Characterization of Environmental Pollution Associated with the Amalgamation Process Based on the Loss of Mercury

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Abstract. This work addresses the problem of indiscriminate use of mercury, in gold amalgamation and refocusing (burning) processes, an element of high toxicity that cause serious damage to the environment and human health; being a conventional method of treatment of gold minerals for its easy operation and extraction of gold, purpose that allows us to study, the loss of mercury and quantify in the area of greatest influence, (Nasca – Ocoña strip) the impacts of mercurial residues, both on the environment and on the mining worker and its environment. proposes new alternatives for the treatment of gold ore that allow the gradual reduction of the use of mercury and cyanide; assesses the working conditions of miners who are currently operating in the research-delimited area. Swipe to gravimetric concentration as an environmentally friendly technology, layers to replace the amalgamation process and avoid relaves with high mercury.

1. Introduction

The methods of exploitation and treatment of gold minerals, which lead to the production of gold, depend on factors, such as: Stratification in the formation of the deposit, types of mineralization, characteristics of the bargain, particle size of gold present in deposits and their mineralogical associations.

In artisanal mining, the ore is extracted using the circado method, the extraction of which is on the vein following the gold-rich ore [1], followed by crushing, grinding and amalgamation, where the use of mercury is intense, an element of high toxicity that causes serious damage to health and the environment despite being an activity that supports more than 22% of rural Peruvian PEA equivalent to 3.19 million [2], 300,000 to 400,000 miners work in the MAPE sector in Peru's 24 departments [3]. In addition, according to the comprehensive mining formalization register, 88,758 mining workers are in the process of being recorded by Peru's Ministry of Energy and Mines [4]. The quantity is current, with a tendency to increase. They voluntarily register a number that is long surpassed within the informality where small-scale artisanal mining takes place.

Gravimetric concentration is an alternative, environmentally friendly process that allows gold to be extracted without resorting to mercury or cyanide, only taking into account the specific difference in gravity and concentration criterion, [1], table 1; in the face of the need to recover ever finer particles, gravitational forces have been replaced by centrifugal forces [5], so that chemical pollution from mining, create minimal risks to the ecosystem and human health. [6]
Table 1. Meaning of concentration criteria – CC

| Concentration criterion | Efficient separation up to |
|-------------------------|----------------------------|
| 2.5                     | 74 µm                      |
| 2.5 – 1.75              | 147 µm                     |
| 1.75 – 1.50             | 1.4 mm                     |
| 1.50 – 1.20             | 6.0 mm                     |

Gold ore with 0.5 ounce/short ton laws, where gold is associated with iron oxide and sulfides such as pyrite called gold pyrite [7] it is directly amalgamated into quimbales, dragging mercury into the relave, leaving a waste material containing mercury, amalgam, fine gold and another product called amalgam with small amounts of mercury.

In consequences of bad management of mercury, contaminates and intoxicates with this metal, not only workers exposed directly during gold benefit processes, but also to people and animals that have no relation to it. [8]

The intense use of mercury to amalgamate and burn gold generates gas fumes and the dispersion of highly polluting mercury particles and causes impacts on public health [9].

Mercury emissions into the environment during the amalgamation and burning phase of gold amalgam pollute air, water and affect flora, fauna and human health. It is estimated that up to 2010, in an area of 2077 ha. Equivalent to 31% of the micro-water, 162.29 ton were issued. Mercury [10].

In Bolivia, gold mining is estimated to be responsible for 82.3% of mercury emissions equivalent to 37,579.2 kg Hg/year, of which 10,146.39 are discharged into the atmosphere, 19,120.29 to water and 12,806.99 to the ground second, there are dental fillings with 3.9%. [11]

1.1. Environmental impact of mercury in air
Particulate mercury and gaseous oxidized mercury (Hg(II)) precipitate in soils, surface water and vegetation generating re-emission to the atmosphere. [12]

1.2. Environmental impact of mercury in soil
Environmental impact of mercury in soil Mercury modifies pH, temperature and humid acid content, favoring the formation of inorganic compounds such as HgCl2, Hg(OH)2 and Hg(II) complexes with organic anions. [12]

1.3. Impact of mercury on man
The man absorbs mercury by: breathing: Which passes directly through the pulmonary alveoli; digestion, if the mercury ingested is in the form of methyl mercury, it is absorbed by 100% at the level of the small intestine; under any of its forms or states, mercury passes through the skin and builds up in tissues [13].

The presence of mercury in the human body generates levels of intoxication that depend on the pathway was absorbed [14], is detailed below, such as acute poisoning, sub-acute poisoning and chronic poisoning:

**Acute Intoxication:** when the penetration pathway is respiratory, trachea bronchitis appears accompanied by coughing and hyperthermia, followed by diffuse pneumonia with interstitial o edema. Massive inhalation of mercury vapors causes dizziness, sudden blindness, muscle spasms and tremor.

**Sub-acute poisoning.** Causes coughing or bronchial irritation, vomiting, diarrhea, stomatitis, mucosal ulcerations of the mouth, mercurial erythroderma and proteinuria. **Chronic Poisoning.** It is the most common form in the workplace and constitutes the so-called "Mercurialism". The main causes are: Gaseous elemental mercury and inorganic compounds, as well as organic derivatives such as methyl mercury.
2. Methodological analysis of the loss mercury
The research is: Applied, determines mercury loss in amalgamation and refocusing. Correlal: seeks the mercurial impact on the environment and human health. Exploratory, because it considers the Nazca – Ocoña strip as a study area. This research is part of the scheme presented in Figure 1.

![Figure 1. Research design scheme](image)

Where:
Exploitation: extraction of the mineral using equipment and manual tools such as auger, chisel, rope and precarious personal safety equipment, the mineral grade is determined in an artisanal way, with puruña. Transportation: transfer of ore from the mine to the local or milling workshop, on foot or by mobility of a transport service loaded with ore whose average distance is variable. Crushing: the ore is reduced to achieve particle sizes of less than ½” using camber. Grinding: discontinuous and dry, with variable capacity using steel balls of various sizes as grinding medium, the largest being 4 “, yielding a product with a fineness of 60% minus 100 mesh. Amalgamation: mercury is used to separate the gold from the pulped ore, whose percentage of solids fluctuates between 25% and 30%. The product is an amalgam and a tailings containing fine gold not trapped by mercury, this is sold to cyanidation plants, while the amalgam is burned. Burned of amalgam: the gold is extracted and the mercury recovered by distillation.

To analyze the loss of mercury, we proceeded:
 a) Calculation of the mineral grade of the area
 b) Mercury loss in amalgamation process
   a. Mercury in tailings
   b. Mercury in amalgam
 c) Loss of mercury in the gold plating process
 d) impact of mercury on the mining worker and their environment

3. Results and presentation of data
Gold ore grade: table No. 02 represents the gold ore grade of the area under study.

| Mesh | % Weight | Weight Accumulated | Law Au Onz/T.C | Distribución Au % | Accumulated Au % |
|------|----------|---------------------|----------------|------------------|------------------|
| + 35 | 3.80     |                     | 0.333          | 2.00             |                  |
| + 65 | 14.30    | 18.10               | 0.396          | 9.00             | 11.00            |

Table 2. Distribución de oro y de plata por fracciones granulométricas
As can be seen, the mineral has a grade of 0.632 oz / tc, which can vary from zone to zone, from vein to box. It indicates that 35.2% of gold is present in minerals with a granulometry greater than 200 mesh, which means that it is relatively coarse gold and can be recovered by amalgamation, while 64.8% of gold is in -200 mesh, as fine gold, that is not recovered by amalgamation, remains in the mineral, which takes the name of amalgamation tailings and is sold to metallurgical cyanidation plants. Finally, the maximum gold recovery margin, in conventional amalgamation processes, is 35%, but in reality it is much less.

3.1. Loss of Mercury in the process of amalgamation

Table 3 show results of mercury loss in the study area, between Ingenio Ica and Huanuhuanu Arequipa.

| R   | f  | X₁  | f + | f*X₁ | X media |
|-----|----|-----|-----|------|---------|
| 0 – 25 | 95 | 12.5 | 94  | 1187.5 | 58.4 Gr/lata |
| 26 – 50 | 150 | 38  | 243 | 5700.0 |
| 51 – 75 | 41 | 63  | 284 | 2583.0 |
| 76 - 100 | 150 | 88  | 434 | 13200.0 |
| 101 - 125 | 4 | 113 | 438 | 452.0 |
| 126 -150 | 9 | 138 | 447 | 1242.0 |
| 151 - 175 | 3 | 163 | 450 | 489.0 |
| 176 - 200 | 12 | 188 | 462 | 2256.0 |
|       | 464 | 804 | 27109.5 |

The table shows an average mercury loss in the study area between Ingenio Nasca - Ica and Tocota, Caraveli - Arequipa of 58.4 gr / can, equivalent to 1770.5 gr / tm, mercury that is distributed between the tailings and the amalgam.

3.2. Mercury in tailings

Mercury in tailings according to laboratory analysis carried out in the district of Chala-Caraveli-Arequipa, gives us values that we present in Table 4.

| code             | Au oz/tc | Hg ppm |
|------------------|----------|--------|
| Amalgamación tailing | 0.560    | 160.75 |

This is equivalent to 160 gr / tm of mercury contained in the amalgamation tailings and a gold grade of 0.56oz / tc.

If we do an exploration of the mercury contents in the amalgamation tailings of the mining centers of the area under study, as presented in table 5, we find different amounts of mercury for each mining
center, so we conclude that the loss of mercury in the amalgamation tailings depends on several factors such as:

- Type of mineral where gold occurs, if it is oxidized quartz, pyritic sulfur.
- Grain size of gold species

### Table 5. Mercury in tailings by mining center

| No  | Gold mining | Au (gr/tm) | Hg (ppm) | X prom |
|-----|-------------|------------|----------|--------|
| 01  | Mollehuaca  | 20.8       | 376      |        |
| 02  | Relave      | 20.9       | 341      |        |
| 03  | Saramarca   | 11.5       | 192      |        |
| 06  | Tulin       | 33.6       | 10       |        |
| 07  | Santa Filomena | 43.2   | 48       |        |
| 08  | Huanca      | 19.6       | 486      |        |
| 09  | Chaparra    | 19.7       | 174      |        |
| 10  | La Joya     | 10.9       | 141      |        |
| 11  | Eugenia     | 23.4       | 1622     |        |
| 12  | Atico       | 11.7       | 757      |        |
| 13  | Caraveli    | 31.5       | 1796     |        |
| 15  | Cerro Rico  | 18.1       | 211      |        |

According to the Table 5, the average mercury lost in amalgamation tailings is 512.8 gr / tm

3.3. *Mercury in amalgam*

The mercury in amalgam is practically given by the subtraction of the mercury lost in the quimbalete (Hg lost), minus the mercury present in the tailings (Hg tailings).

\[
\text{Hg amalgam} = \text{Hg lost} - \text{Hg tailings}
\]

Amalgam Hg = 1770.5 gr / tm - 512.8 gr / tm

Amalgam Hg = 1257.7 gr / tm

Per ton of amalgamated gold mineral, 512.8 g of mercury is lost, which binds to the amalgam, which shows that the amalgam carries free mercury, where only 20% to 25% is gold, the rest is mercury.

3.4. *Burning Amalgam*

Retortas are used for amalgam burning, which are equipment where the amalgam is heated to a temperature of 200 to 230 degrees Celsius, where mercury is recovered by distillation. The amalgam burning process, used for gold mining and mercury recovery, is presented in table No. 06, the description of which is presented at the bottom of that table.

### Table 6. Burning amalgam

| Peso gr | Gold weight (gr) | Hg (vapor) | distribution |
|--------|------------------|------------|--------------|
|        | R1               | R2         |              |
| 30.3   | 8.75             | 8.04       | 22.26        | 26.53 | 73.47 |
| 3.2    | 1.49             | 0.78       | 2.42         | 24.38 | 75.63 |
| 15.7   | 4.8              | 4.09       | 11.61        | 26.05 | 73.95 |
| 13.2   | 3.68             | 2.97       | 10.23        | 22.50 | 77.50 |
| 21.34  | 5.56             | 4.85       | 16.49        | 22.73 | 77.27 |
Table 6 shows the weight of amalgam in the first column; also shows the weight of gold, in column R1 and R2, second and third column; the fourth column shows the weight of mercury recovered; the fifth and sixth columns show the gold content and mercury in the amalgam.

R1; represents the weight of gold extracted, in the first stage of burning the amalgam, probably contains some mercury. Process performed in the amalgamation center and other times in your own home, representing the moment of high risk, depending on where they perform the burning of amalgam.

R2; is the weight of gold obtained in the second stage of amalgam burning, this process occurs, when gold is taken to the gold marketing premises, where all mercury is extracted.

The place where gold is purchased has a retorta, where mercury is recovered by distillation.

The fourth column represents the weight of mercury detached from the amalgam equivalent to 75.62% of the amalgam and 24.38% represents the gold extracted from the amalgam.

The recovered mercury could not be calculated with certainty, because this product is collected after a long time.

But under rigorous control, through communal tweaks in amalgam burning processes, up to 93.7% mercury is recovered which is called the efficiency of the retorta. So it can be assumed that 6.3% mercury emanates into the atmosphere, causing negative impacts on the environment and the health of mining workers and their family environment.

So the mercury released into the environment is:

\[ \text{Hg}_{\text{air}} = 1257.7 \, \text{gr} / \text{tm} \times 0.063 \]
\[ \text{Hg}_{\text{air}} = 79.24 \, \text{gr} / \text{tm} \]

The mercury released into the atmospheric air is 79.24 gr / tm, this is the amount of mercury that directly impacts the environment and human health.

### 3.5. Mercury in Humans

Table 7. Mercury levels by age ranges

| Etáreo group | Frequency | [0 a < 40 µg/L] % | Frequency | [40 a 90 µg/L] % |
|--------------|-----------|-------------------|-----------|------------------|
| Menor a 12 años | 4 | 12.90% | 6 | 19.35% |
| 13 - 23 años | 1 | 3.22% | 3 | 9.68% |
| 24 - 34 años | 3 | 9.68% | 9 | 29.03% |
| 35 - 45 años | 2 | 6.45% | 3 | 9.68% |

Table 7 indicates that 29.03% of miners aged 24 to 34 have mercury content between 40 and 90 g/L in their urine; which far exceeds the maximum permissible level; therefore, we can infer that the environment of amalgamation activity, have high-risk mercury concentrations for human health.

Table 8. Analysis of the age of mining workers

| Old (years) | Total | % |
|-------------|-------|---|
Table 8 shows that 59.85% of mining workers are ages 21 to 35 followed by 30.30% who are 36 to 50 years of age, which means that all workers are exposed to mercury pollution, exposing themselves to their relatives and the entire community.

4. Conclusions
- The loss of mercury in the amalgamation processes is 1770.5 g / mt of treated gold ore that is distributed between the tailings and the amalgam, a study that covers the El Ingenio district. Feel. Ica, to Huancuana - Caraveli - Arequipa
- In the tailings, mercury is lost on average 512.8 gr / tm loss of mercury that depends on several factors such as: as a type of bargain that accompanies it to gold, if it is oxidized or sulfurized.
- Mercury is lost in the amalgamation process which on average is 1257. 7 gr/tm of treated gold ore that when entering the burning process 93.7% mercury is recovered, provided that the burning or refocusing process takes special care, with communal tweaks.
- Finally, 6.3% of mercury is lost to the environment, this is the mercury that is directly inserted into the environment impacting that later precipitates in the soil and due to the temperature of the area it re evaporates affecting plants, surface waters and health of the mining worker and his environment.
- Analyzing the urine of mining workers of different ages, an appreciable amount of mercury was found and this mercury frequently remains in workers who are between 21 and 35 years old, which is the age of greatest frequency in the mining worker.

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