

A Comparison Between a Flotation Mini Pilot Plant and a Copper Concentrator Mill

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ABSTRACT

In 1999, the Mineral Development Centre of CVRD (CDM) acquired a flotation device referred to as Mini Pilot Plant (MPP), which is able to run continuous flotation tests with drill core samples. Since then this equipment has been used to define the flotation circuit and process conditions during the pre-feasibility phase of CVRD's copper sulfide projects. Until now, the MPP results had not been validated for an industrial flotation operation. The present work consists of a comparison and correlation of the results from a flotation MPP and an industrial plant. In order to make this comparison, an industrial plant was completely sampled and the feed ore was tested on bench scale and on a MPP. The metallurgical and mass balances of each test were used for the comparison.

INTRODUCTION

In 1999, Companhia Vale do Rio Doce (CVRD) acquired a flotation Mini Pilot Plant (MPP), which was designed and manufactured by Canadian Process Technologies (CPT).

Since then it has been used on the pre-feasibility phase of copper sulfide projects.

The MPP is a very important acquisition because it can substitute a conventional pilot plant to generate technical information of the projects such as: circuit configuration, equipment size, mass and metallurgical recoveries as well as concentrate quality. It is a very compact flotation device that runs continuously with drill core samples from exploration campaigns. Thus it provides the possibility of performing a variability study program with representative samples from different periods of the mine (Andrade, Santos and Gonçalves, 2004).

The reduced size of the MPP cells allows the use of smaller samples however, it can be questionable in its reproducibility. Some previous works have been published showing that MPP is capable of obtaining the same global recovery of a conventional pilot plant. It was also proven that MPP can achieve similar copper grade and recovery at the rougher stage in comparison to the rougher stage of a copper concentrator mill (Santos, Gonçalves and Andrade, 2003).

The work presented in this paper focuses on a comparison between a copper concentrator mill and the MPP. Mass and metallurgical balances are shown in order to compare the global results and the performances of each stage. This paper also highlights the future steps of this work.

METHODOLOGY

Mini Pilot Plant (MPP) description

The MPP has 12 Denver cells of 1.7 L each. These cells are connected by peristaltic pumps that permit the arrangement of any circuit configuration. The MPP has a control system that allows the variation of the air flow rate and the paddle and

impeller speeds. It also permits the pulp pH and Eh measurements using the available probes. The pulp feedrate rests between 5 and 10 kg/h. Reagents are fed continuously by peristaltic pumps. The primary grinding is performed in a laboratory-scale rod mill in batches of 20 kg of dry solids. The regrinding of the intermediate concentrates is done in a continuous pin mill. Figure 1 shows the MPP in detail.



FIG 1 - Mini Pilot Plant.

Industrial plant (IP)

The copper concentrator mill chosen for this comparison work was Mineração Caraíba. It is located in the northeast region of Brazil. It mines about 1.2 Mt ROM per year from an underground mine and produces 80 000 t/y of a flotation concentrate at 37 per cent Cu. The ore sulfide minerals are chalcopyrite (34 per cent) and bornite (64 per cent) (Reis, 2003). The average copper grade of the deposit is 2.82 per cent. The grinding circuit consists of a 16' x 25' ball mill in closed circuit with a cyclone pack and a flash flotation. The samples are ground at 62 - 63 per cent of solids. The feed of the flotation circuit consists of 200 t/h of ore that has been ground to 70 per cent finer than 100 µm. The target range for the concentrate copper grade is 37 to 40 per cent and 0.3 to 0.4 per cent Cu for the final tailings.

The whole flotation circuit is constituted of Wemco cells. The circuit consists of three banks of eight cells for the rougher stage (340 m³) and two banks of nine cells for the cleaner stage. Each cleaner bank is composed of three cleaner 1 cells (25 m³), one cleaner 2 cell (8.5 m³) and five cleaner scavenger cells (42.5 m³).

Figure 2 presents the flotation flow sheet. It must be highlighted that as the flash flotation could not be simulated on the MPP, it was by-passed during the sampling day.

The IP sampling was carried out using pipeline samplers, manual samplers and hose pipes. The manual sampling consisted of cutting all the flow in order to assure the integrity of the sample. Four samples of each point were taken at 30-minute intervals.

All samples were weighed, filtered and sent to the research centre of CVRD, where the solids percentages were calculated and chemical analysis of Cu, Fe, S and F were done.

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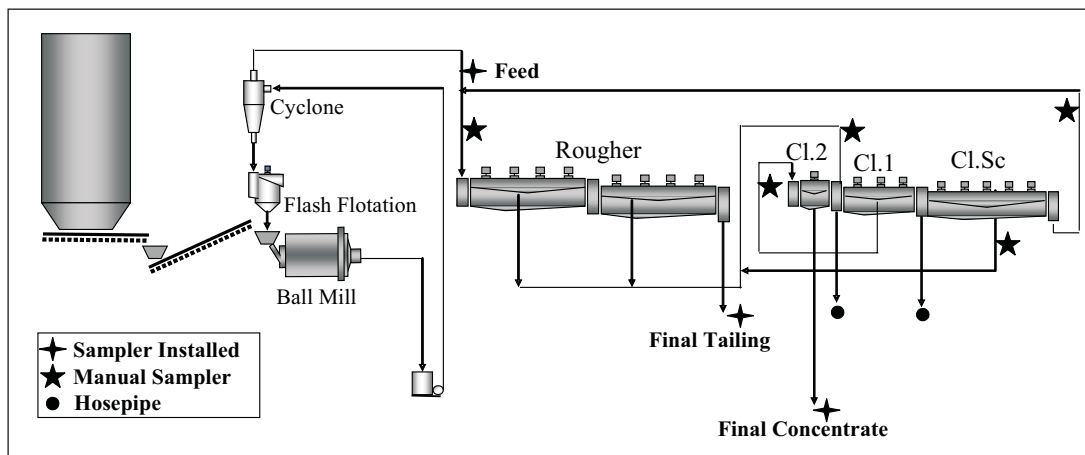


FIG 2 - Concentrator mill flow sheet.

The ore for MPP test was also taken during the industrial sampling period. It was withdrawn from the conveyor belt that feeds the ball mill. The half-inch size sample was sent to CVRD.

Bench scale test

It is usual to recirculate water in industrial plants. Normally the recirculated water carries some frother and so the net consumption of this reagent is reduced. For this reason bench scale rougher tests were performed in three different dosages of frother in order to achieve the same copper grade recovery results as under industrial conditions.

The laboratory grinding test was carried out in a rubber-lined rod mill (Gonçalves, Andrade and Peres, 2003). The grinding media was composed of 20 stainless steel rods of one-inch diameter. The pH of the slurry was adjusted to 10.5 - 11 with lime. The grinding time was determined to achieve a P_{70} of 100 μm .

The laboratory rougher tests were performed in a 2.5 L Denver D12 sub-aerated cell at a rotational speed of 1200 rpm. The pulp was conditioned with Cytec A3477 (44 g/t) and MIBC (21 g/t; 26 g/t; 31 g/t).

All the concentrate and tailings samples were analysed by ICP in order to make a metallurgical balance calculation.

The industrial flotation circuit of Mineração Caraíba was designed for an ore type, copper grade and feed rate different from those that are mined nowadays. This meant that the cells volume may not be optimised.

During the survey campaign the residence time of each stage was not measured. Instead they were calculated (cell volume divided by feed rate) and the results were different from the bench scale ones. For this reason locked cycle tests (LCT) were completed to confirm the residence time that should be applied at the Mini Pilot Plant run.

A LCT is a sequence of flotation tests in which the intermediate products of a cycle are added onto the following cycle, simulating the circulating load. The sequence of tests is finished when the circuit is considered stabilised. In other words, the final products weight and grade become constant and their metallurgical balance must confirm the data of the initial sample.

The samples for the LCT test were prepared using the same methodology of the rougher tests. The residence time of each stage followed the standard bench scale test conditions of Mineração Caraíba. Table 1 presents the conditions of the test.

The rougher stage was performed in a 2.5 L Denver D12 sub-aerated cell and at a rotational speed of 1200 rpm. The cleaner and cleaner scavenger stages were performed in a 1.5 L Denver D12 sub-aerated cell and at a rotational speed of 900 rpm.

TABLE 1
Conditions of LCT test.

Stage	Residence time (min)	Reagents (g/t)	
		A3477	MIBC
Rougher	8	44	26
Cleaner 1	2	-	-
Cleaner 2	1	-	-
Cleaner scavenger	2	-	-

All the concentrate and tailings samples of each stage were analysed by x-ray fluorescence analysis in order to check the stabilisation of the test. All the products generated at the final cycle were assayed by ICP and the results were used in the metallurgical balance.

Mini Pilot Plant (MPP)

The MPP feed sample was crushed to a size finer than 1 mm and split into 20 kg subsamples which were kept in nitrogen to avoid superficial oxidation (Gonçalves, 2002).

The primary grinding was done in a cylindrical rod mill (35.5 × 76.2 cm). The samples were ground at 60 per cent solids. Table 2 presents the rod size distribution. The pH of the slurry was adjusted to pH 10.5 - 11.0 with lime as required.

TABLE 2
The rod size distribution.

Diameter (mm)	Rods number	%	Weight (kg)
38.0	4	20	24.5
25.4	12	27	33.0
19.0	19	21	26.0
12.5	31	15	19.0
6.3	97	17	21.0
Total	163	100	123.5

Each batch of 20 kg of the ground slurry at 70 per cent below 100 μm was transferred to the holding tank and then to the feed tank. In this holding tank, the solids content was adjusted to achieve 41 per cent and the pH was fitted to pH 10.5 - 11.0, when it was necessary. From the feed tank, the pulp was pumped at a feed rate of 7.5 to 8 kg/h.

The flotation reagents, Cytec A3477 (44 g/t) and MIBC (26 g/t), were added in the first cell of the roughing bank using a peristaltic pump.

When the plant became completely filled with slurry, samples of intermediate and final streams were taken, in order to adjust the operational variables such as froth height, air flow rate and water flow rate at the launders.

Hourly samples of the final tail and concentrate were taken to determine whether or not the plant had reached the steady state (Ounpuu, 2001). All the samples were assayed by x-ray fluorescence analysis. As soon as the plant reached the steady state the survey campaign started.

The first survey named 'open survey' consisted of collecting the final products for two and a half hours. In order to simulate the variation of the plant, these samples were taken at 30-minute intervals. The second survey named 'closed survey' consisted of collecting the internal flows. Each flow was taken for ten minutes. The samples were taken by increments so as not to destabilise the circuit.

All the samples were weighed, filtered, dried and weighed again to calculate the solids percentage and to measure the concentration of Cu, Fe, S and F by ICP.

The survey results were used at the metallurgical balance, which was done using Bilco software from BRGM.

RESULTS AND DISCUSSION

MPP feed sample mineralogy

The ROM mineralogy was obtained using optical microscopy supported by semi-quantitative x-ray diffraction, scanning electron microscopy and ICP chemical analysis. Table 3 presents the mineralogical composition.

These results indicate that bornite and chalcopyrite are the main copper sulfides. Pyroxene is the principal gangue.

Bench scale

Table 4 presents a comparison between the performance of the bench scale rougher test and the IP sampling. A bench scale test was performed to establish the amount of frother that most closely approximates to the plant performance.

Tests 1 and 3 presented very similar copper and weight recoveries results. This fact indicates that the extra frother does not improve the metallurgical recovery. The industrial plant and tests 1 and 3 presented very similar results with regard to copper recovery. However, this was not the case for weight recoveries. Here, the difference was due to the higher grade of IP rougher

TABLE 3

MPP feed mineralogical composition.

Mineral phase	Wt %	Mineral phase	Wt %
Quartz	8	Apatite	r
Plagioclase	6	Fluorite	r
Pyroxene	49	Titane Oxi	r
Clay minerals	r	Magnetite	3
Chlorite	r	Hematite	r
Biotite	12	Chalcopyrite	1.3
Sericite	1	Covellite	r
Amphibole	13	Bornite	3.4
Carbonate	1	Chalcocite/Digenite	r
Epidote	r	Pyrite	r
Talc	1	Ilmenite	r
Monazite	r		

rare (r) – < 0.5%

TABLE 4

Rougher concentrate grades and recoveries.

Test	MIBC (g/t)	% Cu initial	Weight rec	% Cu conc	Cu rec
1	26	2.95	22.04	12.3	91.86
2	21	2.96	18.14	14.59	89.43
3	31	3.04	21.16	12.75	91.94
IP	26	4.18	32.9	11.6	91.3

feed due to the circulating load (cleaner scavenger tail). Therefore the chosen frother dosage used in the MPP test was the same one used in the IP.

Table 5 presents the comparison between the results of the LCT and IP.

The metallurgical and mass recoveries obtained on the LCT rougher stage using eight minutes of residence time were very close to the industrial one obtained with 27 minutes of residence time.

In general, the conditions used on the LCT test were adequate and the metallurgical results were similar to those found at the industrial plant.

TABLE 5

Stages performances – LCT × IP.

Stage	LCT			IP		
	% wt rec	% Cu	% Cu rec	% wt rec	% Cu	% Cu rec
New feed	100.0	2.74	100	100.0	3.02	100
Rougher feed	136.2	3.98	198	140.3	4.18	194
Rougher concentrate	40.9	11.82	177	46.2	11.58	177
Final tail	95.3	0.62	22	94.1	0.54	17
Cleaner feed	54.3	15.80	313	61.2	13.12	266
Cleaner 1 concentrate	10.9	39.52	157	9.5	34.06	107
Cleaner 1 tail	43.4	9.86	156	51.7	9.28	159
Cleaner scavenger concentrate	7.2	22.12	58	11.4	17.12	65
Cleaner scavenger tail	36.2	7.42	98	40.3	7.05	94
Final concentrate	4.7	45.81	78.4	5.9	42.29	83.2
Cleaner 2 tail	6.2	34.76	79	3.5	20.26	24

However, the residence time of the cleaner scavenger on the LCT test was not enough to achieve the same recoveries as that of the industrial plant.

Grinding distribution

Figure 3 shows that the MPP feed particle size distribution has not closely matched the industrial plant.

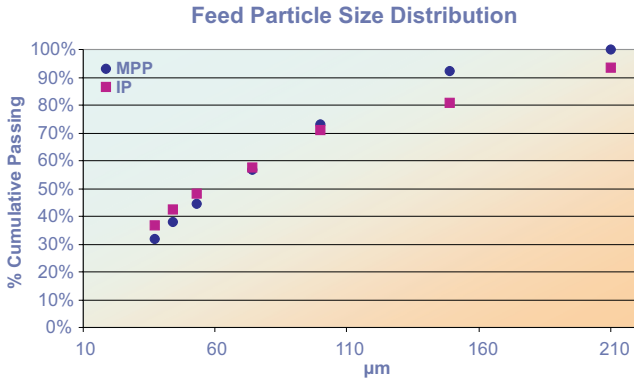


FIG 3 - Feed particle size distribution.

This is due to an intrinsic feature of rod grinding which preferentially grinds the coarser particles while leaving the fines without comminution. The MPP grinding product was finer in the coarser fractions (+ 110 µm) and coarser in the finer ones.

Figure 4 shows the copper distribution, which follows the same tendency of the particle size.

MPP scale up

The number of cells of each stage was established using a scale-up factor of two (Denver, 1995). The residence time to be used on the MPP was reached multiplying the bench scale residence time by two.

The MPP test began with one cell on the cleaner scavenger stage following the scale-up factor. However, during the test, the results of the surveys showed that it was necessary to increase the residence time on this stage. The number of cells was then increased to two.

In the cleaner 2 stage, the residence time was greater than necessary. This was because the MPP has cells of only one size and the feed flow rate of this stage was too small.

Feed Copper Distribution

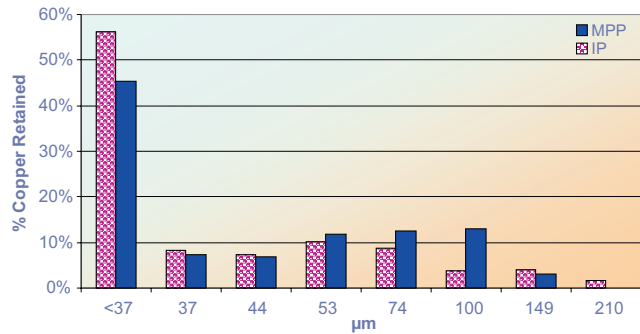


FIG 4 - Feed copper distribution.

Table 6 shows the residence time and the MPP number of cells in each stage. Figure 5 presents the distributions of cells on the MPP.

TABLE 6
Residence time and number of cells.

Stage	Residence time (min)		Cells number
	IP	MPP	
Rougher	27.3	15.2	7+1†
Cleaner 1	13.3	4.3	1
Cleaner 2	5.7	-	1
Cleaner scavenger	13.7	11.5	1+1†

† One cell was left empty

Global results

Table 7 presents the Bilco (BRGM) global results.

By observing the results it can be seen that the MPP simulates the industrial plant quite well in terms of global results.

TABLE 7
Mass balance results.

	IP	MPP
Concentrate % Cu	42.29	44.68
Cu recovery (%)	83.2	83.7
Weight recovery (%)	5.9	5.8

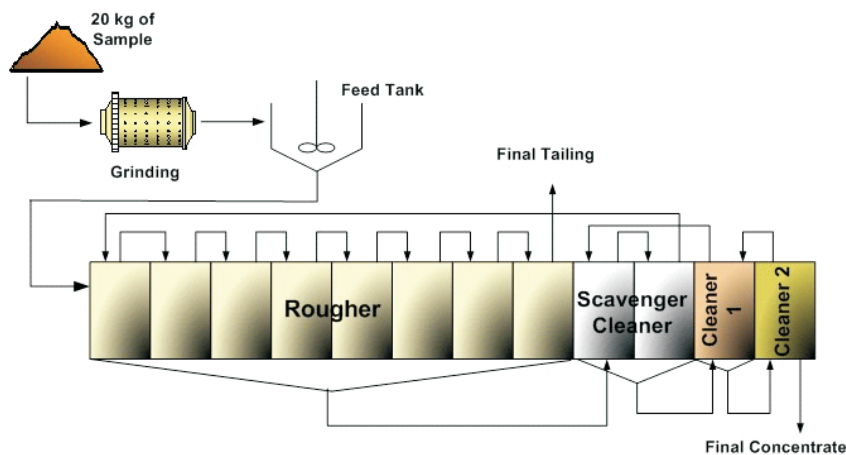


FIG 5 - Distribution of cells on the MPP.

The MPP concentrate particle distribution was slightly finer than the industrial plant (Figure 6). Nevertheless the copper distribution was very similar, as can be seen in Figure 7.

Tables 8 and 9 present the chemical results and mineralogy of the concentrates.

The MPP produced a concentrate of the same quality as the industrial plant. This shows that MPP provides trustworthy results. It can be used to predict metallurgical grade and recovery for feasibility studies of projects.

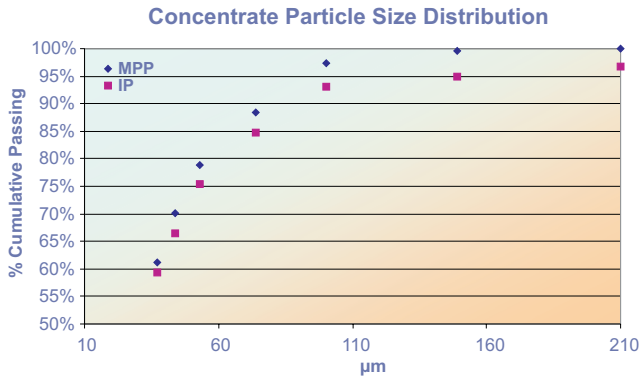


FIG 6 - Concentrate particle size distribution.

TABLE 8
Chemical analysis of concentrates.

Element	IP	MPP
Cu	42.29	44.68
Fe	15.4	14.9
S	21.3	23.0
F	194	227

TABLE 9
Concentrates mineralogy (wt per cent).

Minerals	IP	MPP
Quartz	3	2
Plagioclase	t	t
Piroxene	3	3
Clay minerals	r	r
Chlorite	t	r
Biotite	11	7
Sericite	r	t
Amphibole	4	3
Epidote	r	r
Talc	r	r
Rutile	r	r
Magnetite	r	r
Chalcopyrite	21	23
Covellite	r	r
Bornite	54	58
Chalcocite	t	t
Pyrite	r	r

* trace (t) – > 0.5% e < 1% rare (r) – < 0.5%

Mass and metallurgical balances

The rougher stage had a similar performance to the industrial plant (Table 10).

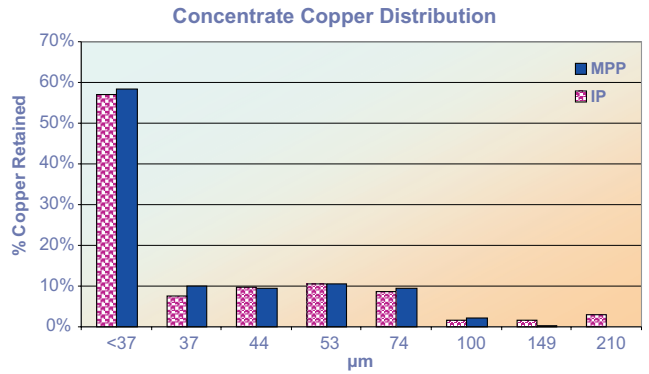


FIG 7 - Concentrate copper distribution.

TABLE 10
Stages performances.

Results		MPP	IP
Rougher	Feed stage % Cu	5.65	4.18
	Feed stage % solids	28.7	34.3
	Concentrate stage % Cu	15.74	11.58
	Concentrate stage % solids	20.2	28.1
	Enrichment ratio	2.79	2.77
	Weight recovery (%)	33.6	32.9
	Stage recovery	93.7	91.4
Cleaner 1	Feed stage % Cu	20.11	13.12
	Feed stage % solids	27.8	23.6
	Concentrate stage % Cu	69.5	25.0
	Concentrate stage % solids	34.93	34.06
	Enrichment ratio	1.74	2.60
	Weight recovery (%)	16.2	15.5
	Stage recovery	28.2	40.2
Cleaner Scavenger	Feed stage % Cu	17.25	9.28
	Feed stage % solids	27.8	25.0
	Concentrate stage % Cu	25.70	17.12
	Concentrate stage % solids	60.8	28.1
	Enrichment ratio	1.49	1.85
	Weight recovery (%)	39.6	22.1
	Stage recovery	59.0	40.8
Cleaner 2	Feed stage % Cu	34.93	34.06
	Feed stage % solids	69.5	25.0
	Concentrate stage % Cu	71.9	40.3
	Concentrate stage % solids	44.68	42.29
	Enrichment ratio	1.28	1.24
	Weight recovery (%)	43.5	62.7
	Stage recovery	55.7	77.8
Global	Concentrate % Cu	44.68	42.29
	Cu recovery (%)	83.7	83.2
	Weight recovery (%)	5.8	5.9

There were differences in the weight and copper recoveries of the internal streams of the cleaner circuit (Figure 8). However, there was a performance make-up among the stages which resulted in a concentrate with similar recoveries to those of the industrial plant.

The performance difference can be explained by the percentage of solids of the feed. The MPP rougher feed was more diluted than that of the industrial plant. This contributed to a better froth flow towards the launder. In order to control the concentrates grade in the cleaner stages, the pulp level and air flow rate were reduced. The froth drained a lot of water and became difficult to recover towards the launder. Aside from that, the solids concentration at the cleaner stages was very high for the MPP cells' size.

Factors that contributed to the difference between the industrial plant and the Mini Pilot Plant included:

1. *The internal flows sampling.* It was difficult to sample the internal flows frequently, in order to adjust each stages operating conditions, as they were very small and any amount taken had the potential to cause circuit destabilisation.
2. *The volume of the MPP cells.* As the MPP has 12 cells of the same volume and the feed rate is small, it became difficult to adjust the number of cells to the correct residence time at cleaner 2 stage.
3. *The cleaner 2 adjustment.* In order to achieve the concentrate target grade, the cell level and aeration were reduced. These

reductions caused the formation of a dense froth that did not flow properly.

4. *Closed circuit.* As the cleaner scavenger tailing returned to the rougher cell any adjustment at the cleaner stage was reflected at the rougher. This difficulty led to an adjustment of the circuit in order to get global results close to those of the industrial plant, without controlling the intermediate stages performances.
5. *Pulp solids percentage.* The solids percentage used was inadequate for the size of the MPP cells. Diluted pulps would facilitate the forward movement of the froth to the launder.

CONCLUSIONS

In comparison, the flotation Mini Pilot Plant simulated a concentrator mill very well in terms of global metallurgical results and concentrate quality. It is a very useful device to evaluate different circuits and confirm bench scale results for projects under development.

The available results confirmed that the MPP rougher stage behaved very similarly to the industrial plant.

For the studied circuit, the adjustment of the cleaner stage was troubled by the elevated solids percentage of the pulps.

It is believed that the MPP would be able to reproduce industrial results, even at the intermediate stages, if some of the points presented here were worked.

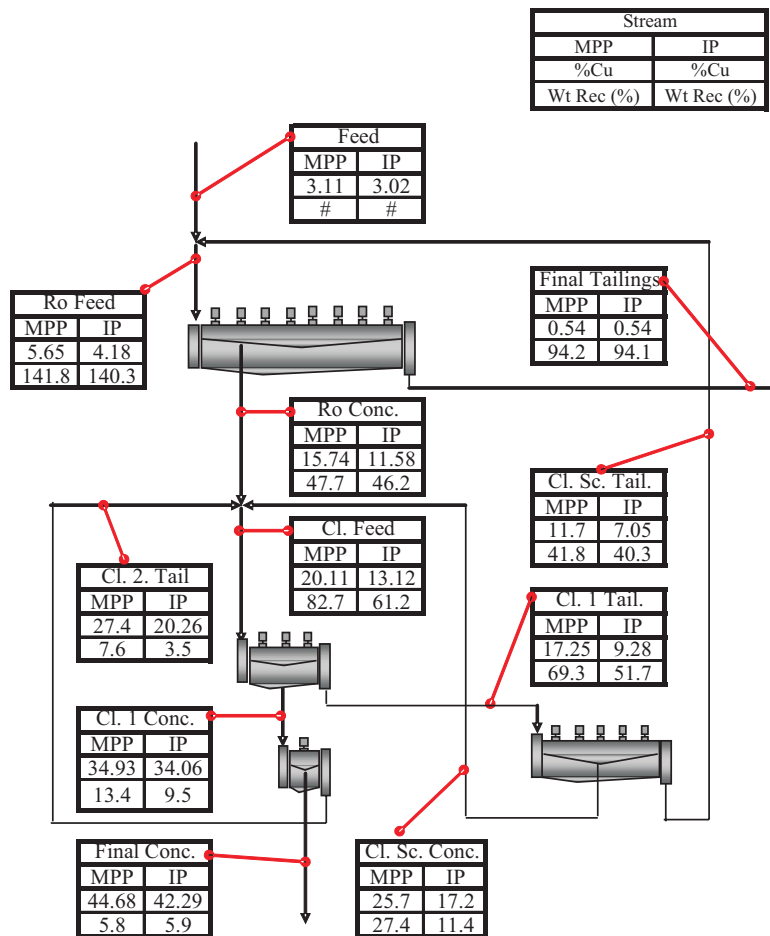


FIG 8 - Mass and metallurgical balance.

FUTURE WORKS

Future works that will be developed are presented below:

1. the use of a grinding kinetics model to estimate the best balls/rods distribution to simulate the size distribution of the industrial flotation feed;
2. the MPP validation for another copper circuit;
3. the measurement of the stages residence time during the surveys; and
4. the checking of the MPP performance for the reverse flotation of silica of an iron ore.

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