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The University of British Columbia
Norman B. Keevil Institute of Mining Engineering
6350 Stores Rd., Vancouver, BC, Canada, V6T 1Z4
ph: (604) 8224332, fax: (604) 8225599; veiga@mining.ubc.ca

Report to UNDP Indonesia

A Critical Review of Suitable Methods to Eliminate Mercury in Indonesia's Artisanal Gold Mining:

Co-existence is the Solution

Marcello M. Veiga, PhD, PEng

Professor

For

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SUMMARY

This report contains an assessment of many international projects on mercury reduction/elimination in artisanal gold mining (AGM) conducted by the author and others, with the intention to elaborate suggestions for the case of Indonesia. The author has participated for more than 40 years across over 35 countries in projects on this subject and his comments intend to bring a constructive critical review about what did and did not work in terms of solutions for mercury pollution in AGM. Well-intended, but with improper objectives, lack of continuity and the low impact, several global projects to reduce or eliminate mercury were reviewed. The whole ore amalgamation followed by cyanidation in processing centers, where miners extract gold from their ores, is occurring in basically all developing countries, particularly in Indonesia This is highlighted as the main source of pollution with metallic mercury being emitted to the atmosphere and mercury-cyanide compounds being discharged to the drainages. It is imperative to transform these centers into responsible processing companies or then, they must disappear. The three main approaches frequently used by a large number of projects aiming at AGM mercury elimination have comprised: 1) environmental & health monitoring campaigns to highlight the high levels of pollution and intoxication of operators and neighbors, expecting that the results will change the polluting behavior of the miners; 2) technical-educational methods to demonstrate cleaner techniques to miners, expecting they learn, build and sustain the techniques they have learned; 3) formalization-legal approach to prohibit the use of mercury in AGM, expecting that the miners follow these regulation where there is enforcement. None of these approaches have been working and the amount of mercury used by AGM is increasing to near 2000 t/a worldwide. The only sustainable model that is in fact working and eliminating mercury use is when conventional mining companies of all sizes buy the ores for a fair price from artisanal miners operating in the companies' mineral titles. These companies process the ore using mercury-free technologies that are more efficient than amalgamation. The report stresses initiatives in Latin America where the conventional companies accept the presence of artisanal miners in their titles and buy the ores according to the gold grades. Suspicion about the analytical process can affect the relationship between ore-buyers and miners. This co-existence process can be improved if an independent party, such as a government agency or company, prepare the ore (crushing and homogenizing) brought by miners, sample it and analyze it to provide reliable and transparent results to both parties, artisanal miners and processors. It is always suggested that the conventional companies provide technical and financial assistance to the miners operating in their titles, creating "de facto" a pacific co-existence system and reducing mining accidents. The co-existence model that the Continental Gold is successfully applying in Colombia is an example on how artisanal miners can be formalized, how employment can be generated, how miners can receive more for the ores they mine and how mercury can be eliminated. In short, the most concrete solution for mercury elimination, which is witnessed in some countries is: MINERS MINE and PROCESSOR PROCESS the ore. Governments must be prepared to moderate this system and facilitate its implementation.

1. MERCURY POLLUTION FROM ARTISANAL GOLD MINERS

1.1. Some Definitions

Some definitions are necessary before discussing the most appropriate solutions for mercury elimination in artisanal gold mining (AGM). It is important to have a clear understanding of what is the artisanal mining sector before creating legal definitions. In many developing countries, legislations related to artisanal mining are fraught with confusing terms. Clearly the large majority of legislations encompass in the same category "artisanal" and "small-scale" mining. These terms are used interchangeably, but they are not the same, as "artisanal mining" refers to the rudimentary activities of mining and ore processing (Veiga, 1997) and the "small" refers only to the size of the operation. The opposite of "artisanal" is in fact "conventional" mining which is usually legal, mechanized, and use more advances technologies for the type of ore being mined and processed (Veiga et al., 2014a). Worldwide, there are thousands of small conventional mining companies working in a regulated fashion, using sophisticated technologies and respecting the environmental and health laws. Alternatively, an artisanal mining operation can process over 10,000 tonnes of ore per day, which cannot be considered small (Fig.Fig. 1). This might sound a case of semantics but, if governments stop using a large glossary of definitions to classify the types of artisanal miners, such as traditional, miners in fact, native, indigenous, or whatever, large part of the legal problems would be resolved.

Type of Mining	Size	Legal Situation	Mechanization
Artisanal (rudimentary)	• Micro • Small • Medium • Large	• Illegal • Informal • Legal	• Manual • Semi-mechanized • Mechanized
Conventional	• Small • Medium • Large	• Legal	• Mechanized

Fig. 1. Fundamental Differences between Artisanal and Conventional Mining Operations (Veiga et al., 2014a)

"Informal mining" is another confusing term constantly present in the media and in many legislations. This is a broader term that comprises all forms of mining that operate without labor or social protection (Chen, 2007) and in some cases without proper mineral titles[1]. Informal mining is fruit of a set of deficiencies in technical assistance, lack of knowledge, unacceptable

[1] **Mineral Title** is herein defined as a parcel of land for which the claimant has asserted the right to develop and extract a discovered, valuable, mineral deposit (US Dep of Interior, 2020). The term "title" has been used to encompass mineral exploration or claims (usually related to geological exploration), and mining permit or mining lease or mining concession, etc. (which are related to production tenure for mining.

working conditions and absence of environmental management and permits (Hentschel et al., 2002). This term is frequently mixed up with "illegal mining", in particular in the media, which it is usually identified when the activity is conducted illicitly, with deliberate criminal intentions such as money laundry.

If legislations focus only on the volume of material being mined per month and the level of gold production, the bureaucratic process of legalization and taxation would be significantly simplified. If miners use, for subsistence, rudimentary methods to extract little gold (panning for example) from a small amount of ore, they should pay less or no taxes. They will not be the main polluters or the main causes for tax evasion, and this should not be the main concern of the legislations. If artisanal miners use a large volume of material and due their inefficiency, they produce little gold, the miners should pay more taxes, which is an "encouragement" for them to improve their gold recovery using better processing methods. The amount of material mined and processed is usually ignored in many legislations regarding AGM. Insistently, governments try to encompass all types of miners in the same legislation creating clauses that simply are not respected. When governments realize the inefficiency of their laws, they start an endless process of re-definitions of different types of miners, in order to accommodate various types of artisanal miners in the same legislation.

Worldwide, there are micro, small, medium and large artisanal miners, always using rudimentary ways to prospect, mine, process ores and manage tailings. Artisanal mining is definitely the main environmental and social problem in mining, where over 40 million individuals are directly involved (IGF, 2017). Artisanal gold mining (AGM) may represent over 20 million people involved, where the estimated production can lie within 380 and 450 tonnes/a in more than 70 countries (Seccatore et al.,2014). The large majority of artisanal gold miners use gold amalgamation processes to extract gold, and this sector, with approximately 2000 tonnes/a of mercury lost to the environment, is currently considered the main source of global anthropogenic mercury pollution (UNEP, 2020a). Other problems related to AGM include water pollution, tropical and sexually-transmitted diseases, deforestation, permanent land degradation, conflicts with companies or other owners of the mining concessions, drugs, gambling, prostitution, property invasions, money laundry, tax evasion, high prices of goods in a town, etc. Then, mercury pollution from AGM is only a tip of an iceberg of problems.

1.2. Mercury in AGM in Indonesia

In Indonesia, the estimated 1 million of artisanal gold miners work in 27 provinces, which represent 80% of the provinces in the country (Balifokus, 2015 and 2017). The Nexus3/Balifokus Foundation has available a good number of reports[2] about mercury in AGM. For decades, Indonesia has experienced a high influx of artisanal miners not only in gold, but also in tin.

[2] Available at https://www.nexus3foundation.org/reports.

According to Maia et al. (2019), more than 60% of refined tin produced in Indonesia which is approximately 27% of the global tin production, comes from artisanal miners in Bangka and Belitung islands. According to McGrew (2016), for over 30 years the artisanal miners are working in different sites in Indonesia producing annually approximately US$ 5 billion worth of gold. This author disagreed with the number of artisanal gold miners in Indonesia estimated by Balifokus (2015), and indicates that currently 300,000 miners are active in over 1000 sites. This author also highlighted the fact that most rural communities do not have too many employment options and become artisanal gold miners. In fact, this is common to all 70 known countries where AGM is prevailing. Siegel and Veiga (2010) reported that it is extremely difficult to move artisanal miners away from this lucrative activity.

A recent report revealed the opinion of the Indonesian Association of People's Mining, APRI (*Asosiasi Petambang Rakyat Indonesia*) that estimated the bizarre amount of 3000 tonnes of mercury released annually to the environment by AGM in Indonesia alone. Other reports indicated 380 tonnes of mercury released and emitted annually to the environment in Indonesia (Ismawati, 2018). Despite the huge discrepancy between these two pieces of data, the information stresses the gigantic magnitude of the problem.

According to data from UN COMTRADE (2020), an international UN branch that reports goods officially exported and imported by countries, Indonesia in 2010 legally imported 3.5 tonnes of mercury but Ismawati et al. (2013) estimated that, in the same year, approximately 280 tonnes of mercury entered illegally in the country. The legal imports of mercury in 2011 were 7.9 tonnes and, according to these authors the illegal amount smuggled to Indonesia doubled the amount from previous year. The UN COMTRADE (2020) has demonstrated that Indonesia passed from importer to exporter of mercury in 2015 (Fig. 2).

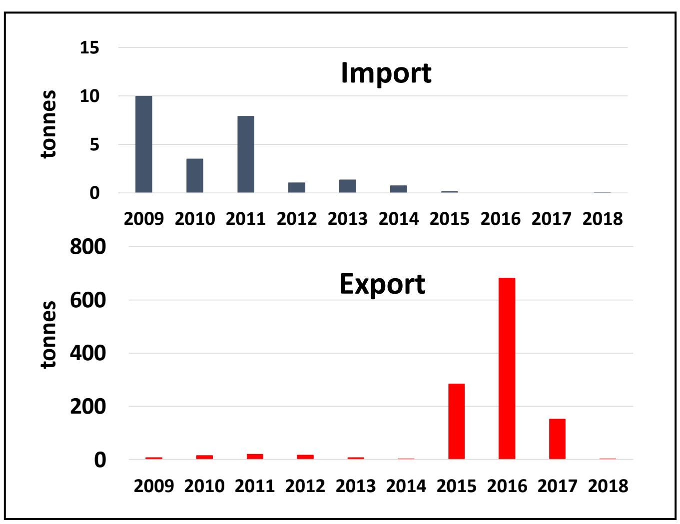

Fig. 2. Indonesian Legal Imports and Exports of Metallic Mercury
(Data:UN COMTRADE, 2020).

Spiegel et al. (2018) explained that exports of mercury from Indonesia increased due to the new cinnabar (HgS) mines developed in the country. This also makes mercury less expensive and more available in AGM sites across the country. In Indonesia, both, the National Regulation No. 74/2001 that manages hazardous and poisonous substances and the Ministry of Trade Regulation No. 23/M-DAG/PER/9/2011, that controls the purchase, distribution and monitoring of hazardous substances, focus in restriction of mercury use in AGM. According to Pidani and Mokui (2017*)* they believed that "…the *government officials demonstrate a lack of knowledge about mercury*"*,* to illustrate the inefficiency of the enforcement of these regulations.

The high level of mercury pollution in Indonesia is caused by undue thermal decomposition of amalgams in open pans and, mainly, from the amalgamation of the whole ore in small ball mills, locally known as "tromols". Like in many other countries in Latin America and Africa, processing centers proliferated in Indonesia providing the miners, for free or a very low fee, with amalgamation of the ores, with the condition that tailings must be left in the centers as a form of payment for the services. Amalgamation of the gold ores in small ball mills recovers less than 30% of the gold in the ores (Veiga et al, 2014b, Garcia et al., 2015). In Sulawesi, probably this might be even lower than 20% since the gold is very fine (Veiga et al., 2009). During the wet grinding of ores with mercury, vapor of mercury has been detected escaping from the mills (UNIDOI, 2007). When, the miners finish their amalgamations, processing centers keep the mercury-contaminated tailings to extract residual gold (which is actually the large majority of the gold) with cyanide, which is much more efficient than mercury to extract fine particles of gold. In this process, about 80-90% of the gold in the tailings is usually recovered. However, the cyanide also dissolves residual mercury in the tailings forming $Hg(CN)_2$ in solution that is discharged into local drainage. This mercury complex contaminates much more the aquatic biota than metallic mercury alone (Drace et al., 2016).

The idea of establishing processing centers to extract gold from ores were initially very welcomed by governments and international agencies as a good way to reduce the investment and operating costs of the miners, as well the use of mercury. The first center established was in Zimbabwe in 1989, where miners could bring their ores to be crushed, ground, concentrated, amalgamated and retorted by specialized operators. The model had its merits. Veiga and Beinhoff (1997) and Hinton et al. (2003) highlighted the advantages of the processing centers as they could also serve to provide training for miners on how to reduce mercury use and other better practices. Nevertheless, the owners of the processing centers realized that amalgamation extracts only the free gold, i.e. gold that is not attached to other mineral particles. Amalgamation is also inefficient to trap fine gold particles below 0.074 mm (Wenqian and Poling, 1983). Therefore, most of the gold is lost to the tailings in a classical amalgamation process. Worldwide, these centers proliferated and the owners convinced the artisanal miners that gold concentration was inefficient and a waste of time. Like in Indonesia, the majority of the centers in many countries, adopted the inefficient and polluting method of whole ore amalgamation in small ball mills or amalgamation on copper plates covered with mercury. The grinding processes used in most processing centers are usually not sufficient to liberate the gold particles for an efferent amalgamation, but they are enough to expose the surface of the unliberated gold particles to be leached with cyanide. Methods to improve the amalgamation and reduce mercury losses were extensively promoted (Pantoja and Alvarez, 2000), including in Indonesia, but these improving methods are not in the interest of the processing centers to be implemented. For the owners of these centers, amalgamation is more advantageous process for them as it leaves more gold in the tailings that can be extracted with cyanide.

With inefficient grinding and amalgamating the whole ore, mercury losses can reach over 80 parts of mercury lost per one part of gold produced (Cordy et al., 2011). Usually, the average ranges widely between 6 and 15 but this depends on the ore, the gold grade, the ball-mill speed and how much mercury is added to the mills. This is also a good business for the owners of the processing centers as they usually sell the mercury used by the miners. In Indonesia, miners use a constant amount of 1 kg of mercury to 40-50 kg of ore to be amalgamated. This enormous amount of mercury added to the mills causes even higher ratio mercury lost to gold produced (Castilhoes etal., 2006). The simple reduction of the ball-mill speed reduces substantially the mercury emissions and the grinding time as well (Garcia ey al., 2015).

Another important source of mercury pollution derived from AGM is the goldshops, which are shops where miners sell the gold. These shops usually first melt the *doré* (gold left when the amalgam is burned and mercury evaporated) with residual 2-5% mercury before paying the miners. In this process, operators and neighbors of the goldshops are highly contaminated with mercury vapor. It is observed all over Indonesia that these shops are distributed in populated urban areas and most of them are in small bazaars selling food, clothes, medicines and other goods. The large majority of the goldshops melt the *doré* in rudimentary fumehoods with no condenser or filter. In extreme cases, goldshops also purchase amalgams with 40-50% of mercury and, before melting the gold, evaporate the mercury inside the shops. This is the most severe way to contaminate workers and neighbors (UNIDO, 2007).

It is important at this point to stress that any solution to eliminate mercury from AGM must compete with the processing centers where miners do not have to pay (or pay a symbolic fee) for equipment acquisition or for the operating costs of the amalgamation step. Many miners realize that they receive a small portion (<30%) of the gold from their ores and the processing centers have the highest profit when using cyanidation. They accept this unfair business system because they have no capital or skills to process their own ores applying better concentration methods or leaching with cyanide.

1.3. Summary of the Main Problems of Mercury in AGM in Indonesia

The main critical points to be stressed related to mercury use in AGM in Indonesia (still valid for many other countries) are:

1. **The whole ore amalgamation process is the main cause for mercury loss to the tailings**. Processing centers cannot continue using this poor technique of amalgamating the whole ore in small ball mills ("tromols"). In average 40 to 50% of the mercury introduced in a "tromol" is lost with tailings, as observed in field tests in Colombia using similar method (Cordy et al., 2011; Garcia et al., 2015).
2. **The processing centers are the main sources of environmental mercury pollution.** As miners do not have capital and skills to have their own processing facility, they take their ores to one of the thousands processing centers spread all over Indonesia. Using the whole ore amalgamation, a small portion of the gold is produced and the owners of the centers keep the mercury-amalgamation tailings, with most of the gold, for further leaching with cyanide. This process forms mercury-cyanide complexes that are discharged into the local drainages together with final tailings. This is exacerbating the level of environmental pollution. Current studies of the toxicity of these mercury-cyanide compounds and preliminary bioassays confirmed that these pollutants accumulate preferentially in the kidneys of the terrestrial and aquatic animals with higher chronic toxicity than metallic mercury alone.
3. **Emission of mercury to the air is a critical public health problem in Indonesia.** The mercury levels in the air around processing centers and goldshops are extremely high and they cannot continue working in populated areas. When the ore is ground with mercury, vapors escape from the mills and the area around processing centers becomes extremely contaminated. Most "tromols" use inappropriate speeds[3] increasing the mercury emissions. Miners must use retorts to condense the mercury vapor when burning amalgams. Goldshops must use condensers and filters and they cannot keep burning amalgams in populated areas. It is imperative that all goldshops must not accept amalgams to be decomposed in their facilities, but only *dorés*.

[3] Blall mils must operate at a rotation of 70% of the critical speed – this is the speed at which the ore becomes stuck on the walls of the mill. The critical speed for a ball mill is calculated by $N = 42.29/D^{0.5}$, where **N** is expressed in r.p.m., and **D** (in meters) is the internal diameter of the mill.

2. SOLUTIONS TRIED TO REDUCE/ELIMINATE MERCURY

The scientific community has revealed sources and impacts of mercury pollution by AGM, but little attention to solve the problem has been dedicated by the academics, governments, NGOs and the conventional mining industry. In a simplistic way, the efforts to reduce/eliminate mercury in AGM can be classified in three categories:

1. Environmental and Health Approach
2. Technological (educational) Approach
3. Formalization - Legal Approach

2.1. Environmental and Health Approach

2.1.1. Monitoring Mercury

Monitoring the levels of mercury in the environment, biota and human beings has been the favorite approach of academics and NGOs to draw attention to authorities and international agencies for the high levels of pollution in AGM sites. Analyses of aquatic biota are definitely important to advise local communities about the risks of eating fish when methylation is confirmed. However, most monitoring campaigns do not have this purpose, and often the results never reach miners or communities impacted by mercury.

It is very common to read scientific articles providing analyses of stream sediments and soils in AGM sites. A large number of scientific papers highlighting the high levels of mercury pollution from AGM have called attention of the Indonesian media and authorities (Limbong et al., 2003, Limbong et al., 2005, Stapper, 2011, Male et al., 2013, Tomiyasu et al., 2013, Lihawa and Mahmud,2018, Idrus, 2019). The mobility of mercury from sediments and the possibility of methylation and bioaccumulation are important issues stressed by these articles or reports, but quantification of total mercury content in sediments is, in most cases, imprecise. Metallic mercury, when released into the environment, causes a "nugget effect" in the sampling process, i.e. individual droplets increase the concentration at discrete locations, creating spatial heterogeneity (Veiga and Baker, 2004). When sediments have too much water, the mercury droplets tend to agglomerate worsening the heterogeneity of the sample. Analyses of sediments are very useful when this intends to locate "hotspots" (sites with high concentration of mercury) if a clean-up plan is intended and if methylation is occurring (Veiga and Baker, 2004). As a self-criticism, after monitoring sediments for years, the author of this report concludes that the best way to quantify mercury releases in AGM sites is by asking the miners how much mercury they buy per month, which is consequently the amount released to the environment. The author and other researchers have conducted many projects assessing mercury vapor in areas where artisanal gold miners or goldshops are operating expecting that authorities would take actions (Veiga et al., 2005, Velasquez et al., 2010, Veiga et al., 2014b, Cordy et al., 2011, Nakazawa et al., 2016, Moody, 2020).

The best monitoring programs to confirm environmental transformations and impacts of metallic from AGM are those analyzing mercury already methylated and accumulated in aquatic biota (Malm et al., 1990, Pfeiffer et al., 1991, Boischio, 1992, Akagi et al., 1995, Barbosa et al., 1995, Palheta and Taylor, 1995, Guimarães et al., 1995, Hacon et al., 1997, Lacerda, 1997, Bidone et al., 1997, Malm, 1998, Dorea and Barbosa,2000, Kambey et al., 2001, Ogola et al., 2002, Barbosa et al, 2003, Castilhos et al., 2006, Soegianto, 2010, Marshall et al., 2018). Analyses of human biological samples (Bose-O'Reilly et al., 2010, Ernawat, 2014, Sherman et al., 2015, Bose-O'Reilly et al., 2016), when the ethical protocols are respected, are also useful to alert the impacted individuals about their health risks.

Frequently, the authorities ask academic researchers to provide further scientific proofs that miners and neighbors are suffering from mercury intoxication in order to enforce the law. The analyses of biological materials (hair, urine, blood) alone does not provide indication of intoxication, but only contamination. It is necessary to combines the analyses of mercury in hair (methylmercury) or urine (metallic mercury) with symptoms (Drasch et al., 2002) to assure the levels of intoxication (Veiga and Baker, 2004). Bose-O'Reilly et al. (2010) have analyzed urine of individuals in Kalimantan and Sulawesi, Indonesia, and, combined with the psychomotor tests and clinical symptoms, revealed the high level of mercury intoxication of some individuals.

Health monitoring definitely needs a more noble purpose than satisfying the researchers' curiosity. A health monitoring makes more sense when treatments are brought to the attention of the intoxicated individuals and authorities (Boese-O'Reilly et al, 2003, Drasch et al., 2007) and then, preventive measures are suggested. Unfortunately, the authorities rarely act to stop mercury pollution and most local doctors do not know what to do. I

n 1999, in the 5th International Coference of Mercury as a Global Pollutant in Rio de Janeiro, a sarcastic picture was presented by the author of this report to stress the lack of importance given by scientists and authorities to find solutions for mercury pollution from AGM (Fig. 3). The health and environmental monitoring projects have by far received more attention than the projects proposing solutions (Bermudez and Veiga, 1999). Only recently the projects' sponsors are paying more attention to solutions, but in many cases, the projects repeat the same mistakes as old projects. Before starting new projects, a critical review of what has been done is strongly recommended to the project leaders.

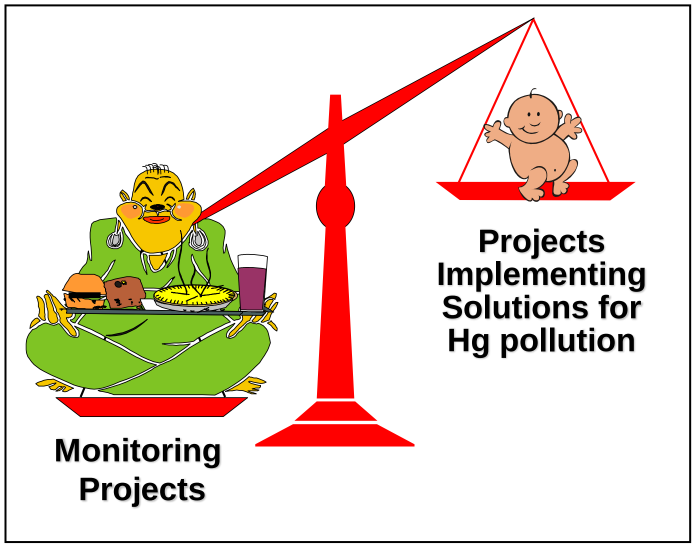

Fig. 3. Projects Proposing Solutions for Mercury Pollution Have Received less Attention than Monitoring Projects (Bermudez and Veiga, 1999)

Another common aspect of the mercury pollution by AGM is the sensationalistic news in newspapers and Internet reporting data from projects. Mercury pollution has received an extraordinary attention of the media, but the information is rarely brought to the public with quality and integrity. In Indonesia, there is a large number of news and reports highlighting mercury pollution from AGM but with the clear intention to cause panic. For example, Paddock (2016) has been systematically publicizing that mercury from AGM is causing birth defects in Indonesian children: "*more than a million small-scale miners in this island nation are poisoned, which is leaving children with crippling birth defects*". Without any scientific evidence, the reporter affirmed that mercury is causing birth defects and brain damage in newborn children (Paddock, 2019). Gunawan (2019) also insists in reporting "fatal birth defects" caused by mercury just to have attention of the readers of the Jakarta Post. These attitudes are also followed by some scientists that correlate, without certainty, one or two cases of birth defects with mercury intoxication of the mothers (metallic and methylmercury): "*photo* of *baby and children with birth defects in gold mining communities in Indonesia*" (Bell, 2017). It is a complete lack of ethics to report cases without clear evidence of mercury intoxication and this behavior does not contribute, in any way, to bring solution to stop the pollution. Miners also do not believe in news and do not read scientific reports and authorities are still thinking and discussing, in endless meetings, what can be done.

Bell and collaborators (2017) mentioned that "*mercury biomonitoring is an essential element of any effective strategy to assess and reduce global mercury pollution",* they are wrong. The exaggerated number of monitoring projects and news in the Press published in the last 40 years have not convinced miners to change their polluting behavior. Authorities, with no funds or political interest, are impotent to enforce the laws based on environmental and health monitoring results. Meanwhile, miners use the argument to keep using mercury: "*we've never seen anyone dying from mercury*". Therefore, it is not efficient to spend millions of dollars to prove environmental contamination of a site or intoxication of human beings in order to suggest solutions to stop the use of mercury.

In some respect, it seems redundant the need of spending large amounts of resources conducting urine and blood analysis of a miner burning amalgams and breathing mercury to show that this person is or will be intoxicated with mercury. In addition, rarely the health authorities treat intoxicated people, due to complete lack of knowledge or negligence.

2.1.2. Lessons Learned

In summary, the environmental and health monitoring projects:

- are contributing to obtain more scientific evidence about the transformations, mobility, distribution of metallic mercury and the impacts of methylmercury in aquatic biota,
- are providing evidence of the atmospheric mercury pollution around processing centers and goldshops,
- are providing evidence of the health effects of mercury vapor and methylmercury (in fish),
- but are not convincing miners and processing centers to adopt cleaner mercury-free techniques to process gold ores, based on the evidence of pollution and intoxication,
- are not compelling governments to look for solutions to solve the problem,
- are not creating awareness and protests among contaminated individuals to protect their families and neighbors,
- are providing disconnected information to the press that is create panic, and panic is not moving the public opinion or governments to take actions against polluters, but only to make more monitoring programs,
- are definitely more important for scientists to have funds for projects than for the authorities to stop pollution.

2.2. Technological Approach

2.2.1. Technology Will Reduce the Mercury POllution

This approach has been extensively used by NGOs, academics and international agencies. The idea has been to demonstrate and train artisanal miners on mercury-free techniques to extract gold. Most technical projects have also incorporated a strong component of awareness, demonstrating to public and miners the toxicity of mercury and how one can avoid contamination by fish ingestion or exposure to vapors.

In the 1990s, many projects have promoted the use of methods to protect the miners and recover mercury vapor in order to recycle it. Many different types of retorts were brought to the miners' attention. Those commercial or homemade retorts intend to condense mercury vapor when amalgams are thermally decomposed (Veiga et al., 2005, Veiga, 2006a, Vieira, 2006). Despite the merits and efforts to reduce mercury exposure, when the trainers are not present or when miners face a difficulty in using retorts, or any other piece of equipment , they return to burning amalgams in open shovels (Jønsson et al., 2009)

The 2000s was characterized by more projects targetting the improvement of the processing methods of the artisanal gold miners, in particular to avoid the whole ore amalgamation. Gravity concentration became the central point of the interventions in order to reduce the mass of the material to be amalgamated or even to eliminate mercury, when this was possible.

2.2.2. Can Gravity Concentration Eliminate Mercury Use?

Some types of gravity conentration equipment are much more effective to concentrate fine particles of gold than others but the majority of them are not efficient for grain sizes finer than 0.074 mm (200 Tyler mesh). The exception are the centrifuges, which are able to recover fine and coarse gold particles. The gravity separation occurs by weight difference between one particle and another. In this case, the size of particles are important as a large grain of a gangue mineral (e.g. quartz) behaves like a small size grain of gold, in a classic gravity separation process counting only with the gravity force. The rate in which a particle of gold settles in a liquid depends on the viscosity of the liquid (in this case the pulp of ore) and the type of equipment. In conventional mining plants, gold particles coarser than 150 mesh (0.10 mm) is usually recovered by gravity methods and finer particles are concentrated by flotation.

In the last 40 years, few publications have described or suggested processing methods to recover gold with gravity concentrators **to reduce losses or eliminate amalgamation** (Priester et al., 1993, Veiga and Meech, 1995, Hentschel et al., 2002, Veiga et al., 2006, Sousa et al., 2010, Veiga et al., 2014a, Veiga and Correa, 2019). Gold concentration, in fact, was and should be, the priority of the AGM technical-educational projects. If only gravity concentrates were amalgamated, this would reduce drastically the use and losses of mercury as the mass of these concentrates are usually less than 1% of the original ore mass.

Many projects have introduced concentrators like jigs, shaking tables, elutriators among many others. As discussed above, these pieces of equipment are usually not very useful for fine gold particles in order to yield high gold recoveries. When the gold particles are naturally flaky or become flat in a ball mill, due to the relative hydrophobicity of gold, they are lost in a laminar system like a shaking table, for example. For micro-miners, these machines can be more useful than a pan ("*batea*") as they can process more material per hour, but it is questionable if they are more efficient than a well carpet-lined sluice box (especially set up in zigzag), which is quite cheap, appropriate and can be locally made (Veiga et al., 2006). Centrifuges, that are the best gravity concentrators in the market, require capital and knowledge to operate them. A centrifuge Icon, with capacity of 2 tonnes/h, costs in Canada approximately US$ 5000 but in developing countries the price can doubled. Frequently, it is observed in AGM sites many centrifuges not operating. The main reason is that miners do not know how to calibrate critical parameters inherent to this type of concentrator.

The Artisanal Gold Council (AGC, 2020) has currently a 3-year project in Indonesia to train miners and government authorities in mercury-free practices. As Indonesia banned the use of mercury and cyanide in AGM, the project has to bring solutions to obtain gold by gravity concentration alone (McGrew, 2016). Despite the efforts and good intentions of the project, the gold recovery by gravity methods cannot be expected to be substantially higher than the processing centers using whole ore amalgamation, unless for site-specific ores. In addition, the capital and operating costs of any process to be suggested to miners must take into consideration that miners have no or little cost when processing their ores in processing centers, except for the mercury they buy. Another aspect is how replicable is the developed gravity process to be extrapolated as a unique mercury-free solution for all types of gold ores in the country. This was a typical mistake witnessed in Colombia where the federal government hired a company to spread jigs and shaking tables all over the country for formalized artisanal mining operations. Currently, most of the plants are not working.

Not always gravity concentration convinces Indonesian artisanal miners to adopt a mercury-free process. This was noticed when different gravity concentration methods were compared with the low gold recovery (around 10 to 20%) of the whole ore amalgamation in Talawaan, Sulawesi, Indonesia. The Knelson centrifugal concentrator and the magnetic sluice have obtained gold recoveries between 5 and 8%. The fine characteristic of the gold particles in this ore does not bring any benefit when gravity concentration is applied. However, the cyanidation of the whole ore leached 84% of the gold in less than 8 hours (Veiga et al., 2009). Probably flotation would provide better results than gravity processes but, in the specific case of this ore, most conventional mining companies would adopt whole ore cyanidation, as the gold is fine and the rock is porous enough to allow cyanide penetration. It is questionable whether flotation or cyanidation would be technically appropriate methods to promote to Indonesian miners. Without a permanent technical assistance, any "new" technique to artisanal miners will not be sustainable.

The UNDP has also introduced a five-year project "The Integrated Sound Management of Mercury in Indonesia's Artisanal and Small-scale Gold Mining (GOLD-ISMIA)" to train Indonesian artisanal miners in the Provinces of Yogyakarta, Nusa Tenggara Barat, Gorontalo, North Sulawesi, North Moluccas and Riau. The project intends to reduce the mercury use by at least 15 tonnes at the end of the project (UNDP, 2019). It is not clear in the available public documents about this project, what is the focus of the training, but it seems that it is the model of "training miners". Since amalgamation of the whole ore is the main source of mercury losses in the country, it seems to make sense in bringing to miners solutions to concentrate gold. The key problem is to know whether the methods taught to miners will be sustained or not when the project ends. This is in fact the main challenge of any type of technical intervention.

The GEF/UNDP/UNIDO Global Mercury Project - GMP (2002-2007) was a ground-breaking project training 30,000 artisanal miners and community members in six countries (Brazil, Indonesia, Laos, Sudan, Tanzania and Zimbabwe). The project also focused on monitoring health and environmental impacts of mercury to satisfy the government authorities of the countries. Many simple retorts were locally manufactured and gold gravity concentraion methods demonstrated (McDaniels et al., 2010). The GMP in Indonesia focused its activities on capacity building of miners using the Training-of-Trainers (ToTs) approach and bringing a series of different pieces of equipment to demonstrate gold concentration. Two ToTs were held in Rungan Sari, Central Kalimantan and one in Kotamobagu, North Sulawesi. Additionally, an introductory workshop on cyanidation was held in Pasaman, West Sumatra, following a request from the Pasaman District's environmental agency. The events have also provided health and technical information to miners motivating them to change their polluting behavior (UNIDO, 2007). The project also introduced in Indonesian goldshops simple methods, using Tupperware and PVC ducts, to condense mercury vapor in water tanks. At a local price of US$ 35 per unit, these fumehoods captured over 90% of the mercury emitted (Telmer and Stapper, 2007, Telmer, 2008). All measures introduced by the GMP were tested and could efficiently reduce the mercury emissions but there is no news if the Indonesian miners and goldshops are still using all the techniques they learned.

Another approach to popularize gold concentration methods was implemented by a project that taught Colombian artisanal miners how to build their own equipment. This project was sponsored by the Global Affairs Canada through the Colleges and Institutes Canada (CICAN) and led by the Collége d'Enseignement Général et Professionnel (CEGEP) group from l'Abitibi-Témiscamingue, Rouyn- Noranda, Québec. A series of homemade concentrators (grinding, gravity and flotation) were built to process less than 2 tonnes of ore per day that would be useful for micro-miners (Veiga et al., 2018). A Colombian institution received training and was supposed to disseminate the equipment for artisanal miners. Since micro-miners work for subsistence, are widely dispersed and usually have mining as a seasonal job, the difficulty to implement the suggested solutions is understandable.

Most interventions are currently pursuing for the total elimination of mercury using gravity concentration techniques. Gravity concentration alone cannot provide very high gold recoveries, except if all gold particles are relatively coarse (>0.10 mm) and well liberated from the other minerals, which is usually the case of some alluvial ores. Even tough, this cannot be generalized for all types of gold ores. It is not evident in the objectives of many projects in AGM whether they want to establish a local equipment-manufacturing company or simply recommend miners to buy the recommended and demonstrated machines. In most cases, the artisanal miners, in general micro-miners, wait for the projects to donate to them the concentrators and accessories.

As projects do not have continuity, there is no follow-up whether the donated concentrators are still in use. In addition, it is unclear what the projects recommend to miners in terms of tailings containment.

The gold recovery by gravity concentration of any ore is a much better environmental solution than the current whole ore amalgamation method used in Indonesia, but a chemical process is necessary to extract gold from the concentrates generated by gravity processes. This is another complicated step for unskilled and impoverished miners

2.2.3. Concentrating Fine Gold with Flotation

The tailings from any gravity concentration usually carry the majority of the gold from an ore, as rarely the gold particles are coarse enough to be fully recovered by gravity methods. Then, the gold from gravity separation tailings must be recovered by flotation, if a fine grinding is applied. A bank of flotation cells is relatively inexpensive but its operation is not simple demanding controls or pH, water levels, pulp density, conditioning time, type of minerals associated with gold and reagents. Knowledge is fundamental to deal with flotation. Some small processing plants in many South American countries are currently using flotation to obtain a concentrate to be sold or leached with cyanide.

Froth flotation is a process to separate minerals of interest from gangue based on the hydrophobicity (water repulsion) of each mineral. Surfactants and wetting agents are used to increase the difference in hidrophobicity between minerals creating selectivity. Froth flotation is a process widely used industrially to separate sulphides and gold from carbonates, oxides and phosphates. Flotation works well for particle grain sizes between 0.1 and 0.01 mm.

Flotation depends on surface chemistry of the minerals, which can be adjusted by pH modifiers and other reagents. Flotation occurs when a collector reacts with the surface of a mineral making it hydrophobic. Air and a frother are added to the flotation cells to create bubbles to carry the hydrophobic minerals to the surface of the flotation cell. Air is injected into the agitated pulp of 20 - 30% solids and the hydrophobic mineral adheres to the air bubbles and float to the surface to be collected. Non-hydrophobic minerals, such as oxides and silicates, sink and are removed from the flotation cell from the bottom. Most sulphides and gold in the world are concentrated by flotation. Large particles of sulphides and gold are more difficult to be floated as they are heavy and are not sustained by the bubbles. Then coarse gold particles are previously removed from the circuit by gravity separation.

There are many different types of flotation cells, squared or cylindrical. Mechanical flotation machines are the most common ones. They operate with impellers that agitate the pulp typically with 20 to 30% solids and disperse air in the cells creating bubbles. The tailings from this first bank of flotation cells called "rougher" go to another circuit called "scavenger" to float any gold not collected in the rougher. The grade of gold in the rougher concentrate is of secondary importance because the material is subjected to further downstream processing to improve the grade, the "cleaner". The concentrate from the "scavenger" can return to the "rougher" circuit to be floated again. The objective of the cleaner circuit is to produce a gold concentrate of high grade, usually with 100 to 500 g/tonne (ppm) of gold, depending on the ore. Nowadays mechanical cells can be all large as almost 30 m^3. Cylindrical cells are also available in all sizes. They also have impellers and their sizes can reach 1000 m^3. (Fig. 4).

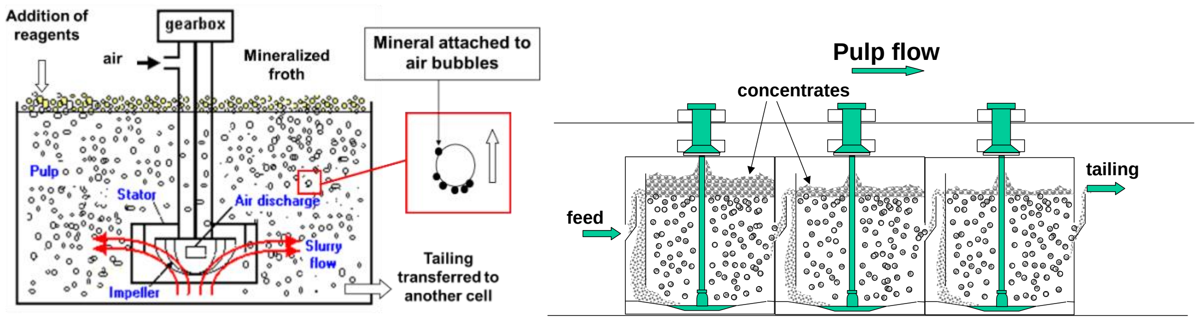

Fig. 4. Scheme of a Mechanical Flotation Cell (left) and a Bank of Cells (right)

Collectors are chemical reagents that make a mineral more hydrophobic than another, for example, for sulphides and gold the main collectors are (sodium or potassium ethyl) xanthates and, sometimes dithiophosphates. Both of them have low toxicity and are used in very low concentrations (<100 g/t of ore). It is also important to mention that these collectors do not go to the tailings as they adsorb selectively on sulphides and gold surfaces, then there is no environmental concern about toxicity of tailings due to these reagents.

Gold is somehow naturally hydrophobic and can be floated even without collectors (Marsden and House, 2006). Gold particles tend to float in the same conditions as the sulphides. More than 90% of the gold is usually recovered. Gold flotation concentrates usually have 1 to 10% of the mass of the ore feed. The grades of a gold flotation concentrate are not usually high (100 to 1000 mg Au/kg) when compared with gravity concentration processes. The reason is that the bubbles usually drag large amounts of gangue (worthless) minerals to the concentrate. A flotation circuit comprises a series of steps to clean the concentrates. Unliberated gold can also be concentrated if it is exposed and the surface adheres on the bubbles.

Oxidized ore, as found in many tropical countries, have high amounts of HFO (hydrous ferric oxides) and clayminerals. Gold flotation is difficult as these fine minerals involve the gold particles reducing recovery. Many companies prefer to use cyanidation of the oxidized gold ores, removing only the coarse gold by gravity concentration.

2.2.4. Extracting Gold from Concentrates by Amalgamation

When artisanal miners use gravity concentration (or flotation), as observed in some countries, some individuals use to extract the gold by amalgamation of the concentrates. But, as explained above, **amalgamation of gravity concentrates** works only for the gold particles liberated from the other minerals and flotation concentrates have fine particles of gold that are difficult to be amalgamated. Even when the gold particles are liberated, as usually occur in alluvial ores, many miners still use unnecessarily mercury. In Fig. 5, it is observed an Indonesian female miner in Kalimantan showing a sluice box (gravity) concentrate with liberated yellow gold particles. After the picture was taken, she added mercury to amalgamate the gold from this concentrate, as she has not believed that panning would be enough to capture all free gold. As the association of gold with silicates can change the density of a particle**, unliberated gold can also be concentrated but not amalgamated**. When a concentrate is obtained by gravity methods, it can be melted with borax, if the gold grade is high, for example above 5 kg of gold/tonne, but most artisanal miners prefer to use mercury to extract gold from concentrates as well.

Fig. 5. Gold from Alluvial Is Liberated, but the Indonesian Miner Uses Mercury

2.2.5. Extracting Gold from Concentrates by Leaching

Cyanide is the most used method to extract the fine, liberated or only exposed, gold particles. Coarse gold particles (>0.1 mm) take too long to be dissolved in normal cyanidation conditions then gravity concentration to remove these gold particles is used before cyanidation. Nowadays, there are commercial methods of intensive cyanidation to leach coarse gold from gravity concentrates. Cyanidation is more difficult to be used by artisanal miners and is dangerous if not operated in a controlled alkaline pH. But in the long term, cyanide is definitely less dangerous than mercury because the most toxic forms of cyanide can be naturally or artificially decomposed by oxidation. The cyanidation of concentrates utilizes high levels of oxygen in the reaction.

Leaching only concentrates is an excellent solution to reduce the use of cyanide and to facilitate the cyanide destruction by oxidation after the gold leaching reaction. Unfortunately this is not a widely used solution used in conventional and artisanal mining. In some cases, when the gravity and flotation methods do not provide high gold recoveries, the whole ore or the gravity tailings are subjected to cyanidation. This implies in large or a series of tanks and most conventional companies, more than 2000 in the world, make use of this process. For artisanal miners without a leaching process to recover gold from concentrates, the only feasible option is to sell the concentrates instead of amalgamation. When the concentrates have high grades of copper minerals, the smelters are keen to pay for the gold and copper contents. In Ecuador, many small processing plants sell their gold and copper concentrates for smelters in China

Instead of using amalgamation in small ball mills, miners can use cyanidation in these same mills to recover more than 90% of the gold from concentrates (Veiga et al., 2009, Sousa et al., 2010). The mill-leaching process was very efficient to leach gold from a Talawaan ore, in Sulawesi, but the Indonesian authorities hindered the field demonstration, once cyanide is not allowed to be used in AGM. Another problem is the extraction of the gold from the cyanide solution by activated charcoal or by precipitation with zinc . In Indonesia, it was observed many artisanal cyanidation plants burning the activated charcoal and amalgamating the ashes to avoid the elution-electrolysis process of the activated charcoal that is usually slow, costly and demands good knowledge to operate (Veiga et al., 2014b).

The increasing public concerns about the use of cyanide in gold processing have encouraged a large body of research on alternative lixiviants. Most of them are generally not available in remote mining regions in Indonesia and they have been developed with objective to be used by the conventional gold mining sector. The gold leaching chemistry is not that trivial to be used by artisanal gold miners, as yet. However with training, these techniques have great potential to substitute mercury and cyanide.

Many reagent manufacturers offer "black-boxes" which are proprietary commercial reagents to replace mercury and cyanide but the type of reagents is not disclosed. This does not work for authorities and artisanal. In addition, they will not be widely available in Indonesia.

As Hilson and Monhemius (2006) well commented, a replacement for cyanide must be:

1. inexpensive and recyclable
2. selective
3. non-toxic and
4. compatible with the process (applicable to the type of ore in question)

Thiourea (NH_2CSNH_2) has been investigated for long time as a reagent to dissolve gold in acidic (pH 1-2) and very oxidizing condition (using Fe^{3+} or peroxide or ozone, etc,). It was commercially used as a gold lixiviants in a small operation in Brazil treating artisanal mining tailings (G. Nobre

– pers. communication). The reaction is rapid and very efficient but the pH and Eh must be permanently controlled. The reaction of gold with thiourea forms the complex $Au(NH_2CSNH_2)^{2+}$ and soluble gold can be precipitated with aluminum. Despite the low toxicity of the thiourea, Marsden and House (2006) commented that it can be carcinogenic. These authors also mentioned that the cost of thiourea is still expensive for the wide use of this process in the gold processing industry, let alone artisanal operations. There are projections to reduce the thiourea consumption in the reaction but so far this can reach 200 g of thiourea per kg of material being leached. This factor, associated with the high consumption of acid to reduce the pH to 1 and high levels of oxidizing agent (e.g. 50 g of $Fe_2(SO_4)_3$/kg of material) are economic impediments for a wide use of this reagent (Li and Miller, 2006).

A promising reagent to substitute cyanide is the **thiosulphate** that works in ammonia solution (as an oxidant stabilizer) forming $Au(S_2O_3)^-$ and $Au(S_2O_3)_2^{3-}$. The chemicals involved are relatively cheap, of low toxicity and forms soluble complexes with gold and silver in ammoniacal solutions using cupric ion (Cu^{2+}) as a catalyst. However, it is unstable and can decompose under anaerobic or conditions. For specific types of ore, e.g. those with organic matter that adsorb gold from the solution (known as "preg-robbing ores"), thiosulphate is an alternative to cyanide (Muir and Aylmore, 2004). Only one industrial application of the process has been reported in the Goldstrike mine in Nevada, where Barrick Gold Co, had cyanide leaching problems due to high preg-robbing organic carbon. Currently the broad use of this reagent is not economically attractive as the thiosulfate consumption is high There are ways to reduce the costs, for example by controlling the dissolved oxygen, addition of SO_3^{2-} and S^{2-} , replacement of Cu^{2+} as a reaction catalyst or in-situ generation of thiosulphate by bacteria (Xu et al., 2017).

Chlorine was used to leach gold in the 1800s, but the lack of corrosion-resistant equipment, at that time, gave place to cyanidation to be more popular. MINTEK, a South African research centre, developed in the 90s a method for artisanal miners using chlorine to extract gold from concentrates with more than 1,000 g Au/tonne. The iGoli Process uses a solution of HCl and sodium hypochlorite with concentration of 16% v/v. The pulp is filtered after leaching and gold is precipitated with sodium metabisulphite ($Na_2S_2O_5$). The effluents are treated with calcium chloride, sodium hydroxide and apatite to precipitate other metals in solution. MINTEK reported gold recoveries as high as 98% (Mahlatsi and Guest, 2003). As chlorine forms an insoluble compound with silver (AgCl), this must be recovered using another chemical process. The main problem of the process is the storage of concentrated sodium hypochlorite. This solution is not stable in hot climates and decomposes easily (Veiga et al., 2014a).

A gold lixiviant with high stability that has good advantages over mercury and cyanide is the mixture of **iodide-iodine**. Konyratbekova et al. (2015) mentioned that iodide-iodine solutions dissolves gold 22 faster than cyanide. An affordable process was developed by the Canadian company EnviroLeach (2020) and it is has been used in Canada by at least two small conventional gold mining plants to leach gravity and flotation concentrates. With high efficiency, the method is cheaper than cyanidation as the reagent is recyclable.

The use of **cyanogenic plants** is also an interesting solution for leaching gold from concentrates. This has been studied by the author at the University of British Columbia. Bitter cassavas contain a glycoside named linamarin, that when crushed, it is hydrolyzed forming acetone and free cyanide. In preliminary tests with a Brazilian bitter cassava extract with 300 mg/L of free CN, over 50% of gold was extracted in 8 hours from a flotation concentrate with 48 g Au/t. This can be an interesting technical solution for Indonesia which is the 4th largest cassava producer in the world with almost 20 million tonnes/a of production (Otekunrin and Sawic. 2019). However there no public information about the production of bitter cassava (usually useful to make starch and flour) in the country.

A probable suitable reagent for gold leaching is **Dimethyl sulfoxide (DMSO)**, which is a water-free reagent and an appropriate solution for regions where water is scarce or problems of water contamination is an issue for the communities. DMSO is less expensive than sodium cyanide and it is an FDA approved chemical known to be non-toxic, used in cosmetics, is biodegradable and widely available. It has applications as a solvent and in medicine as a dietary supplement that can be taken orally, applied topically or injected into the body. The justification for the assessment of the industrial use of DMSO as a lixiviant for gold recovery stems from the successful use of the chemical compound by researchers in Japan for gold production from e-wastes (Yoshimura, A. & Matsuno, Y. 2016). These researchers had an average gold recovery above 90% as reported in preliminary laboratory experiments in the Chiba University, Japan. At the University of British Columbia, a preliminary test of the same procedure recovered 47% of gold recovery from a flotation concentrate in less than 6 hours.

The main problem in implementing these leaching techniques in AGM sites is the capital and operating costs as well as the miners' skills needed to use them safely. Therefore, the most affordable and simpler method in gold leaching processes must be developed but a strong procedure of permanent training and technical assistance must be in place.

If a full, efficient and environmentally friend small processing plant with crushing and grinding equipment, pumps, classifiers, gravity and flotation concentrators, cyanidation of concentrates, infrastructure, electric power, water supply, tailing dams, etc., is proposed, large capital costs must be obtained. The investment in an appropriate and complete gold processing plant ranges from US$ 250,000 for a plant processing 2 tonnes/day to US$4 million for 200 tonnes per day (Veiga and Jimenez, 2018). The lower the production rate, the higher the capital cost per tonne. This is not implemented with micro-credits and most artisanal miners, even the wealthiest ones, do not want to invest that much to have a proper plant.

2.2.6. Other Methods Have Tried to Extract Gold from Concentrates

It is not infrequent to see that some interventionists believe that all gold ores are the same everywhere in the world and one technique fits all. This is the case, for example of a well-promoted method to eliminate the use of mercury in AGM using borax - $Na_2B_4O_7.10H_2O$ (Appel and Na-Oy, 2011). Borax has been used as a flux in gold foundry since the Egyptian times (5,000 and 2,000 B.C.). Babylonian goldsmiths also used borax more than 4,000 ago. Borax reduces the melting point and dissolves all oxides and silicates in a gold concentrate. It also protects the gold surface to be oxidized as at high temperature the borax bath has a reducing behavior (ABC, 2020). Conventional and artisanal miners know for long time the properties of borax in the gold melting process. Before melting, the authors of the "**Borax Method**" indicate that a gravity concentration process must obtain a very high grade, yellow concentrate (>30,000 ppm Au or 3% Au or 30 kg Au per tonne). The authors are right when they say that the concentrate must be very rich in gold. If not, a large portion of gold is retained in the slag. This is actually what the conventional companies do, but they apply gravity concentration followed by melting only to remove coarse gold particles from the flotation and/or tailings cyanidation circuit. In addition, all companies send the ground gold-rich slag to the cyanidation process. But, in the case of the "Borax Method", what do the authors recommend for the gravity concentration tailings? Most of the gold will be there. What happen with the slag with high grade of gold? If miners do not have a yellow concentrate and do not want to have too much gold in the slag, they could add more gold into the concentrate to be melted in order to carry most gold fine particles to the bottom of the bath. Which miner will do this? Probably silver can be a solution to carry the gold. Another question is: if a micro-miner processes 2 tonnes of ore per day and this would generate 20 kg of concentrate, which miner has a furnace to melt this amount? Definitely, the so called "Borax Method" will create more animosity of miners against the interventionists when they know they are losing most of the gold in their ores.

Mineral processors know that in the majority of the cases "*the more you concentrate, the more gold you lose*". In other words, a very yellow concentrate usually has high gold grade but often low gold recovery (Fig. 6). Of course, there are exceptions, for example when the gold particles are relatively coarse and fully liberated as in some alluvial ore, but this is not always a universal rule. Gravity concentration of gold from hard rocks does not usually produce concentrates with 30,000 g Au/t. The "Borax Method" can be a solution for a very specific ore being concentrated by nano-miners, but it cannot be generalized as a method for all artisanal miners. For example, if sulfides are present in the concentrate, this method is not efficient and too much gold is carried to the slag (Veiga et al., 2014a). How can someone convince an artisanal miner to have a high grade concentrate, but with very low gold recovery (say 10%)? This means that the miner will lose 90% of the gold in the tailings before melting with borax. Will this convince the miner to stop using mercury? Once a researcher mentioned in a conference: "*it is better for the miners to lose 90% of the gold but have better health*". This is clear for a researcher with a good salary and good health, but is this obvious to an artisanal miner fighting for survival?

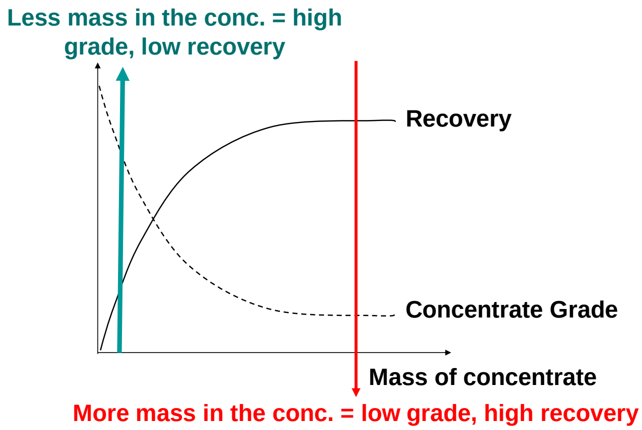

Fig. 6. More Gold in the Concentrate, less Recovery had the Process

Another tentative to avoid use of mercury in AGM was witnessed in the field in Kourossa and Mandiana, Guinea, Africa, where the enforcement to avoid amalgamation is very rigid. In the upper part of Guinea there are almost 300,000 artisanal gold miners, most of them women and children producing approximately 6 tonnes/ of gold. All shafts are established by a local Government representative who also controls the entrance of the miners into the site, charging them US$ 0.10/miner/day. The process is totally manual, basically conducted by women, from crushing to concentration in the shell of calabash gourds. Once the concentrate is obtained, miners **blow** it to eliminate the other mineral grains, including flaky iron oxides. Evidently, that fine and flaky gold particles were also lost. Visually following the whole blowing process, it was estimated that about 5-10% of the gold is recovered in this rudimentary processing step. The local miners are not stupid and said that some of them make amalgamation at the bottom of the shafts, 15 m deep. This has caused fatality as they also burn the amalgams in this hidden place (Veiga, 2006b). Amankwah et al. (2010) claimed they had an extraordinary gold recovery of 99.8% blowing the concentrate from Ghana and using the Borax Method. This a very particular and peculiar case that definitely cannot be extrapolated to all types of ores.

2.2.7. Promoting Mercury-free Techniques

Handbooks and pamphlets have also been the preferred method by many projects to reach out miners and bring awareness to community members impacted by mercury. (Veiga et al., 2006, UNEP, 2012, Veiga and Correa, 2019). The efficiency of this strategy was never measured. Awareness campaigns, meetings, courses, street theater, movies, technical demonstrations, posters, banners and pamphlets have been used in the last 40 years of AGM projects and the use of mercury more than doubled during this time. The low impact in changing miners' behavior and adopt cleaner techniques was also reported by Shandro et al. (2009) when they visited the same artisanal miners in Mozambique who received a training program from UNIDO four years earlier. This included classes and practical demonstrations of gravity concentration and use of retorts.

In 2013, the UNIDO Mercury Project in Colombia reduced 63%, or 46 to 70 tonnes/a less mercury entering the environment in five municipalities in Antioquia. Strong awareness campaigns to the public impacted by extremely elevated levels of atmospheric mercury and small changes in the whole ore amalgamation methods used by the processing centers helped in the mercury reduction process and reduce the costs of miners buying mercury. The enforcement by the Colombian police to removed processing centers from those mining towns, had also an outstanding result (Garcia et al., 2015). It is unknown whether the processing centers returned to their original sites in the urban core when the police left the towns. Another important factor to reduce mercury use in these municipalities was the presence of the conventional mining company Gran Colombia Gold buying ore from artisanal miners.

2.2.8. Lessons Learned

For any "novel" technique to be demonstrated and adopted by artisanal miners in order to replace their polluting methods, it is important, in first place, to create confidence between interventionists and miners. One effective way to convince miners to learn new techniques is to extract gold from their tailings. Even tough, most artisanal miners do not have sufficient knowledge to understand the benefits of using a "new" techniques. If miners do not have gold or cash in their hands in short rime, any process to replace amalgamation will not be successful. Even being inefficient, this is what the whole amalgamation delivers.

In addition to all hurdles to introduce mercury-free techniques, another important question is posed: **why do most projects focus on micro-miners?** The answer is: the micro-miners are more numerous than the small, medium and large artisanal miners and more receptive to any idea to help them to produce more gold than the processing centers. They enjoy the training time with food, soda, good conversation, and sometimes payment for their time in classroom. **But are the millions of micro-miners producing less than 1 g of gold per day the main mercury polluters?** The answer is probably not. Worldwide, the micro-miners likely represent the largest contingent of artisanal gold miners but, they are dispersed in a large area and they release less mercury in the local mining environment than the processing centers.

The technological-educational approach has its merit and should be pursued, but the interventions must be carefully studied and **planned with miners**. Definitely, technology is not the only answer to eliminate the use of mercury, but can help reduce it drastically if only concentrates are amalgamated. In short, the large majority of the interventions focusing on bringing mercury-free techniques to micro-miners have not fulfilled their objectives and the impacts have been minuscule. Training centers, as a permanent source of technical support for artisanal miners have been suggested to many authorities in developing countries but, unfortunately, governments prefer to enforce formalization of the miners instead of organizing and educating them (Veiga et al., 2014a, Veiga et al., 2015).

The most difficult part of implementing any type of techncial solution is to change the miners' behavior. Rarely projects see this and infrequently the researchers ask the miners about their **needs**, **motivations** to keep mining and **skills** to adopt cleaner practices when designing a project (Stocklin-Weinberg et al., 2019).

In summary, the technological approach:

- has its merits but the efforts are enormous and costly to make significant changes in the miners' practices,
- gravity concentration is not enough to result in high gold recovery in most ores when gold is fine and not liberated from the gangue,
- flotation is useful to recover fine gold particles but fine grinding is needed,
- a chemical leaching process is necessary to extract gold from the concentrates,
- most mercury-free projects bring technical solutions for micro or nano-miners; the results have usually micro or nano local impacts,
- demonstrations to miners of "new" mercury-free methods are not sustainable solutions if there is no clear benefit for the miners to make more money,
- there is no generic silver bullet to replace amalgamation for all types of ores in Indonesia or in other parts of the world,
- it is hard to find experts in simple and appropriate[4] technologies to process gold, then most interventions to eliminate mercury use in AGM are conducted by individuals with little understanding of mineral processing concepts and practices; this creates mistrust,
- projects have short duration and rarely ask the miners about their needs, motivations to mine, and their skills to adopt cleaner techniques,
- any method to be proposed to replace amalgamation must be affordable and the equipment must be locally available,
- many projects repeat the same mistakes over and over again because they have not learned the lessons from old projects,
- without permanent training and a technical assistance, which is expensive, miners do not sustain the lessons learned in a project and return to their polluting method,
- any technique to bring to the attention of the miners must be simple and compete with the whole ore amalgamation in processing centers, that do not require miners' capital and has no or little operating cost,
- awareness campaigns have had little effect on miners and their communities,

[4] http://lsa.colorado.edu/essence/texts/appropriate.htm. Appropriate technology relates to simple, locally available and small-scale technology that makes use of traditional skills available in a local community.

- and finally, projects should previously ask the miners if they want to learn mineral processing concepts and techniques. **Usually they do not have any interest in this subject** but only in how to mine safer and more efficiently.

2.3. Formalization - Legal Approach

2.3.1. Formalization Is Not Working

The legal approach has as its main principle the use of legal instruments to eliminate mercury pollution from AGM. The approach also intends to bring to the attention of artisanal miners the need of formalization. In 1995, the World Bank stressed that "*none of the problems related to artisanal mining could be effectively tackled until a prime need was met: legal titles*" (Barry, 1996). This has been proven unattainable as, for example, less than 1% of artisanal miners Latin America are somehow formalized (Marshall and Veiga, 2017, Stocklin-Weinberg et al., 2019).

Formalization of artisanal miners has been a priority of all governments, supported by international agencies. The order of actions cannot be different than **educate**, **organize** and **formalize** a miner. The formalization of uneducated artisanal miners has been formalizing only the pollution, as miners do no change their processing methods when they have legal mining rights. Without education and organization, formalization is a mere piece of paper and does not eliminate the mercury problem.

From one side, miners do not understand the advantages of being formal and from another side, governments keep forcing artisanal miners to become legal and taxpayers. This divergence of purposes has been creating more illegality. Mercury has been smuggled from one country to another, the price increased and the middlemen, selling mercury and buying gold for low prices, are the main beneficiaries of cumbersome legislations (Thomas et al., 2019). Hilson and Vieira (2007) outlined very well the incapacity of the governments to deal with the mercury issue: "*in order for governments to tackle the mercury problem effectively, the relevant regulatory units must be equipped with adequate resources".* In fact, most authorities in the developing countries do not have appropriate knowledge about mercury impacts, its consequences and how to solve the problem. Many government officials have never been in a contaminated site. The formalization of artisanal miners is in the agendas of international sponsoring agencies with millionaire projects that have had little success (Marshall and Veiga, 2017). This, in part, is attributed to a large burden of bureaucracy in the countries impacted by AGM. All formalization processes are disconnected from the actual objectives and the meaning of formalization, which is not simply legalization, but integration of miners into the main economic and social streams of the society (Siegel and Veiga, 2009). There is no formalization without education.

The intricate authorization framework established by governments of developing countries for formalization assumes that artisanal miners are "educated businessmen" (Hilson and Maconachie, 2017). Millions of dollars in projects have been invested to formalize small groups of individuals, most of them owners of some mineral titles, usually not in a proper condition. For those without any type of title, the formalization process is a heavy burden. For example, according to a member of the USAID Oro Legal Project in Colombia, there are 380 steps for an artisanal miner to be formalized in the Ministry of Mines and Ministry of Environment as well. In July 2018, the government of Colombia implemented the Law 1658 prohibiting the use of mercury in AGM. In the same year, after visiting 71 formalized small-scale gold processing plants in that country, it was observed that the legal operations were misusing mercury and cyanide, creating the same pollution as the processing centers or those "informal miners" (Veiga and Marshall, 2019). Nonetheless, in a field trip in 2019 to an artisanal mining site in Colombia, miners were observed conducting amalgamation of the whole ore in front of the police officers. This is not different in other developing countries.

The low level of formalization in gold mining in developing countries is not different from many other economic sectors such as informal settlements in urban areas, informal agriculture, informal street vendors, informal occupation of rural plots, etc. The informal laborers in the world represent 61% of the workforce. Excluding agriculture, this drops to 50%. All developing countries represent 82% of world employment in which 70% is informal. Africa has 86% of informal employment, the Arab States have 69%, Asia has 68 % and Americas have 54% in which Central America has 58%, Caribbean has 59%, South America has 51% and North America has 18% (ILO, 2018).

The informal employment in Indonesia includes from 61% to 70% of the total labor force of the country (Rothenberg et al., 2016). The World Bank (2019) estimated that the informal employment in Indonesia reached, in 2018, 76% of the national non-agricultural workforce. Mining and quarrying (artisanal and conventional) in Indonesia represent 11% of the country GDP with the highest daily labor economic productivity among all Indonesian sectors. Out of the 70% of the total informal employment, as considered by the Asian Development Bank (2009), the Indonesian informal mining represents 18%. In summary, artisanal-informal mining is not an isolated case in the country and the actions to include these squad of individuals into the conventional economic activities must be integrated with other economic sectors.

Another recent step to curb mercury use in AGM in the world is the UNEP Minamata Convention (MC) that intends to control and even stop mercury trading between countries when the use is not justifiable With 128 signatory countries and 116 ratifications, the convention came into force on Aug. 16, 2017 (UNEP, 2020b). In 2018, more than 32 countries were exporting metallic mercury to developing countries according to data from UN COMTRADE (2020). Most of these countries signed and ratified the MC. The largest official exporters of mercury in 2018 were: Mexico (163 tonnes) followed by Russia (105 tonnes), United Arab Emirates (99 tonnes), and Canada (91 tonnes).

Indonesia signed the MC on Oct 10, 2013 and ratified on Sept 22, 2017. As mentioned above, Indonesia passed from importer to exporter of mercury in 2015. In 2016, Indonesia exported over 680 tonnes of mercury. It is doubtable whether the exported mercury was to be used in legitimate applications such as chlorine plants, electronics, fluorescent lamps or dentistry or to go to AGM sites. From this large amount of mercury exported, Japan imported 369 tonnes, followed by Singapore (110 t), India (67.5 t), United Arab Emirates - UAE (45.9 t) and many other countries. Japan, also in 2016, exported 147 tonnes of metallic mercury to India (72.5 t), Colombia (36.2 t) and other developing countries. In 2017, Indonesia was legally exporting approximately 152 tonnes of metallic mercury mainly to UAE (61.9 t), Hong-King (34.4 t) and many others. In the same year UAE was exporting 89 tonnes of mercury to Sudan (51.6 t), Iraq (17.4 t) and other African countries. In 2018, Indonesia exported officially only 4 kg of metallic mercury. Nowadays, all the legal trades of mercury became difficult to follow after the MC came into force in 2017. Currently, most mercury used in AGM is either clandestinely traded or traded under other legitimate designations (there are nine other international classifications for mercury compounds and mercury-containing products). However, in the field, no miner stopped using mercury and they purchase the metal easily from processing centers or other local dealers.

2.3.2. Lessons Learned

In summary, the formalization-legal approach:

- has its merits but no positive result has been observed using legal procedures in countries impacted by mercury from AGM,
- developed countries that signed and ratified the Minamata Convention, including Indonesia, are exporting metallic mercury, in particular to developing countries,
- governments are introducing laws to prohibit the use of mercury in AGM, but they do not provide any other solution or technical assistance for the artisanal miners,
- government personnel has little information about mercury, cyanide and other mineral processing techniques,
- in the field, in most developing countries, including Indonesia, it is not observed any type of enforcement to curb the mercury use by AGM,
- the price of mercury has increased and many middlemen selling mercury to AGM are taking advantage of this,
- smuggling of metallic mercury is increasing,
- artisanal miners are (re)open mercury mines in Indonesia, China and Mexico,
- all regulations to legalize artisanal miners are extremely bureaucratic and complex and they are not helping the formalization of artisanal miners,
- and the main hurdle to formalize artisanal miners is that most of them do not have legal rights of the gold deposits they discovered, then they cannot be legalized if the mineral

titles belong to others. This is observed in the majority of countries impacted by mercury in AGM, including Indonesia.

3. A POSSIBLE SUSTAINABLE SOLUTION

After analyzing the failures of most projects in reducing and eliminating mercury use in AGM, the author describes a solution that has been observed in the field and with large impact to reduce mercury use.

3.1. Miners Don't Have Mineral Titles

Governments know that the main gold deposits discovered by the artisanal miners were passed to the hands of conventional mining companies that have more organizational capacity to deal with the complex system of formalization. It is also common to see individuals with the mineral titles (exploration or exploitation) of deposits discovered by AGM. They have the sole intention to negotiate the areas with large companies. These speculators usually do not conduct any geological exploration or mining activity and blame artisanal miners for invading their claims (Veiga and Marshall, 2017).

Without changing the legal *status quo* of mining activities in most developing countries, it seems that the solution to eliminate mercury pollution in AGM is much more in the hands of the owners of the mineral titles of the gold deposits than with governments or international agencies. In this case, a co-existence system in which artisanal miners can work in the mining concessions from companies or other owners of the mineral titles, seems to be a feasible solution. In fact some forms of co-existence are already in place with some companies, most of them in Latin America. The differences among the types of co-existence observed in the field are commented as follows and a small improvement is suggested.

3.2. Co-existence: Leave an Area for AGM and Make a Blind Eye

This model is actually not a co-existence between mining companies and artisanal miners, but just a tolerance of the mining companies with the presence of the AGM in their areas. This has been observed in Nicaragua where the government requests to conventional mining companies to accommodate traditional artisanal miners in a small part of the titles. However, miners keep using mercury and rudimentary processes. This was observed not only in Nicaragua but also in Honduras, Peru and Suriname. This acceptance of artisanal miners in a company's area is definitely a first step of tolerance, but without technical assistance from the mineral titles' owners, accidents occur and miners can keep using mercury and polluting the companies' claims (Veiga et al, 2014b). If the liability is not transferred to miners, this model can bring problems for the companies in case of fatal accidents or pollution of the streams.

Smith et al. (2017) also defended the idea that the conventional mining companies, together with government, should separate an area in their titles for artisanal miners to work, but the methodology of implementing this concept was not developed by the authors.

Another example of this method to deal with AGM was implemented in Brazil, where the government created in 1983 "artisanal mining reserves", mainly in the Amazon, where artisanal miners could freely operate (Sousa et al., 2010). Unfortunately, artisanal miners have never received any training and these areas are currently extremely polluted and degraded. Furthermore, isolation of the problem does not resolve the mercury pollution problem. The state or companies must provide technical assistance to miners processing their own ores.

3.3. Co-existence: Make a Processing Plant for AGM

The idea of making a processing plant for the artisanal miners seems interesting and in some cases, this resolved the frictions between AGM and companies. This co-existence model was firstly implemented in 1993 in Las Crisitinas, Venezuela (Davidson, 1997). Placer Dome, a Canadian company with the mineral titles of the Venezuelan gold deposit, organized the artisanal miners already working in the company's area and separated a small part of the claim to allow them to work. They also provided technical assistance to the miners and built a simple processing plant for them with grinding and concentration of gold without mercury (Siegel, 2007). This co-existence model has the benefit of encouraging artisanal miners to organize themselves and create cooperatives to operate the mines and the plant built by the company. The approach also comes with the added benefit of formalization and, possibly, training for the miners, who eventually can be employed by the conventional mining company. In addition, formalized miners can protect the conventional mining company against invasions of other artisanal miners. The legal aspects of this strategy are not easily resolved if the company does not provide a permanent support to miners.

AngloGold Ashanti and B2Gold are initiating a process of co-existence in their Gramalote Project, in Colombia. After a meticulous inventory of the origin and type of individuals mining in the area, with participation of legitimate traditional miners, the project has been built a processing plant for the artisanal miners. An assigned area in the project mineral title was designated for the miners and a preliminary drilling established a minimum reserve. With the UBC Dept of Mining Engineering, metallurgical tests complemented the pre-feasibility study of the new small plant. But the problem of this good idea was that not every one of the 207 identified legitimate artisanal miners are participating in this small plant project, buy only 18 selected miners. This, and claims for financial compensation for those not contemplated in the co-existence plan, gave resulted in road blocks and protests (El Tiempo, 2017).

This co-existence model was also used by MINESA, in Colombia, which has established a small plant (20 tpd) for the artisanal miner in its titles. In another case, Mineros S.A., a Colombian company, acquired the Bonanza Gold Mine in Nicaragua from HEMCO. This American company had introduced in 2010 a co-existence model whereby 2,000 artisanal miners have been bringing and selling ore to two small (100 tpd) processing plants. The company provides technical assistance and also offers training to miners in security, geological exploration, explosives, etc.

(Bonanza Model, 2014). It seems that, even changing the owners, the Bonanza Gold is working well, with no mercury use and has been supporting the local artisanal miners.

3.4. Co-existence: Buying Ores from Miners

A different co-existence model has been used by the Canadian companies Continental Gold and Gran Colombia Gold in Colombia (CMJ, 2019). These companies allow the miners to operate in the companies' titles and buy the ores to be processed in the companies' plants. Miners bring a truck load of ore to the company that is sampled and analyzed in the companies' chemical lab. Usually the payment is around 40% for low grade ores and can reach over 60% of the gold content for high-grade ores. Each company has a payment table based on grades and volumes of ore to be purchased. Considering that processing centers recover less than 30% of the gold by amalgamation, this seems a good idea for the miners.

Continental has established what they call "formalization of the miners". After training in occupational health and safety, use of explosives, environment and financial management and other social programs, the miners organize themselves in formal companies. Then, the company has two possibilities of a formal agreement: 1) operation contract, when the miners are located inside the productive area of the company (established to operate for 15 years); 2) subcontract, when the miners are located in the company's claim, but outside the mining area. In the first case, the company has already the environmental and mining permits, then reducing the paper work for the miners. In the second case, the company provides substantial assistance to miners to obtain all the legal and environmental permits and establish subcontracts with the formalized miners. Currently the Continental has four operation contracts and four subcontracts. In 2019, these miners sold to the company approximately 3000 wet tonnes of ore with an average grade around 28 g Au/t. The company buys the ore based on sampling and analyses. Just one mining operation crushes the ore before bringing to Continental plant. The other ones do not have crushing facilities. In these cases, the company samples from 1 tonne of ore in 20 sacks of 50 kg. The material is still coarse but the company found a way to obtain a representative sample. Then, the miners receive 1/3 of this subsample, Continental analyzes another 1/3 in its lab and keep 1/3 in case of divergences between grades of the company's and miners' subsamples. Miners can analyze their subsample in private labs but they are usually far from the mining sites. After 3 months, Continental paid private labs to analyze the miners' samples, but miners are currently comfortable with the analyses in the company's lab. The payment for the ores depends on grades and on the participation and loans that Continental has provided to the miners. The difference between the Continental model and other existing models observed outside Colombia is that, the company provides technical assistance once a week to miners to indicate where are the rich ores in the mines and safer mining methods. The success of the co-existence model is pushing the company to expand subcontracts to three more organized mining companies. About 780 people in the small town of Buritica were positively impacted by this co-existence process.

In 2005, the American company HEMCO conducted a similar process in Venezuela, but sampling the miners' ore after crushing. This creates a more homogeneous heap to be sampled by both, miners and company before analyses. But still, the miners do not have ways to confirm the analytical results if there is no private labs in the region.

B2Gold also resolved the risks of conflicts with artisanal miners in their titles in Nicaragua, Philippines and Mali using different processes of co-existence. According to the B2Gold Responsible Mining Report (2018), the company has built a small cyanide processing plant in Nicaragua for the miners and in Philippines B2Gold purchases ore from miners to be processed in the company's plant. In this report, B2Gold stated: "*our strategic approach to artisanal mining is to seek and maintain a peaceful co-existence, balancing the need to protect our operations with the right to a livelihood for artisanal and small-scale miners*". It seems that the relationship with artisanal miners was not always harmonious but the company revealed that they never had any confrontation with them.

In Piura, Peru, this process has also been used by two local companies that sent the bought ores to their cyanidation plants. The companies sample the ore brought by miners and analyze it in their own labs. The miners do the same using private labs in the town. A third party is indicated to have a third sample in case of disagreement between the two analytical results. Once a consensus is reached about the gold grade, the company pays in cash the miners the equivalent of a percentage, usually 50% (depending on the grade) of the gold content in the ore. This process usually takes less than one day. The problem of homogeneity and sampling is still a point of conflicts between miners and companies. One identified problem is that, as the companies' plants are located 1000 km from Piura, the gold grades must be high to justify the transport, but usually the ores are very rich. Not long ago, the miners were using "quimbaletes" (a large rock swinging on the crushed ore) to make amalgamation. The miners were convinced that the best option would be to sell the ore instead of the whole ore amalgamation process when they found out they were producing very little amount of gold and the companies were paying much more for the ores than the gold they extracted. This process had a strong participation of a project sponsored by the US Dept of State (Veiga et al., 2015).

In fact, divergences can occur when the gold grades of the subsamples analyzed by the company and miners are different. This, actually, is caused by the heterogeneity of the ores and not often by the chemical analytical process. The miners can also have a bad perception when the company has different agreements with different miners. This actually must be avoid to have a transparent business.

Another option of buying ore from miners was tried in Ecuador and in this case the company tried to avoid the issue of divergences on chemical analyses due to the lack of representatively of the samples. The company operating the processing plant engaged completely the miners in its operation showing how the gravity, flotation and cyanidation plant operated and how the gold would be produced at the end of a week or more. The company has paid 20% of the gold content up in front, based on chemical analyses of samples brought by the miners. After the gold bar was produced, the company shared the operating costs with the miners and split the net profit in half. Miners then, received money related to additional 30% of the obtained gold minus the costs to produce it. This was a very fair and transparent deal, but it is feasible only when the miners have enough trust in the processing company, which was not the case. Another problem was that miners wanted to have all money in their hands in short time, not only 20%. This is actually a reason why they use amalgamation, as they believe they receive around 50% of the gold content in the ore. The miners must also wait one week or more for the cyanidation of the ores to receive their remaining money. Another complication of this option was that the company should stop the processing operations every time a miner came with a new ore. In fact, this method did not work well in Ecuador and conflicts with miners stopped the transactions.

Miners can be convinced about the business model of selling their ores when they find out how inefficient the amalgamation process is. If gold is analyzed in the ores before and after the amalgamation, the miners will witness (but not really convince yet) how much gold they are losing, i.e. leaving for the owners of the processing centers. A good gold balance in the place where amalgamation is taking place can be laborious but miners must be educated and engaged in the process of obtaining samples and gold grades of their ores and tailings. When miners observe how much gold has been extracted from their tailings by a more sophisticated process, they will finally accept the fact they are losing money. This is a first step to convince them of selling the ores for a fair price. Currently most processing centers tell them that the amalgamation process extract 50 to 70% of the gold from their ores. This procedure can prove that this is a lie.

3.5. Co-existence: A Suggested Improvement

Conflicts over the grades of the ore brought by the miners can be resolved with a good homogenization, reliable sampling and education of the miners to understand the whole analytical process and how mercury-free processes work. The lack of homogeneity of the ore can be solved if the ore-buying companies provide crushers to the miners and teach them how to make a homogeneous heap before bringing the ore to be sold. In this case, the company goes to the mines to obtain samples, and not vice-versa. This reduces the miners' costs to transport tonnes of ore to the companies' plant with the risk that the grade is low and not interesting to the buyers. However, this increases the company's work load to travel to the mining sites and sample the homogenized (if correctly done) sample prepared by the miners.

The miners' confidence in the chemical analyses is also harder to be solved only with trust, in particular when miners do not have other labs to test the samples. A possibility is to have an independent intermediate entity, for example a company from the national or regional government, that provides primary and/or secondary crushing reducing the ore to sizes between

7 and 70mm. A small jaw crusher 8"x 5" (15 x 7.5 cm) would require power of 2.2 kW (2.9 HP), consuming 0.5 kWh/tonne of ore, with price ranging from US$ 3,000 to 5,000. Some small jaw crushers can reduce the ore in one pass to below 0.1 mm or the facility can also have a cone crusher. This independent entity, under the miners' inspection, would carry out crushing, sampling and analyses (Fig. 7). The proposed entity is sole responsible to produce a homogeneous heap of sample and accurate reports of the ore grades. The companies purchasing the ore can also check the results. This eliminates discrepancies in the sampling and analytical processes and the credibility of the gold grade results in the samples to be sold would be transferred to the independent entity. This model can still have problems reangungsuch as salted samples, wrong reports of the analytical results, breakdown of the crushing and analytical processes, etc. Problems that any ore-buying system will also face. Without trust and integrity of the parties, all models would always be vulnerable to corruption by any side of the transaction.

Government of Indonesia should exert pressure on the established and legal processing centers to adopt this business method instead of exploiting the miners using rudimentary amalgamation to keep their rich tailings. Processing centers must become "real" processing companies buying ores from miners. The owners of the mineral titles (companies or individuals) should adopt this co-existence model instead of using force to remove traditional artisanal miners from their areas. The formalized miners, with contracts with the companies, should be the first ones to protect the companies against intruders.

This co-existence model, conducted with transparency and trust, has been proved as the **best solution to end mercury use and pollution,** as the companies buying ores do not use amalgamation. Miners do not have to invest in processing plants and they also will receive more money in the same or less time than if they amalgamate the whole ore.

The conventional mining companies and other owners of the mineral titles must be involved in providing miners with adequate technical, health and safety assistance in the mining steps. This will eliminate the large number of fatalities and occupational problems currently observed in artisanal mines. Without technical assistance, accidents occur and the companies are usually liable for them. Another lesson learned is that, when ores are not properly sampled and analyzed, this can generate serious conflicts between miners and ore-buyers.

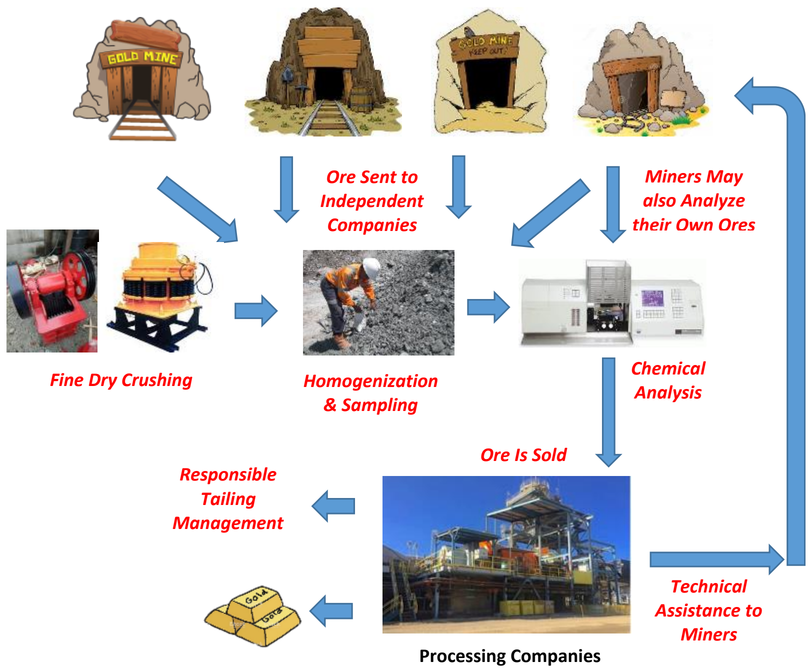

Fig. 7. Proposed Co-existence Model for Indonesia

4. CONCLUSION

Artisanal miners are kept in a cycle of poverty and at the mercy of the processing centers for amalgamation. The environmental and health problems associated with mercury pollution have not been solved by monitoring campaigns, regulations or technical training.

Projects promoting mercury-free technologies have limited duration, little impact in changing the polluting behavior of artisanal miners and most of them have focused on micro-miners. Gravity concentration alone will not provide substantial improvements in the gold recovery and it will be hard to convince miners to change their polluting processes. Hundreds of technical solutions exist to fully eliminate the use of mercury in AGM, but implementation of these techniques is expensive, needs skills and is unsustainable if miners do not have constant technical assistance or even interest in being mineral processors. However, it is understandable that permanent technical assistance is very costly to governments or other stakeholders.

Creating awareness on the environmental and health impacts, have not yielded, as yet, the desired results of mercury elimination. Firstly, because miners do not read or even believe in news from monitoring projects and secondly, because authorities do not take any action to eradicate the main polluters (the processing enters). Formalization and other legal actions, which are the preferred measures of governments and international agencies, are not working properly and do not reach most miners as the formalization process is usually extremely bureaucratic. In addition, it is very hard to find mineral titles available to artisanal miners. Most of them are currently in the hands of conventional mining companies or individuals.

All these solutions are usually specific in their objectives and do not contemplate the complexity of the problems. As a consequence, the number of informal miners and mercury pollution have been increasing. Projects must focus on changing the business model of the miners instead of spending millions of dollars to formalize or train them in processing methods.

The co-existence system, in which miners sell ores to regulated and responsible conventional companies (of any size), is definitely the best way to eliminate mercury use and formalize the miners. This has been witnessed working in many Latin American countries. The main problem for miners is to fully accept a system to buy their ores, when they do not have clear knowledge about gold grades or sampling procedures. Currently the miners do not have a way to confirm the gold grades in their ores, which in some case, only the company acquiring the ores has analytical facilities. This is the main origin of suspicions that can generate conflicts between miners and ore-buying companies. Two solutions can be implemented: 1) build trust in the sampling and analytical process, as Continental Gold has done or 2) introduce an independent governmental entity that will receive the ore from miners, prepare and analyze them before the sale process. This procedure will provide reliable chemical grades of the ore for both parties, companies and miners, and will transfer the credibility of the business to the government.

Any solution model of co-existence must be encouraged by a thorough discussion with all stakeholders in order to build trust. Governments and owners of the mineral titles must facilitate the process in which: MINERS MINE, PROCESSORS PROCESS the ore. The co-existence process for artisanal miners and owners of the mineral titles who have processing facilities is the best solution for miners who will receive fair remuneration for the ores they extract in a short time and technical assistance from the processing companies. This reduces costs from governments, miners and companies as well as conflicts. Owners of the mineral titles should be more tolerant and accommodate legitimate artisanal miners in their titles, educating and working with them to avoid accidents and to provide better results in the mining process.

Unfortunately, the co-existence model is not a good solution for the existing processing centers that currently receive in the tailings left by the miners, at least 70% of the gold not extracted by amalgamation. Owners of processing centers, who want to evolve, must be consulted and educated to understand they cannot continue with the exploitation of miners and polluting activities. They must be converted into responsible processing companies, otherwise they must disappear. **The co-existence process is the only method being employed in some countries that has brought full elimination of mercury**. Miners have been receiving more money with this solution than using amalgamation and their health and environmental problems have been drastically reduced.

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