

Study of solid and liquid behavior in large copper flotation cells (130 m³) using radioactive tracers

F. Díaz¹, O. Jiménez¹, J. Yianatos² and F. Contreras²

¹ Nuclear Applications Department, Chilean Commission of Nuclear Energy, PO Box 188-D, Santiago, Chile

² Chemical and Environmental Engineering Department & CASIM, Federico Santa Maria Technical University, PO Box 110-V, Valparaíso, Chile

Abstract. The behavior of the solid and liquid phases, in large flotation cells, was characterized by means of the radioactive tracer technique. The use of radioactive tracers enabled the identification of the Residence Time Distribution, of floatable and non-floatable solid, from continuous (on-line) measuring at the output streams of the flotation cells. For this study, the proper radioactive tracers were selected and applied in order to characterize the different phases; i.e. for liquid phase Br-82 as Ammonium Bromide, for floatable solid recovered in the concentrate Cu-64, and for non-floatable solid in three particle size classes (coarse: >150 μm , intermediate: <150 μm and >45 μm , and fine: <45 μm), Na-24. The experimental results confirmed the strong effect of particle size on the Residence Time Distribution, and mean residence time of solids in larger flotation cells, and consequently in flotation hydrodynamics. From a hydrodynamic point of view, the experimental data confirmed that a single mechanical flotation cells, of large size, can deviate significantly from perfect mixing. The experimental work was developed in a 130 m³ industrial flotation cell of the rougher circuit at El Teniente Division, Codelco-Chile.

1. INTRODUCTION

Froth flotation is a mineral concentration process where finely ground solids are selectively separated in a multiphase system (solid, liquid, gas). Here, two zones can be distinguished; the collection zone (pulp), where the selective capture of floatable particles by bubbles occurs, and the froth zone, where the particle-bubble aggregates are separated from the pulp zone, reducing the mineral entrainment of gangue into the concentrate. In this process, mechanical cells (external agitation) and pneumatic (bubble column) cells are used, which have shown an important increase in size in the last years, reaching unitary volumes of 300 m³. However, the impact that big size (gigantism) has on cell performance, especially on the mixing regime (hydrodynamic) is still not known.

The mixing regime for each component in a flotation system can be described by the residence time distribution (RTD) [1–3]. RTD can be measured using the radioactive tracer technique [4–6], which has advantages in comparison to other measurement techniques, because it is non-invasive, the tracers have the same physical and chemical characteristics of those in the actual system and the activity signals can be captured by on-line sensors, which allow a high rate of data acquisition and reliable data. This information is relevant in process modeling, scale-up and circuit design [3]. In this work, the radioactive tracer technique was used for measuring the residence time distribution in a 130 m³ cell of the rougher circuit at El Teniente Division, Codelco-Chile. Experimental tests were developed for water and non-floatable solids (gangue) at three particle size classes: coarse (>150 μm), medium (<150 μm and >45 μm) and fine (<45 μm) and floatable mineral.

2. EXPERIMENTAL PROCEDURE

2.1. Tracer selection

For proper radioactive tracer selection, the following points must be considered [7], especially that the physical and chemical characteristics of tracer must be similar to those of the component of study, half-life time of tracer must be compatible with the time of experiment. In this case, experiments of around two hours are typically developed and also radioactivity type and intensity must be determined, considering the work space characteristics, in order that the tracer signal may be detected adequately. Also, this simplifies the possibility of on-line (in situ) measurements. To accomplish the above requirements, samples of non-floatable and floatable solids from the flotation circuit were characterized by chemical analysis for element detection, in order to produce radioisotopes by gamma neutron activation. Based on these results and considering the time of each experiment for the different phases, the selected tracers were Cu-64 for floatable solid and Na-24 for non-floatable solids in three size classes. All samples (tracers) were activated in the RECH-1 reactor belonging to La Reina Nuclear Center in Santiago, Chile. For the liquid case, the Br-82 as Ammonium Bromide in solution was selected as tracer. Considering that signals (tracer activities) must be detected at the entrance and discharge cell pipes, and based on previous knowledge, the activity quantities utilized for obtained an adequate rate of count were 25mCi for Na-24, 30mCi for Cu-64 and 50mCi for Br-82.

2.2. Residence time distribution

The residence time distribution identification by radioactive tracer technique consists of the injection of an impulse

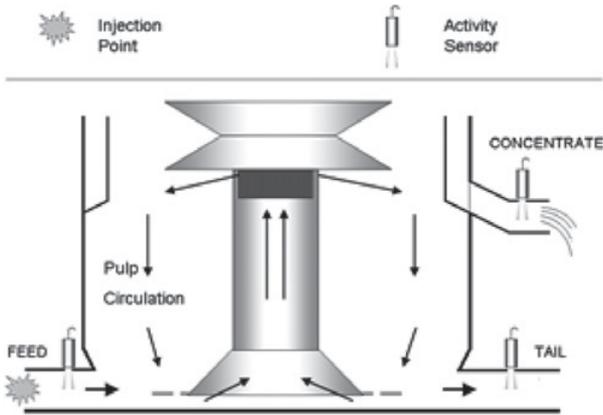


Figure 1. Experimental set-up.

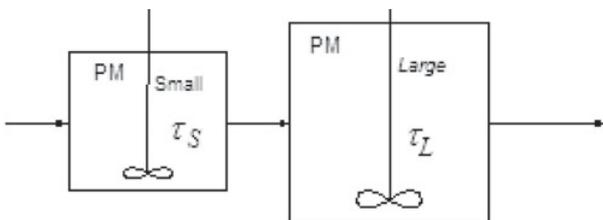


Figure 2. Large and small tank-in-series model.

signal (liquid or solid) at the feed pulp entrance of the cell, using a pneumatic system designed and built specially for this type of experiment, Figure 1. In this type of self-aspirating cells the pulp circulates from the feed through the central tube into the rotor, where the fresh pulp is firstly contacted with the air entering from the top of the cell. The presence of tracer leaving the cell, at the concentrate and tailings streams, was on-line recorded by non-invasive sensors. Each sensor is provided with scintillating crystal sensors of NaI(Tl), of 1×1.5 inch Saphymo-SRATTM (Massy, France) consisting of pre-amplifiers and amplifiers located in the same sensor. All sensors were connected to a data acquisition system KontronTM, which gives electric energy to all sensors and allows for on-line signals observation (display on screen). Later, the signals are corrected by radioactive decay [7]. The RTD data was obtained by de-convolution using the recursive Least Square Error method [12].

From residence time distribution results, RTD models were used to fit the data set using the least squares adjustment method [6,8]. A common approach is the use of the N tank-in-series model given by [1],

$$E(t) = \frac{t^{N-1} \cdot e^{\left(\frac{-t}{N}\right)}}{\left(\frac{\tau}{N}\right)^N \cdot \Gamma(N)} \quad (1)$$

Experimental evidence [3,9] has shown that the RTD of a single large flotation cell can be better described by a LSTS (large and small tank in series) model, consisting of one large perfect mixer, with residence time τ_L , and one small perfect mixer, with residence time τ_S , in series [10,11]. Figure 2 shows the model description.



Figure 3. Sensor located on feed box pipe.

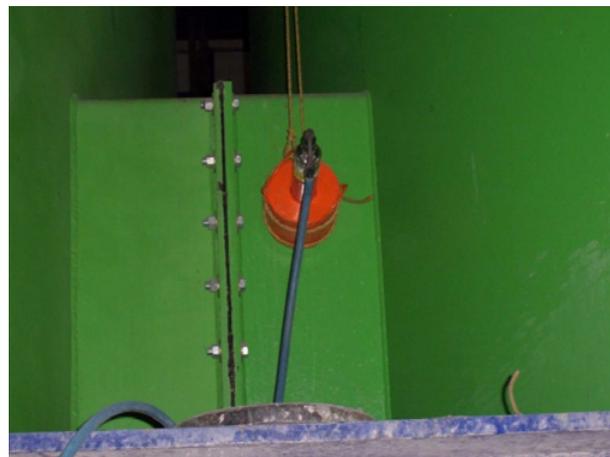


Figure 4. Sensor located on cell tailings connection duct.

The analytical solution for the LSTS model is given by [3,10],

$$E(t) = \frac{\exp[-t/\tau_S] - \exp[-t/\tau_L]}{(\tau_S - \tau_L)} \quad (2)$$

and the overall mean residence time τ is given by,

$$\tau = \tau_S + \tau_L. \quad (3)$$

Thus, the mean residence time and model parameters can be estimated, which allowed for representing the dynamic behavior of all components in the flotation system. Also, the effective volume of each phase (liquid, solid and gas) in the system can be calculated.

Figures 3, 4 and 5 show the sensors location for the signal detection in plant experiments.

3. ANALYSIS AND RESULTS

Figures 6, 7, 8 and 9 show the residence time distribution obtained by data de-convolution and the adjusted models for non-floatable solid and liquid measured by sensors located on tailings pipe.

The flow pattern observed in Figures 6, 7, 8 and 9 shows a close to perfect mixing condition, which

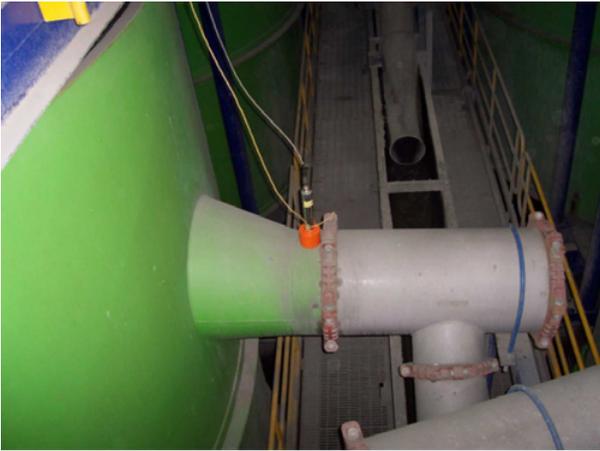


Figure 5. Sensor located on cell concentrate pipe.

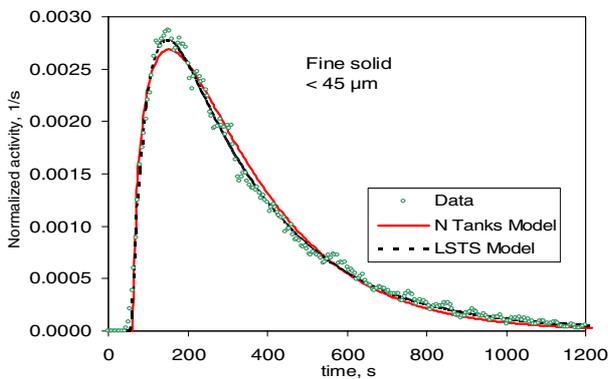


Figure 6. Normalized activity response and adjusted models for fine solid tracer in cell tailings.

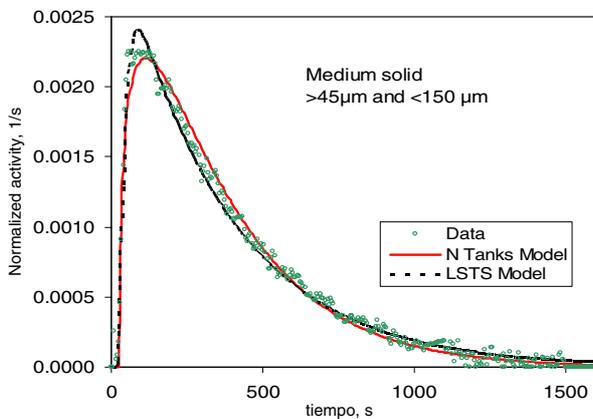


Figure 7. Normalized activity response and adjusted models for medium solid tracer in cell tailings.

is required for enhancing the collision between mineral particles in the pulp and air bubbles generated at the rotor level. On the other hand, it was observed that most of the pulp leaves the cell in a time larger than required for a single circulation through the rotor, approximately 80 s [10], so that most of the mineral particles circulate through the rotor at least one time before leaving the cell (minimum by-pass flow). This condition allows for enhancing the mineral recovery in the first cell of the rougher flotation bank, which significantly affects the overall recovery in the flotation bank.

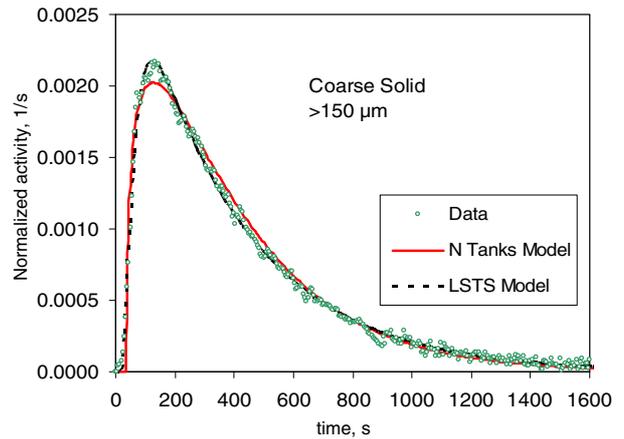


Figure 8. Normalized activity response and adjusted models for coarse solid tracer in cell tailings.

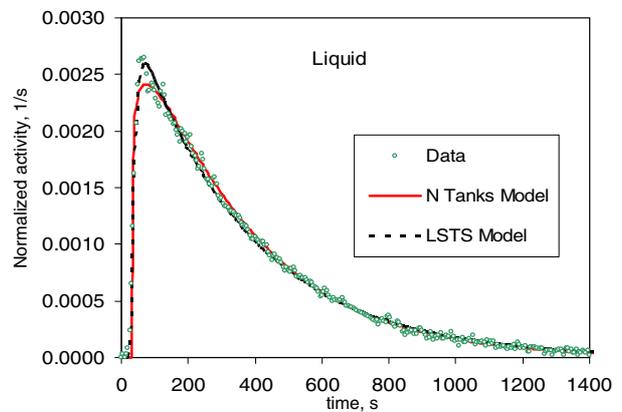


Figure 9. Normalized activity response and adjusted models for liquid tracer in cell tailings.

Table 1. LSTS and N tanks in series model parameters.

Tracer	τ_s (min)	τ_L (min)	τ (min)	N
Liquid	0.2	5.71	5.93	1.38
Coarse solid >150 μm	0.7	4.04	4.81	1.32
Medium solid >45 μm and <150 μm	0.4	5.84	6.39	1.33
Fine solid < 45 μm	0.7	5.84	6.58	1.48

Table 1 shows the model parameters obtained from data adjustment, where N corresponds to the non-integer regression solution for the N tanks in series model, Equation (1). The liquid and solid tracing experiment were carried out in different conditions, for this reason only the data of solids by size class can be directly compared between them.

The mean residence time in the cell is strongly affected by the particle size, which indicates that the finer solid has a larger effective residence time than coarser particles.

The liquid and solid show a dynamic behavior (flow regime) equivalent to $N = 1.32\text{--}1.48$ perfect mixers in series. Otherwise, performance was slightly better than

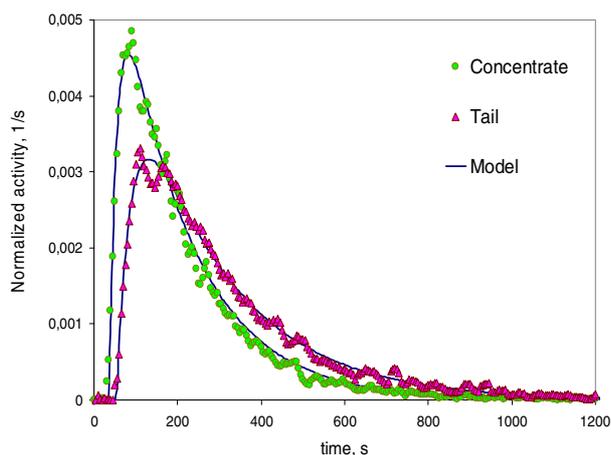


Figure 10. Residence time distribution of floatable mineral measured in the concentrate and tailings output streams.

a perfect mixer ($N = 1$) with a lower short-circuit. Even so, because single cells operate near a perfect mixing regime a significant fraction of the feed pulp stays a shorter time than the mean residence time τ , which decreases the mineral recovery. For this reason industrial flotation cells are typically arranged in banks of 3–10 cells in series.

Figure 10 shows the residence time distribution of floatable mineral measured in the concentrate and tailings output streams. In this case, the floatable solid was transported to the concentrate and tail streams by different mechanisms: true flotation (collected in bubbles) and liquid transport (entrainment), respectively. Figure 10 shows that the mean residence time of floatable minerals reported to the concentrate was smaller than the mean residence time of the minerals reported to tailings.

This result confirms that the fast floatable minerals, or the more liberated minerals showing higher flotation rates, are mainly collected in the first cells. Downwards the rougher flotation bank the less floatable mineral particles (lower liberated particles) are then collected and after reaching the froth zone a significant drop back occurs because of the lower froth stability, due to the lower solid content. This effect increases the mean residence time of less floatable minerals and decreases the cell recovery along the flotation bank.

4. CONCLUSIONS

Tracer tests for liquid and solids per size class were performed in a 130 m³ flotation cell.

From RTD measurements it was found that the flow regime in these self-aerated cells was a measured number slightly higher than it was expected for the perfect mixer, showing an equivalent $N = 1.3$ – 1.5 (perfect mixers in series). Also it was found the effect that particle size has on the mean residence time. Fine particles spent a larger residence time in the cell if compared with coarser particles.

The above methodology has been applied for testing industrial flotation circuits with different cell sizes, up to 250–300 m³. It was shown that this approach is a

useful tool for flotation cells characterization, as well as to evaluate the effect of design and operating variables upon cells and circuit performance.

The authors are grateful to El Teniente Division CODELCO-Chile for providing access to their plant and for valuable assistance in the experimental work. Funding for process modelling and control research is provided by CONICYT, project Fondecyt1100854; NEIM Project P07-087-F MINECON; Santa Maria University, Project 270522; and the Chilean Commission of Nuclear Energy.

References

- [1] Mavros, P., “Mixing and hydrodynamics in flotation cells”. In: Mavros, P., Matis, K.A. (Eds.), *Innovation in Flotation Technology*, NATO Series, vol. E208. Kluwer Academic Publishers, The Netherlands, pp. 211–234 (1992)
- [2] Dobby, G.S., Finch, J.A., “Mixing characteristics of industrial flotation columns”. *Chemical Engineering Science* **40**, 1061–1068 (1985)
- [3] Yianatos, J., “Fluid flow and kinetic modelling in flotation related processes: columns and mechanically agitated cells”. *Chemical Engineering Research and Design* **85** (A12), 1–13 (2007)
- [4] Blet, V., Berne, P., Chaussy, C., Perrin, S., Schweich, D., “Characterization of a packed column using radioactive tracers”. *Chemical Engineering Science* **54**, 91–101 (1999)
- [5] Lelinski, D., Allen, J., Redden, L. and Weber, A., “Analysis of the residence time distribution in large flotation machines”. *Minerals Engineering* **15**, 499–505 (2002)
- [6] Yianatos, J.B., Larenas, J.M., Moys, M.H. and Díaz, F.J., “Short time mixing response in a big flotation cell”. *International Journal of Mineral Processing* **89**, 1–8 (2008)
- [7] International Atomic Energy Agency. *Guidebook on Radioisotopes Tracers in Industry. Reports Series N°16*. Vienna (1990)
- [8] Sugiharto, S., Su’ud, Z., Kurniadi, R., Wibisono, W. and Abidin, Z., “Radiotracer method for residence time distribution study in multiphase flow system”. *Applied Radiation and isotopes* **67**, 1445–1448 (2009)
- [9] Yianatos, J.B., Bergh, L.G., “RTD studies in an industrial flotation column: use of radioactive tracer technique”. *International Journal of Mineral Processing* **36**, 81–91 (1992)
- [10] Yianatos J., Bergh, L., Tello, K., Díaz, F., Villanueva, A., “Residence time distribution in single big industrial flotation cells”. *Minerals&Metallurgical Processing Journal* **25** (1), 46–52 (2008)
- [11] Tello, K., 2006. Caracterización hidrodinámica y metalúrgica de un banco de flotación industrial. *Metallurgical Engineering Tesis*, Santa Maria University, Valparaíso, Chile
- [12] The MathWorks, Inc., 2010. *Optimization Toolbox™ 5.0 User’s Guide, Matlab* (The MathWork, Inc., Natick, MA)