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MERCURY REMOVAL AND GOLD RECOVERY FROM ARTISANAL GOLD MINING TAILINGS USING SILVER ELECTROPLATED COPPER PLATES

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Abstract: Artisanal gold mining/small-scale gold mining uses elemental mercury to amalgamate gold contained in gravity concentrates. In fact, it is observed that the amount of mercury used is much higher than the actual amount actually needed, which is a real case of misuse of this element. As a consequence of this practice, the tailings that are being generated, bearing high mercury contents, need to be treated to exempt them from this element in order to avoid contamination of the environment, in the first place, and of the operator ahead of this extractive process. Therefore, new ways of removing the mercury contained in these tailings have been applied, among them we can mention the use of amalgamating plates, such as the ones developed at CETEM, which aim at capturing the elemental mercury from mercury-bearing tailings by simply contacting it with metallic copper surfaces coated with an electrolytic silver deposit.
Keywords: Gold, artisanal mining, mercury.

INTRODUCTION

The extraction of gold in artisanal and small-scale mining uses elemental mercury for amalgamating gold contained in ores and gravity concentrates. In fact, it is observed that the amount of mercury used is much higher than the actual amount actually needed for this extraction process, which is a real case of misuse of this element (M. M. Veiga et all). As a consequence of this practice, the waste generated has high levels of mercury and needs to be treated for the complete removal of this element, aiming at not contaminating the environment, in the first place, and the operator directly involved in this process (John A. Meech et all.) (Dario Bermudez et all.) (Gustavo Angeloci-Santos).

To this end, new ways of removing the mercury contained in the waste, arising from this extractive process, have been applied, among them we can mention the use of amalgamating plates that aims at capturing the elemental mercury contained in these wastes by simple contact with metallic surfaces containing a silver electrolytic deposit. However, a very polluting way of removing the mercury contained in these wastes has been the use of cyanide with consequent formation of soluble mercury cyano-complexes, which being available in the environment can cause a tremendous environmental impact (Bruce G. Marshall et al.) (Caryn S. Seney et al.).

These amalgamating plates, used in this study, are stationary plates of metallic copper coated with a thin layer of silver, used in the decontamination of mining wastes, which carry microdroplets of elemental mercury, precious metals amalgams, as well as unamalgamated gold particles. The presence of these phases in the tailings is due to the ineffective form of the amalgamation process used in the mines. These plates are placed in a box, in a zig-zag arrangement, with a slope of 10 degrees, which, in operation, receive ore or gold-bearing waste slurries (with 10 to 20% solids), and the amalgamation takes place when the referred phases come into contact with the surface of the plates, more precisely with the surface of the electrolytic silver deposit. The slurry flow velocity must be low enough so that the elemental mercury, present in the waste, in appreciable amounts, can be retained when in contact with the metallic silver of the plates and also, due to the excess of retained mercury, allow the retention of gold particles still present in wastes being processed; and sufficiently high so that other mineral constituents, present in the tailings, are dragged by the suspension flow and do not remain on the plates. The plates used in this study are made of copper and electrocoated with a thin layer of silver (*i.e.*, around 0.1 mm thick).

To find the most economical way to produce silver plates, different metal substrates can be used, such as mild steel, galvanized steel and copper. Each of these substrates must be treated or coated with zinc, copper and finally silver, depending on the nature of each one of them. Figure 1 shows the recommended electrolytic baths to produce the silver finish depending on the metallic substrate to be used.

The efficiency of the waste treatment process under consideration depends on the skill of the operator, and must be optimized with successive processing of the aforementioned waste. Accumulated amalgam on the plates is removed (*i.e.*, by scraping the plates) with periodic interruption of the process.

EXPERIMENTAL

The device, on a semi-pilot scale, designed at CETEM, we used for extracting elemental mercury from tailings, generated during the extraction of gold from gravity concentrates in artisanal and small-scale gold mines. This unit contains 4 copper plates, electroplated with silver, from a cyanide bath, in a zig-zag arrangement, with an inclination of 10^o, in dimensions of 50 cm in height, 12 cm in width and 27 cm in depth, with plate dimensions of 10.5 cm wide and 23.5 cm high, as shown in Figure 2. Photo [A] shows the lab-scale amalgamation unit, made of acrylic, measuring 35 cm high, width of 7.5 cm and depth of 15.5 cm, where one can observe the arrangement of silver electroplated copper plates measuring 7.0 cm wide and 12.5 cm long. Photo [B] shows the same unit in semi-pilot scale, with plates in dimensions of 10.5 cm wide and 23.5 cm long.

This waste processing system works by pumping a mechanical suspension of it in water, in different solid-liquid ratios (*i.e.*, 10, 20 and 30% w/v), in the upper part of the amalgamation box, at different flow rates.

Initially, the waste was mechanically suspended in water, at a solid: liquid ratio of 10%, and then the suspension was pumped, using a peristaltic pump, to the top of the amalgamation box, as shown in Figure 3. Four liters of waste suspension were used at a flow rate of 200ml.min^{-1}. After pumping the total volume of the suspension, this volume was collected in a tray, where the system was placed. The collected material was filtered and the solid material was sampled, after homogenization, for subsequent quantification of the remaining mercury. The just collected solid material was, again, resuspended in water and passed, once more, through the amalgamation box. The same procedure was repeated twice more and four samples were sent for proper measurement of mercury levels at the Environmental Mercury Speciation Laboratory-LEMA/CETEM, using the LUMEX device that uses the Atomic Absorption Spectrometry technique with a Zeeman corrector.

RESULTS AND DISCUSSION

The first analytical result, referring to the quantification of the mercury content in the original sample of the waste, was 13.55 mg.kg^{-1}. The other determinations, referring to the solid phases collected in the tray, positioned at the base of the amalgamation box, after each passage of the suspensions through the treatment system (*i.e.*, the amalgamation box), were 5.21, 4.94 and 1.62 mg.kg^{-1}. These analytical results demonstrate the effectiveness of the reaction system under analysis. Optical microscope analyzes of the surfaces of the plates were carried out, after carrying out the mercury removal tests, which showed the retention of mercury on these surfaces; although the amount of mercury in 100g sample of the waste, suspended in 4 liters of water, being 1.3 mg.

Figure 3 shows the formation of silver amalgam in some regions of the plates.

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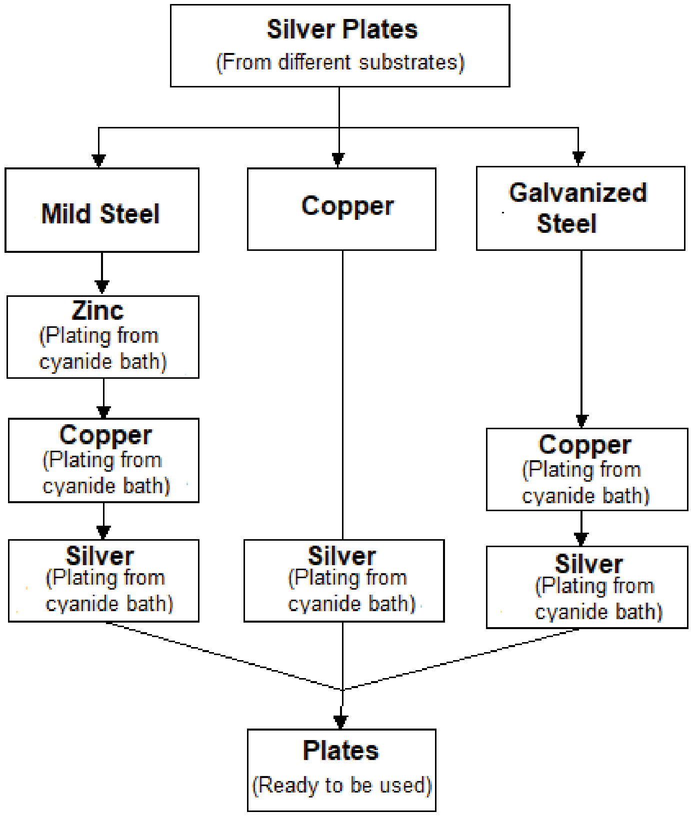

Fig. 1- Electrolytic baths recommended to produce a silver finish on different metallic substrates (Source: Authors).

Fig. 2- Amalgamation boxes used in experiments to remove mercury and gold remaining in mining tailings. [A] laboratory scale amalgamation box, [B] semi-pilot scale amalgamation box, [C] Silver plated Copper plate used in the semi-pilot unit.

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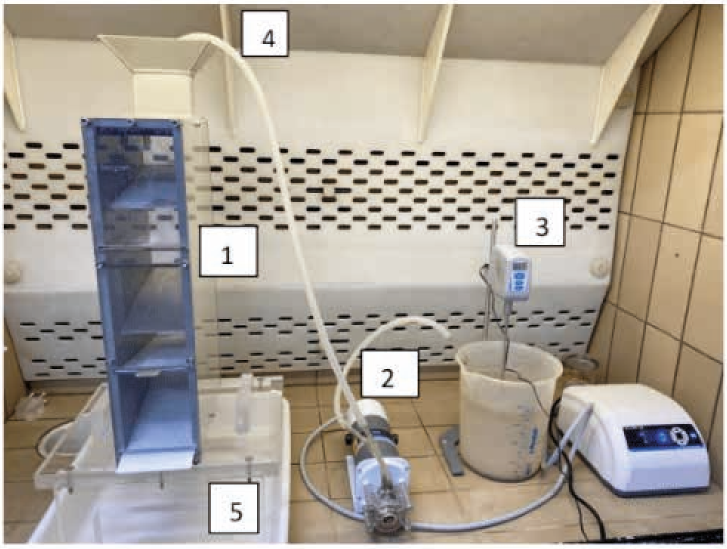

Fig. 3- Semi-pilot mining tailings treatment system containing 4 silver electroplated copper plates in a zig-zag arrangement. (1) Amalgamation box, (2) peristaltic pump for pumping the waste pulp, (3) mechanical stirrer for suspending the waste in water, (4) feeding the pulp into the amalgamation box, (5) tray for collecting the suspension of the treated pulp.

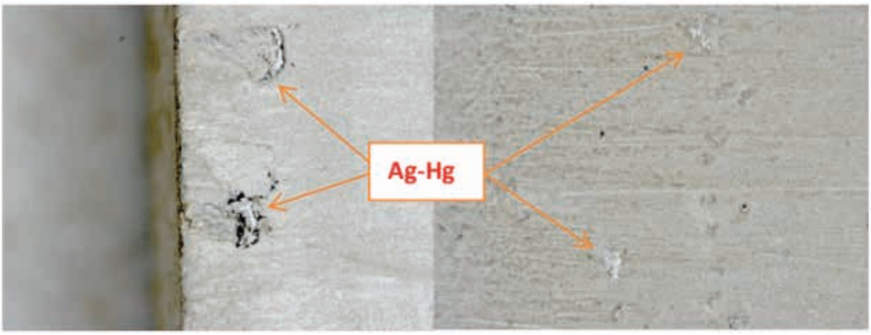

Fig. 3- Deposit of silver amalgam on the surface of silver plates.

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However, it has not been possible, until now, due to the low amount of amalgam formed, to detect the presence of gold as part of this intermetallic compound. Certainly, with the continuity of the tests, it will be possible to accumulate a substantial amount of amalgam so that it will be possible to remove, with the use of a plastic spatula, a sample of the referred amalgam so that it will be possible to process it chemically and, with that, to evidence the presence of mercury and gold.

The aforementioned chemical processing consists, first, in reacting the amalgam sample with nitric acid to solubilize mercury and silver with formation of the respective soluble nitrates, as shown in reactions 1 and 2:

$$Ag^o + 2HNO_3 \rightarrow AgNO_3 + NO_2^{\uparrow} + H_2O \quad (1)$$

$$Hg^o + 4HNO_3 \rightarrow Hg(NO_3)_2 + 2NO_2^{\uparrow} + 2H_2O \quad (2)$$

The resulting solution from the reaction of amalgam with nitric acid is firstly treated with chloride ions bearing solution, which may be hydrochloric acid or sodium chloride solutions, to precipitate silver chloride, which is then reduced to metallic silver by reaction with an alkaline solution of glucose, or even commercial sugar, as shown in the following reaction:

$$2AgCl + 3NaOH + C_6H_{12}O_6 \rightarrow 2Ag^o + 2NaCl + C_6H_{11}O_7Na + 2H_2O \quad (3)$$

Ionic mercury in solution, in the form of Hg^{2+}, can be reduced using metallic aluminum scrap, as shown in the following reaction:

$$Hg^{2+} + Al^o \rightarrow Hg^o + Al^{3+} \quad (4)$$

Once the solubilization reaction of the amalgam sample, removed from the surface of the plates, has ceased, it will be possible to observe that the gold contained remains insoluble, which can later be dissolved in aqua regia for proper quantification by the atomic absorption spectrometry technique.

$$Au^o + HNO_3 + 3HCl \rightarrow AuCl_3 + NO^{\uparrow} + 2H_2O \quad (5)$$

CONCLUSIONS

The operating system used for removing/decontaminating the mining waste proved to be efficient, promoting the formation of silver amalgam on the surface of silver-plated copper plates in a zig-zag arrangement;

It is necessary to emphasize that the effectiveness of the referred system takes into account the appropriate definition of the operating conditions, such as the solid-liquid ratio of the residue suspension, the flow of the suspension to be fed into the amalgamating box, bearing in mind that such conditions may undergo changes depending on the mercury content in the waste to be processed. Certainly, a given volume of suspension will have to pass successive times through the aforementioned box in order to allow the complete removal of the mercury content;

The successive passages of the aqueous suspension of the mercury-bearing waste are necessary so that, depending on a given set of operating conditions, it is possible to define the path that such suspension should follow, as if it were an inclined plane made up of a silver surface, so that all the mercury is retained during the formation of the silver amalgam. In addition, when free gold particles are present, which were not amalgamated, and almost always part of the mining wastes, such particles will be amalgamated when in contact with the mercury accumulated in the plates during the processing of the wastes;

In summary, the processing of mining waste is justified not only by decontaminating it, preventing this recalcitrant element from being made available in the environment, with the possibility of forming organo-mercury compounds, much more harmful than elemental mercury, but also by extracting gold still present in these residues.

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