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Residence time distribution of an industrial mechanically agitated cyanidation tank

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Abstract

The flow behavior of the liquid phase of an industrial gold leaching tank is studied using lithium chloride tracer. The residence time distribution is interpreted using an arrangement of simple ideal reactors, the parameters of which are calibrated by a standard least squares method. The measured net volume of the reactor is 62% of its nominal volume, due to the space occupied by the agitation assembly, the gas phase and the accumulation of solid material on the tank walls. The results show that the tank mixing behavior is dominated by a perfectly mixed volume, corrupted by the presence of bypass and stagnant zones. The mixing pattern is modeled as two parallel flows, one which contains the dominant perfect mixer and a series of perfect mixer reactors with cross-flow to match the stagnant zone, and the other one which account for the bypass represented by a series of perfectly mixed reactors.

Keywords: Cyanidation; Gold ores; Leaching; Agitation; Modelling

1. Introduction

Leaching by cyanide solutions in an aerated alkaline pulp has been the main process for gold extraction from ores for more than one century. This process takes place either in tanks, mechanically agitated or equipped with airlift, or in heaps, dumps and vats (Habashi, 1987; Marsden and House, 1992). Continuous leaching tanks are large multi-phase reactors, which have a volume between 150 and 1500 m^3. Because of the large amount of pulp in the vessel and the mixing method used, these tanks may exhibit dead and by-passing zones that deteriorate the performance of the process. The hydrodynamic behavior of industrial leaching tanks is not well documented despite its importance for the comprehension and eventual optimization of this gold extraction method used in many plants around the world.

The residence time distribution (RTD) analysis is a classical and important tool used to study the performance of non-ideal chemical reactors and industrial circuits. It allows, for instance, the diagnosis of stagnant and bypassing zones in stirred tanks or the dispersion and dead zones in plug flow reactors. An RTD experiment consists in an input–output response test where the most commonly used inputs are either impulse, or step, square pulse, ramp, sinusoid and random variations. This method has been widely used for the development of realistic models to describe complex industrial reactors (Nauman and Buffham, 1983; Levenspiel, 1999; Marchand et al., 1980; Bazin and Hodouin, 1988; Iyer and Sohn, 1994; Aminian et al., 1998; Lelinski et al., 2002; Yianatos et al., 2001). The RTD of a leaching tank describes its flow pattern and mixing properties and can be used together with a kinetic model of gold

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cyanidation for the simulation of this process, using, for instance, the segregated flow model approach (Levenspiel, 1999; Crundwell, 1995; Dixon, 1996).

The objectives of this paper are the evaluation of the flow behavior in an industrial gold leaching tank, using an impulse tracer experiment, and the development of a model of the normalized residence time distribution of this equipment. This study deals only with the hydrodynamics of the liquid phase. It might be different from those of the ore or the gold particles; however, in a leaching tank, the segregation is, most likely, less strong than in other parts of the plant, such as in the grinding-classification section where the hydrocyclones and the recycling loops can promote the concentration of the most dense materials.

This paper is organized as follows. Section 2 presents the residence time distribution theory and its associated functions used for the analysis of reactor hydrodynamics, Section 3 presents the experimental procedures, and Section 4 the experimental results and the model parameter estimation.

2. Theoretical aspects

In the population balance approach to flow pattern and mixing properties of chemical reactors, three main functions are used to characterize the distribution of residence time of the various fluid elements, molecules, or particles (Danckwerts, 1953; Himmelblau and Bischoff, 1968; Nauman and Buffham, 1983; Froment and Bischoff, 1990; Levenspiel, 1999):

- The internal age density distribution $I(t)$ which refers to the time elapsed since the element enters the reactor.
- The residence time distribution $E(t)$, which gives the age distribution frequency of the fluid elements leaving the reactor; it is related to $I(t)$ by:

$$E(t) = -\frac{\mathrm{d}I}{\mathrm{d}t} \tag{1}$$

- The intensity function Λ(t) which is the fraction of the elements of age t in the reactor that will leave the reactor at a time between t and $t + \Delta t$; it is related to E and I by (Naor and Shinnar, 1963):

$$\Lambda(t) = \frac{1}{\bar{\tau}}\left[\frac{E(t)}{I(t)}\right] \tag{2}$$

where the average residence time ($\bar{\tau}$), the first moment of $E(t)$, is defined as:

$$\bar{\tau} = \int_0^\infty tE(t)\,\mathrm{d}t \tag{3}$$

One can also define the fraction of material in the exit stream younger than age t, $F(t)$; it is given by:

$$F(t) = \int_0^t E(u)\,\mathrm{d}u \tag{4}$$

and related to $I(t)$ by

$$F(t) = 1 - \bar{\tau}I(t) \tag{5}$$

The RTD of a reactor is usually measured from an impulse response test of a tracer behaving as the elements to be characterized for their mixing properties. $E(t)$ is related to the tracer exit concentration $C(t)$ by:

$$E(t) = \frac{C(t)}{\int_0^\infty C(t)\,\mathrm{d}t} \tag{6}$$

The age distribution functions can be expressed in dimensionless forms as functions of the dimensionless time ($\theta = t/\bar{\tau}$) as follows:

$$E(\theta) = \bar{\tau}E(t); \quad F(\theta) = F(t); \tag{7a,b}$$

$$I(\theta) = \bar{\tau}I(t); \quad \Lambda(\theta) = \bar{\tau}\Lambda(t) = E(\theta)/I(\theta) \tag{7c,d}$$

The hydrodynamics of non-ideal reactors can be modeled using arrangements of simple ideal reactors, such as the perfect mixer and the plug-flow reactor, or using distributed parameter models such as the dispersed plug flow reactor. The first approach is usually simpler to implement, and it is used in this study. In order to simulate the RTD of real reactors, i.e. their unit impulse responses, one can use and solve the corresponding differential equations in the time domain, or more easily, the algebraic equation in the complex domain using the Laplace transformation. The Laplace transform of $E(t)$, i.e. the transfer function of the mixing system, is given by:

$$G(s) = \int_0^\infty E(t)\mathrm{e}^{-st}\,\mathrm{d}t \tag{8}$$

where s is a complex variable. Using the standard complex domain algebraic rules, the response of any arrangement of ideal reactors can be derived, and then converted into its time domain expression (Himmelblau and Bischoff, 1968; Nauman and Buffham, 1983; Levenspiel, 1999). The transfer functions of some ideal reactors are given below for (Nauman and Buffham, 1983):

(a) The ideal continuous stirred tank reactor (CSTR):

$$G_\mathrm{c}(s) = \frac{1}{\tau s + 1} \tag{9}$$

where τ is the average residence time of the liquid, gas or solid inside the reactor.

(b) The ideal plug flow reactor (PFR):

$$G_\mathrm{p}(s) = \mathrm{e}^{-\tau s} \tag{10}$$

where τ is the delay or the residence time of the liquid, gas or solid inside the reactor.

(c) The cross-flow model, composed of two CSTR regions with exchange between the active and stagnant zones: