A Comparison of BHP-Billiton's Minera Escondida Flotation Concentrators

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ABSTRACT

BHP-Billiton's Minera Escondida Limitada, in Chile, is one of the world's largest copper producers. It treats a combined 10500 tph of copper ore through its two concentrators: Los Colorados and Laguna Seca. The performance of the rougher circuit at each concentrator was measured and analysed using the JKTech flotation optimisation methodology. This involved developing a flotation model for each concentrator based on cell operating parameters (for example bubble surface area flux and froth recovery) and feed ore floatability characteristics. The rougher circuit performance was evaluated in terms of traditional measures, such as grade and recovery. The operation was also analysed using the measured cell operating parameters and ore floatability and the effect of these with regard to performance (grade / recovery) was assessed.

This paper presents a comparison of the rougher circuit at each concentrator in terms of these parameters. The main differences in rougher circuit performance between the two plants were attributed to differences in feed ore floatability characteristics and froth recovery. The comparison highlighted opportunities where performance improvements could be made. The study also showed the usefulness of separating the flotation process into easily measurable sub-processes to further identify the different mechanisms occurring in each rougher circuit. Traditional measures like grade and recovery are useful for monitoring flotation operation but this data lacks the depth to determine the root cause behind operational issues. Determining the operating parameters and ore floatability provides the operating plant metallurgist better tools to assess and manage these issues.

INTRODUCTION

Over the past decade, the flotation research groups at the Julius Krutschnitt Minerals Research Centre - JKMRC (Brisbane, Australia), University of Cape Town (Cape Town, South Africa) and McGill University (Montreal, Canada) have been developing a methodology for optimising flotation plants using actual plant data together with a semi-empirical sub-process model. The project is being conducted as part of the Australian Minerals Industry Research Association (AMIRA) P9 Project, titled "The Optimisation of Mineral Processes by Modelling and Simulation". The project first commenced in 1964 and is currently in its "Nth" phase.

The flotation circuit analysis methodology used in this study has been described previously in the literature (Alexander and Morrison, 1998; Alexander et al, 2000, Harris et al, 2002) and applied to numerous industrial sites within the AMIRA P9 Project (Alexander and Wigley, 2003; Alexander et al, 2005; Schwarz and Kilgariff, 2005). The primary outcomes of applying this methodology include:

- Diagnostic evaluation of flotation plant performance including cell hydrodynamics;
- Bench-marking and optimisation of flotation cells and circuits;
- Development of a flotation model and flotation simulator (JKSimFloat);
- Estimating the outcomes of various flotation circuit designs;
- Estimating the outcomes of changes to circuit operating parameters (e.g. feed rate, grind size, residence time).

In 2001, JKTech (the technology transfer company of the JKMRC) commercialised the AMIRA P9M methodology for flotation optimisation. Subsequently, JKTech was approached by BHP-Billiton's Escondida Minera Limitada to provide flotation models of the two Escondida concentrators (Laguna Seca and Los Colorados) and hence assist in identifying potential areas of flotation performance improvement. Traditional measures, such as grade and recovery, as well as new flotation measures, such as ore floatability, bubble surface area flux and froth recovery were used to assess the rougher flotation performance of these two concentrators. This paper presents the findings of this comparison.

ESCONDIDA MINERA LIMITADA

Escondida is one of the largest producers of copper in the world, representing 8 percent of all world production. Escondida is located at an altitude of 3000 metres in the Atacama Desert in northern Chile, 170 kilometres southeast of the city of Antofagasta. Escondida produces copper concentrate, by flotation of the sulphide ore, and copper cathodes, using leaching of the oxide ore. All of the ore is extracted from an open pit mine, which produces approximately 350 million tons of material per year. In its final stage, the Escondida open pit is expected to measure 4.1 kilometres in length, 2.9 kilometres in breadth and 670 metres in depth. Construction of the mine started in August 1988, and the first batch of ore was processed in November 1990. After successive phases of expansion, total investment in Escondida since that time has been approximately US$ 4 billion.

Escondida consists of an open pit mine, two concentrator plants for the processing of the sulphide ore (Los Colorados and Laguna Seca) and an oxide plant for cathode production. The Los Colorados Concentrator treats approximately 5500 tph at a copper head grade of 1.0%. The Laguna Seca Concentrator treats approximately 5000 tph at a copper head grade of 1.3%. The Escondida copper concentrate is characterised by a relatively high grade of copper (35 – 40%) and low content of metallic impurities.

Circuit Flowsheets

The Laguna Seca (LS) and Los Colorados (LC) circuits are shown in Figures 1 and 2.

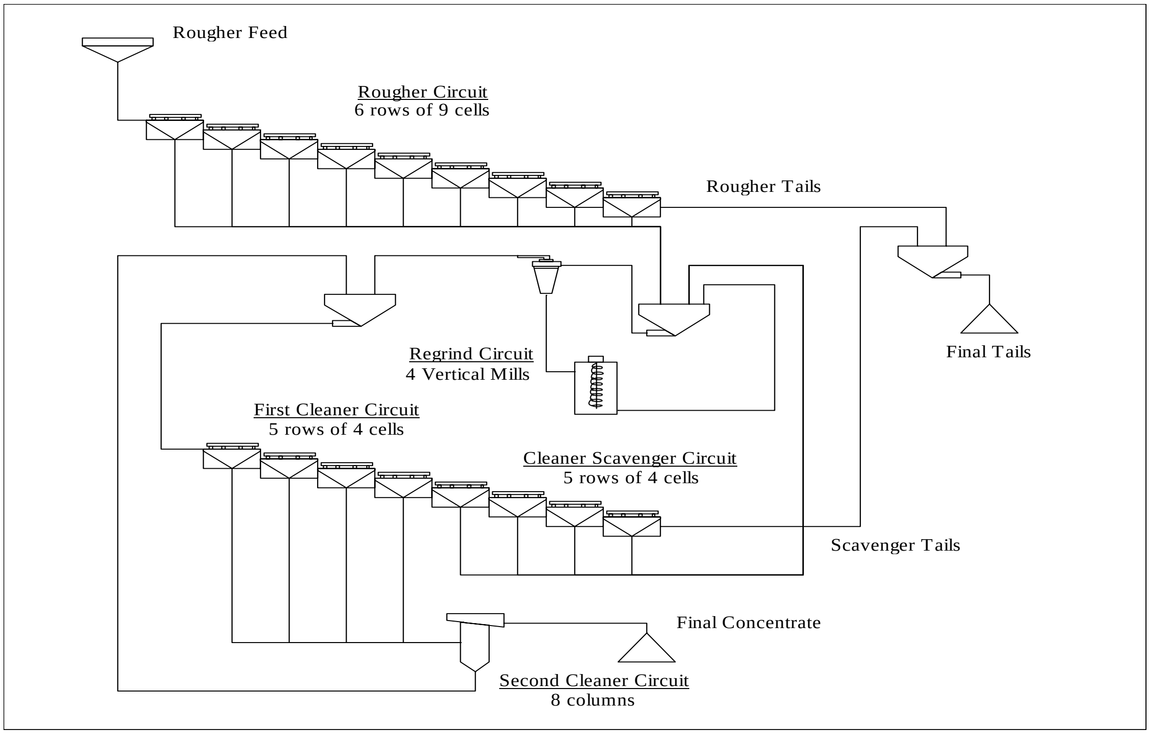

Figure 1: Laguna Seca Concentrator

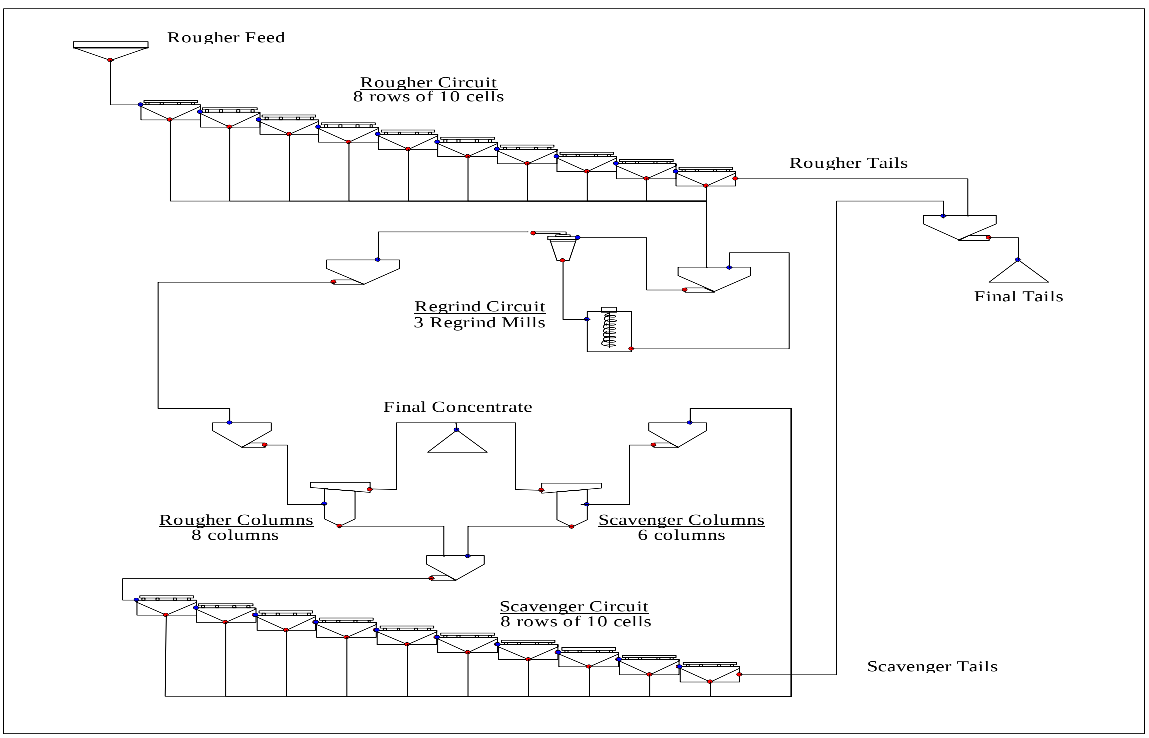

Figure 2: Los Colorados Concentrator

Equipment Specifications

A summary of the Laguna Seca (LS) and Los Colorados (LC) flotation circuit equipment specifications are shown in Table 1 and Table 2, respectively.

It should be noted that the total volumes of the cells reported are based on the overall dimensions of the cell and that the effective cell volume is used in subsequent analysis. The effective cell volume will take into account the volume reduction by launders, impeller and air hold-up.

Table 1: Laguna Seca Flotation Circuit Cell Specifications

Section	Cell Type	Number of Cells	Cell Vol. (m^3)	Cell Area (m^2)	Launder Type
Roughers	Wemco	54	160	12.9	Concentric
Cleaners	Wemco	20	160	12.9	Concentric
Cleaner Scavengers	Wemco	20	160	12.9	Concentric
Cleaner Columns		8	215	15.9	Concentric

Table 2: Los Colorados Flotation Circuit Cell Specifications

Section	Cell Type	Number of Cells	Cell Vol. (m^3)	Cell Area (m^2)	Launder Type
Roughers	Outokumpu TC100	80	100	16.3	Concentric
Scavengers	Dorr Oliver	80	44	12.4	Single
Cleaners	Cominco	14	208	16.0	Square

EXPERIMENTAL PROGRAM

In the development of the flotation circuit models at Escondida, an extensive on-site test program was conducted by site and JKTech personnel. The test work was performed in July 2004. The measurements that were conducted included:

- Site surveys;
- Laboratory batch flotation tests;
- Cell hydrodynamic measurements;
- Froth performance measurements;
- Entrainment measurements;
- Residence time measurements.

Site Survey Procedure

The surveys were planned and conducted using the guidelines outlined in the paper by Mosher and Alexander (2002). The main points noted for the surveys were:

- Two overall surveys of each concentrator were performed as well as down-the-bank surveys of selected rows of roughers and cleaners in each concentrator;
- Total survey time for each overall survey was two hours;
- Four sample cuts were taken in 30 minute intervals;
- Previous day and night shift data were used to determine the stability of the survey before commencement;
- No operating parameter changes occurred during the survey period (including reagent addition rates, grinding throughput, cell levels, etc.).

Samples collected from each survey were weighed wet and dry to determine percent solids and sent for standard Escondida assay to determine copper, iron, sulphur and insolubles. Splits of the overall and down-the-bank survey samples were sent for size by assay analysis.

All available data were mass balanced to give the best estimates of mass flows around the circuit. Least squares minimisation techniques were used to estimate the assay in each stream such that all data were consistent. In this study, all surveys were mass balanced and the balanced data used in the flotation model-building phase of the work.

Laboratory Batch Flotation Test Procedure

To map the floatability components, standard laboratory batch flotation rate tests were conducted on major streams in the circuit. The following conditions were used in the tests:

- Tests were conducted in the JKTech bottom driven flotation cell;
- Both air rate and impeller speed were fixed for each test;
- Four concentrates were collected over the following times:
  - Con 1 - 1 minute
  - Con 2 - 2 minutes
  - Con 3 - 4 minutes
  - Con 4 - 8 minutes
- Throughout each test, froth depth was maintained at constant level of 1 cm. The shallow froth depth was used to ensure the froth recovery was approximately 100%;
- No additional collector, frother, activator, pH modifier, or depressant was added in any test;
- The froth pull rate from the cell was constant at 6 scrapes per minute;
- Other measurements included:
  - Wet weights of each product;
  - Impeller speed;
  - Air pressure.

Cell Hydrodynamic Measurements

The bubble surface area flux was calculated or estimated in each of the flotation cells from data collected using a superficial gas velocity probe (J_g probe), a McGill bubble viewer and an air hold-up probe.

The J_g probe (Gorain et al, 1996) measures the average rise velocity of bubbles in the flotation cell. The J_g probe can also be used to determine the degree of dispersion in the cells by multiplying the J_g by the cross sectional area of the cell and comparing this to the measured volumetric air flowrate.

The bubble surface area flux is a measure of the rate of bubble surface area rising up through the cell per unit cell open area. The greater the bubble surface area flux, the higher the recovery rate in the pulp zone of a cell (Gorain et al, 1997). Bubble surface area flux can be measured directly using:

$$S_b = \frac{6.J_g}{d_{32}} \qquad \text{(Equation 1)}$$

Where: S_b = Bubble surface area flux (m^2/m^2 s)
d_{32} = Sauter mean bubble diameter (m)
J_g = Superficial gas velocity (m/s)

Alternatively, bubble surface area flux can be estimated using measurements of the J_g, impeller speed, impeller design and viscosity of the pulp (from Gorain et al, 1999):

$$S_b = a.N^b.J_g^c.A_s^d.P_{80}^e \qquad \text{(Equation 2)}$$

Where: S_b = Bubble surface area flux (m^2/m^2 s)
J_g = Superficial gas velocity (m/s)
N = Impeller tip speed (m/s)
A_s = Impeller aspect ratio (ratio of impeller height to impeller diameter)
P_{80} = 80% passing feed size (μm)
a, b, c, d, e = Model constants: a=123; b=0.44; c=0.75; d=-0.10; e=-0.42.

The Sauter mean bubble diameter is measured directly within the pulp region of the flotation cell using the McGill bubble viewer. The McGill photographic bubble viewer is designed to estimate bubble size in a flotation cell by analysing images of bubbles rising within a specially designed chamber. Figure 3 is a schematic presentation of the McGill bubble viewer (Hernandez-Aguilar et al, 2002).

Bubble size measurement involves filling the chamber and rise tube with frother dosed plant water (to prevent bubble coalescence), placing the rise tube into an appropriate position in the flotation cell below the pulp-froth interface, removing the stopper at the end of the rise tube and then collecting images of the bubbles as they impact on a sloped glass plane. The sloped glass plane is illuminated by a light source at the back of the chamber; light rays pass through a light diffuser to ensure well focused and high contrast images. Details of the bubble viewer operation are outlined in Hernandez-Aguilar et al (2002).

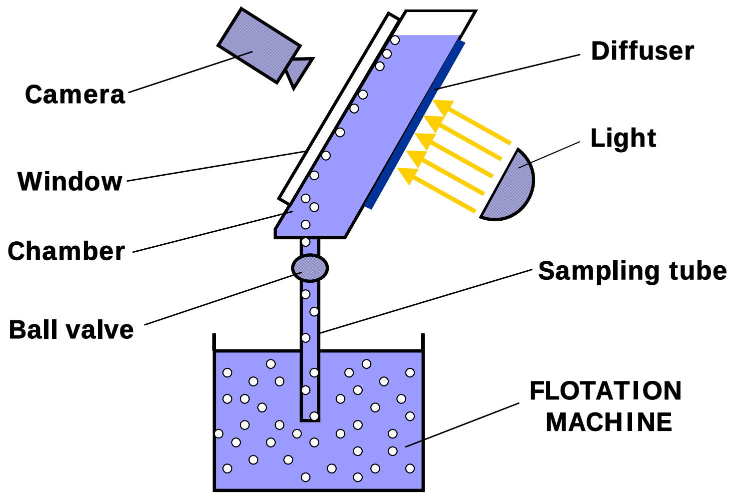

Figure 3 Schematic of McGill Bubble Viewer (Hernandez-Aguilar et al, 2002)

The air hold-up probe (Gorain et al, 1995) measures the proportion of air in the pulp. The air hold-up probe consists of a vertical cylinder with pneumatic valves at the top and bottom of the cylinder. The probe is lowered into the pulp zone of the cell and the valves are maintained open to allow pulp and bubbles to pass through the probe. After 30 seconds the valves are closed and the volume of pulp collected is measured. This volume (V_p) is then used to calculate the air hold-up fraction using Equation 3.

$$\varepsilon_g = \frac{V_d - V_p}{V_d} \qquad \text{(Equation 3)}$$

Where: ε_g = Air hold-up (%)
V_d = Volume of probe (1020 ml)
V_p = Volume of pulp collected (ml)

These measurements were taken in the majority of operating cells in both flotation circuits either during or around the time of the flotation surveys.

Froth Performance Measurements

The overall recovery of the floatable mineral in a flotation cell is a function of both pulp phase recovery and froth recovery. This is mathematically represented by Equation 4.

$$R_f = \frac{k}{k_c} \qquad \text{(Equation 4)}$$

Where: R_f = Froth recovery
k = Overall first order rate constant (min^{-1})
k_c = Collection zone first order rate constant (min^{-1})

Froth recovery is defined as the recovery of attached particles across the froth phase. Bubble coalescence in the froth phase results in some particles dropping back into the water phase in the froth. Some of these particles (depending on size) drain back into the pulp phase. Froth recovery measurement techniques have only recently been developed within the flotation research group at the JKMRC. The most common method for measuring froth recovery involves taking samples at various froth levels and relating the first order rate constants derived from the samples with froth level (Vera et al, 1999). This method was not used in this study since it has a large impact on the production performance of the plant (due to large variations in concentrate flows and grades). Instead, a new technique developed by Alexander et al (2003) was used which involves taking samples of feed, concentrate, and tail, as well as a "top of froth" and air hold-up sample. The "top of froth" sample is used to estimate the attached particle grade. The sample is taken at the very top of the froth by gently pressing a bucket lid on the surface of the froth. All of the samples were assayed and a mass balance of attached and entrained particles was conducted. A size-by-assay analysis was also performed. The froth recovery was calculated using the ratio of attached particles entering (at the pulp-froth interface) and leaving the froth phase (concentrate).

These measurements were taken in selected operating cells in both flotation circuits either during or around the time of the flotation surveys.

Entrainment Measurements

Entrainment is defined as the unselective recovery of a mineral due to mechanical carry over with the water phase. Savassi et al (1998) defined the degree of entrainment as the ratio of solids that report to the concentrate due to entrainment to the solids that enter the froth phase due to entrainment (Equation 5). The degree of entrainment at each size fraction is determined using the assay of a non-floating liberated mineral. As the mineral is non-floating, the mass in the concentrate is due to the entrainment mechanism alone.

$$ENT_i = \frac{M_{Conc}^{ENT}}{M_{Pulp}^{ENT}} \qquad \text{(Equation 5)}$$

Where: ENT_i = Degree of entrainment for size class i
M_{conc} = Mass of solids suspended in the water in the concentrate
M_{pulp} = Mass of solids suspended in the water in the pulp phase

Samples of cell concentrate and pulp (tails) were taken from selected operating cells in both flotation circuits. Size-by-assay analysis was performed on each sample.

Residence Time Measurements

The mean cell residence time is used in the flotation model. The mean residence time is the average time liquid or solids are contained in the flotation cell, and is calculated as follows:

$$\tau = \frac{V \cdot (1 - \varepsilon_g)}{Q_t} \qquad \text{(Equation 6)}$$

Where:
- τ = Residence time (min)
- V = Cell volume (m^3)
- ε_g = Air hold-up (%)
- Q_t = Volumetric flow of the tails (m^3/min).

COMPARISON OF LAGUNA SECA AND LOS COLORADOS ROUGHER CIRCUITS

From the results of the test work, the Los Colorados (LC) rougher circuit outperformed the Laguna Seca (LS) rougher circuit in terms of copper recovery. A comparison of the metallurgical performance of each rougher circuit with respect to cell hydrodynamics, cell operation and feed properties is presented in the following sections. The possible reasons for the differences in circuit performance are discussed.

Metallurgical Performance

Unsized Basis

A comparison of the rougher circuit recovery and grade results from the mass balanced surveys is shown in Tables 3 and 4. The recoveries presented in Table 3 are based on the recovery to the rougher feed of each circuit.

Table 3: Comparison of LS and LC Circuit Recoveries (based on Rougher Feed)

Stream	Laguna Seca					Los Colorados				
	TPH	Recovery to Feed (%)				TPH	Recovery to Feed (%)			
		Cu	Fe	Insol	S		Cu	Fe	Insol	S
Feed	4970					5483				
Rougher Con	619	83.1	34.9	9.30	93.0	479	85.9	38.8	5.94	84.7

Table 4: Comparison of LS and LC Circuit Grades

Stream	Laguna Seca					Los Colorados				
	TPH	Grade (%)				TPH	Grade (%)			
		Cu	Fe	Insol	S		Cu	Fe	Insol	S
Feed	4970	1.33	2.40	88.6	1.14	5483	1.02	2.31	88.1	1.65
Rougher Con	619	8.90	6.70	66.4	8.50	479	10.0	10.3	59.9	16.0

In the key traditional measures of flotation performance:

- The copper feed grade at LS was 0.3% higher than LC.
- The rougher circuit copper recovery at LS was 2.8% lower than LC.
- The copper grade in the rougher concentrate at LS was also lower than LC (1.1%) primarily due to a higher recovery of non-floating insoluble material at LS.

Size-by-Size Basis

Table 5 shows the 7 size fractions that were used in the analysis and the LS and LC size distributions in the rougher feed. The rougher feed at LS and LC had a feed size P_{80} of 172 microns and 180 microns, respectively.

Table 5: Laguna Seca and Los Colorados Feed Size Distributions

Size ID	Size Fraction (micron)	Mean Size (micron)	Feed Size Distribution (%)	
			Laguna Seca	Los Colorados
1	-417+295	356	4.91	6.72
2	-295 +208	252	9.21	8.33
3	-208 +147	178	10.1	10.6
4	-147 +106	127	9.72	10.1
5	-106 +75	91	9.25	8.75
6	-75 +53	64	8.16	7.38
7	-53	27	48.7	48.1

Table 5 shows that there was more material in the +295 micron size class at LC than LS and approximately the same amount of material in the -53 micron fraction.

Figure 4 shows the comparison between the LS and LC rougher circuit size-by-size recoveries for copper, iron and insolubles. Figure 5 shows the comparison of copper losses to the rougher tails on a size-by-size basis. Figure 6 shows the comparison of the size-by-size distribution of copper in the rougher tails.

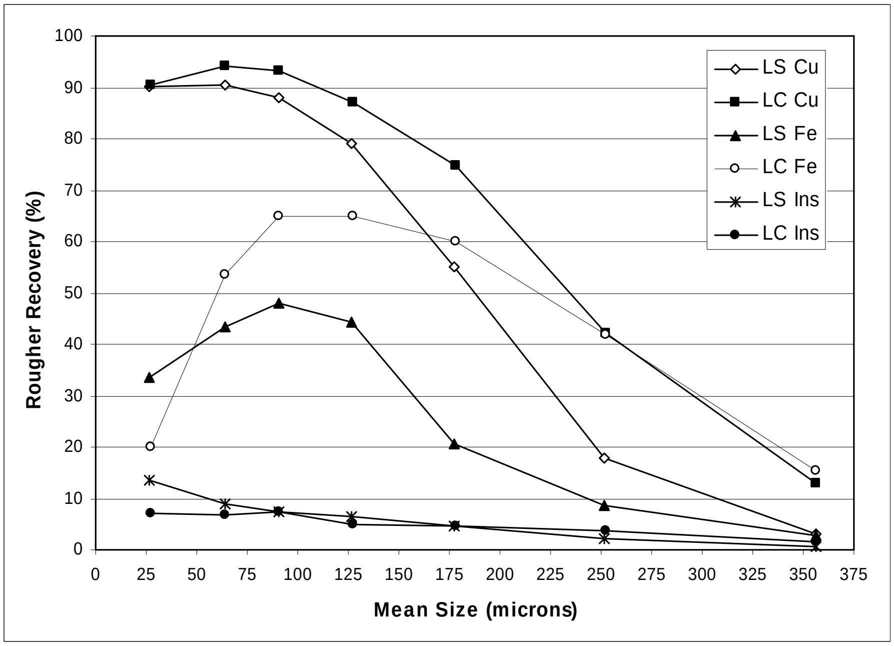

Figure 4: Comparison of LS and LC Rougher Circuit Size-by-Size Recoveries

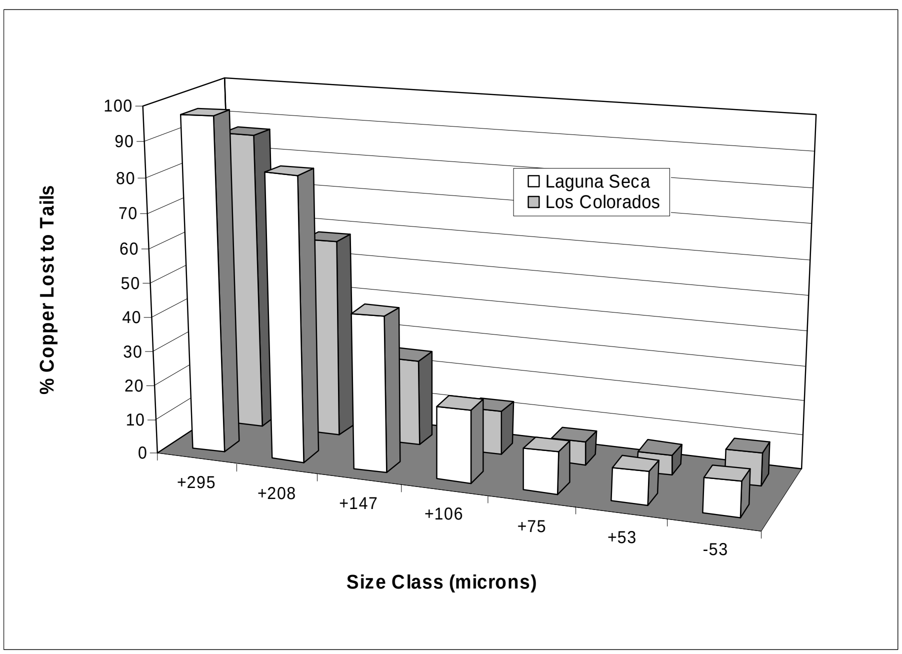

Figure 5: Comparison of Copper Losses to LS and LC Rougher Circuit Tails on a Size-by-Size Basis

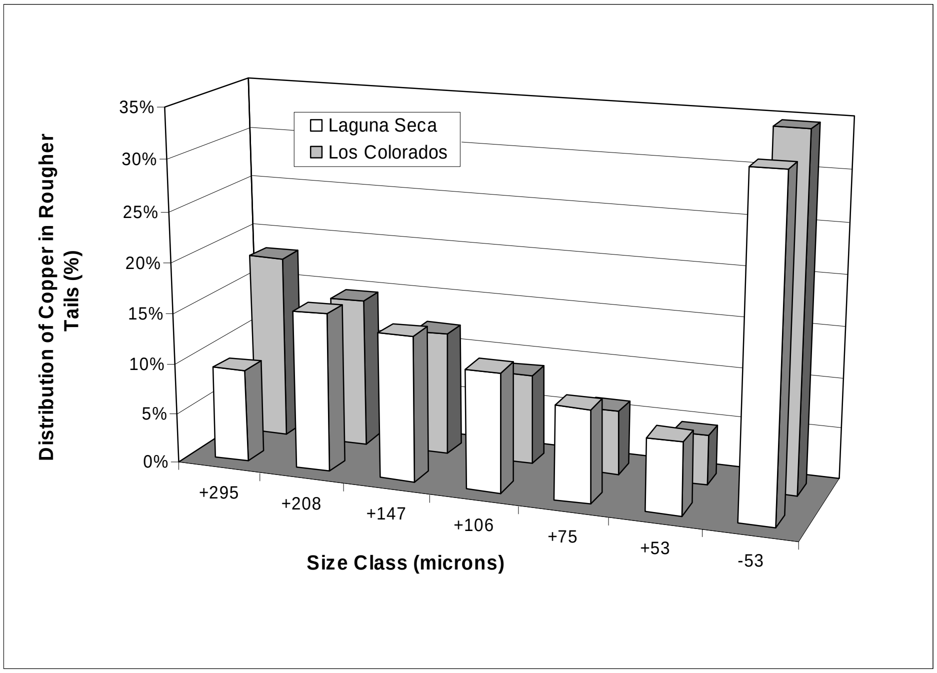

Figure 6: Comparison of Size-by-Size Distribution of Copper in Rougher Tails at LS and LC

The following observations can be made from Figures 4 to 6:

- At both LS and LC, the maximum recovery of copper was observed at particle sizes between 53 and 75 microns.
- The recovery of copper at LC was higher than at LS for all size classes especially in the +105 micron class. Consequently, the copper losses to the rougher tails at LS were higher than at LC for all size classes.
- In both concentrators, the copper losses to the rougher tails were greater than 25% in the +147 size fraction. Furthermore, in both concentrators the amount of +147 micron material was greater than 40%. This clearly shows that improvements in copper recovery could be achieved by reducing the amount of +147 micron material.
- The recovery of iron at LC was significantly higher than at LS except in the -53 fraction.
- The recovery of insolubles was approximately equal at LS and LC except in the -53 fraction where LS was higher. Insolubles are likely to be recovered to the concentrate via entrainment and this shows the effect of entrainment at both concentrators was approximately equal.

Gas Dispersion Measurements

The average gas dispersion results for the measured rougher cells at LS and LC are compared in Table 6. Table 6 also includes the standard deviations and 95% confidence intervals for each measurement.

Table 6: Comparison of LS and LC Rougher Cell Gas Dispersion Results

Parameter	Laguna Seca			Los Colorados		
	Average	SD	95% Conf Limits	Average	SD	95% Conf Limits
Superficial Velocity (cm/s)	1.1	0.2	0.1	1.0	0.2	0.1
Air Hold-up (%)	14	2	1	10	1	1
D_{32} Bubble Size (mm)	2.2	0.3	0.1	1.8	0.2	0.1
Bubble Surface Area Flux (s^{-1})	30	6	2	30	5	3

The average gas dispersion results from the rougher cells at LS and LC were approximately equal at a 95% confidence limit. The bubble size at LC was smaller than at LS but the overall bubble surface area flux was approximately equal. This suggests that any differences in metallurgical performance (in terms of copper grade and recovery) between the two flotation circuits were likely due to differences in froth performance (including entrainment) or the ore characteristics.

According to the JKTech database of gas dispersion measurements in industrial flotation cells (Schwarz and Alexander, 2005), the average superficial gas velocity and bubble surface area flux in both plants were low compared to other industrial flotation cells of the same size and type. An increase in the superficial gas velocity by increasing the cell air rate should increase the bubble surface area flux and improve the recovery across the rougher circuit. This should be applicable to both concentrators.

Froth Recovery

The measured froth recoveries in each rougher circuit were calculated using the mass balanced results and the froth recovery measurements discussed previously. The froth recoveries were calculated on a size-by-size basis.

Figure 7 shows the average size-by-size froth recovery results for all characterised rougher flotation cells at LS and LC.

The average froth recovery at LC was higher than LS in all size classes except the -295 +208 micron class. The froth recovery in the 3 fine size classes (-75 microns) was 6%, 13% and 9% higher at LC. The overall froth recovery for all size classes combined was 33% at LS and 39% at LC. This difference in froth recovery could account in part for the differences in copper recovery between the two rougher circuits. Froth recovery was affected by several factors including froth chemistry, cell operating conditions and cell type (manufacturer). An improvement to the pulp phase recovery may also lead to an improvement in the froth recovery across the rougher circuit.

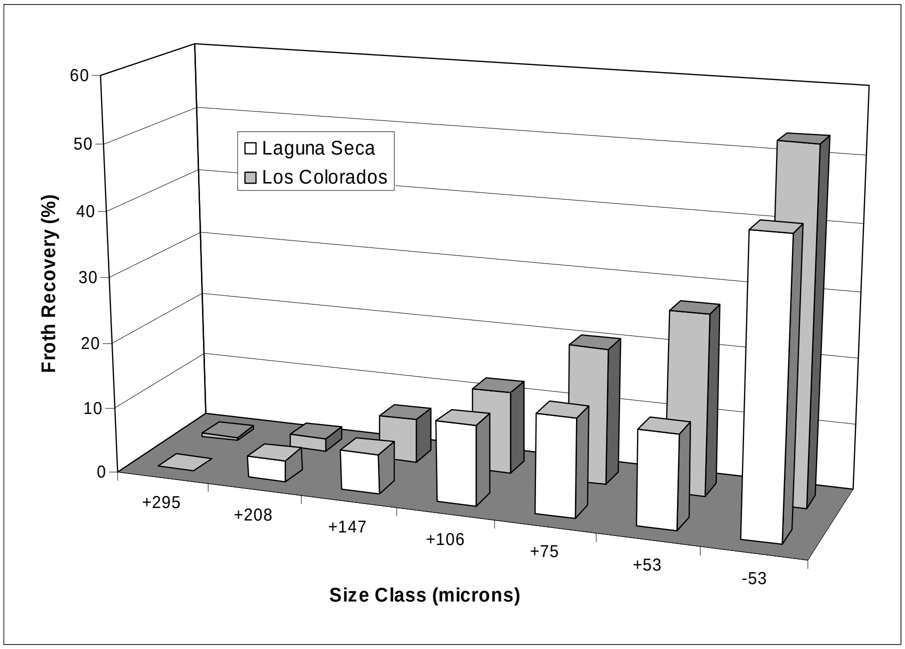

Figure 7: Comparison of Average Size-by-Size Froth Recovery in LS and LC Rougher Circuits

Entrainment

The degree of entrainment was calculated for all measured rougher cells at both concentrators. Table 7 compares the average degree of entrainment on a size-by-size basis for the measured rougher cells at LS and LC.

The degree of entrainment in the rougher circuits at LS and LC were very similar. Therefore large differences in performance between the two concentrators can not be attributed to the effect of entrainment. The average water recovery from each characterised rougher cell was approximately 1.2% at each concentrator.

Table 7: Comparison of Size-by-Size Degree of Entrainment in Rougher Circuits at LS and LC

Size Class (microns)	Degree of Entrainment	
	Laguna Seca	Los Colorados
+295	0.00	0.00
+208	0.00	0.00
+147	0.00	0.00
+106	0.00	0.00
+75	0.31	0.34
+53	0.37	0.38
-53	0.70	0.72

Residence Time

Table 8 shows the average effective volume per cell and average residence time per row in the rougher circuits at LS and LC.

Table 8: Rougher Circuit Effective Volumes and Residence Times at LS and LC

Circuit	Average Effective Volume per cell (m^3)	Number of Cells	Overall Effective Volume per Circuit (m^3)	Average Residence Time per Row (min)
Laguna Seca	134	54	7236	42.3
Los Colorados	86	80	6880	29.7

The average effective volume per cell and residence time per rougher row at LS were significantly higher than at LC. Although the overall effective circuit volumes at LS and LC were comparable, the volumetric flows in the rougher tails of each circuit were significantly different (10200m^3/h at LS and 13825m^3/h at LC). This was due to the difference in the amount of water in the feed to each circuit (32% solids at LS and 29% solids at LC).

With approximately 40% higher residence time per rougher row at LS, the copper recovery was expected to be higher than at LC. Therefore the higher copper recoveries at LC were not due to the effect of residence time.

Ore Floatability Characteristics

The ore floatability characteristics for each concentrator were calculated using a combination of overall plant and down-the-bank survey data, batch test data, froth recovery measurements, bubble surface area flux measurements and entrainment measurements. Floatability rates and mass fractions were estimated by using a non-linear least squares fitting routine on the above data (Alexander and Morrison, 1998; Alexander et al, 2000, Harris et al, 2002).

Tables 9 and 10 show the comparison between the ore floatability rates and mass fractions for each concentrator, based on the size-by-size flotation model. The comparison is made for the copper-sulphide (CuS), iron-sulphide (FeS) and non-sulphide gangue (NSG) minerals in the ore.

The ore feeding the flotation circuit can be characterised by three floatability components – fast, slow and non-floating. The floatability rates for CuS and FeS are in the same range for both concentrators in both floatable classes. However, there is 6% more fast floating CuS mineral at LC and consequently 8% less slow floating material. This may contribute to the higher CuS recoveries achieved at LC. The non-floating fractions for the CuS mineral in the feed to both concentrators are most likely copper oxide minerals. The floatability rates for the NSG are higher in LC with similar floating fractions.

Table 9: Comparison of Ore Floatability Rates for LS and LC Feed

Mineral	Laguna Seca			Los Colorados		
	Fast	**Slow**	**Non**	**Fast**	**Slow**	**Non**
CuS	$1.83x10^{-03}$	$7.22x10^{-05}$	0.00	$2.20x10^{-03}$	$6.57x10^{-05}$	0.00
FeS	$1.48x10^{-03}$	$1.82x10^{-05}$	0.00	$1.93x10^{-03}$	$1.40x10^{-05}$	0.00
NSG	$4.32x10^{-05}$	$8.48x10^{-07}$	0.00	$3.33x10^{-04}$	$7.98x10^{-07}$	0.00

Table 10: Comparison of Ore Floatability Mass Fractions for LS and LC Feed

Mineral	Laguna Seca			Los Colorados		
	Fast	**Slow**	**Non**	**Fast**	**Slow**	**Non**
CuS	0.77	0.16	0.07	0.83	0.08	0.09
FeS	0.22	0.18	0.60	0.31	0.18	0.51
NSG	0.06	0.14	0.80	0.03	0.18	0.79

These results show that an improvement in rougher circuit recovery could be achieved by changing the floatability characteristics of the copper ore. This could be achieved through improved liberation, size reduction or changes in reagent chemistry.

PROCESS IMPROVEMENTS

This benchmarking study has identified possible operating issues and has assisted Escondida in making a range of changes to improve the copper recovery in the flotation circuit at the Laguna Seca Concentrator (along with improvements to the Los Colorados concentrator in the future).

Daily laboratory batch flotation tests were performed by Escondida in the three months following the benchmarking study. As each plant had slightly different feed ore material, it was difficult to directly compare the grade-recovery performance for each plant on a daily basis. To overcome this, laboratory batch flotation tests were performed each day on composite samples of the rougher feed and rougher tail to compare a standard laboratory test result with the plant rougher performance.

The differences between the copper recovery achieved in the laboratory batch flotation tests of the rougher feed and the copper recovery achieved in the plant rougher circuits are shown in Figures 8 and 9 for Laguna Seca and Los Colorados, respectively. These results show a greater difference between the laboratory and plant results for Laguna Seca (4.3% average) compared to Los Colorados (2.8% average).

Figure 10 shows the copper recoveries achieved in the laboratory batch flotation tests of the rougher tails for both concentrators over the three month period. These results show an average copper recovery from the rougher tails of 48% for Laguna Seca and 36% for Los Colorados. The copper recovered from these tests was mostly liberated ultra-fine copper minerals, as shown in Figure 6.

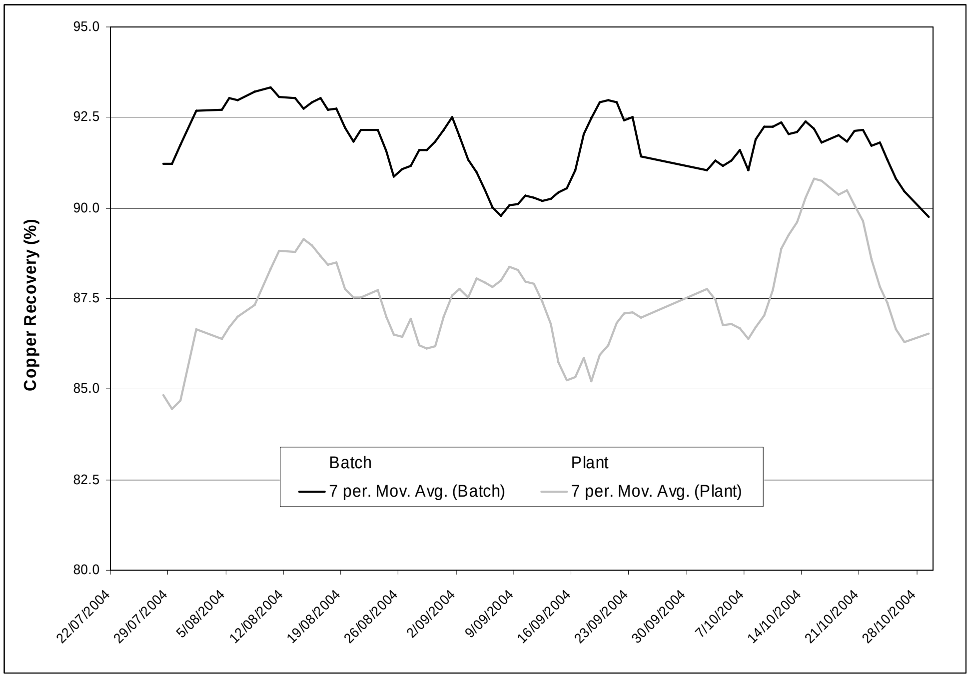

Figure 8: Comparison of Rougher Feed Batch Test and Plant Rougher Copper Recovery at LS

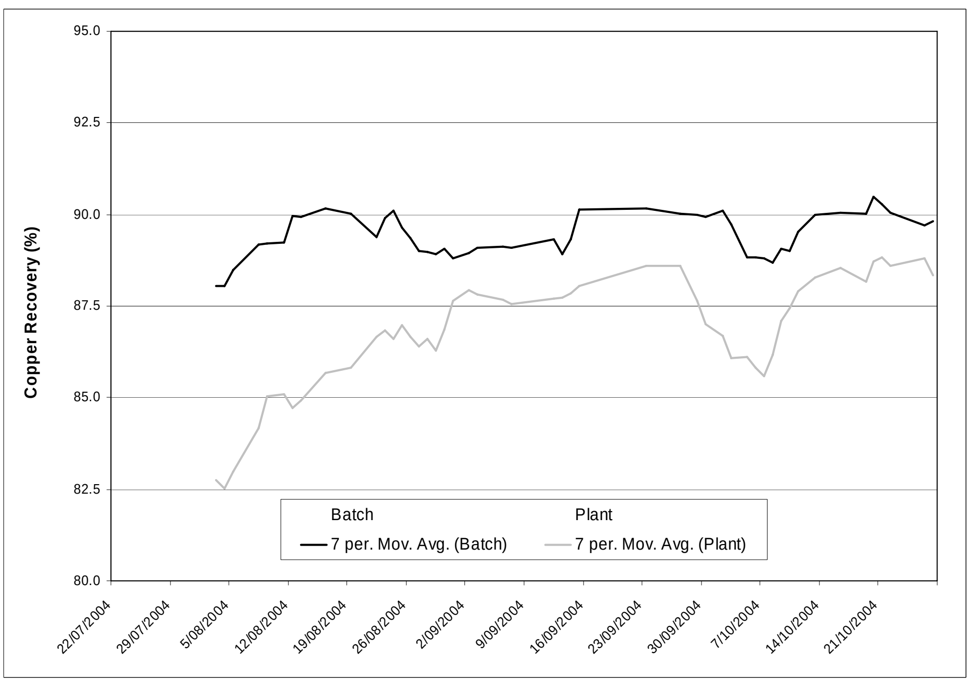

Figure 9: Comparison of Rougher Feed Batch Test and Plant Rougher Copper Recovery at LC

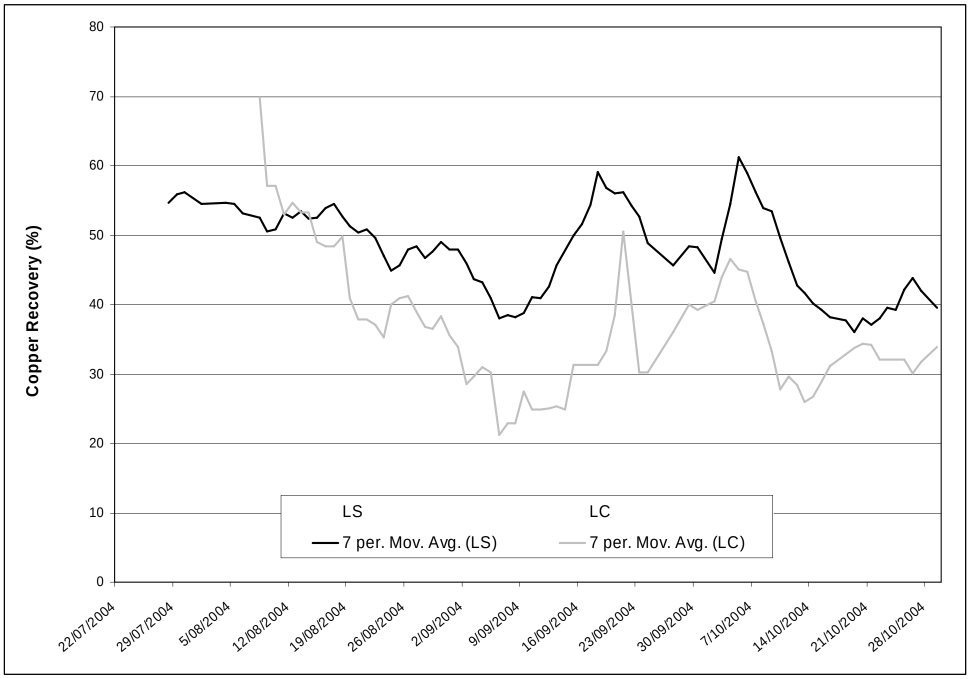

Figure 10: Copper Recoveries from Laboratory Batch Tests of Rougher Tails for LS and LC

This test work provided a continuing internal benchmark of the operation of each concentrator and improved the understanding of the operating issues. The Laguna Seca Concentrator was identified as having the greatest scope for improvement and hence test work was focussed on first improving the Laguna Seca performance.

Table 11 shows the actions taken by Escondida to improve the copper recovery in the flotation circuit at the Laguna Seca Concentrator.

Table 11: Actions taken to Improve Copper Recovery in the Laguna Seca Flotation Circuit

Date	Action Taken
August 2004	Overhaul and cleaning of Wemco cells
September 2004	Cleaning of Wemco cells air aspiration system
September 2004	Wemco cells maintenance and cleaning programs developed
September 2004	Additional replacement of worn Wemco parts
October 2004	Training course on the operation of Wemco cells
January 2005	Improvements to operation of column cells
May 2005	Testing of impeller speed increases in 1 row of rougher cells

The process improvements made by the metallurgical team at Escondida resulted in a significant increase in copper recovery in the rougher circuit and overall circuit of approximately 1.5% and 1.4%, respectively.

Through cleaning the Wemco aspiration systems and increasing the impeller speed, the superficial gas velocity is expected to have increased leading to a higher bubble surface area flux and therefore higher copper recovery. By overhauling and cleaning out the Wemco cells and removing dead cell volume, the cell performance would have improved and the residence time in each cell would have increased leading to a higher pulp phase recovery and therefore an improved froth recovery. Finally, through the development of a Wemco maintenance and cleaning program and greater understanding of the operation of the cells, these performance improvements should be able to be maintained over the future operation of the mine.

These improvements to the Laguna Seca flotation circuit will provide Escondida with approximately 7000 tons of additional copper per year. At current copper prices, this amounts to additional revenue of approximately US$ 25 million per year.

CONCLUSIONS

JKTech was commissioned by Minera Escondida Limitada to perform test work at the Laguna Seca and Los Colorados flotation concentrators in July 2004. The aim of the test work was to provide flotation models of the two Escondida concentrators and hence assist in identifying potential areas of flotation performance improvement. A comparison of the flotation performance of each concentrator was made based on traditional measures, such as grade and recovery, as well as on the flotation model parameters, such as ore floatability, bubble surface area flux and froth recovery.

The results from the benchmarking surveys on both concentrators showed the rougher circuit copper recovery at Los Colorados was higher than the Laguna Seca rougher circuit, with similar feed size distributions. Along with these traditional measures of plant performance, the rougher cell operating conditions and feed ore floatability characteristics were compared for the two concentrators to identify the differences in circuit performance. The gas dispersion, froth recovery, entrainment, residence time and ore characteristics were compared.

The gas dispersion characteristics (in terms of superficial velocity, air hold-up, bubble size and bubble surface area flux) were similar for the measured rougher cells at both concentrators. The superficial velocity and bubble surface area flux were found to be low compared to industrial flotation cells of the same size and type. The average froth recoveries in the measured Los Colorados rougher cells were up to 13% higher than at Laguna Seca. The difference in the froth recovery was most significant in the -75 micron size class. The degree of entrainment on a size-by-size basis was similar for the measured rougher cells at both concentrators as well as the water recovery per cell. The residence time in the rougher circuit at Laguna Seca was approximately 40% higher than the residence time at Los Colorados. This was mainly due to the higher feed rate of water at Los Colorados. The overall effective volumes of each rougher circuit were comparable. The ore floatability rates of the copper minerals were similar at both concentrators. However, at Los Colorados, the amount of fast and slow floating copper mineral was 6% higher and 8% lower, respectively, than Laguna Seca.

From this comparison, the differences in performance between the two rougher circuits were identified to be mainly due to differences in the froth performance in the rougher cells and the feed ore characteristics.

This benchmarking study identified possible operating issues and assisted Escondida in making a range of changes to improve the copper recovery in the rougher circuit at the Laguna Seca Concentrator. These changes included improvements to the operation of the Wemco cells and an improved cleaning and maintenance program for the flotation cells.

Through these improvements the copper recovery in the rougher circuit increased by 1.5% which resulted in an increase to the overall recovery of copper from the Laguna Seca Concentrator of 1.4%.

The results that have been obtained from Escondida demonstrate that the flotation circuit analysis and benchmarking technology is able to assist in providing real financial and operational benefits to flotation plants. After many years of research by the AMIRA P9 flotation group, the current JKTech commercialised methodology provides flotation operators with a useful tool to further understand and improve their flotation circuit performance.

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