Copper Plates Implementation Protocol

PURE EARTH

November 2024

Acknowledgements

This document was written by:

Alfonso Rolando Rodríguez Pinilla | Pure Earth

Lizeth Olaya Zambrano | Pure Earth Colombia

Angie Tatiana Ortega Ramírez | Pure Earth Colombia

Diego Fernando Marín Maldonado | Pure Earth Colombia

Laura Andrea Vera Álvarez | Pure Earth Colombia

The following people reviewed and provided comments on the document, and their contributions are gratefully acknowledged:

Marcello Veiga | University of British Columbia

Dr. Luis Sobral | Center of Mining Technology CETEM/MCTI

Disclaimer

Contents

1. Overview

1.1. Main objective

Silver-coated copper plates are a technology developed to reduce mercury contamination from mining tailings generated by Artisanal and Small-Scale Gold Mining (ASGM). These tailings can often be found scattered throughout the environment, causing harm to nearby exposed communities. The copper plates technology could be utilized, among others, by governments that are aligned with the principles established under the Minamata Convention.

1.2. Background

The use of this type of plate in mining is not new; there is evidence of its use to capture free gold in mining material throughout many years, accompanied by the use of mercury (when the use of mercury in mining was allowed). Considering the environmental issues that have been generated due to the release of mercury into the environment from mining tailings, this technology has taken on a different use – not to capture gold (Au), but to capture mercury (Hg).

With an aim to reduce health and environmental effects from mercury-contaminated tailings, Pure Earth has worked in Colombia under various projects funded by the United States Department of State (US DoS), Conservation X Lab, the Colombian government, and the planetGOLD Program led by the United Nations Development Programme (UNDP). These projects have included adaption and optimization of the silver-coated copper plates technology with the aim of capturing the residual elemental mercury present in the tailings, accumulating the heavy metal on the plates and thus preventing its release to the environment.

More than 200 tons of tailings have been processed since 2018 during pilot tests of the copper plates under the US DoS project. These pilot tests were conducted to evaluate different operating variables to optimize the copper plates technology, aiming to improve the design of the plate module and the quality of the electroplating process. The pilot tests yielded important results in terms of percentage of mercury recovery, ranging between 50 to 84 percent, depending on factors such as tailings age and chemical composition and the operating conditions for the prototypes used.

Thanks to the support of GEF through the planetGOLD program, 140 sets of tailings in Colombia were characterized between 2020 and 2022. Among these 140 sets of tailings were those with the highest concentrations of mercury in 11 departments of Colombia. Taking into account this distribution and the difficult access of some tailings, further progress was made on this issue thanks to the financial support of Conservation X Labs through their Amazonian Artisanal Mining Grand Challenge. Under this program, Pure Earth developed additional improvements to the plate module, focusing on creating a module that was easy to implement so that it could be used autonomously by miners in remote sites.

1.3. Scope

Pure Earth has concluded that the copper plates technique is a viable and low-cost means of recovering mercury from tailings based on a thorough technical review and pilot testing, including technical support from Marcello Veiga (who has conducted several studies on the use of copper plates for mercury removal in small-scale mining).

This technology consists of covering the copper plates with a silver film which, due to its chemical affinities, has the possibility of retaining the maximum amount of elemental mercury present in contaminated tailings. However, it is important to keep in mind that there are limitations to the technology. For example, copper plates are most effective at capturing elemental mercury and may not be as effective at capturing organic or inorganic mercury.

2. Development of the copper plate technology (amalgamation plates)

The copper plates technology consists of the use of copper (Cu) plates coated with silver (Ag). The principle behind its use is that elemental mercury adheres to the plates due to silver's affinity for mercury. Both silver and mercury are transition metals and have the ability to form an alloy together, which makes mercury capture possible.

2.1. Required materials

To prepare the copper plates, the reagents and materials listed in ***Table 1*** are necessary. Note that the quantities of reagents presented are those required for a set of 4 plates with dimensions of 30 cm x 30 cm.

Material	Quantity
Nitric acid (HNO_3)	300 ml
Silver Nitrate ($AgNO_3$)	30 g
Potassium Cyanide (KCN) / Sodium Cyanide (NaCN)	29.5 g
Distilled water	12 L
Glass cell (35 x 10 x 35 cm)	2
Stainless steel sheet type 430 gauge 0.9 mm 30 x 30 cm	2
Glass Stirrer	2
Filter paper (box)	1
Universal Stand	2
Glass Beaker 600 ml	4
Glass Beaker 1 L	2
Graduated Cylinder 1 L	1
Spatula	1
Analytical Balance	1
Power Supply 12V 30A	1

Table 1. Materials and reagents for electroplating silver onto four copper plates. Source: Pure Earth, 2023.

2.2. Silver coating procedure

The plates require prior preparation before use. Pure Earth recommends that each plate have dimensions of 30 cm x 30 cm x 2 mm, although the thickness can be reduced to 1.5 mm depending on availability of materials and cost. Note that using a thickness of less than 1.5 mm could result in the plates being less effective due to low resistance to the mechanical action of the tailings. A thickness of more than 2 mm may make handling the plates difficult due to their weight.

Figure 1 describes the procedure for preparing a set of four copper plates. For every step with a letter in parentheses, a corresponding picture of the step can be found in Figure 2.

Figure 1. Procedure for the preparation of a set of 4 copper plates. Source: Pure Earth, 2023.

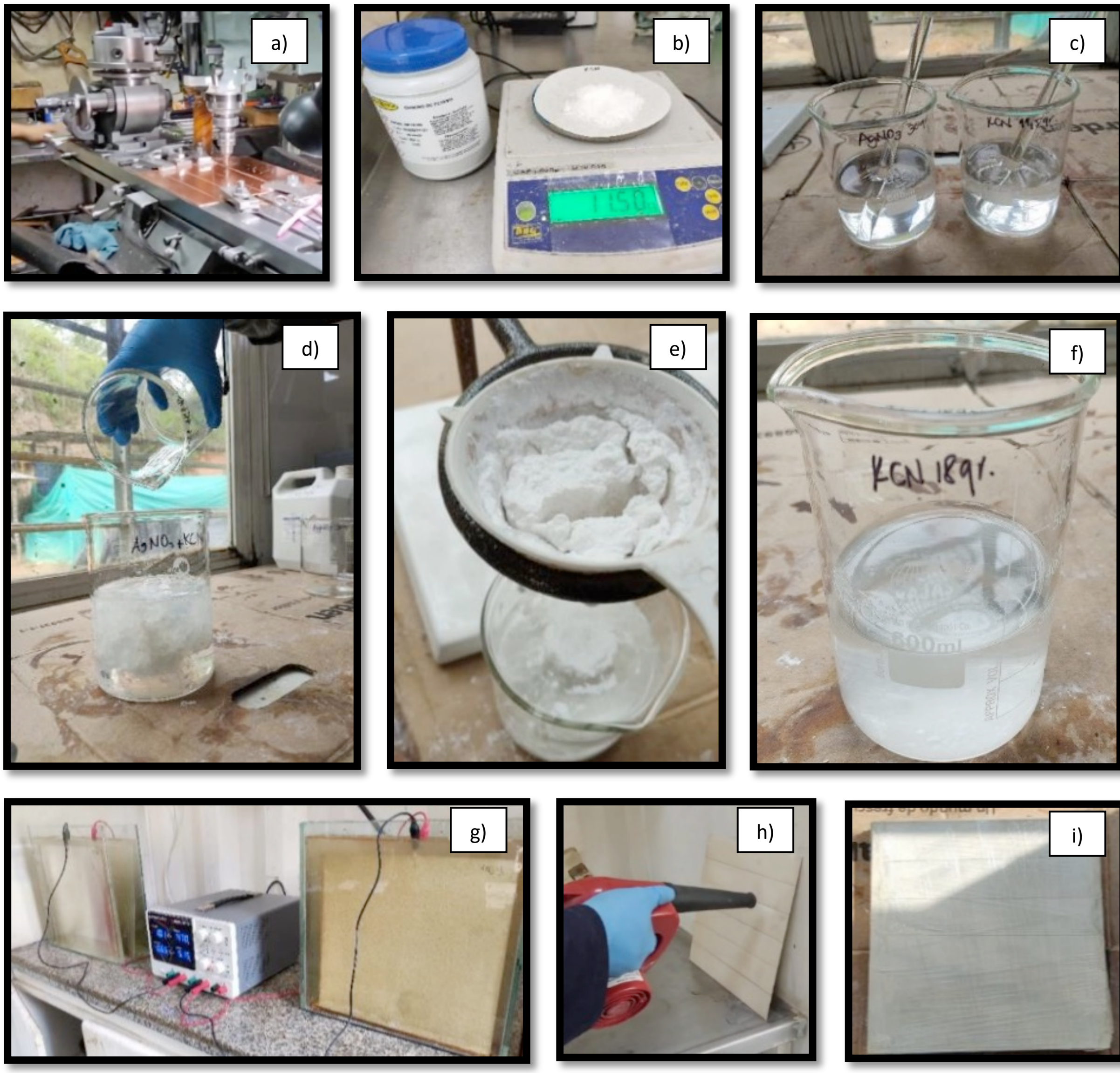

Figure 2. *Process of coating the copper plates with silver. Source: Pure Earth, 2023.*

3. General considerations for using the copper plates

To effectively process mercury-contaminated tailings, the plates must be properly positioned, the exact configuration of which can be determined during a field visit. Two potential modules have been developed which are shown below.

3.1. Plate modules

Copper plates can be set up into two different types of modules: gutter and waterfall. The action mechanism of each module is explained below.

3.1.1. Gutter module

The gutter module consists of two rows of plates arranged along a flat surface. This surface is usually made of wood, but other types of more resistant materials can also be used. The surface should be installed with an incline of at least 15° so that the tailings move with gravity. To achieve a certain degree of turbulence in the flow, a metal mesh can be installed over the plates, which will allow for increased contact of the mercury with the plate and, therefore, a longer residence time.

Figure *3* shows the gutter module with the mounted plates ready for processing.

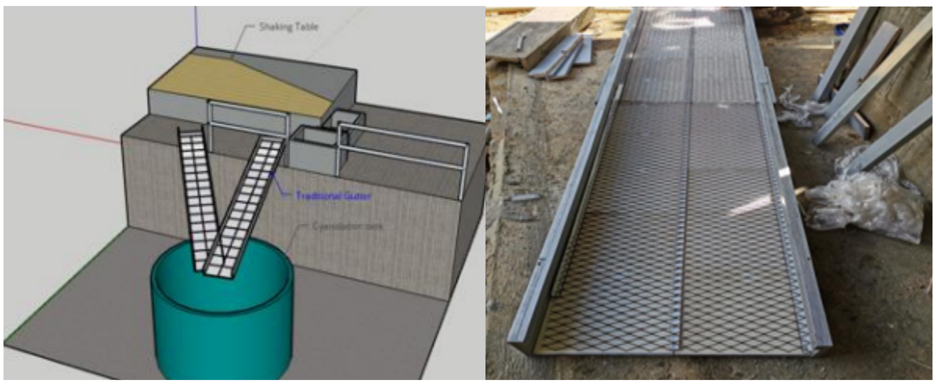

Figure 3. Gutter module example. Source: Pure Earth, 2023.

There is no set length for the gutter module, as it depends on the distance between the equipment in the processing plant where the module will be installed. However, during the pilot tests, Pure Earth used a total of 30 copper plates distributed between 2 rows (15 plates per row), as shown in **Figure *3***.

One limitation of the gutter module is the time required to change plates, since the mesh must be uninstalled.

3.1.2. Cascade module

In the cascade module, the inclined plates are arranged at a certain height, allowing there to be contact of the tailings and the plate on each level of the module. **Figure *4*** shows a schematic and picture of the cascade module.

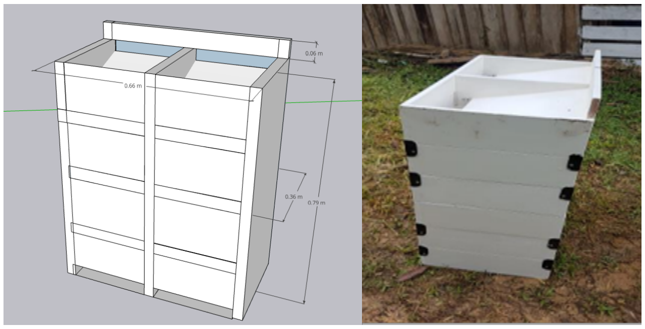

Figure 4. Cascade module.

Source: Pure Earth, 2023.

The cascade module performed better than the gutter module during pilot tests (30 to 40% more mercury capture). During tests with the cascade module, drops of mercury appeared that had amalgamated with the plate. The prototypes developed for the cascade module have rectangular sections for the positioning of two copper plates, which allowed for tailings to be processed with a much higher flow than the gutter module. In this type of positioning, as many sections as required can be added; however, during the pilot tests, 6 sections were placed with a total of 12 plates (see **Figure *4***).

The implementation of the cascade or gutter module depends mainly on the physical facilities and the amount of tailings to be processed, however, the cascade module is recommended for better efficiency for small quantities (up to 1 ton or less) and the gutter module is recommended for larger quantities.

3.2. Tailings characterization

A characterization analysis of the tailings should be performed prior to processing with the copper plates. It is important to identify the texture of the rock (e.g., sand, silt, or clay) that will be subjected to the process in order to define flow conditions and processing times. To determine soil texture, the feel method can be used (Wolf, Carson, & Parrish, 1979). This method can be used to fill out **Table *2*.**

Sample		Features (Yes or No)			Tape Length (cm)	Texture Class Name
		Sandy	Smooth	Sticky		
0–15 cm / 15–30 cm	Tailings name	YES/NO	YES/NO	YES/NO		

Table 2. Results of the feel method to determine soil texture. Source: Pure Earth, 2023.

Identifying the texture of the soil to be processed is important to understand the type of agitation needed in remote sites. The sandier the soil, the less effort will be required for agitation. Meanwhile, a greater agitation effort will be required for soils that are more clayey.

4. Process assemblies

Two types of assemblies can be used with the copper plates: 1) adaptation to an existing processing plant or 2) isolated configuration in remote sites. The type to be used depends largely on the accessibility of the processing location. Below are some generalities for plant and field application.

4.1. Plates assembly in processing plant

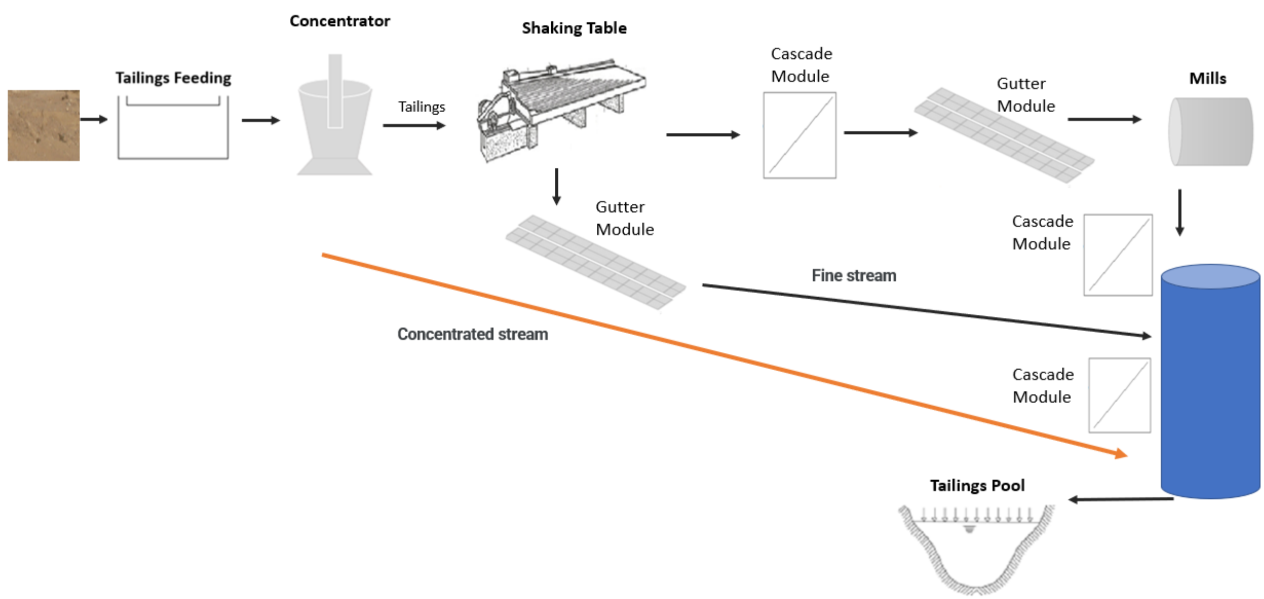

Figure 5. Example of plate assembly in processing plants. Source: Pure Earth, 2023.

The arrangement in **Figure 5** is an example of a recommended assembly pattern. The location of equipment should be evaluated prior to assembly to identify which is the most appropriate module to use. Types of equipment to be evaluated can include mills, vibrating tables, and others.

Pure Earth recommends that the process for mercury decontamination of mine tailings through copper plates be done in processing plants when possible, since the equipment can generally handle any type of soil regardless of texture or large particle diameter. In addition, the equipment can usually handle larger quantities of processed material per day. However, if it is not possible to adapt a processing plant for this purpose, a proposed assembly for isolated sites is described below.

4.2. Plates assembly in isolated sites

The assembly for installing the copper plates in isolated sites is based on the circulation of tailings slurry (i.e., tailings suspended in water in a 1:6 ratio), which is done in tanks. The slurry is driven from the first tank, which has a capacity of 2 m^3, by a 0.67 hp pump. It is then agitated at the bottom with a 1 hp pump in order to avoid settling at the bottom of the tank. The slurry is then recirculated to another tank with the same capacity (2 m^3). Approximately 300 kg per day can be treated under these conditions.

From the tanks, the tailings flow onto the copper plates, installed in a cascade module in the middle of the two tanks. The design can be seen in **Figure *6***:

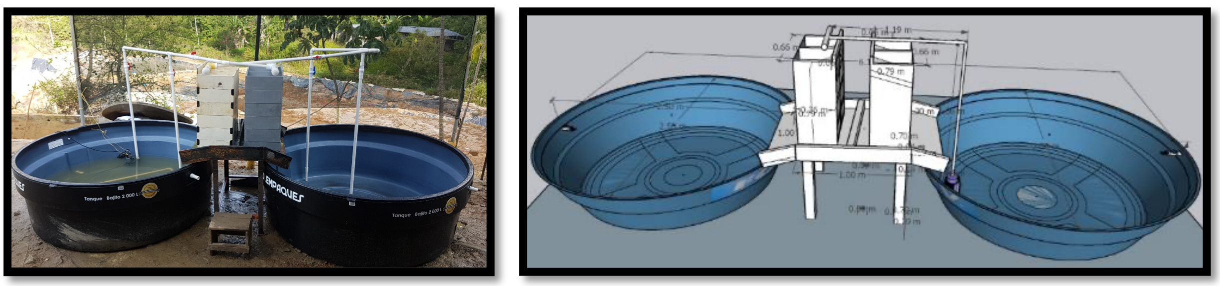

Figure 6. Copper plates assembly in isolated sites. Souce: Pure Earth, 2023.

Figure *6* shows that this type of assembly allows for processing in a versatile and fast way. One drawback is that the assembly does not include the simultaneous extraction of gold. Each cascade module has space for 12 copper plates, so the total assembly may require 24 copper plates, or 12 plates that can be changed from one module to the other at the end of recirculation.

This assembly can be installed through three phases, explained below:

4.2.1. Adaptation of the location

A firm, level space is required for this assembly to function properly. If the area does not already have a proper space, the ground must be flattened and leveled to correctly position the equipment required for processing.

Figure 7. Adaptation of the location for assembly; a) Securing of solids pumps, b) Suitability of the land. Source: Pure Earth, 2023.

The pumps should be covered with mesh, which allows the entry of solids with a particle diameter of less than 5 mm. This mesh helps to prevent the entry of unwanted material such as tree branches or stones that can damage the equipment. The ground should be level as much as possible before placement of the tanks or else there is a risk of the plastic tanks becoming damaged due to the weight of the tailings combined with water.

4.2.2. Installing the assembly

Using the schematic shown in **Figure *6***, the materials and equipment needed for the assembly in the field should be obtained. The list of materials and equipment can be seen below in **Table *3***. In the second phase, the equipment is organized and assembled at the site. The complete assembly of the copper plates is shown in Figure 8.

Materials & Equipment	Number
Submersible Pump (1 hp)	2
Water Tanks (2 m^3)	2
PVC Pipe (m)	70
Wooden modules	2
Support table for wooden modules	1
Electric generator (3.5 hp)	1
Motor Oil	1
Gasoline (1.6 gallons)	1
Water (2 m^3)	1

Table 3. Materials and equipment needed for remote site assembly installation.

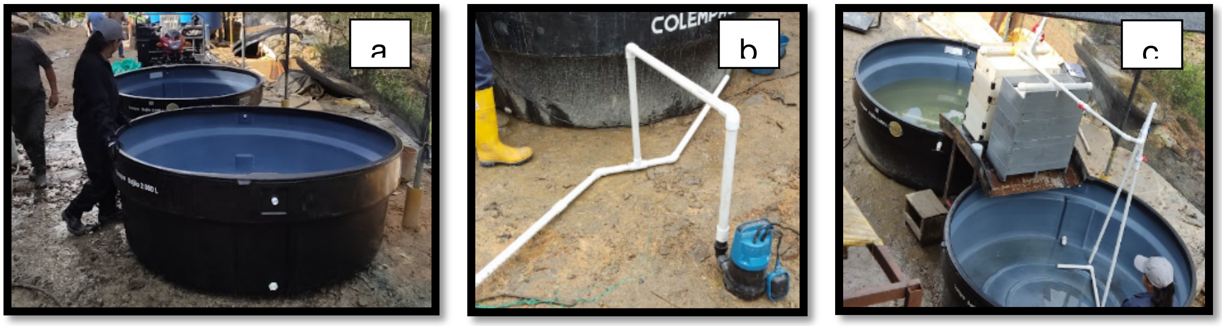

Figure 8. Field assembly installation; a) Arranging the water tanks in the field, b) assembling the PVC for the agitator and the pump that transports the tailings from one tank to another, c) assembling support modules. Source: Pure Earth, 2023.

4.2.3. Assembly operation

This section will describe the procedure used to process tailings with the copper plates.

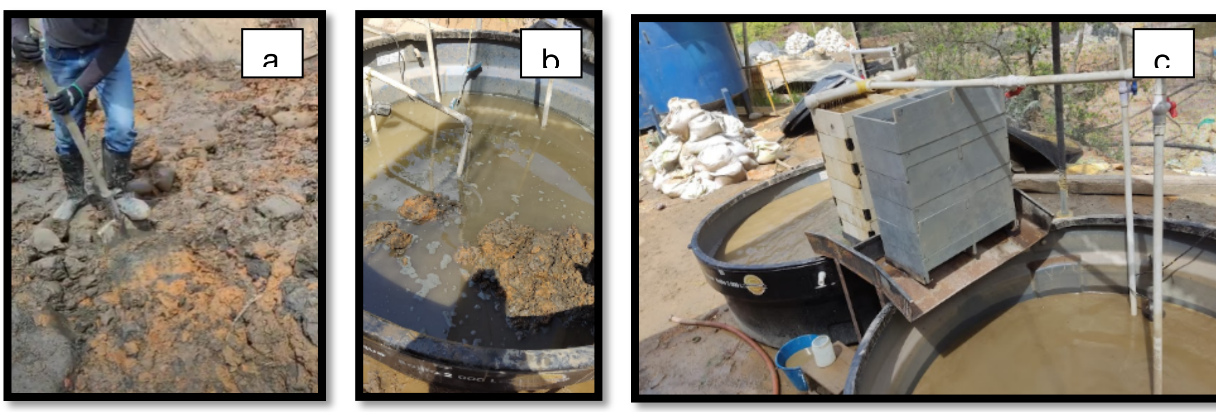

Figure 9. Stages of the pilot tests; a) material loading, b) preparation of tailings slurry solution, c) ignition of pumping equipment. Source: Pure Earth, 2023.

To process the tailings, the following steps can be used:

- To generate the slurry, mix loads of 50 kg of contaminated tailings with water until solids are suspended, and any lumps are dissolved. This should be done until a total of between 300–500 kg of slurry, depending on material type, is reached, with a final solids ratio of 1:6 in a volume of 2,000 liters.

- When the material is fully submerged, turn on the pump to agitate the material, increasing the suspension of solids in the tank. This pump, like the one that transports the material from one tank to another, must be connected to a 110-volt electrical source. If the energy source is portable, it must have an autonomy of at least 12 kWh.

- The number of plates required should be available, according to the number of cascade modules selected (e.g., for 6 modules, 12 copper plates are required).

- Open the valves to start material flow and vary the opening of the outlet valve until the average flow rate of 20 L/min is reached.

- After circulating 2,000 liters of slurry from one tank to the other, the recently vacated tank must be cleaned to be able to receive recirculated material again. Each recirculation through the plates can be called a "pass".

- Pure Earth recommends that a minimum of 8 passes between tanks is performed to ensure increased mercury retention by the plates.

5. Final considerations

Final considerations for this technology include post-processing activities for the mercury-contaminated tailings such as sampling for analysis of contaminant removal and final disposal of waste.

5.1. Mercury removal analysis

The amount of mercury removed from mine tailings through the use of the copper plates should be measured. To do so, representative composite samples should be taken to measure mercury concentration using field equipment or laboratory analysis.

5.1.1. Tailings Sampling

To properly measure the amount of mercury retained by the plates, an adequate and representative sampling strategy should be developed. Compound samples should be taken for mercury analysis with each use. Pure Earth recommends that samples be taken periodically (every 15 to 20 minutes), for subsequent drying and measurement with portable X-ray fluorescence (XRF) equipment, if available. **Figure *10*** shows the sampling procedure to measure mercury concentrations in the processed tailings.

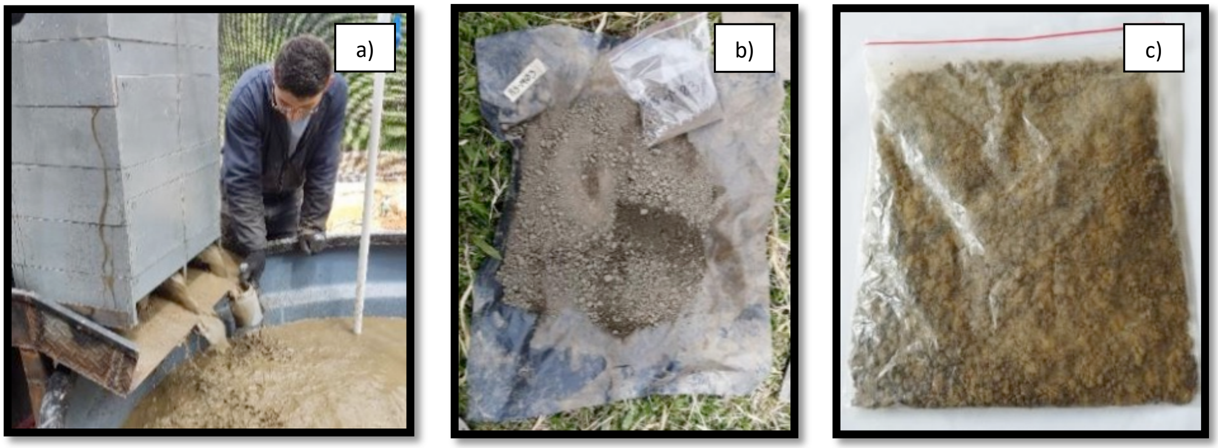

Figure 10. Tailings sampling process; a) Sampling, b) Sample drying, c) Sample preparation for XRF measurement. Source: Pure Earth, 2023.

The tailings should be measured before processing in order to determine the initial mercury concentration and to have a point of comparison to the final mercury concentration.

Drying samples can take up to 8 hours or more, depending on moisture content. The material is generally approximately 15% solids and cannot be dried in ovens or stoves. These appliances can evaporate mercury, affecting the measurement.

5.1.2. Removal Percentage Calculation

To determine the percentage of mercury removal or plate yield, the following equation is used:

$$\%\, plate\ yield = \left(\frac{C_{Hg,i} - C_{Hg,f}}{C_{Hg,i}}\right) * \ 100\%$$

Where

CHg,i: initial mercury concentration

CHg,f: final mercury concentration

Concentrations of mercury or any other substance of interest should be measured beforehand with field equipment such as the XRF or through laboratory analysis. The above equation can be used not only to determine percentage of mercury removal, but also to evaluate the behavior of other compounds throughout processing the tailings with copper plates.

Should it be necessary to evaluate the performance of the plates in a processing plant, the equation should be applied in each area where there is a gutter module or a cascade module to identify the operating area with the highest mercury retention. However, the overall yield can also be calculated to identify the total concentration of mercury removed from the tailings. In the case of having more than one operating area, the following equation can be used:

$$\% \, plate \; yield = \left(\frac{m_i * C_{Hg,i} - m_i * C_{Hg,f1} - m_i * C_{Hg,f2}}{m_i * C_{Hg,i}} \right) * \, 100\%$$

Where

m_i: mass of stream i (1, 2, or 3)

CHg,i: Initial mercury concentration

CHg,f1: Final mercury concentration at outlet 1

CHg,f2: Final mercury concentration at outlet 2

Pilot tests with more than 300 tons of processed tailings have shown up to an efficiency of 84% in reducing the initial concentration of mercury under ideal conditions. On the other hand, the age of the tailings is a fundamental factor in the efficiency of the plates, since old tailings (5 years or more after generation) have a large number of oxides that reduce the useful life of the plates and reduce their efficiency.

5.2. Final disposal

Final disposal is the last stage in this process of using copper plates for gold mining tailings management. Two main types of waste are generated, which need different treatment: copper plate waste and tailings waste. The treatment of each is explained below.

5.2.1. Copper plate waste

The useful life of the plates is determined by the saturation of the plates with mercury. Mercury is categorized as a hazardous waste and must comply with final disposal according to the hazardous waste regulations of each country. In many cases, this corresponds to disposal in safety cells. **Figure *11*** shows the indications of end-of-life of the copper plates.

Figure 11. Mercury-saturated copper plates. Source: Pure Earth, 2023.

The plates should be wrapped in plastic film to avoid direct contact with the skin. The plates must be delivered to an appropriately permitted facility for hazardous waste management. This can involve filling out forms and making corresponding payments.

5.2.2. Processed tailings management

The tailings waste resulting from the mercury recovery process must be disposed of in tailings holding areas, which consist of pools with an impermeable barrier that prevents the migration of toxic compounds into the environment. **Figure *12*** shows an example of a tailings holding area.

Figure 12. Panoramic view of pools or tailings, where the inert tailings material is located. Source: Pure Earth, 2023.

In these tailings, certain compounds such as cyanide are expected to degrade, upon which the tailings are loaded into bags to transport them to companies that can use the tailings, either through further extraction of gold or for use in the production of road material.

6. References

CNN Español. (2021, 09 24). *¿Cuál es el costo de la electricidad en un mundo afectado por el cambio climático?* Retrieved from CNN Mundo: https://cnnespanol.cnn.com/2021/09/24/costo-electricidad-mundo-afectado-cambio-climatico-orix/

Rodriguez, A., Ortega, A., Marin, D., Vera, A., & Veiga, M. (2024). Homemade copper-silver plates as an alternative for cleaning mercury-contaminated tailings from artisanal and small-scale gold mining in Colombia . *International Journal of Sustainable Energy and Environmental Research, 13*, 12-24. Retrieved from https://archive.conscientiabeam.com/index.php/13/article/view/3681

Veiga, M. H. (2006). Origin and consumption of mercury in small-scale gold mining. *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2004.08.010

Wolf, D., Carson, E., & Parrish, D. (1979). *Notes: A replica method of determining stomatal and epidermal cell density*. Retrieved from Agronomy.org: https://www.agronomy.org/files/publications/nse/pdfs/jnr008/008-01-notes.pdf