Leaching Practices at Mantos Blancos

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ABSTRACT

Empresa Minera de Mantos Blancos S.A. operates two copper mines in Chile: Mantos Blancos and Mantoverde. Oxide ore is processed by acid leaching followed by SX-EW to produce copper cathodes. In order to define the leach process adequately for each ore, an extensive metallurgical testwork program was carried out during the feasibility study for each of these projects. A combination of heap and dump leaching was selected for Mantoverde, while a modification to the existing vat leach operation was selected for Mantos Blancos.

INTRODUCTION

Empresa Minera de Mantos Blancos S.A. operates two open pit copper mines in Chile: Mantos Blancos, located 45 km NE from Antofagasta and Mantoverde, 120 km N from Copiapó, both mines in the Atacama desert. Mantos Blancos ore process comprises of two plants to treat oxide and sulphide ore separately. Sulphide ore is processed by milling and flotation to produce copper concentrate as a final product. Oxide ore is acid leached to produce copper cathodes in a solvent extraction and electrowinning (SX-EW) plant.

Mantoverde mine has only oxide ore which is processed by acid leaching, also to produce copper cathodes through an SX-EW plant. The leaching method adopted in each plant is the result of an extensive metallurgical testwork program carried out during the feasibility study for each of these projects.

The main oxide copper minerals present in Mantoverde ore are brochantite, malachite, chrysocolla and pitch limonite; while in Mantos Blancos oxide ore, atacamite is the predominant species with a minor amount of chrysocolla.

Mantos Blancos oxide plant was commissioned in 1960 with a capacity of 6,000 t/d using vat leaching to dissolve the copper. Continuous improvements allowed the process by the end of 1991 to increase to 9,500 t/d in ten vats of 4,000 t each in a counter-current leach circuit. The ore was crushed to less than 6 mm and loaded into the vats. Then, they were leached in an up-flow mode at a rate of 375 l/h/m^2. The rich solution tenor was 35-40 g/l Cu and 30-35 g/l chloride, and was the overflow of the most recently loaded vat. The barren

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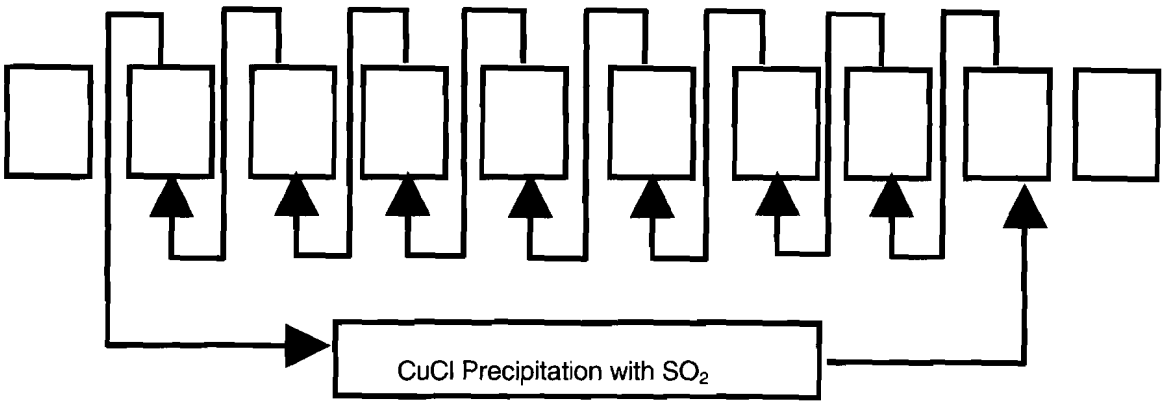

FIGURE 1 Old Mantos Blancos vat leaching circuit

solution from the downstream process, at a tenor of 7-10 g/l Cu, was fed to the oldest vat and the overflow was passed successively through the vats until it reached the new ore as shown in Figure 1.

The Mantos Blancos downstream process comprised of a stage of cuprous chloride precipitation with SO_2, followed by reduction with limestone and coke at high temperature to produce copper ingots. As part of the project to replace this process by an SX-EW plant, it was necessary to evaluate the alternative of changing the existing vat leaching by heap leaching, or modifing the existing vat circuit to produce copper solution suitable for solvent extraction.

Mantoverde was a completely new project and it was necessary to define the complete process. Metallurgical testwork for both projects were carried out in parallel at bench scale and pilot plant scale.

BENCH SCALE TESTWORK

Bottle rolling tests with ground material from drill core samples were carried out as preliminary tests on the Mantoverde project. These tests were only indicative of the amenability of the ore to leaching and were not used to predict the industrial results.

Composites samples taken from the current operation of Mantos Blancos and from the exposed ore and from the existing underground works from Mantoverde were used for column and pilot plant tests.

In order to have a short test to reproduce the vat leaching process, a bottle rolling test with crushed material was developed. This test allows the study of the effect of some variables and compares the effect against the current process. In a similar way for heap leaching, column tests were used to study the effect of the main variables.

Basically, bench scale tests were used to define the range of the variables for study in the pilot plant and as a base of the sizing for the pilot plant circuit.

Vat Leaching

The basic parameter for simulating the vat leaching process was the amount of solution per ton of ore applied during the process. In the case of vat leaching of Mantos Blancos ore, this number was 3 m^3/t. The bottle rolling test then was carried out using 1.5 l of solution and 0.5 kg of ore for 24 hours. The results obtained are shown in Table 1.

TABLE 1 Bottle rolling test (BRT) of crushed ore for Mantos Blancos

	Crush Size % + 6 mm	Copper Extraction % Soluble Copper	Net Acid Consumption Kg/t ore
Commercial Vat	15.2	78.6	38.1
BRT 1	15.2	79.0	38.5
BRT 2	10.2	86.0	45.0
BRT 3	9.3	87.0	46.0

As can be seen, copper extraction and acid consumption are well represented by the test. The results show that the effect of crush size significantly affects the final extraction. Based on these results, a pilot plant for vat leaching was designed.

Heap Leaching

Plastic columns of different diameters and heights were used to study the heap leaching alternative both for Mantos Blancos and Mantoverde. The variables studied were particle size, acid in agglomeration, irrigation rate and heap height. Selected results obtained are shown in Table 2 and Table 3.

Both for vat and heap leaching, the criteria for stopping the test was based on the incremental profit in the period, considering the acid consumption as the main cost of leaching, the downstream process cost and the copper extracted.

For example:

Copper price: 1.00 US$/lb or 2.20 US$/kg

Acid Cost: 65 US$/t

SX-EW Cost: 15 US¢/lb or 33 US¢/kg

The break even point is given when:

2.20 US$/kg Cu = 0.065 x MAC + 0.33 US$/kg Cu

Where MAC: maximum acid consumption

MAC = 29 kg H_2SO_4/kg Cu

Thus, the test was stopped when the differential acid consumption reached 29 kg H_2SO_4/kg Cu in one day, both for vat or heap leaching.

TABLE 2 Column test results - Mantos Blancos ore

Height m	Irrigation Rate l/h/m²	Acid in Agglom. Kg/t ore	Acid in Leach Soln. g/l	Leaching Time Days	Head Grade % Sol. Cu	Recovery % Sol. Cu	Net Acid Consumption Kg/t Ore
5	30	13	24	34	1.06	95.6	50.5
5	20	13	24	40	1.12	96.1	51.0
5	30	13	18	34	1.08	94.9	50.0
5	20	13	18	44	1.13	94.4	43.5
5	30	15	24	30	1.07	94.2	47.7
5	20	15	24	38	1.11	95.4	47.8
5	30	15	18	30	1.02	93.9	41.1
5	20	15	18	44	1.05	95.1	43.1
10	30	15	24	54	1.03	95.9	53.6
10	30	15	18	60	1.05	95.0	45.8

TABLE 3 Column test results - Mantoverde ore

Height m	Crush Size mm	Irrigation Rate l/h/m²	Acid in Agglom. Kg/t ore	Acid in Leach Soln. g/l	Leaching Time Days	Head Grade % Sol. Cu	Recovery % Sol. Cu	Net Acid Consumption Kg/t Ore
4	12	7.5	21	35	47	1.11	84.7	63.4
4	10	10.0	21	35	47	1.11	86.9	75.3
6	10	7.5	21	35	47	1.10	81.4	51.3
6	12	10	21	35	43	1.11	84.4	57.9
5	10	7.5	14	50	43	1.18	83.1	59.5
5	10	7.5	23	50	39	1.18	87.0	59.9
5	10	10	14	37	43	1.18	83.6	55.1
5	10	10	23	37	39	1.20	87.4	58.2
5	10	15	14	25	43	1.18	85.8	54.0
5	10	15	23	25	39	1.16	88.4	54.4

PILOT PLANT TESTWORK

Based on the previous results, pilot plants were built to confirm and scale-up the results. Boxes of 2 x 2 m and 6 m in height for heap leaching testwork and columns of 0.70 m diameter and 8 m in height for vat leaching were installed in pilot plants on site. The leaching circuit was completed with solvent extraction and electrowinning facilities in both projects.

The results obtained in these tests are summarized in Tables 4, 5 and 6. All the leaching tests were stopped when the incremental acid consumption reached the maximum economic limit, as explained before.

The samples fed to the vat leaching pilot plant were taken from the feed to the commercial vats in the existing plant that were working with the old process explained before. The results obtained in the pilot testwork were compared with the results obtained in the corresponding commercial vat.

The results shown in Table 4 are the average of 165 tests in the pilot plant.

TABLE 4 Vat leaching pilot plant results

	Pilot Plant Result	Commercial Vat Result
Head Grade % Cu Soluble	0.95	0.92
Tailing Grade % Cu Soluble	0.19	0.20
Extraction % Cu Soluble	79.9	78.7
Net Acid Consumption Kg/t ore	23.7	23.4

TABLE 5 Average results of heap leaching tests at the Mantos Blancos pilot plant

Heap Height m	Irrigation Rate $l/h/m^2$	Leaching Time Days	Head Grade % Sol. Cu	Residue Grade % Sol. Cu	Extraction % Sol. Cu	Net Acid Consumption Kg/t ore
4	20	36	0.93	0.07	92.5	37.6
5	15	66	1.22	0.15	87.9	48.7
5	20	43	0.93	0.07	91.9	44.8
5	28	42	1.32	0.10	92.6	47.8
6	20	63	1.32	0.11	92.2	53.6

TABLE 6 Average results of heap leaching tests at the Mantoverde pilot plant

Heap Height m	Particle Size mm	Leaching Time Days	Extraction % Sol. Cu	Net Acid Consumption Kg/t ore
5	203	116	45.3	11.9
5	64	94	54.3	14.1
5	38	80	66.9	24.7
5	25	93	76.6	29.1
5	19	67	78.2	31.1
5	13	60	83.0	33.6
5	10	50	86.5	27.9

In order to select the final conditions for the design heap leaching, each alternative was evaluated on a financial basis considering the following aspects:

- Capital cost of the SX plant that depends on the Pregnant Liquor Solution (PLS) flowrate.
- Operating costs in the leaching area that are mainly the following:
  - Acid consumption
  - Leach area preparation

Leach area is a function of the heap height and leaching cycle and can be calculated for each case. Evaluating the economic effect of the variables, it was found that the best criteria for the design are the following:

	Mantos Blancos	Mantoverde
Particle Size	90% - 6 mm	100% - 10 mm
Irrigation rate ($l/h/m^2$)	20	15
Heap Height	4 m	5 m

Vats v/s Heap Leaching

As shown in the previous table, the recoveries obtained through heap leaching were significantly higher than those obtained in vat leaching, but also resulted in a higher acid consumption. In order to decide which alternative to select, basic engineering for both cases was prepared, including the required SX-EW plant. The results are shown in Table 7.

TABLE 7 Vat v/s heap leaching

	Vat Leaching	Heap Leaching
Capital Cost (US$ 000)	68,000	94,000
Average Plant Operating Cost (US¢/lb Cu)	32.0	38.2
I.R.R. (%)	14	5

Thus, the vat leaching alternative was selected for Mantos Blancos.

One of the main disadvantages of the vat leaching process is the amount of solids in the PLS. As the leach is carried out in the upflow mode, during the first two hours of the process, suspended solids can reach up to 10 g/l. As the effect of solids in the solvent extraction plant is well known, exhaustive study of several alternatives of clarifier available in the industry was carried out to guarantee a maximum of 20 ppm of suspended solids in the feed to SX. Equipment from three suppliers were tested at pilot plant scale, achieving the required results.

Dump Leaching Test

During the development of the projects a significant amount of low grade material (lower than the economic cut off grade) was being extracted from the mine. It was proposed to treat this material in a separate way.

Preliminary testwork showed that 70-80% of the total copper may be extracted in material crushed to -2 inches. However, the grade was not high enough to justify crushing this material. Two tests with ROM material were carried out for Mantoverde and Mantos Blancos achieving encouraging results, as shown in Table 8.

PLANT CONSTRUCTION

Vat Leaching (Mantos Blancos)

In order to adapt the existing vats for the production of PLS required for the SX plant, major modifications to the piping in the area were required.

The crushed ore is blended with acid in two drums and loaded by a stacker into twelve vats. The loading is done in layers of 50 cm to avoid segregation. Intermediate solution is fed in such way to bring the solution level approximately 50 cm lower than the ore level.

Once the vat is fully loaded, the rich solution overflows to the clarifiers; leaching time with intermediate solution is 40 hours. Then raffinate solution from the SX plant is fed to the vats for another 40 hours; the overflow solution of this stage is collected in intermediate tanks to be pumped to the first leach

TABLE 8 Dump leaching test

	Head Grade		Recovery		Acid Consumption	Cycle
Ore	Total Cu	Sol. Cu	Total Cu	Sol. Cu	Kg/t ore	Days
Mantoverde	0.34	0.29	51.7	62.0	16.8	121
Mantos Blancos	0.44	0.30	47.8	70.0	22.3	180

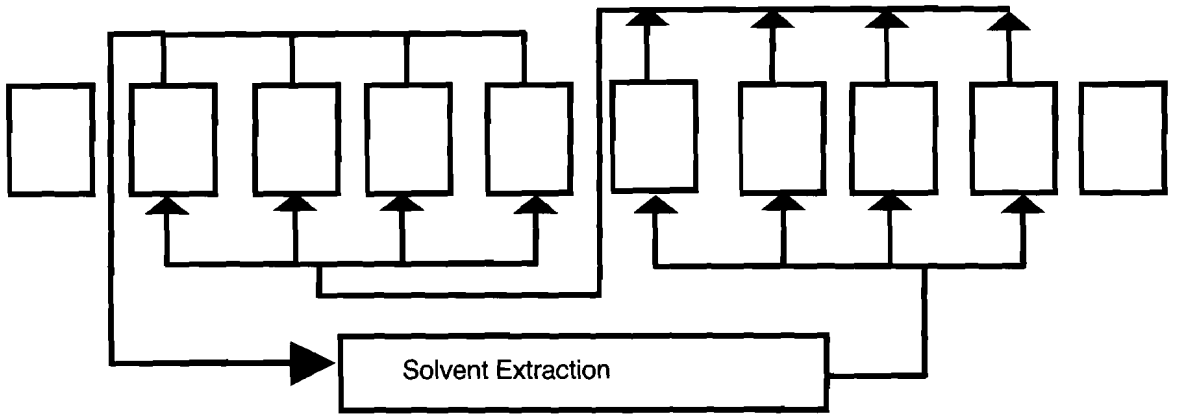

FIGURE 2 Modified vat leaching circuit

cycle. Finally the vat is unloaded by cranes and the tails are disposed on special dumps. The false bottom of the vat is cleaned and repaired when necessary before the next batch.

In order to avoid any contamination of the organic phase with asphalt, it was also necessary to change the vat lining from asphalt to HDPE. A minimum amount of asphalt in the organic phase immediately results in severe problems in the SX plant; phase disengagement of the emulsion from the mixers increases dramatically.

Two EIMCO reactor clarifiers were installed after the vats and prior to the SX plant to control the suspended solids.

Heap Leaching (Mantoverde)

The area required was prepared with a maximum slope of 5%. Due to stability conditions, a maximum height of 50 m can be reached in each pad. Heap stacking is made by a combination of mobile conveyors and a stacker in layers to a height of 5 m. The first layer is loaded over a protective lining of PVC of 0.75 mm thickness. Over this layer is loaded a second lift and, in this case, a PVC liner of 0.3 mm is used. Drainage pipes of 150 mm are installed prior to stacking the agglomerate. Two agglomeration drums provide the blending of the acid required for the leaching.

The ore is stacked in heaps of 100 m wide and 800 m long. The solution is applied through a piping system that divides each heap into 8 modules. Each module has 10 lines of sprinklers that is the operational unit. The leaching cycle starts by irrigating intermediate solution over the ore for 33 days to produce

rich solution (PLS) at a rate of 15 l/h/m^2. The PLS is collected in a storage pond and pumped to the SX plant. The raffinate solution from the SX plant is pumped to the second leach stage at the same irrigation rate to produce the intermediate solution for another 17 days.

Dump Leaching

An area was prepared to receive the dump material (0.3 - 0.5% Cu) at Mantoverde. The area preparation is as follows:

- Grading
- 150 mm sand
- PVC membrane
- Drain pipes
- 1 m protection of graded material, minus 1/2"

Dump material will be irrigated at 10 l/h/m^2 for 180 days with raffinate solution from the SX plant. Rich solution will be combined with the intermediate solution of the heap leaching circuit (Figure 3).

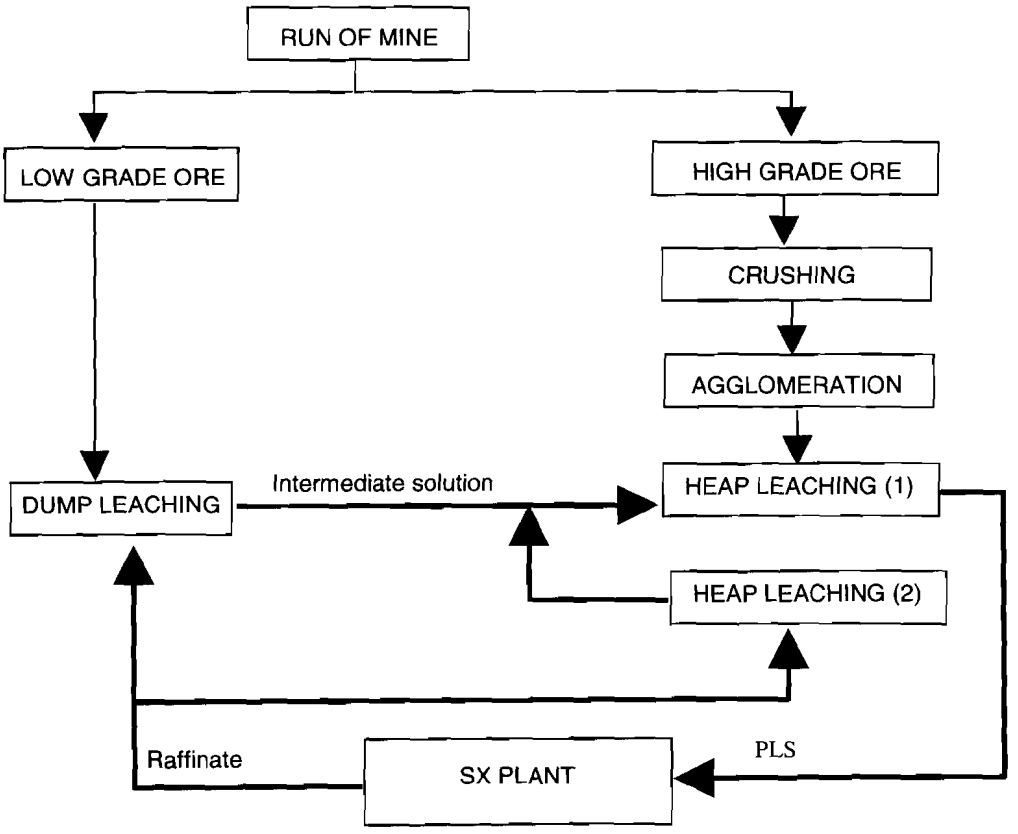

FIGURE 3 Mantoverde leaching circuit

The material is loaded by trucks in 10 m lifts; before leaching, the surface is ripped and then the dump material is preconditioned with acid solution (70-200 g/l H_2SO_4).

PLANT RESULTS

Both projects were commissioned at the end of 1995 and reached the nominal capacity in a very short period. Some differences with the pilot plant results have being obtained, both in the vat leaching and heap leaching processes.

Vat Leaching

Since the commissioning of the plant a significant increase in copper extraction was obtained in the commercial plant compared with the results obtained in the pilot plant. The higher copper dissolution also affected the impurity balance, and the dissolved silica reached 2.5 g/l compared with 0.2 g/l obtained in the pilot plant, producing significant amounts of crud in the SX plant.

The reason why this did not occur in the pilot plant has not been completely understood and probably is a result of the better mixing of the ore with acid during the preconditioning stage in the drums. This operation in the pilot plant was difficult to make, due to the small acid flowrate required during the loading of a column.

Heap Leaching

The current results up-to-date obtained in Mantoverde have shown that the expected irrigation rate of 15 l/h/m^2 cannot be reached. The maximum rate that can possibly be applied to the ore is 11 l/h/m^2, without producing excessive ponding on the heaps and slumping, which affects the stability of the heap. In spite of the fact that pilot plant was tested at a much higher irrigation rate, this effect was not observed, probably due to the wall effect. The net result of the lower irrigation rates has been a significant increase in the leaching time, in the same proportion as the irrigation rate decrease (50%); leach time is now 90 days in order to obtain the expected copper extraction.

REFERENCES

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