model. The TISEx model fitted very well with the experimental data. It is therefore the best model to predict the pattern of slurry flow in the tanks more accurately.

According to the TISEx model the pattern of flow in the tanks is such that two types of volumes exist. These volumes consist of perfectly mixed active and stagnant regions with parallel exchange of flow between them. It was also observed that the value of the time constant for fluid exchange are relatively high with respect to the MRT of the active volume. This signifies slow exchange of fluid between the two zones, showing the severity of fluid stagnation in the tanks. It takes a long time for part of the radiotracer trapped in the stagnant zones to completely washout. Thus resulting in the long tailing effect of the tracer washout curves and explains the reason why the experimental MRTs exceed the theoretical values. The optimum values of the model's MRT are in good agreement with the experimental MRTs determined from the method of moments; a factor which confirms the suitability of the TISEx model.

CONCLUSION

The radiotracer residence time distribution methodology was successfully used to study the flow dynamics in gold leaching tanks. The following conclusions were drawn:

- The measured distribution curves exhibited long tails, showing deviation from ideal mixing conditions.
- The experimental mean residence times evaluated from the method of moments exceeded the corresponding theoretical values calculated with respect to the volume and flow rate. This implies that the time required for efficient processing of ore slurry was longer than expected. This indicates abnormal operation of the tanks due to stagnancy and could adversely affect gold recovery.
- The perfect mixers-in-series with exchange model was found suitable to describe the pattern of flow in the tanks. The model confirmed the tailing effect of the distribution curves and suggested the existence of stagnant zones in the tanks. These zones could trap

dissolved gold causing decrease in productivity. The model's total MRTs were in good agreement with the MTRs from the method of moments.

- According to the results the general performance of the leach circuit, during the time of the investigation was below average. There is therefore the need for plant revamp.

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