Revista de metalurgia

Methods to reduce mercury pollution in small gold mining operations(•)

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Abstract

The use of mercury for gold beneficiation is still a current practice in small mining operations, mainly in underdeveloped countries, due to the low investment required and necessity of easy to operate systems. But the lack of basic protections makes unavoidable the high pollution of water streams, soils, and in fact, human bodies. Some improvements have been done at site like that related to the removal of the mercury from the amalgam, that usually was done in the open air and now have been changed to the utilization of artisan iron retorts which considerably reduce the emissions of mercury vapors to the atmosphere, but there are still high losses of mercury into the waste solids or tailings coming from the amalgamation process (nearly most of the total weight of the ore treated). In order to reduce the mercury losses into the tailings from the process, this research work has been based in the use of cheap systems, available to the isolated miners, to proof that it is feasible to get an important reduction of the losses and the pollution. The procedure has been accomplished by means of washing the ores with alkaline or detergent agents, together with the use of activated mercury purified by electrowinning in a simple device, easily manufactured in site by the own workers. It is also proven herewith that controlling the time of amalgamation and the total amount of mercury used could reduce the total pollution, and in addition, the gold recovery would be improved. This investigation reports the possibility of a reduction of mercury losses down to 2.4 g per 100 g of gold produced (case of rich ores like LaBruja), with gold recovery up to 94 %; and 8,6 g per 100 g of gold produced (from ores with average grades like La Gruesa), and gold recoveries in the range of 92 %.All that is about 20 to 100 times lower than data reported in current bibliography. The introduction of a previous step of the ore concentration in shaking tables, decreases the total amount of solids for the process of amalgamation in the range of 70 %, then reducing the contaminated solid waste. By doing so the recovery of gold is improved in the case of rich ore, but not with the ore of lower grade when comparing with direct amalgamation. In that case it would be required a combination of shaking tables and flotation of the gravity tailings, but that process is more expensive and complicated for the small miners. The described method involves a low capital investment in equipment, and the training to operate the system is not difficult.

Keywords Gold. Mercury. Amalgamation. Pollution. Preconcentration.

Métodos para reducir la contaminación por mercurio en la pequeña minería del oro

Resumen

La utilización del mercurio para la extracción de oro es, todavía, una práctica habitual en las pequeñas instalaciones mineras, especialmente en los paises en desarrollo, debido a la baja inversión requerida y a la facilidad de operación. Pero la falta de medidas de seguridad hace inevitable una importante contaminación de los rios, de los suelos y también de los trabajadores. Se han realizado algunos avances, sobre el terreno, como en lo relativo a la eliminación de mercurio de la amalgama que se realizaba al aire y ahora se utilizan sencillas y baratas retortas de hierro que disminuyen mucho la emisión de vapores de mercurio a la atmósfera, pero sigue habiendo muchas pérdidas de mercurio en los residuos o estériles del proceso de amalgamación que es, fundamentalmente, casi todo el peso de mineral tratado. Para la reducción de estas pérdidas de mercurio en los estériles del proceso se ha realizado esta investigación, utilizando procesos muy baratos, asequibles a los mineros aislados, demostrando que es posible lograr una disminución muy importante de dichas pérdidas y de la contaminación consiguiente. Para ello se han utilizado técnicas de lavado con detergentes alcalinos de la mena y de purificacion electrólitica del mercurio con un sencillo y barato equipo que puede ser construido por los propios mineros, así como la demostración de que un sencillo ensayo de control de los tiempos de amalgamación y proporción de mercurio utilizado puede disminuir también las pérdidas, conjuntamente con un aumento

(•) Trabajo recibido el día 22 de julio de 2004 y aceptado en su forma final el día 26 de enero de 2005.

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de la recuperación de oro. De esta forma, es posible alcanzar pérdidas totales de mercurio de 2,4 g por cada 100 g de oro producido para menas muy ricas y recuperación de oro del 94 % (La Bruja), y de 8,6 g de pérdidas de mercurio por 100 g de oro producido en menas tipo medio de la zona y recuperación de oro del 92 % (La Gruesa), que son del orden de 20 a 100 veces menores que las pérdidas corrientes de los pequeños mineros, reflejadas en la bibliografía. La introducción de una fase previa de concentración gravimétrica en mesas de sacudidas disminuye hasta un 70 % la cantidad de material a amalgamar y, por lo tanto, los residuos sólidos contaminados, mejorando en el caso de la mena rica utilizada la recuperación de oro y empeorándola en el caso de la mena menos rica, en la que con un tratamiento combinado de concentración en mesas y flotación de los estériles de mesa se logran recuperaciones mejores que con la amalgamación directa pero,, en este caso, especialmente por la flotación, el proceso no será de uso general entre los pequeños mineros por su mayor dificultad de utilización y de coste de equipamiento.

Palabras clave Oro. Mercurio. Amalgamación. Contaminación. Preconcentración

1. INTRODUCTION

The technological development of methods for gold beneficiation has has been fully described by specific research groups[1] not only when the source of raw material is coming from the mine, but also from old tailings dams[2 y 3]. The current practice of using high contaminant mercury or cyanides is now changed by the main gold producers for new clean processes such as bioleaching[4 y 5] or pressure oxidation, which reduce the total material to be treated and the consequent risk of pollution to the humans and the environment.

But the amalgamation process is still widely used for gold recovery by the small size mining operations mainly in the underdeveloped countries of the tropical region. That is due to the simplicity of the methods used to get profitable results, and the requirement of low capital investments. We shall refer in this paper to those small operations, because the medium and important mining firms usually have a better control of their processes, and follow the international safety regulations.

The inadequate use of the mercury in these small operations leads to produce high losses, not only in the form of elemental mercury as it happens in the ore beneficiation process, but also as inorganic compounds or vapours produced in the extraction of gold from the amalgam. Another important fact in the small operations is the low level of the precious metal recovery, because of the defective application of the amalgamation process.

Usually, the workers are not taking in consideration the risks of human health or the environmental conditions. The exposure to this substance is not just limited to the operators, but also to their families, as it is the case when the amalgam distillation is made into the home kitchen or back yard[6 y 7].

Once the human body absorbs the mercury, it goes directly to the blood system, crossing the cellular membranes, and finally, it accumulates into the liver, bowels, kidneys, and nervous net system[8]. Chronic exposure to the mercury can motivate the sickness called "mercurialism" or "hidrargirism".

The environmental accumulation of the mercury from the gold processing emissions is mainly in the form of metal (Hg^{o}), or compounds (Hg^{++} or Hg^{+}), as the case of the mercuric nitrate produced during the gold chemical extraction from the amalgam. Under certain conditions, in the riverbeds and in the soil of the ground, mercury can be transformed into organic mercury, mainly methylmercury, by specific bacteria[9-11]. This form of mercury is very toxic for humans and when it is accumulated into the water streams it can be transmitted, by example, by the fact of eating contaminated fish. When it is accumulated in soils it usually ends up with marked accumulation in local food webs[12-14].

However, the most urgent premise is that concerning to the health of the miners and their families, due to the continuous exposure to the mercury.

The following data reflects the situation of the problem in different Latin America countries:

- The calculated emissions in the operations of southern Colombia, are in the range of 3 to 10 kg of mercury per kg of gold produced. An average figure is about 5 kg [15].
- Operations using mercury in the grinding stage of the ore in Brazil and Bolivia, the losses are

between 5 and 10 kg (up to 25 kg) per kg of gold produced[7].

- In the alluvial mining, the losses are similar, mainly in those where the mercury addition is done directly to the gravel in the ground, or into mixing chutes located at the head of the open channels, or directly into them. That is current practice in operations in Venezuela, Brazil and Colombia[7].
- The mercury losses originated by the informal mining operations in Brazil ("garimpeiros") are estimated in 2 kg of mercury per kg of gold produced[16] .The mercury emissions in the Amazonian are calculated in 300 ton per year (1,000 to 2,000 ton acummulated by now into this important ecosystem)[17-20].
- For an estimated number of 100,000 workers on this activity in Ecuador the reported annual losses are in the range of 50 ton [21].

In spite of the above data, the amalgamation process appears to be one of the preferred methods for the small mining gold operators still in the future. Therefore, it is very important to improve the actual methods, by implementing technologies of simple application, using equipments of low capital and operating costs, sometimes making it possible by the use of local manufacturing capabilities. At the same time, it is important to look for the advantage of increasing the total gold recovery, and decreasing the mercury losses. That would be a challenging opportunity for the small producers, who will be in turn ready to participate in the project. That is not just the case of reducing their profits by having a better environmental control, which could be mandatory in the future.

There are current technologies and apparatus which are starting to have a good acceptance, such as it is the amalgamation of concentrates in closed circuit, or the distillation in retort, in order to make possible a better mercury recovery from the amalgam without emissions, or the activation of the mercury by electrowinning. The description of the mentioned methods are shown in several papers[22].

This research work try to demostrate that by simple procedures it is feasible to reduce the pollution by mercury in the amalgamation process. Such systems are cheap and easy to operate by the isolated miners: Previous washing of the ore with water and a detergent, and utilization of activated mercury. Also introducing initial tests to control the amalgamation time and total amount of mercury used, contribute to decrease mercury losses and improves the gold recovery.

It is also proven that the introduction of preconcentration systems easy to operate, such as the shaking tables, it is possible in some cases to reduce the pollution due to the disposal of less quantity of contaminated solids. When the gold recovery is decreased, it is proposed to add the flotation of the tailings from the shaking tables, but then the process is more complicated to be used by the small producers.

2. EXPERIMENTAL SECTION

The research work to improve the gold recovery and the reduction of the mercury losses, were made with different samples received from the gold mine "Nueva Esparta", located in the south west of Colombia, and they represent the two veins called "La Bruja" and "La Gruesa".

Table I shows the main characteristics of the two types; the samples from La Bruja, represent a typical high grade gold ore, and that one from La Gruesa, with a lower grade, is more representative from most of the small mines in Latin America and other world operations.

Table I. Samples characterization

Tabla I. Caracterización de las muestras

Characteristic	Ore	
	La Bruja	La Gruesa
Au (g/t)	317.4	44.4
Ag (g/t)	180.1	62.2
SiO_2 (%)	83.35	88.35
TiO_2 (%)	0.23	0.18
Al_2O_3 (%)	3.79	2.57
Fe_2O_3 (%)	3.30	2.31
MnO (%)	0.03	0.03
CaO (%)	2.11	1.56
MgO (%)	1.34	0.89
K_2O (%)	0.88	0.59
Na_2O (%)	—	—
P_2O_5 (%)	0.02	0.01
S (%)	1.35	1.00
Pb (%)	0.19	0.13
Zn (%)	0.17	0.13
Loss on ignition (%)	4.64	3.50

Analisys of usual elements are made by means of X-ray fluorescence; gold and silver by fusion and cupellation, and sulfur by the gravimetric-analytical method.

It is important to note that instead of pure gold, the native metal found into the samples, could be "Electrum" (natural alloy with aprox. 20 % silver). The microprobe analysis of the silver content into the gold, as an average of the results obtained over several native metal particles from both types of ore, is shown in table II.

It is also important to determine the presence of sulphide minerals, such as pyrites, arsenopyrites, galena, etc., because they can contribute to form the so called "mercury flour" when ions sulfide are liberated, and also they are heavy and flotable minerals that drives to increase the weigth of the preconcentrates. In case of the ores investigated, the sulfur content averages 1 %, what means less than 5 % in sulfides mainly arsenopyrite, followed by pyrite, tetraedrite, sfalerite, galena and chalcopyrite.

First of all, a research was done to see the influence of the parameters to be considered in amalgamation (mercury/ore ratio, unwashed ore or washed ore with detergent, amalgamation time, and the use of normal mercury or activated one). All test made on samples of ores as received, without any preconcentration, and just ground to minus 2 mm.

All the equipment and apparatus selected for the ore treatment, are feasible for the small mining operations, low in cost to buy and operate, and easy to be implemented into actual installations.

Amalgamation method used is by the barrel system, in which the mercury and ore are mixed by rotation in a sealed vessel in order to avoid the pulp leaking, and direct handling contact by the workers

To have a good control over the formation of "Mercury flour" (small drops of mercury which do not coalesce), it is recommended to make the grinding of the ore and the amalgamation process

Table II. Mean analysis of several grains of native gold

Tabla I. Análisis medio de varios granos de oro nativo

Element	Ore	
	La Bruja	La Gruesa
Au (g/t)	75.7	80.4
Ag (g/t)	24.3	19.6

into the barrel in separate steps[22], so avoiding important mercury losses. That is the reason why the two samples were previously ground to minus 2 mm.

The amalgam and mercury in excess are recovered by settling of tailings in water and dragging. The amalgam is separated from the mercury by pressure filtration in a textile package containing the mixture. Latex gloves must be used for this operation. Finally, the gold is recovered by distillation in a small covered retort with a threaded cap, locally manufactured in Colombia. This device has been well accepted by the small gold producers, with better results than the open vessels to recover the mercury from the amalgam.

For the tests using activated mercury, the mercury material coming from the recovery step is treated by electrowinning in a small cell, locally manufactured, consisting of a plastic bowl with a graphite electrode at the bottom connected to a negative pole of a 9 to 12 volt car battery. A layer of mercury is decanted over this electrode, and also a 10 % solution of NaCl is poured onto it. A new electrode is then introduced into the solution (anode) connected to the positive pole of the battery, and the power is driven around 5 min. Some sodium amalgam is produced by this way, but it reacts with the water to get NaOH, and both are cleaning the coating oxides from the mercury surface. The activated mercury has metallic brightness and when breaking in drops form round spheres of easy coalescence.

In order to investigate the influence of the pre-washing treatments, that was carried out in a rotary drum (barrel) with addition of high quantities of water containing lime soda and detergent, and then, the solution was decanted before proceeding to the amalgamation process. By that method, the coating is removed from the solid particles and the pH is modified, thus decreasing the formation of mercury flour.

Mercury flour formation is favored[23] by the presence of sulfides reacting with the small mercury drops produced by the mechanical actions and the coating by HgS, which motivates the electrostatic repulsion of the droplets, so avoiding the union between them. Under alkaline environment, it is generated a complex ion HgS_2^{2-} instead of the HgS, and then, the coating effect and the mentioned repulsion is not feasible[24].

In this research work has been also investigated the reduction of contamination by lowering the total amount of solids to be amalgamated by introduction of a previous preconcentration process. The concentration by gravity, is carried out in a Wilfley shaking table, a very well known device used by the small producers, easy to operate, and to be adapted to any process parameter.

In the case of treating the ore "La Gruesa", the total gold recovery result lower by using the preconcentration than by direct amalgamation, due to losses of gold in the tailings. By this reason it was tested an adittional flotation of the tailings in both samples (all minus 0.25 mm).

Samples from gravity were then ground to minus 0.25mm. and floated to obtain a rougher concentrate and a final tailing. A cleaner flotation of the first concentrate produced a high-grade concentrate, and a second one of lower quality.

The flotation essays were made in a laboratory size cell Denver Sub A, commonly used to scale up a lot of industrial flotation machines for medium and large plants, but not so frequently used into the small operations, because of the expensive chemical reagents required by the system. Flotation conditions were : pH=7.5, percent solids by weight = 25 % (average), reagent colector (K-amilxantate)= 200 g/t. Neither Na-silicate nor Na-carbonate were added because lower gold recovery was noted.

3. RESULTS AND DISCUSSION

3.1. Direct amalgamation of La Bruja ore

The best results from this research work on the La Bruja ore, were those carried out with activated mercury, and using a previous washing step of the ore with alkalis or detergents to remove clays and other surface contaminants such as sulfides and greases, which could cause problems in the amalgamation process. Figure 1 shows the influence of the ratio of mercury used on gold recovery and the total of mercury losses (sum of the losses in decanted water after washing and in the solid wastes, in terms of g of mercury per 100 g of produced or recovered gold).

The influence of the total amount of mercury used is clearly noted, not only for gold recovery, but also in the losses of this element. The optimum ratio is 3 kg of mercury for metric ton of ore, which leads to 94.2 % gold recovery and losses 2.4 g of mercury for 100 g of gold obtained. Using lower mercury ratio for same time of treatment, the collection of gold decreases, and the amalgam

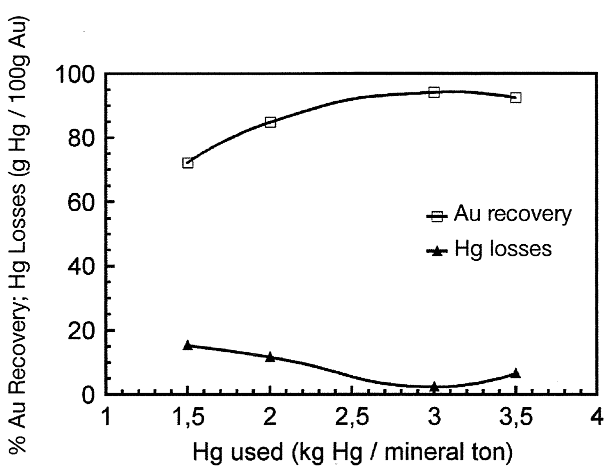

Figure 1. La Bruja ore: Influence of the quantity of activated mercury on the gold recovery and on total mercury losses (previous washing of the ore).

Figura 1. Mineral de La Bruja : Influencia de la cantidad de mercurio activado sobre la recuperación del oro y en las perdidas totales de mercurio (con lavado previo del mineral).

becomes more consistent, with a higher difficulty to coalesce, increasing the losses in small drops trapping the gold (higher mercury losses and lower gold recovery).

When the amount of mercury used is excessive, the effect is similar, because the amalgam becomes more fluid and there is more opportunity to get losses into the small drops.

As a matter of fact, each gold producer has to investigate the optimum ratio of mercury required, in order to reduce the pollution by lowering the losses to a minimum, and also to improve the total gold recovery, which means healthy environment and higher revenues for the mining operation.

Operating conditions, mainly those related to the previous washing of the ore and the use of activated mercury, are the key to reduce the mercury contamination and at the same time, to improve the gold recovery. Fig. 2 shows the results of using 3 kg of mercury per ton of ore treated, which is the optimal ratio given in figure1, for 2 hours of amalgamation time, and different operating conditions (ore without washing, ore washed and standard mercury, and washed ore and activated mercury)

Utilization of activated mercury and mainly when the ore is previously washed show an important improvement in gold recovery. It is noted a high decreasing of the contaminating effect, which could go down to only one eighth of the samples when using normal mercury.

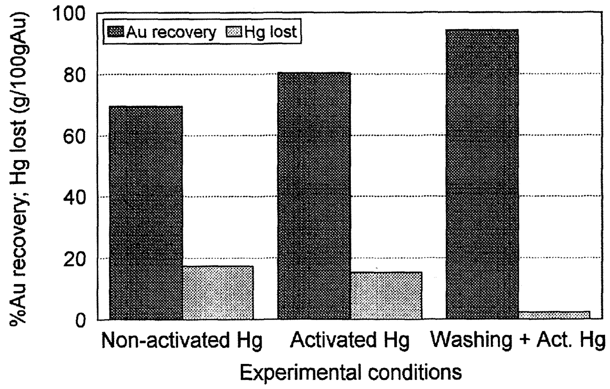

Figure 2. La Bruja ore: Gold recovery and mercury losses using 3 kg of mercury per ton of ore and 2 h of amalgamation time.

Figura 2. Mineral de La Bruja: Recuperación del oro y pérdidas de mercurio usando 3 kg de mercurio por tonelada de mineral y 2 h de tiempo de amalgamación.

The beneficial effect of the activated mercury and the previous washing is going along even when optimal amounts of mercury and treatment times are not maintained. Figure 3 shows the result of a mercury addition of 3.5 kg per ton of ore, and an excess of 4 h treatment time, so facilitating the losses by mechanical breakage of the mercury and the amalgam (mercury flour formation). The mercury losses are higher and the recovery of gold is somehow lower than that of the previous case presented (Fig. 2, 2 hours and 3 kg of mercury per ton). This fact shows the importance of treatment time due to the formation of mercury flour and leads to the use of activated mercury and previous washing to improve the relative gold recovery and reduce mercury losses to one thirteenth.

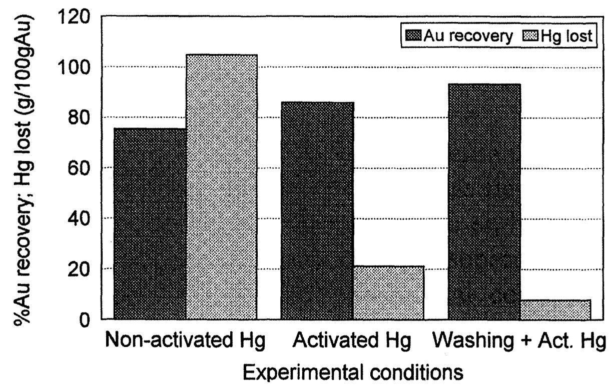

Figure 3. La Bruja ore: Gold recovery and mercury losses using 3.5 kg of mercury per ton of ore and 4 h of amalgamation time.

Figura 3. Mineral de La Bruja: Recuperación del oro y pérdidas de mercurio usando 3,5 kg de mercurio por tonelada de mineral y 4 h de tiempo de amalgamación.

Test results by using activated mercury under similar operating conditions, are always positive, mainly when compared with the mercury losses by adding non-activated mercury. Microscopic examination of the tailings by using activated mercury, shows lower losses of gold particles than those verified with utilization of normal mercury.

The activated mercury drops and the gold amalgam join together faster and more efficiently than in the case of normal mercury, what drives to have lower gold losses and lower demand of mercury for its collection. The amalgam filtration is also improved, looking more consistent, brighter, and in a whole mass, what means a better formation of the gold sponge, more compact, and easier to separate in the distillation retort.

The most important fact from this research work about the amalgamation process is to be able to determine the effect of the previous washing. In this sense, tests done with the same times, and quantities of mercury, activated or not, when the ore was pretreated by a simple washing step, were reporting higher gold recoveries and relatively lower mercury losses. The washing step is used to remove the greasy contamination and the superficial coating on the gold grains, thus avoiding the detrimental effect of other substances in the amalgamation process (arsenic, antimonium, bismuth, lead, iron and copper sulfides etc.), which are frequently found pollutants in most of the primary gold deposits, as it is the case of the ores from La Bruja and La Gruesa.

Another conclusion from the tests made with previous washing is the decreasing of the mercury consumption and the time of the treatment to get the same gold recovery. That reduces the production costs and produces higher cash flow from the gold and mercury recovered and, at the same time improves the environmental conditions.

The recovery of the silver values is always lower than that of the gold, getting a final silver content in the recovered gold just a little higher than the one found into the native gold-silver alloy. That shows that the amalgamation is acting directly on the allotted silver with gold, and not on the silver contained in sulfides.

La Bruja ore is too rich to be taken as a general example, but the results are very illustrative of the amalgamation efficiency under different conditions. La Gruesa ore represents better most of the gold veins in Latin America.

3.2. Direct amalgamation of La Gruesa ore

This ore shows the same tendency, but due to its lower grade, the total recoveries are somehow lower, and higher the mercury losses per kg of gold produced. Under optimal conditions (previous washing of the ore, 3 kg of activated mercury per ton of ore, 2 h of amalgamation), the total recovery reached up to 92 % of gold, just 2 points below that one in the case of La Bruja ore (Fig. 4). The mercury losses were less than 8.6 g by 100 g of produced gold, what means 20 to 100 times lower than usual numbers reported on papers about this subject, but are higher than those of the La Bruja case.

When not applying optimal conditions, as it happens with excessive time of 4 h (for same mercury dosing of 3 kg per ton), the gold recovery went down and the mercury losses increased, as it is shown in figure 5. In this case, for activated mercury and previous washing of the ore, the reported losses are 31 g by 100 g of produced gold, which corresponds to a multiplication factor of 3.6 compared to that of the optimum time. Gold recovery also drop down from 92 % to aprox. 86 %.

Following the above fact, the inadequate dosing of mercury leads to poor results; figure 6 shows the results when using just 2 kg per ton and an optimum time of 2 h. There is a tendency to decrease the gold recovery and to increase the mercury losses (lower than in the case of 4 h (Fig 5), but higher than when using the optimal conditions (Fig. 4)). Therefore, by having previous washing of the ore and activated mercury, the losses of this element are averaging 29 g per 100 g of produced gold.

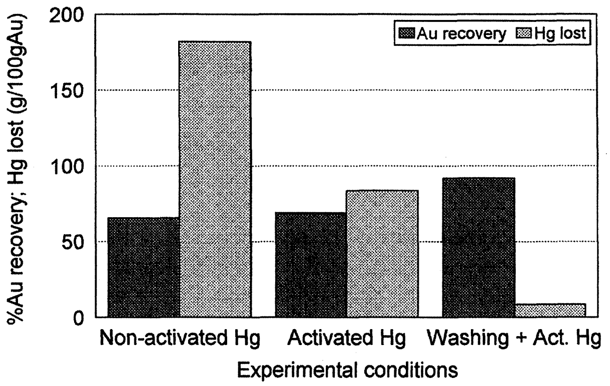

Figure 4. La Gruesa ore: Gold recovery and mercury losses using 3 kg of mercury per ton of ore and 2 h of amalgamation time.

Figura 4. Mineral de La Gruesa :Recuperación del oro y pérdidas de mercurio usando 3 kg de mercurio por tonelada de mineral y 2 h de tiempo de amalgamación.

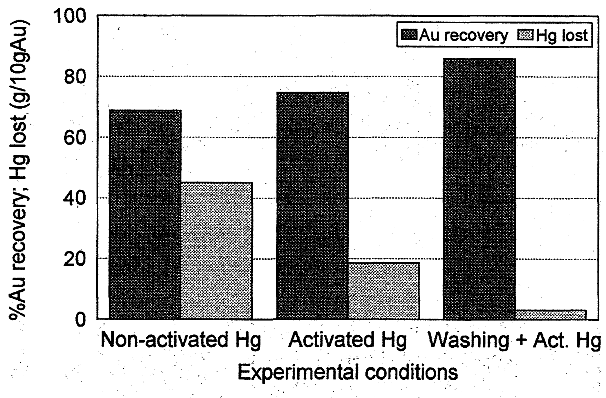

Figure 5. La Gruesa ore: Gold recovery and mercury losses using 3 kg of mercury per ton of ore and 4 h of amalgamation time.

Figura 5. Mineral de La Gruesa: Recuperación del oro y pérdidas de mercurio usando 3 kg de mercurio por tonelada de mineral y 4 h de tiempo de amalgamación.

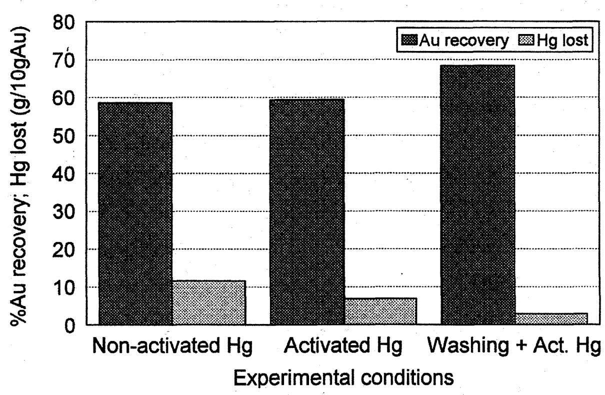

Figure 6. La Gruesa ore: Gold recovery and mercury losses using 2 kg of mercury per ton of ore and 2 h of amalgamation time.

Figura 6. Mineral de La Gruesa: Recuperación del oro y pérdidas de mercurio usando 2 kg de mercurio por tonelada de mineral y 2 h de tiempo de amalgamación.

Another important parameter is the ratio between the mercury losses in the water and that in the solid wastes. Table III shows the data for the samples of figure 1. That water is coming from the amalgamation process, used in a ratio of 1 weight of water to 2 of solids. Water was decanted and filtered in a paper media with retention of most of the solids, obtaining just water with dissolved mercury or a very little particle in suspension, simulating a good decantation.

From table III and other similar tests, it is deducted that the losses in the water are in the range of 100 to 1000 times lower than into the

Table III. La Bruja: Mercury losses (g/ 100 g Au produced) in amalgamation of previously washed ore with activated mercury during 2 hours

Tabla III. La Bruja : Pérdidas de mercurio (g/100 g de oro producido) en la amalgamación de mineral previamente lavado con mercurio activado durante 2 horas

Mercury used	Mercury lost (g/100 g Au produced)	
	In water	In solids
3.5 kg Hg/t	0.06	6.5
3 kg Hg/t	0.008	2.4
2 kg Hg/t	0.0005	11.6
1.5 kg Hg/t	0.16	15.3

solid wastes (sometimes even lower). It is very important to take notice of the storage system and disposal of the solids, as a better way to control the environmental pollution. Preconcentration methods must be considered in the desire to reduce the total amount of ore to be treated by amalgamation, and therefore to decrease the total solid wastes produced for final disposal or further treatment.

Most of the mercury losses are in the solid wastes, and this fact drives to a potential contamination[10 y 11] which calls for an imperative regulation in its final disposal or the requirement of further treatment of the wastes, which is difficult to be implemented by the small producers. In order to investigate the possibility of reducing that contaminating factor, several gold preconcentration tests were conducted in Wilfley shaking tables, a well known gravimetric separation machine, easy to operate, with low power requirements from an electric or hydraulic source.

3.1. Investigation by introducing a previous preconcentration step

Table 4 shows the results of the preconcentration essays done with ores ground to minus 0.25 mm in a shaking tables circuit composed by a rougher treatment and a cleaning stage of the concentrate, obtaining a very high grade final concentrate, easy to be beneficiated by direct melting, and a second one suitable for the amalgam.

From above tests, it is clear that the yield of the gold recovery is high, mainly in those concentrates coming from La Bruja ore due to its high feed

Table IV. Wilfley shaking table preconcentration

Tabla IV. Preconcentración en mesa de sacudidas Wilfley

Fraction	Menas	Weight	Assay		Recovery	
		%	Au g/t	Ag g/t	Au %	Ag %
1st Concentrate	La Bruja	0.11	88,885	25,877	32.21	14.45
2nd Concentrate	La Bruja	28.22	623.2	368	63.54	52.74
Tailings	La Bruja	71.67	17.96	90.12	4.25	32.81
Total	La Bruja	100	303	197	100	100
1st Concentrate	La Gruesa	0.04	22,594.7	8,256	20.75	2.55
2nd Concentrate	La Gruesa	16.69	164	306	62.86	39.46
Tailings	La Gruesa	83.27	8.57	90.1	16.39	57.99
Total	La Gruesa	100	43.5	130	100	100

grade, and therefore, the amount of solids for the amalgam is dramatically reduced.

In the case of La Bruja ore, the overall recovery of the concentrates reaches up to 95.75 %, and gets just 83.61 % in the case of the samples from La Gruesa ore. For the first one, the recovery is higher than by direct amalgamation, but it is lower in the second. Both second concentrates have been amalgamated under the 3 alternatives of using normal mercury, activated one with previous washing of the ore, and just the utilization of activated mercury. Figures 7 and 8 show the results from La Bruja and La Gruesa samples respectively, reaching recoveries under optimal conditions of 97.82 % and 97.42 %, which are considered as a very good results for the amalgamation stage. For the global process of concentration-amalgamation, the recoveries are in the range of 94.4 % and 82 % respectively, being equal to those from La Bruja using direct amalgamation, but lower than in the case of La Gruesa, which in this case makes the preconcentration alternative not so attractive for the small miners.

Mercury losses under optimal conditions are in the range of 8.5 and 15 g per 100 g of gold produced by amalgamation. Keeping in mind the gold recovered with the first concentrates, the mercury losses would be between 5.6 and 11.3 g by 100 g of produced gold, getting closer to the results from the direct amalgamation, but having less volume of solids, 28 % of the feed in the case of La Bruja, and 17 % in La Gruesa, so facilitating the total solid waste management.

By doing balance of the concentrates amalgamation advantages, has to be take in mind

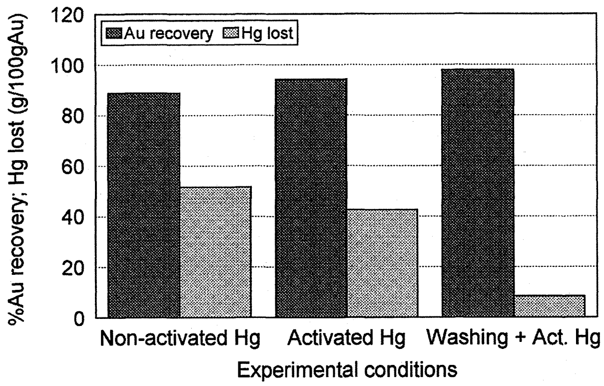

Figure 7. La Bruja second gravity concentrate: Gold recovery and mercury losses using 6.67 kg of mercury per ton of concentrate and 2 h of amalgamation time.

Figura 7. Segundo concentrado por gravedad del mineral de La Bruja: Recuperación del oro y pérdidas de mercurio usando 6,67 kg de mercurio por tonelada de mineral y 2 h de tiempo de amalgamación.

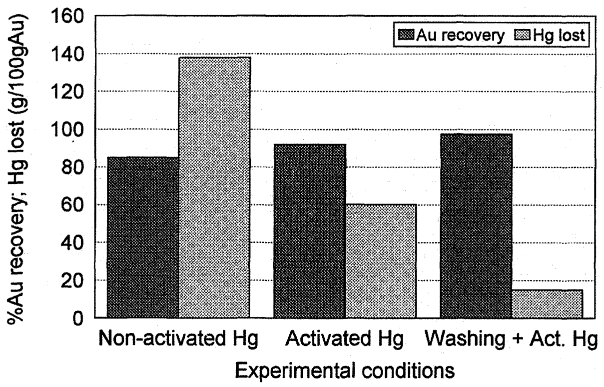

Figure 8. La Gruesa second gravity concentrate: Gold recovery and mercury losses using 4.67 kg of mercury per ton of concentrate and 2 h of amalgamation time.

Figura 8. Segundo concentrado por gravedad del mineral de La Gruesa: Recuperación del oro y pérdidas de mercurio usando 4,67 kg de mercurio por tonelada de mineral y 2 h de tiempo de amalgamación.

the lower capital investments required and the low operating costs, compared to those generated by directly processing higher tonnage of run of mine ore. The versatility and easy combination of the gravity concentration systems (shaking tables), barrel amalgamation and direct melting of the richest concentrates, makes it possible a high efficiency operation at low cost. That is an alternative method to be considered when planning a new project, mainly thinking in the reduction of the total amount of contaminated waste produced. In any case, a research work must be developed to determine the feasibility and convenience of the results.

In the case of La Gruesa ore, the total gold recovery after preconcentration result lower than that by direct amalgamation. By this reason the froth flotation has been investigated as a potential preconcentration step of the ore, even when this process is more expensive and requires higher process know-how. Direct flotation of ground ores to minus 0.125 mm., leads to recoveries in the range of 91 %, lower than those of the direct amalgamation, but in the other way, the total tonnage was reduced to 8-9 % of the original feed, what means an important advantage for the environmental control.

When tailings from the gravity concentration of the ore previously ground to 0,25 mm for the shaking table are then treated by flotation (pH 7.5, 200 g/t Amil-xantate without any Na-carbonate neither Na-silicate) it is possible to get a concentrate of 2,5 points higher in gold recovery from La Bruja ore and 11,49 points from that of La Gruesa. It is clear that using both methods together, gravity preconcentration and flotation of the tailings the results are better than just with gravity concentration in shaking table, and it remains the important reduction of the total contaminated solid wastes, because the amount of concentrates from flotation are very low compared to those from the shaking table.

4. CONCLUSIONS

- Better results are expected in the amalgamation process by using electrolytic activated mercury obtained in a simple device called "mercury activator". In the same time treatment it is not only improved the gold recovery, but also decreased the mercury losses, what means a more friendly method for the environment?
- By a simple previous washing of the ore with detergents and alkalis, the mercury losses are also reduced in the amalgamation process, and the total gold recovery is increased.
- The optimization of mercury dosage and shorter time of treatment by training leads to a significant reduction of mercury and gold losses.
- A preconcentration of the ore by a gravity system dramatically reduces the tonnage to be processed, and consequently the total contaminated tailings wastes, what makes easier and cheaper its disposal or further treatment. It is then recommended to check the feasibility of that method compared to the case of treating the total run of mine ore by amalgamation, and the cost of the tailings management

- Barrel amalgamation of gravity concentrates produced in the shaking table, using a previous washing and a correct ratio of activated mercury, leads to a practical total recovery of the gold values. The control of the global process is then the recovery rate at the gravity preconcentration step.
- A combination of ore preconcentration in shaking tables followed by froth flotation of the tailings, gives quite a good results, but the capital and operational costs are higher, and the training more difficult for the workers, what means that the alternative is not so recommended.

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