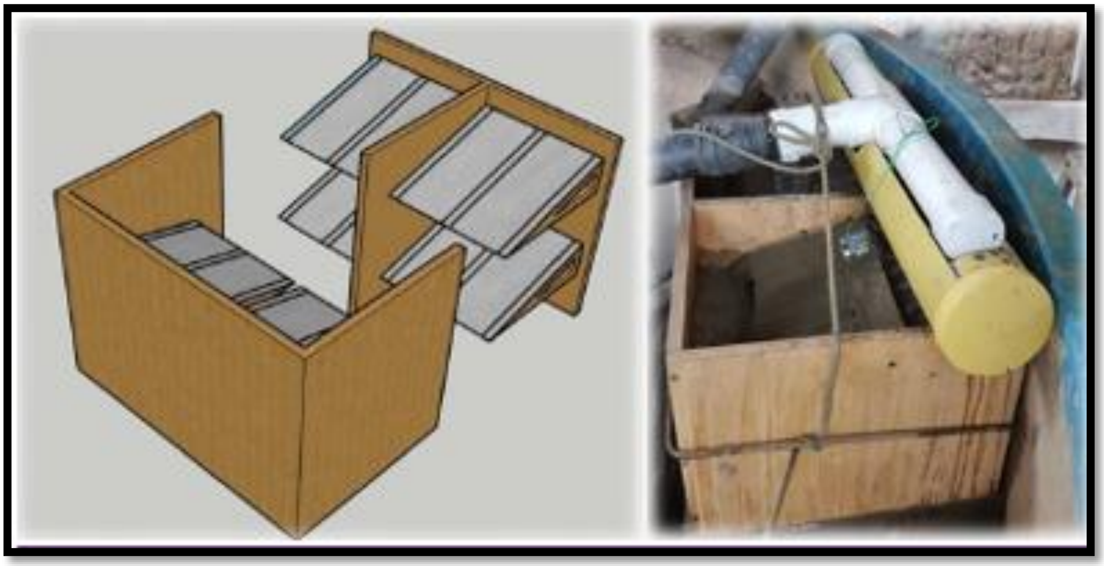
Promoting the recovery and responsible management of mercury in contaminated tailings from artisanal gold mining in Colombia.

Interim Technical Report of Copper Plate Pilot Test Results, phase I
August - 2020



Funded by:

Partner:

El ambiente es de todos
Minambiente

Implemented by:

PURE EARTH

With the technical support of:

Centro Nacional de Producción Más Limpia

This publication was funded by a grant from the United States Department of State. The opinions, findings and conclusions stated herein are those of the authors and do not necessarily reflect those of the United States Department of State.

Technical Team

Alfonso Rodríguez Pinilla
Country Director Pure Earth Colombia

Angie Tatiana Ortega-Ramirez
Project Coordinator Pure Earth Colombia

Lina Hernández
Regional Coordinator for Latin America and the Caribbean Pure Earth

Natalia Echavarria Gómez
Support Professional National Center for Cleaner Production

Acknowledgments

Shun-Ping Chau
U.S. Environmental Protection Agency (EPA)

Marcello Veiga
Professor Emeritus, University of British Columbia

Table of Contents

1. Introduction

Pilot field tests for mercury recovery in tailings generated by artisanal and small-scale gold mining (ASGM) are carried out under the development of the project entitled: “Promoting the recovery and responsible management of mercury in the contaminated tailings of artisanal gold mining in Colombia,” which is executed by Pure Earth and funded by the U.S. Department of State. As a strategic partner of the project for technical support, the National Center for Cleaner Production and Environmental Technologies (CNPMLTA) is added.

The overall objective of the project is to reduce the amount of mercury present in tailings from the use of this element in artisanal and small-scale gold mining in Colombia. The specific objectives are:

- Identification of promising mercury recovery techniques and increased understanding of criteria for the selection of a technique for use in the context of ASGM in Colombia.
- Develop a model for the responsible and cost-effective recovery of mercury and gold from tailings, based on previous experiences in experimental processing plants.
- Development of technical protocols to safely manage, store and dispose of mercury recovered or seized from ASGM activities, including contaminated tailings and mercury captured from amalgam burning.

This document is developed within the framework of the second specific objective of the project, which presents the results obtained from the pilot field test of mercury recovery present in the tailings generated by artisanal gold mining in Colombia, Using the technology called “Copper Plates,” which was one of the most promising identified in the first phase of the project.

2. Main Objective of the Tests

The main objective of the pilot field tests is to test the effectiveness of the technology called "Copper Plates" in the recovery of elemental mercury (Hg°) that may be present in tailings that are reprocessed for gold by small-scale mining.

3. Description of the plant and tailings

3.1 Location of the plant

The tailings processing plant where the pilot tests were conducted belongs to the mining title of the "Juan Diaz" mine, which is located in Yali municipality in Antioquia department.

Figure 1. Geographical location of the pilot silver

Taken from: https://www.google.es/maps/previewo

Figure 2. Processing plant in Yali

Source: Pure Earth - 2020

3.2 Description of the plant process

The Juan Diaz plant is equipped to realize the benefit of both free gold and associated gold. The construction of the installations takes advantage of the morphology of the land to use gravity in the passage of material from one stage to another, in the upper part of the plant (see Figure 2) are the equipment associated with the recovery of free gold, which, these are mechanical and gravimetric methods that do not use mercury for profit, and include crushers, mills and vibrating table, however, this part of the plant is currently in disuse.

Physically, in the central part of the facilities are the equipment for the recovery of associated gold, which are mainly the cyanidation tanks, flotation, the activated carbon recovery column and the electrochemical desorption unit.

At present the process begins with the reception of the tailings, the space for this activity is physically located at the base of the facilities (see Figure 2), the tailings are wetted with water and dragged to the filter and solid pump, which, it takes the now-called slurry to the flotation tank or directly to the cyanidation tanks, depending on the processing indications.

After the cyanidation has been completed it passes to the absorption unit with activated carbon and finally the electrochemical desorption unit is filtered and passed, which is not continuous, i.e. electrochemical desorption is performed by accumulation of treatment of several tailings over a period of time. At the end of the process the tailing is taken to the pool. Figure 3 shows a schematic of the gold extraction process of the plant.

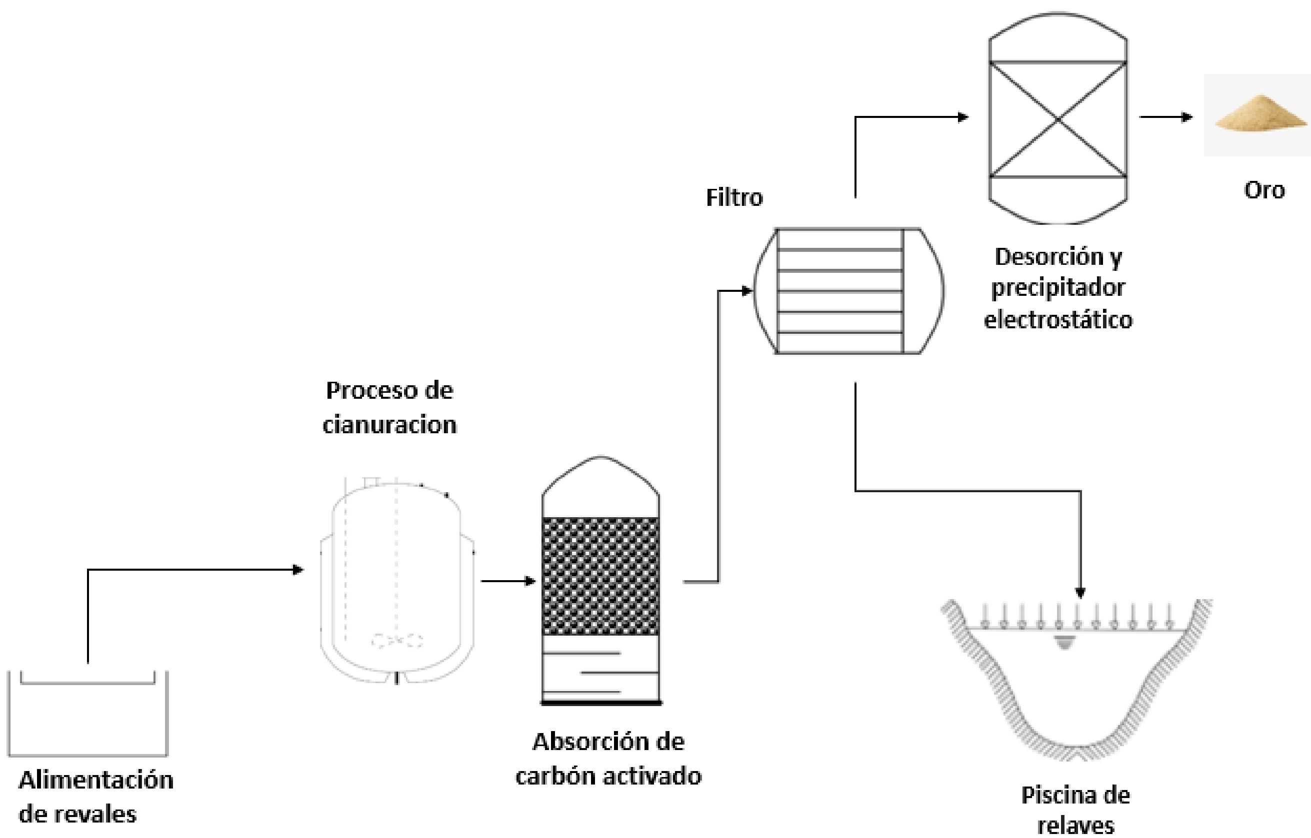


Figura 1. Proceso de la plata piloto

Fuente: Pure Earth – 2020

Some of the parts of the plant are shown in the following photographs.

Figure 4. Tailings feeding

Source: Pure Earth – 2020

Figure 2. Soil pumps

Source: Pure Earth – 2020

Figure 3. Tailings pool

Source: Pure Earth – 2020

3.3 Description of tailings

The tailings used for the pilot tests come from three municipalities of Antioquia, where small-scale mining has been developed and which contain the presence of mercury and residual gold, the age of generation of these tailings is obtained by information from the miners of the area, but they are not sure of 100% of the real age of the same.

Table 1. Description of the tailings

Tailings Denomination	***Quantity processed (ton)***	***Estimated age***
Monda	6,4	6 months
Floresta	4,5	+10 years
Anza	5,3	8/10 years

Figure 4. Tailings used in the process

Source: Pure Earth – 2020

Figure 5 shows the location of the provenance sites of the tailings used in the mercury recovery process during the pilot test.

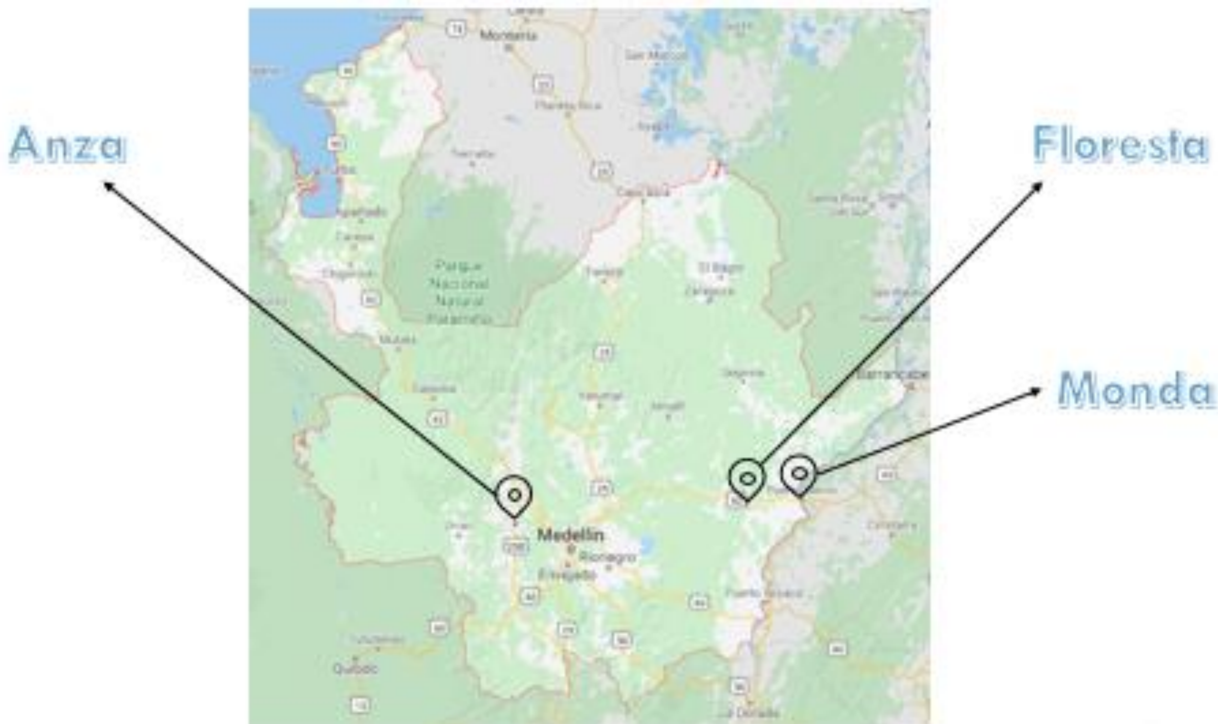


Figure 5. Location of the tailings

Taken from: https://www.google.es/maps/previewo

4. Description of pilot tests

4.1 Preparation of copper plates

In order to carry out the mercury recovery tests from the tailings, two (2) sets of copper plates were built, each with six plates located in the form of a ladder with a slope of approximately 30° of inclination.

Each of the plates have a size of 30 x 30 cm, which corresponds to a total contact area of 5,400 cm^2 of the six plates with the tailings.

The key principle in the capture of mercury in this technology is in the affinity of silver for mercury, so it is necessary to perform an electrochemical silvering of copper plates, which is one of the most recognized processes in the industry and is considered an interesting teaching activity for the integration of electrochemistry, chemistry, physics and art (Lagos & Camus, 2017). The main purpose of silvering is to be able to generate a sufficient contact area for an amalgam to form between the silver superimposed on the plate and the mercury, available in elemental form (Hg°), in the tailings.

The overall manufacturing process of the plates is described in Figure 6.

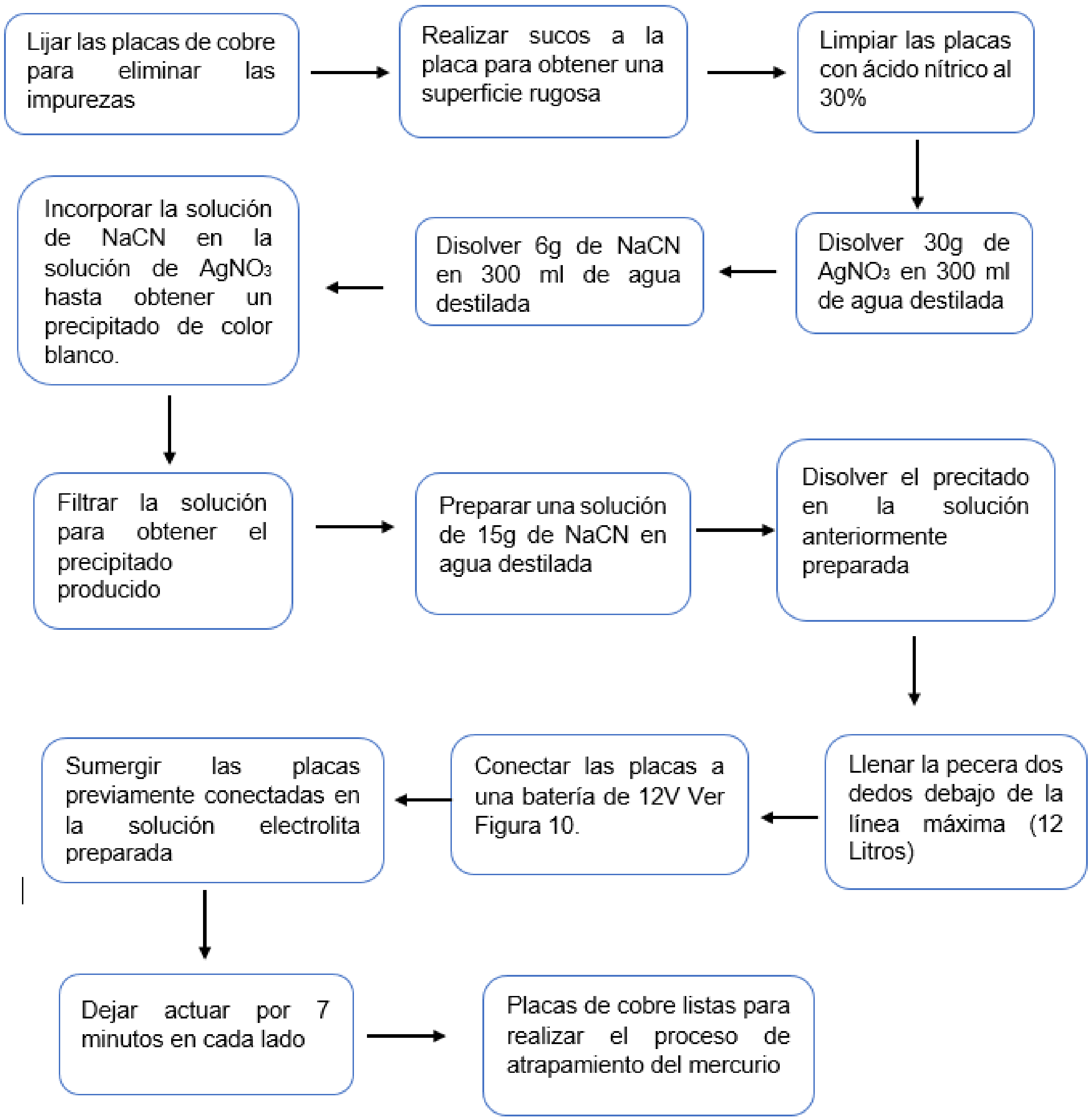


Figure 6. Procedure for the manufacture of copper plates amalgamated with silver

Some of the chemical reactions involved in the process are:

$$(1) \quad AgNO_3 + NaCN \rightarrow [Ag(CN)] + NaNO_3$$

$$(2) \quad AgNO_3 + 2NaCN \rightarrow Na[Ag(CN)_2] + NaNO_3$$

Figure 7. Assembly of the electrolysis process

Source: Pure Earth – 2020

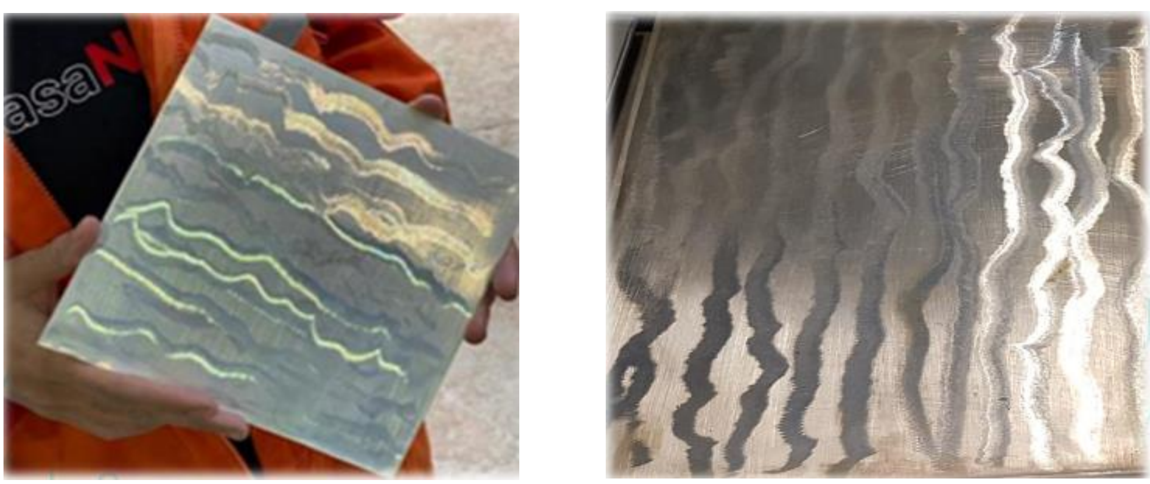


Figure 8. Results obtained silver copper plates

Source: Pure Earth – 2020

4.2 Installation of copper plates in the process

Taking into account that the main purpose of the use of copper plate technology corresponds to removing mercury before the tailings beneficiation process to obtain residual gold, one of the plate sets was installed just before the cyanidation process (point A), which is currently being developed by the Juan Díaz plant. Likewise, to estimate the efficiency of the process, the other set of plates was installed at the exit of the process and before the deposit in the tailings (Point B), as shown in the following figure.

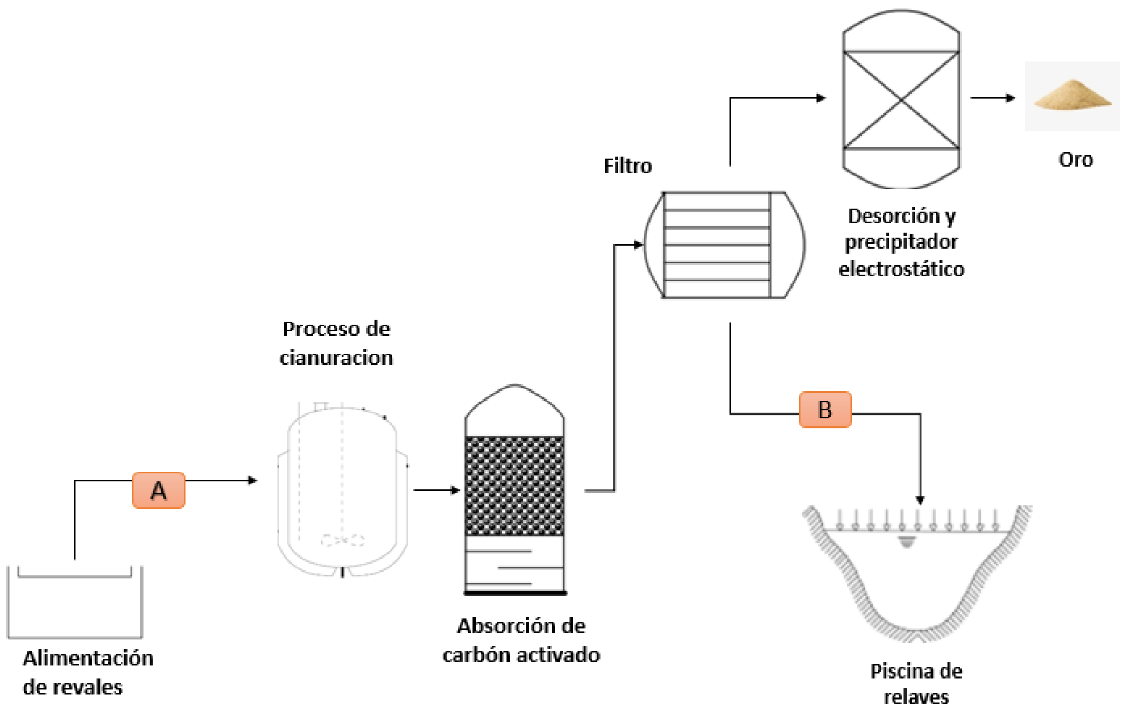


Figure 9. Location of copper plates in the process

Source: Pure Earth – 2020

The plates must be installed on a support to ensure the passage of the pulp through the plates. The installation of the plate support at point A was carried out on the top of the cyanidation tank where a flow distribution circuit was adapted at the inlet of the plates, so that the fall of the tailings solution had contact over the entire extension of the plates, as seen in the following photographs.

Figure 10. Copper plate support module and flow distribution circuit

Source: Pure Earth – 2020

Figure 11. Location of the media at Point A. Before the cyanidation process

Source: Pure Earth – 2020

The installation of the plate support at point B was carried out taking advantage of the difference in height of the last process (filter) in relation to the tail pools. Likewise, the same flow distribution circuit was used at the entrance of the plates, so that the fall of the tailings solution had contact over the entire extension of the plates, talc as can be seen in the following photographs.

Figure 12. Location of the media at point B. After the cyanidation process

Source: Pure Earth – 2020

4.3 General conditions of operation of the tests

For each of the field tests, a preparation of tailing pulp (Dissolution of the tailings with water) between 25% and 30% of solids was carried out, which was pumped into the initial cyanidation tank, passing first through the plates.

Sample:

During the process, samples were carried out at three (3) strategic points of the process which correspond to the beginning, intermediate and end. The conditions of the sampling protocol were:

- Homogenized compound sampling
- Drying of the sample, to obtain the least variation of the data in the reading of the X-ray Fluorescence (XRF) equipment
- Take 3 samples replicated per point
- Quantity per sample of approximately 300 grams

- Sample stored in a bag with an airtight seal.

Determination of Mercury and Gold:

For each of the samples, the following readings were made:

- Minimum of 20 Mercury (Hg) readings per sample with XRF equipment, Olympus Delta Reference brand.
- Measurements were made in the form of a grid distribution on each side of the bag containing the sample.
- The reported value of mercury concentration corresponds to the average of the readings made.
- Each bag with the sample was read from mercury vapors with the HERMES equipment, which has a detection range between 0 and 2.000 $\mu g/m^3$.
- The same reading sample with the XRF is sent to an accredited laboratory for confirmation of the fe Hg value for Atomic Absorption in cold steam and the amount of Gold present by the fire test.

5. Results

Below are the results obtained in the operation of the plates for each of the tailings.

5.1 Monda tailing

Table 2 shows the general process conditions for Monda tailings and Table 3 shows the concentrations obtained of mercury in each of the stages of the control process, i.e. the initial phase, after step A and after Step B.

Table 2. Monda Tailings Overview

General	Information
Age	6 months
Flow (m^3/hr)	6,4
Ton	6,34
Solids %	28,7

Table 3. Monda Tailings Concentrations

	Relave Monda				
		Despues	% Reduccion	Despues	% Reduccion
	Inicial	Paso A	Paso A	Paso B	Total
Hg (ppm) (Lab)	74,9	58,2	22,30	19,6	73,83
Hg (ppm) (XRF)	62,37	17,70	71,62	10	83,97
Hg (ug/m3) Vapor	37,45	14,50	61,28	10,60	71,70
Au (gr/ton)	10,79	10,96		1,52	85,91

The results obtained for the Monda tailings report a trend of reduction of the mercury concentration present in the tailings in all types of measurement and in each of the stages of the executed process, which corresponds to the expectations of the use and purpose of the copper plate technique.

In order to show if the copper plates are performing the function of recovering or removing mercury from the tailings, readings of the plates were made with the XRF equipment before the process where the reported mercury concentrations were "zero" (0), that is, without the presence of mercury. Likewise, readings of the plates were made after the process with the Monda tailings where the following concentrations of mercury were evidenced in different parts of the plates. The results of these measurements are shown below.

Table 4. Concentrations obtained for copper plates point A

Plate Nro	Average concentration Hg (ppm) on copper plates
1	56,2
2	183
3	118
4	68,8
5	118
6 *	1,717

* *This value was taken on one of the grooves of the copper plates and not on the smooth surface as was done in the other readings reported in this table.*

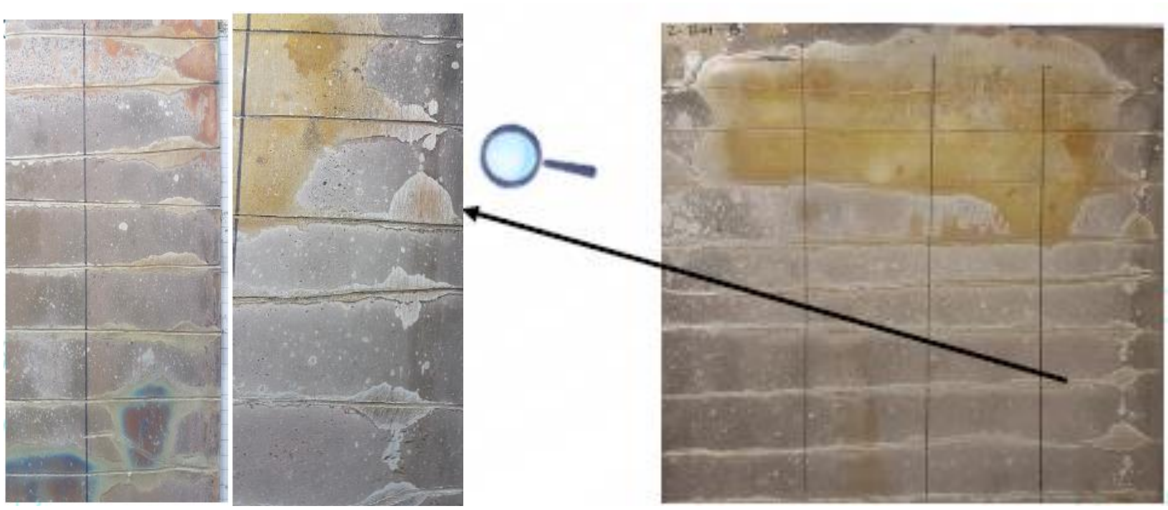


Figure 13. Copper plates point A after the process

At the time of making the measurements on the plates, it is evident that a greater concentration is found in the grooves of the plate, so it was decided to make the measurements of the plates of point B directly in the grooves where the following results are obtained.

Table 5. Concentrations obtained for copper plates point B

Plate Nro	Average concentration Hg (ppm) over the grooves of copper plates
1	39,130
2	63,623
3	26,959
4	22,101

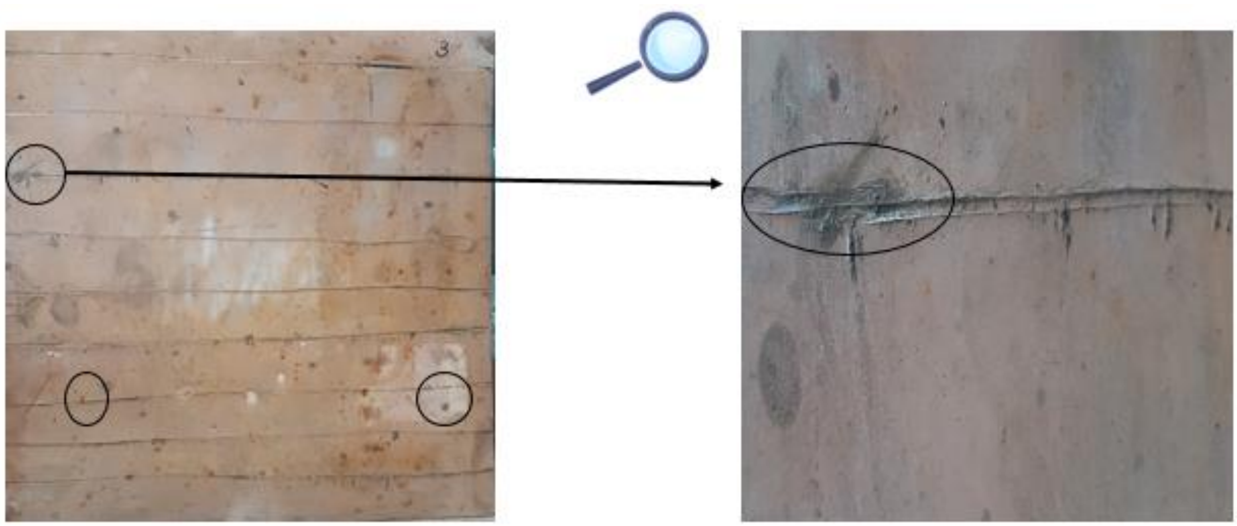


Figure 14. B-spot copper plates after the process

5.2 Anza Tailing

Table 6 shows the general process conditions for the Anza tailings and Table 7 shows the concentrations obtained of mercury in each of the stages of the control process, i.e. the initial phase, after step A and after Step B.

Table 6. Anza Tailings Overview

General	Information	
Age	8/10 años	
Flow (m3/hr)	7,4	
Ton	5,2	
Solids %	33	

Table 7.Anza Tailings concentrations

	Revale Anza				
		Despues	% Reduccion	Despues	% Reduccion
	Inicial	Paso A	Paso A	Paso B	Total
Hg (ppm) (Lab)	100	51,5	48,5	80	20
Hg (ppm) (XRF)	92,33	3,83	95,85	56,21	39,13
Hg (ug/m3) Vapor	27,55	12,10	56,08	0,95	96,55
Au (gr/ton)	12,84	10,4	[redacted]	2,33	81,85

The values reported for the Anza tailings show a decrease in mercury concentration in steps A and B compared to the initial concentration. However, the concentrations in Step B report a higher value than those reported in Step A, which requires a more detailed analysis of external operating conditions during the process of obtaining gold that the plant performs.

On the other hand, one of the values reported by the laboratory yields 100 ppm. This is the maximum value reported by the laboratory according to the calibration that the team had at the time of analysis, which represents for the study that this sample could have a concentration greater than 100 ppm. This limitation has already been identified with the laboratory and will be controlled for when phases II and III are executed.

5.3 Floresta Tailing

Table 8 shows the general conditions of the process for the tailings of the Forest and Table 9 the concentrations obtained of mercury in each of the stages of the control process, that is, the initial phase, after step A, however, due to logistical reasons it was not possible to make measurements at the end of the process in Step B.

Table 8. Floresta Tailings Overview

General	Información
Edad	10 años
Flujo (m3/hr)	7,6
Ton	4,5
Solidos %	32

Table 9. FlorestaTailing Concentrations

	Relave Floresta				
		Despues	% Reduccion	Despues	% Reduccion
	Inicial	Paso A	Paso A	Paso B	Total
Hg (ppm) (Lab)	100	100	NA	NA	NA
Hg (ppm) (XRF)	174,07	108,57	37,63	NA	NA
Hg (ug/m3) Vapor	7,70	15,30	-98,70	NA	NA
Au (gr/ton)	7,25	9,18	[redacted]	NA	NA

The values reported for the Floresta tailings show that for the mercury vapor readings there is an increase of almost 98% that does not respond to the trends found in the other tailings. This point will be taken into account in future readings and look for possible deviations in the process of taking a sample or reading.

Likewise in the tailings of Anza, two of the samples report mercury concentration values 100 ppm made by the laboratory. It should be remembered that this value corresponds to the maximum reported by the laboratory according to the calibration that the team had at the time of analysis, which represents for the study that this sample could have a concentration greater than 100 ppm, for this reason it was not possible to determine the % reduction of mercury in step A. Esta limitante, ya fue identificada con el laboratorio y se tendrá controlada para cuando se ejecuten las fases II y III. This limitation has already been identified with the laboratory and will be controlled for when phases II and III are executed.

5.4 Comparison of results

Below are the results obtained in comparison by tailings for each of the types of mercury concentration measurements of tailings.

Table 10. omparison of tailings results

	(LAB) - Hg (ppm)				
		Despues	% Reduccion	Despues	% Reduccion
Relave	**Inicial**	**Paso A**	**Paso A**	**Paso B**	**Total**
Monda	74,9	58,2	22,30	19,6	73,83
Floresta	100	100	NA	NA	NA
Anza	100	51,5	48,50	80	20,00

	(XRF) - Hg total (ppm)				
		Despues	% Reduccion	Despues	% Reduccion
Relave	**Inicial**	**Paso A**	**Paso A**	**Paso B**	**Total**
Monda	62,37	17,70	71,62	10	83,97
Floresta	174,07	108,57	37,63	NA	NA
Anza	92,33	3,83	95,85	56,21	39,13

	Hg Vapores (ug/m3)				
		Despues	% Reduccion	Despues	% Reduccion
Relave	**Inicial**	**Paso A**	**Paso A**	**Paso B**	**Total**
Monda	37,45	14,50	61,28	10,60	71,70
Floresta	7,7	15,3	-98,70	NA	NA
Anza	27,55	12,1	56,08	0,95	96,55

6. Comments on the results

- Pilot scale test at Yalí plant demonstrates an effectiveness of copper plate technology in reducing mercury content in contaminated ASGM tailings (39% - 84%). However, the phase II and III tests need to be developed in order to draw final conclusions.

- Although there is a consistency of the mercury reading data between the XRF and the laboratory of the samples of the Monda and Floresta tailings, variations are evident for the Anza tailings, which must be analyzed under further pilot tests.

- The values reported by the laboratory of 100 ppm, correspond to the maximum value reported by the laboratory according to the calibration that the team had at the time of analysis, which represents for the study that the samples could have a concentration greater than 100 ppm. This limitation has already been identified with the laboratory and will be controlled for when phases II and III are executed.

- More information needs to be collected in order to determine the existence of a direct relationship between the amount of mercury removed by copper plates versus the age of the tailings.

- It is necessary to improve the method of drying samples in the field to take standardization of XRF, laboratory and mercury vapor readings. The time factor is decisive.

- According to the results obtained so far, there is no evidence that copper plates affect the gold content present in the tailings.

- The pre-treatment of some tailings by miners may be affecting the effectiveness of the process and the useful life of the plates.

7. Future actions

- Pending development of pilot tests of Phase II and III, it is barely possible due to issues of mobility restrictions due to the pandemic situation. (Estimated date from September onwards)

- Field control variables will be included to estimate the service life of copper plates. However, the plate washing process continues as an option within the process.

- Adjustments will be made to the plate plating process by testing tin as a support part on the copper plate.

- The support module of the copper plates will be optimized, so that it is more functional and allows rapid changes in the field, increasing the surface area of contact between the tailings and the plates.

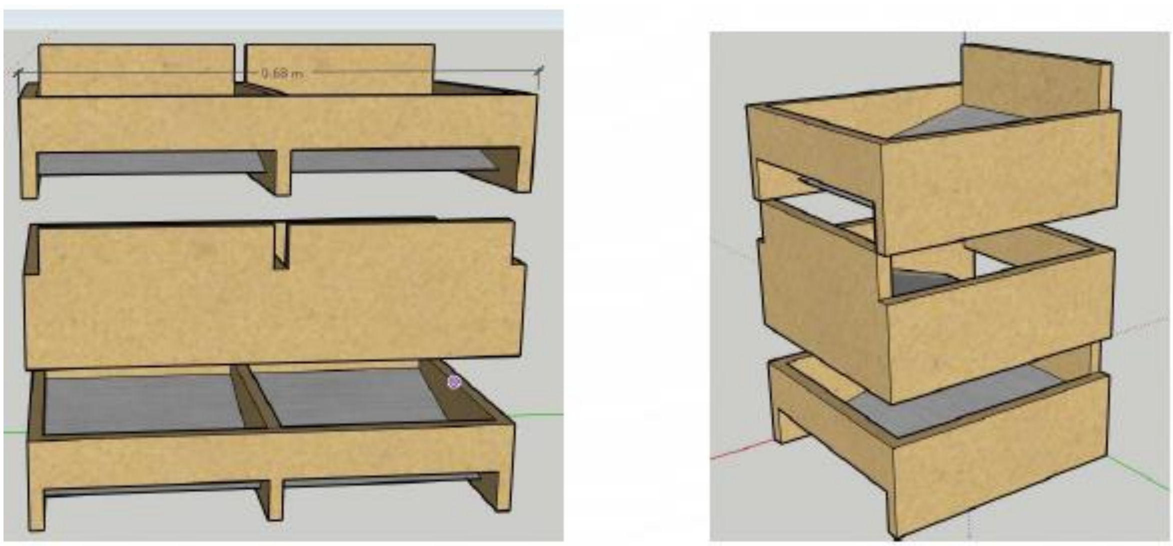


Figure 15. Prototype copper plate support module

8. References

Lagos, R., & Camus, J. (2017).El plateado: una actividad electroquimica para integrar diversas ciencias con el arte, 84–90. https://doi.org/10.1016/j.eq.2016.11.004