

JKSIMFLOAT V6.1^{PLUS}: IMPROVING FLOTATION CIRCUIT PERFORMANCE BY SIMULATION

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Abstract

Analyzing, optimizing and designing flotation circuits using models and simulators have improved significantly over the last 15 years. Mineral flotation is now generally better understood through major advances in measuring and modeling the sub-processes within the flotation system. In addition, new and better methods have been derived to represent the floatability of particles as they move around a flotation circuit. A simulator has been developed that combines the effects of all of these sub-processes to predict the metallurgical performance of a flotation circuit. This paper presents an overview of the simulator, JKSimFloat V6.1^{PLUS}, and its use in improving the industrial flotation plant performance. The application of the simulator at various operations is discussed with particular emphasis on the use of JKSimFloat V6.1^{PLUS} in improving the flotation circuit performance.

INTRODUCTION

Simulations of mineral processing circuits are performed for a variety of reasons including the optimization and design of the flotation circuit, the assessment of the effect of circuit disturbances (eg surges in feed rates) and the assessment of the impact of control strategies (eg the sensitivity of the circuit to changes in operating parameters).

JKSimFloat is a software program that incorporates selected flotation outcomes of the Australian Minerals Industry Research Association (AMIRA) P9 project, titled 'The Optimization of Mineral Processes by Modeling and Simulation'. This is a collaborative research project between the Julius Kruttschnitt Mineral Research Centre (JKMRC) at the University of Queensland in Australia, the Mineral Processing Research Unit at the University of Cape Town in South Africa and the McGill University in Canada. The methodology used to develop the model parameters used in JKSimFloat has been described in detail elsewhere in the literature (Harris et al, 1997; Alexander et al, 2000; Harris et al, 2002). This methodology has been applied to over 30 sites world-wide in commodities including base metals (eg lead, zinc, copper) and precious metals (eg gold, platinum).

JKSimFloat V6.1^{PLUS} is a general purpose computer software package for the simulation of flotation plant operations. The package is designed to service the diverse needs of plant and development metallurgists, plant operators, researchers and academics, and consultants. The program is Windows-based and is coded in C++ to maximize program speed. For instance, the most complicated circuit simulated to date included over 80 flotation cells (all with individual operating conditions), 10 floatability components, 15 size fractions and 3 different minerals. Simulations of this circuit required approximately 2-5 seconds to converge, compared to previous spreadsheet-based methods, where simulation times of up to 1 day were common for complex circuits.

JKSimFloat V6.1^{PLUS} is a simulator only and does not have the capability of calibrating the equipment models used in the flowsheet. The model parameters are derived off-line from experimental data using a combination of survey and batch test data. Once a simulation model has been built, the user can then assess the impact of altering various plant conditions on metallurgical performance in the program. The results of the simulations can be transferred to other Microsoft programs, such as WordTM or ExcelTM, for printing, graphing and further analysis.

Development of JKSimFloat V6 is continuing, with funding by a sub-group of Australian Minerals Industry Research Association (AMIRA) P9 sponsors, the Queensland government, JKMRC and JKTech. The current development project (P868A) comprises the incorporation of mass balancing (JKSimFloat V6.2), with the facility to import and view mineralogical data. Future development projects will include the ability to fit the model parameters within the program.

SIMULATION PRINCIPLES

The main calculation method of the simulation module in JKSimFloat is the concept of particle classes. A particle class is defined as a collection of particles that can be considered to have the same properties. The particle classes are the 'material' that flow around a flowsheet and are acted upon by the model calculations in each equipment unit in JKSimFloat.

Each process unit in the flowsheet is represented by an equipment unit. JKSimFloat allows the user to select the equipment from a list of flotation plant equipment types and to display their icon on the flowsheet. There are a number of choices for the process models to be used for each equipment unit. Streams represent the flow of material between process units and include information on the floatability, mineralogy, and size of the particles throughout the circuit. An example of the flowsheet drawer is given in Figure 1.

Once a flowsheet has been created, the system properties are defined and a particle class list is generated. This table, or stream specification, defines the properties of each particle class, for example -38 μm fast floating galena, would describe one of the particle classes. The proportion of material contained within each particle class is used throughout the circuit and can be translated into mineral (or element) grade and recovery values. The simulation engine is based on a highly flexible stream structure, which allows for current and future models of flotation systems, and ultimately all mineral processing systems.

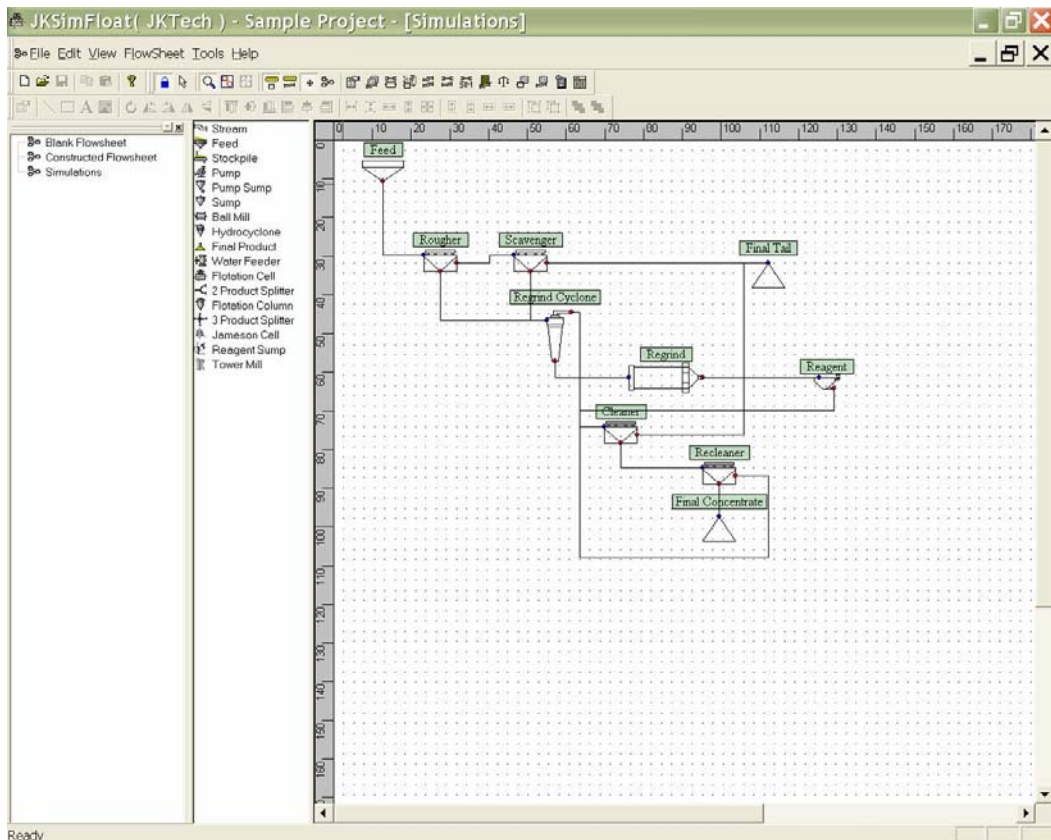


Figure 1 – Example of flowsheet drawn in JKSimFloat V6.1^{PLUS}.

An example of the initial stage of simulation is shown in Figure 2. In this Figure, the user has defined two minerals as mineral 1 and mineral 2, three floatability classes for mineral 1 ($P_{1,1}$, $P_{1,2}$ and $P_{1,3}$) and one floatability class for mineral 2 ($P_{2,1}$). The proportion, or mass fraction, of each of these particle classes is shown by the size of the

bar. The flowrate of water feeding the flotation cell is also incorporated (shown by the size of the bar next to 'W' in Figure 2).

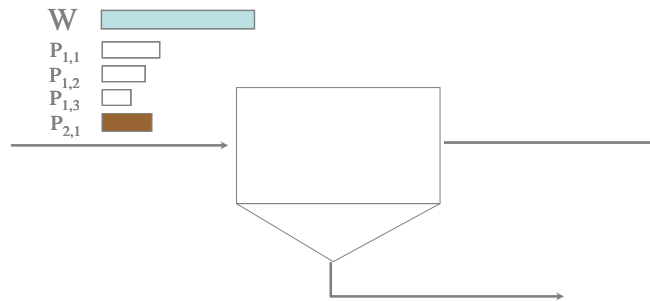


Figure 2 – Example of the initial stage of simulation where the system properties and feed characteristics are defined.

Once the system properties and feed characteristics have been defined in the program, data is entered into the equipment units via the graphical interface using the flowsheet. After simulation, relevant data for the equipment, such as calculated residence time based on the simulated flowrate from a particular flotation cell, can also be viewed on these screens.

Steps in simulating using JKSimFloat

1. The user specifies the bubble surface area flux (S_b) to be used for the flotation cell, based on experimental results of superficial gas velocity (J_g) and Sauter mean bubble diameter (d_b), according to the various methods described in Tucker et al (1994), Gorain et al (1996), Gorain et al (1997), Power et al (2000) and Chen et al (2001). The calculation of bubble surface area flux is given in Equation 1 (from Gorain et al, 1997):

$$S_b = \frac{6 \cdot J_g}{d_b} \dots\dots\dots(1)$$

The bubble surface area flux can also be determined from an empirical relationship derived by Gorain et al (1999), based on the superficial gas velocity, impeller speed and dimensions, and a pulp property (normally the 80% passing size of the pulp).

2. For each particle class, froth recovery (R_f) and entrainment (ENT) are determined from the user defined values. Froth recovery can be measured using various techniques, as described in Vera et al (1999), Alexander et al (2003) and Seaman

et al (2004). The froth recovery can also be determined by relationships with the froth residence time of slurry (FRT), according to Equation 2 (from Gorain et al, 1998):

$$R_f = (1 - P_d) + P_d \eta_p \dots\dots\dots(2)$$

where η - non-draining fraction, with the ability to be based on the entrainment parameter, and P_d - probability of detachment, related to the froth residence time (FRT) by an empirical parameter (β) according to Equation 3 (from Gorain et al, 1998; Mathe et al, 2000):

$$P_d = 1 - \exp(-\beta \cdot FRT) \dots\dots\dots(3)$$

Entrainment can be determined by direct or indirect methods, as described in Savassi et al (1998), and is defined by Equation 4:

$$ENT = \frac{R_{entrainment}}{R_{water}} \dots\dots\dots(4)$$

Entrainment can also be determined from empirical relationships based on the particle size (Savassi et al, 1999) or the froth residence time of slurry (Mathe et al, 2000).

- 3. The iteration begins by assuming 10% of the feed reports to the concentrate, as shown in Figure 3.

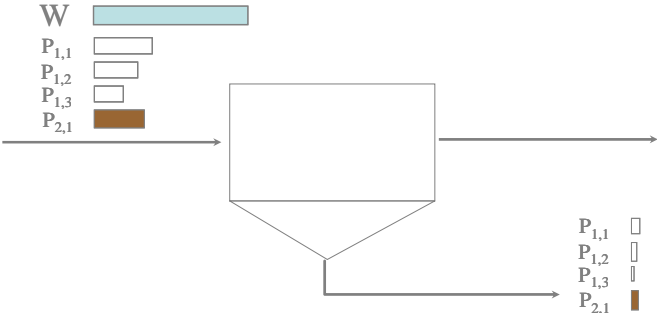


Figure 3 – Initial iteration conditions of 10% of the feed reporting to the concentrate.

- 4. The water flowrate in the concentrate is estimated using the water recovery option defined by the user. The options available include calculating the water flowrate based on a relationship with the solids flowrate in the concentrate, as

well as defining a specific % solids required in the concentrate. The flowrate of solids and water in the tails stream is then calculated by the difference between feed and concentrate streams, as shown in Figure 4.

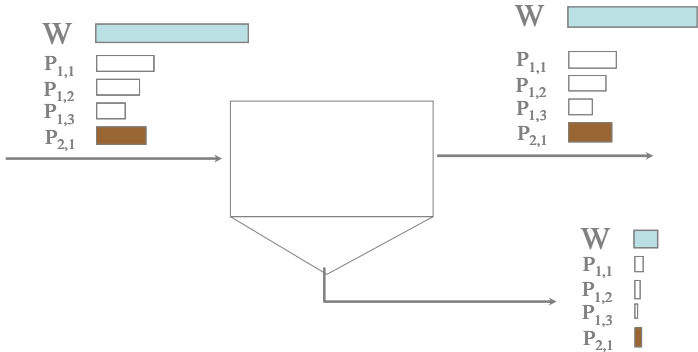


Figure 4 – Initial simulation conditions including solids and water flowrates of concentrate and tails streams.

5. The simulated cell residence time is then calculated using Equation 5:

$$\tau = \frac{V(1 - \epsilon_g)}{Q_{tails}} \dots\dots\dots(5)$$

where τ - residence time (min), V – pulp volume (m^3), ϵ_g – gas hold-up (%) and Q_{tails} – volumetric flowrate of tails stream (m^3/min).

6. The overall rate constant (k_i) is then calculated for each particle class using Equation 6, with the recovery of each particle class (R_i) calculated from Equation 7 for perfect mixing environments (from Harris et al, 2002):

$$k_i = P_i \cdot S_b \cdot R_f \dots\dots\dots(6)$$

$$R_i = \frac{P_i \cdot S_b \cdot R_f \cdot \tau}{1 + P_i \cdot S_b \cdot R_f \cdot \tau} \dots\dots\dots(7)$$

The recovery and flowrates of each particle class in the tail is calculated by difference between feed and concentrate streams, as shown in Figure 5.

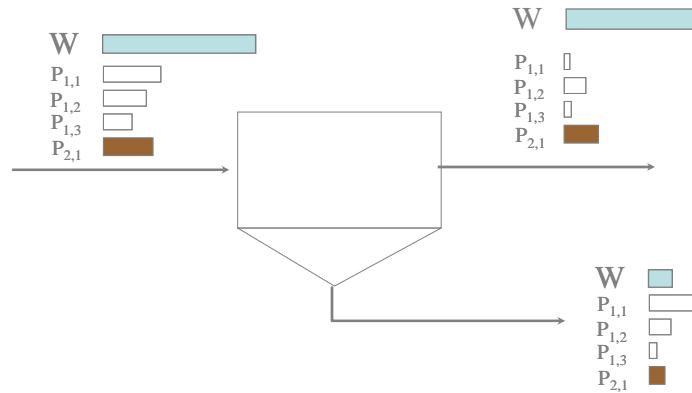


Figure 5 – First pass simulation incorporating calculated residence time.

7. A proportion of each component in the tail fraction is then recovered to the concentrate by entrainment, if this has been specified by the user, with the tail recalculated again by the difference between feed and concentrate streams, as shown in Figure 6.

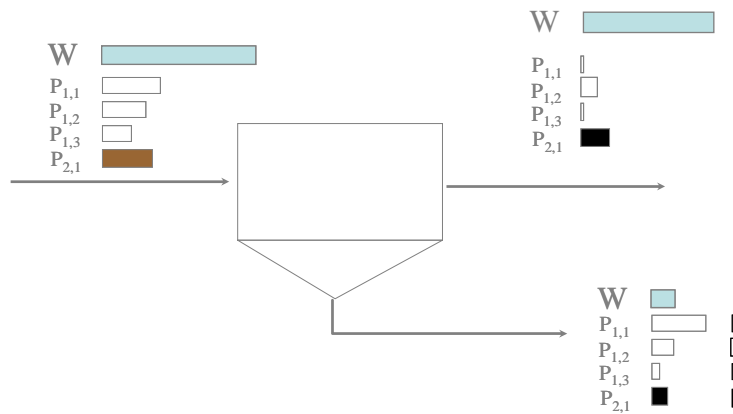


Figure 6 – Simulation incorporating additional concentrate recovery due to entrainment.

8. This loop is repeatedly performed until the mass in each particle class converges to a constant value, when the simulation is complete.

CASE STUDIES

It should be noted that the act of collecting data to develop a model to be incorporated in a simulator also provides benefits to the plant. The cell characterization measurements, such as gas velocity, gas hold-up, bubble size and froth recovery, can be benchmarked with data obtained from similar types and sizes of cells around the world (Schwarz and

Alexander, 2005). This benchmarking can provide large improvements to the circuit in a short time period, especially if the cells are operating at significantly lower air rates compared to the typical range. If there is the capacity to increase the air rates without detrimentally affecting the downstream processing, those cells can result in higher recoveries and, taking the froth phase performance into account, better grades with good flotation operation. JKSimFloat V6.1^{PLUS} can also apply the increase in air rates to indicate what can be achieved from the circuit.

Case Study 1

Case study 1 was conducted at Kanowna Belle Gold Mine (KBGM), a gold flotation plant in Western Australia, and used JKSimFloat V6.1^{PLUS} to conduct simulations after a model had been developed of the circuit. The recommendations from the simulations, as well as the circuit analysis, resulted in substantial improvements in flotation performance (1.3% increase in flotation gold recovery), as well as reducing operating costs, producing a US\$1.3 million a year improvement to the mine operations (Alexander et al, 2005).

Figure 7 shows the flotation circuit, as drawn in JKSimFloat V6.1^{PLUS}.

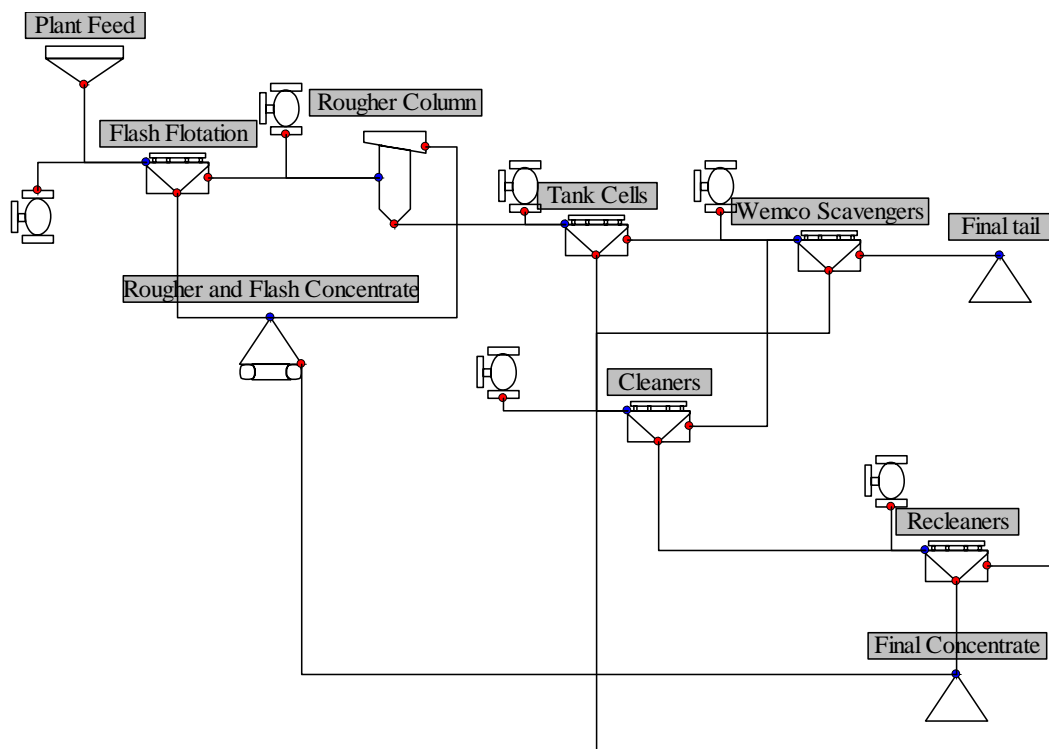


Figure 7 – Overview of the KBGM flotation circuit in JKSimFloat V6.1^{PLUS}.

The circuit analysis involved surveys of the flotation plant, batch flotation tests of samples from the critical streams within the circuit, hydrodynamic measurements and froth performance measurements. All data collected was used in developing a floatability components model, according to the methodology described in Alexander and Morrison (1998) and Alexander et al (2000). Simulations were conducted using the derived model parameters within JKSimFloat V6.1^{PLUS} and these ranged from changing operating parameters, such as water additions to the cleaner feed, to changes in circuit layout.

Surveys were conducted on site to determine the base case scenario, and to validate the model by a change in the circuit. It was decided to increase the water addition rate to the recleaner feed sump for the validation survey, as plant personnel determined the operating density of the cleaner circuit was not optimum. The trends obtained from experimental data and simulated data were similar, and are shown in Table 1. Note that the difference in absolute values was due to changes in experimental feed conditions, eg head assay, flowrates etc. The simulator predicted very similar results when the feed conditions from the second survey were used.

Table 1 – Flotation Circuit Simulator Validation Results

Plant Performance Measurement	Experimental change from base case (%)	Simulated change from base case (%)
Flotation Circuit Gold Recovery	-0.7	-9.0
Flotation Circuit Sulphur Recovery	-3.6	-9.5

The decrease in both gold and sulphur recovery was due to the decreased residence times through the recleaner circuit with the additional water. However, the gold and sulphur grade significantly increased experimentally and this trend was also observed when entrainment models were incorporated in the simulator.

From these results, plant personnel conducted over 80 surveys over a 3 month period to determine the optimum flotation density within the cleaner circuit. Operating at this density has since resulted in a 1% increase in the flotation recovery, improved concentrate thickener and filter performance, and enabled the reduction in some flotation chemical addition rates.

Case study 2

Case study 2 was conducted at Perilya Broken Hill, a lead/zinc operation in New South Wales, Australia, where the flotation circuit contained the capacity to recycle almost any stream to any position. Studies were conducted on both the lead and zinc circuits, with the full details of the lead circuit analysis given in Schwarz and Kilgariff (2005). The flowsheet of the lead circuit at the time of the study is shown in Figure 8.

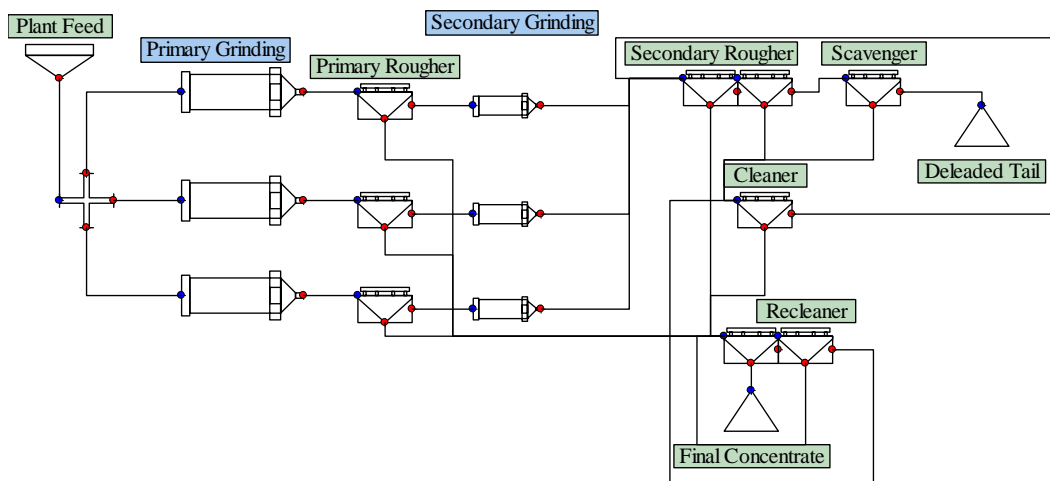


Figure 8 – Overview of the Perilya Broken Hill lead flotation circuit in JKSimFloat V6.1^{PLUS}.

Surveys of the circuit, batch flotation tests and cell characterization measurements were again conducted during the study. A major project at the time of this study was to reduce the number of recirculating streams within the circuit. Simulations were conducted to indicate the effect of the current practice of recirculating the concentrate streams from the last two cells of the cleaner bank back to the feed of the cleaner circuit (Simulation 1). Simulations were also conducted to determine the impact of open circuiting the cleaner tails (Simulation 2). The changes in circuit performance in these simulations are given in Table 2.

Table 2 – Flotation Circuit Simulator Results

Plant Performance Measurement	Simulated change from base case (%) Simulation 1	Simulated change from base case (%) Simulation 2
Flotation Circuit Lead Recovery	-0.8	-12.7
Final Concentrate Lead Grade	-0.1	+6.1

Simulation 1 indicated a decrease in both recovery and grade, showing that recirculating this stream was detrimental to the overall lead circuit performance. Instead, it was recommended that the total cleaner concentrate should continue to sent to the recleaner circuit, which is now the current practice.

Simulation 2 indicated a significant decrease in lead recovery, but a substantial increase in lead grade with the open-circuited lead tails. Also noted during the simulations was that the cleaner bank may be residence time limited; further simulations were conducted using the open-circuit cleaner tails scenario but with increases to the capacity of the

cleaner bank. The results of these further simulations are shown in the grade-recovery curve in Figure 9.

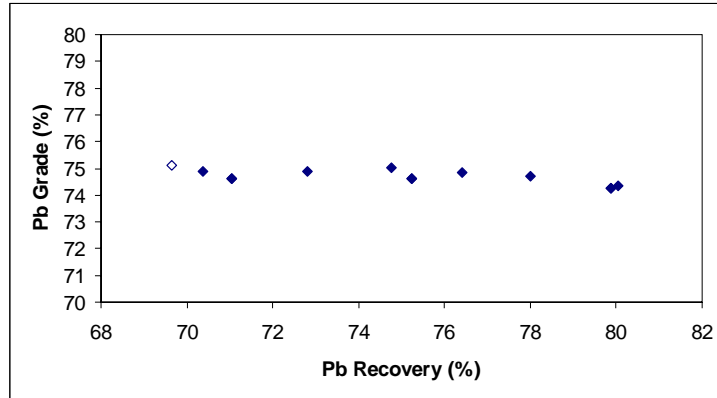


Figure 9 – Final concentrate grade-recovery curves resulting from increasing cleaner capacity in the lead circuit.

The further simulations indicated that great improvements in recovery could be achieved by increasing the capacity of the cleaner circuit, without significant losses in final concentrate lead grade. Since this study, plant personnel have investigated increasing the cleaner capacity, with trial runs of additional cleaning stages currently being undertaken. Due to these results, the lead circuit has improved its performance significantly in terms of product quality and operation stability.

CONCLUSIONS

JKSimFloat V6.1^{PLUS} is a user-friendly software package that enables metallurgists and operators alike to assess the impact of various operating and circuit changes on the overall performance of a flotation circuit. It incorporates a highly flexible structure, allowing current and future flotation models to be included in the simulation. The current models used in the package have been derived from the AMIRA P9 project and have been used successfully in over 30 sites world-wide.

Two case studies were presented, where the use of the simulator resulted in substantial monetary and operating improvements to the sites, with further improvements obtained from the accompanying analysis of the circuit. The simulations ranged from changing circuit layouts to changing operating conditions and including extra cells within the circuit.

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