This Technical Paper is the first in a series being developed by WWF-Guianas Regional Program Office as an information sharing service to increase awareness of key conservation issues in the Guianas and foster the general public interest in taking corrective actions. The ultimate goal is to ensure that the natural ecosystems of the Guianas continues to play their role to sustain the region's biological diversity, cultural enrichment and socio-economic development.

Mercury-Free Gold mining Technologies:

Possibilities for Adoption in the Guianas

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Abstract

Goldmining plays a significant economic role in the Guianas, yet the rudimentary nature of small to medium scale gold mining activities often generates a legacy of extensive degradation and deplorable social-conditions, both during and after activities have ceased. This form of mining usually involves the extraction of secondary gold from placer deposits (alluvial, colluvial or elluvial), which can be liberated and treated using gravity methods. In the Guianas, the most popular form of small-scale gold mining is referred to as "land dredging", a combination of hydraulicking and suction dredging. This method requires application of large volumes of water for both mining and mineral processing; in most cases, there are no containment structures for the waste tailings generated. Mercury, a dangerous pollutant, is the preferred method employed by small-scale miners for gold recovery. Gold extraction using mercury is comprised of the following four stages: 1) amalgamation, 2) separation of amalgamation, 3) removal of excess mercury, and 4) burning of the remaining amalgam to produce a gold sponge. Mercury can be released into the environment at each stage, which makes the promotion of mercury-free alternatives imperative. By January 2006, the use of mercury in the gold mining sector will be banned in La Guyane.

During the last three years some small and medium scale operators have initiated steps towards improved practices by using tailings impoundment facilities, mercury retorts and mercury free techniques.

Technical alternatives for small-scale gold mining, however, must be thoroughly evaluated, pre-tested, modified accordingly and successfully transferred. Moreover, technology must be inexpensive, relatively simple and easy to adapt, while allowing a rapid rate of return. In partnership with the regulatory agencies and other relevant stakeholders of the Guianas, the WWF Guianas program is working towards reducing the environmental footprints caused by small to medium scale mining. The major aspects of this program are to assist in the developing the capacity and regulatory mechanisms, to promote mercury free technology, and monitor mercury in the environment. This technical paper reviews the alternative technologies being investigated by the Guianas for use in the small-scale gold mining industry.

Keywords: *mercury, amalgamation, hydraulic, tailings, gravity, chlorination, garimpeiros*

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Introduction

Small-scale gold mining activities have been carried out in the Guianas for over one hundred years. They continue to provide a source of livelihood for communities where alternative economic opportunities are limited. During the past fifteen years, there has been a new gold rush with several persons becoming small-scale miners to escape complete social marginalization. Coupled with this, is the exhaustion of accessible placer ore deposits in Brazilian Amazon[1,2,3,4], which are pushing *garimpeiros* (Brazilian gold miners) to invade neighboring countries. Suriname and the French Department of La Guyane are experiencing a rampant increase in illegal mining activities while Guyana is trying to contain them.

The environmental impacts associated with small-scale to medium scale gold mining are of major concern to the region's policy-makers and inhibitants. Some of these problems include:

- Mercury pollution;
- Disposal of tailings and effluents into rivers affecting fish spawning areas
- Contamination from improperly constructed tailings impoundments;
- River damage in alluvial areas;
- Erosion damage and deforestation (loss of habitat, etc.);
- Landscape destruction; and
- Social fabric deterioration, especially in the interior

The antiquated nature of many of the small-scale gold mining operations often generates a legacy of extensive degradation and deplorable social conditions, both during and after mining activities have ceased. Collectively, small-scale gold mining operations tend to do more environmental damage than the larger and more modern companies. A lack of awareness – particularly of the less visible or long term consequences of their actions – combined with a lack of information about affordable methods to reduce impacts and a lack of obvious incentives to change, all contribute to the problem. The reasoning behind this is that miners there tend to focus more on their immediate concerns (quick revenue) rather than the impacts of their actions.

Regulatory agencies in the Guianas are often unable to effectively monitor operations because of their remoteness, inaccessibility and geographically-scattered nature. Taking into consideration the number of people reliant on small-scale gold mining activities and the magnitude of the environmental impacts, appropriate measures must be developed and implemented to mitigate the associated problems and reverse the impacts wherever possible. The environmental issues in the industry which is receiving increasing attention are mercury pollution and the possible consequences for the local people and siltation of the water bodies. Small-scale to medium scale mining usually involves the extraction of secondary gold from alluvial, colluvial or elluvial materials (i.e. gold that has been liberated from its source and can be concentrated by gravity methods) using mercury.

This paper examines the chemical pollution aspect, as it pertains to mercury use, the gold mining and processing technologies currently being used by miners in the Guianas (Suriname, Guyana and French Department of La Guyane), and identifies some alternative mercury free techniques that can be adopted. Future Technical Papers will examine other aspects of the gold mining sector.

Gold Processing Technologies in the Guianas

The mining and mineral processing implements used by small-scale gold miners in the Guianas are as follows:

a. Manual (pick axe, shovels etc.) / sluice;

b. Metal detectors;

c. Hydraulic monitors/ hammer mill/ sluice;

d. Hydraulic monitors/ gravel pump/ sluice;

e. Excavator/ hydraulic monitors/ gravel pump/ sluice; and

f. Missile and Cutter head dredge/ sluice.

Each is reviewed briefly in this section of the paper.

Manual (pick axe, shovels etc.) / sluice

Activities carried out by individuals and small groups that involve mining shallow placer deposits are termed "pork knocking". Mine pits are excavated manually and ore is stockpiled for processing. Pits vary in size, ranging from $2m^3$ to as much as $12m^3$, and processing is carried out via a shaker (a perforated ½ metal drum) to remove large gangue particles, followed by washing on a matted long tom (small sluice). At the end of the process, mats are removed, cleaned and the concentrate upgraded by panning. Mercury is then added to the pan to form amalgam (gold/ mercury) which is eventually heated to remove the mercury, resulting in gold sponge residue.

Metal detectors

The operation of metal detectors is based upon the principles of electromagnetic induction. Metal detectors (see Figure 1) contain one or more inductor coils that are used to interact with metallic elements in the earth. A pulsating current is applied to the coil, which induces a magnetic field. When this current moves across a metal

such as a nugget, electric currents are induced (eddy currents). These eddy currents induce their own magnetic field, which generates opposite currents in a nugget and subsequently emits a signal indicating its presence.

Metal detectors are basically used as a prospecting equipment to locate nuggets in shallow saprolitic and lateritic ores. Once an area has been identified the material is mined manually, sluiced, and hand panned to recover the gold. In most cases, the nuggets are large and can be easily hand picked and do not require the use of mercury.

Figure 1: Metal Detector

Hydraulic monitors/ hammer mill/ sluice

Figure 2: Hammer Mill / Sluice

Hammer mills (Figure 2) have become very popular in the Guianas. It providing fast grinding and reasonable throughput. Hammer mills operate on the principle that most materials will grind or crush upon impact with the hammers. The material is fed into a hammer mill from the top and falls into the grinding chamber where it comes into contact with a series of rotating hammers. It is ground by repeated contact with the hammers, with the walls of the grinding chamber and other particles. The grinding process continues until the particle size is suitably to pass through the perforated screen that covers the bottom half of the grinding chamber. The screens are interchangeable, with hole diameters ranging from 1mm to 4mm to facilitate course or fine grinding. The output (volume) of the hammer mill is dependent upon the screen size, shaft speed (normally between 1800 to 3,600 rpm), and the configuration of the hammers.

The main problem related to hammer mills is the high wearing rate of the structure and the hammers, which are usually made of cast iron. In cases involving hard-rock ores rich in quartz, hammers must be changed frequently. In the case of milling weathering (softer) ores, hammer mills are very durable and appropriate for small scale gold mining. However, even working with lateritic and saprolitic ores, miners do excavate eroded layers of quartz-gold-veins which have a high Bond Index (i.e. are very hard).

Hammer mills work in conjunction with hydraulic mining, where ore is disintegrated by high pressure water jets and channeled to feed the mill. The mill product is then concentrated by matted sluice and upgraded by panning.

Hydraulic monitors/ gravel pump/ sluice

This is the most popular method of hydraulic mining of placer deposits[3,5], and is commonly referred to as "land dredging" (see Figure 3). This method utilizes high pressure water jets to disintegrate the ore and channel the slurry to a sump where gravel pumps transport the slurry to

Figure 3: Hydraulic Monitors

riffled and matted sluices for gravimetric separation. The capacity of these operations is based on the suction intake of the gravel pump (ranges from 7 to 25cm), and can process 45 to 150 m^3 weekly, depending on the compaction of the material, type of material mined and equipment availability. These operations are batch process and are stopped for cleaning after 2-10 operating days. The concentrates are manually removed from the boxes for upgrading and amalgamation.

Excavator/ hydraulic monitors/ gravel pump/ sluice

This method (Figure 4) is similar to conventional hydraulic mining, the main difference being that excavators are utilized to clear the land, remove the topsoil, strip overburden, and stockpile ore for processing.

Figure 4: Excavator aided Hydraulicking

This method is more efficient than the conventional method in that only the gravel is processed, hence, less tailings discharge, less water requirement per square meter (surface area) mined, and topsoil and overburden is available for rehabilitation and re-vegetation.

Miners are also using excavators to feed grizzles (parallel bar screens) to remove oversized waste rock, thereby enabling sluices to function more effectively (the effect of gravity separation is more pronounced when the particle size range is limited).

Missile and Cutter head dredge/ sluice

These operations are river-based and rely on suction pumps to vacuum alluvial sediments from the beds of larger rivers. This slurry is then transferred to barge-based sluices for primary concentration. Due to the large capacity and nature of the ore, final clean up is more frequent than land-based operations.

Figure 5: "Missile Dredge"

The missile dredge Figure 5 is essentially a hydraulically-operated suction intake with diameters varying from 20-35cm. The cutter head Figure 6 is essentially a rotating saw-tooth conical device that penetrates the hard crust in the river bed to retrieve consolidated material. The suction intake systems are basically similar.

Figure 6: "Cutter head Dredge"

Amalgamation Practices in the Guianas

Mercury is the preferred recovery method used by small-scale gold miners in the Guianas, and is used in a variety of ways to produce amalgam, including:

- Distribution on the pit floor to amalgamate gold particles before processing;
- Placement behind riffles in sluice boxes and;
- Final clean up process.

When conducting hydraulic mining, some gold miners distribute large quantities of mercury on the pit floor, believing that the mercury will move through the ore to capture all the gold particles available. When this is done, mercury and gold losses are very high since the impeller of gravel pump disintegrates the amalgam to form very small droplets referred to as "floured mercury", which contains some gold. This process reduces the effective density of the gold; thus these droplets pass through the sluice box with the tailings. Estimates suggest that losses to the environment are as much as three time the gold recovered[3].

Another practice is the placing of mercury behind the riffles to amalgamate the entire ore. The turbidity of the slurry in the sluice boxes creates floured mercury that is also lost with the tailings.

Most miners, however, only amalgamate gravity concentrates Figure 7. This practice utilizes less mercury than those mentioned earlier and hence losses to the environment are significantly reduced. Approximately eight grams of mercury is used to recover one kilogram of gold, since most of the course gold particles are hand sorted. The amalgam is separated from the gangue by panning in water courses, ponds and in containers such as half drums or wooden jig boxes. The excess mercury is removed by hand by squeezing the amalgam in a piece of fabric, which is then recovered and bottled for reuse. The amalgam should then be burned in a retort but in most cases is heated in the open air as Figure 8 illustrates.

Figure 7: Amalgamation of gold

Figure 8: Burning of Amalgam

Alternative Mercury-Free Mineral Processing Technologies

Gravity Concentration

Gravity concentration separates minerals based on differences in densities. Effective gravity separation processes occur when applied to narrow particle size range. The most important factor for successful gravity separation is the liberation of gold from gangue minerals. The main advantages of gravity concentrators over other hydrometallurgical methods are as follows:

- They are relatively simple pieces of equipment low capital and operating costs);
- Little, if any, reagent is required; and
- They can be applied to relatively coarse particles as well as finer materials

Some practical implements for gravity separation are reviewed below.

Sluice Boxes

At first glance, because of their visually turbulent flow characteristics, sluice boxes appear crude and are usually considered inefficient relative to modern gravity concentrators. Yet, they are widely used in most of the small-scale gold mining operations in the Guianas. Their low capital and operating costs are the major reasons behind their adoption, furthermore, from an operational standpoint, they achieve a very high concentration ratio, typically in the range of 10,000:1 to as high as 500,000:1.

The clearly re-iterated fundamental principle of mineral processing is that any given piece of equipment can effectively treat only a limited size range at once. Placer gold particles vary in size hence, the justification for considering different treatment conditions for different particle size ranges. It may be desirable to have the sluice box tuned to catch swings of larger-to-finer particles, rather than trying to capture the mean particle size.

To operate a sluice box successfully several procedures can be adapted [7]. These are as follows:

1. Establishing the slope, plus water and solids feed rates to prevent compaction behind each riffle, appears to be the most important factor behind optimizing gold recovery. Maintaining an elliptical eddy, scouring out the riffle bed to approximately one half appears to be adequate.

2. Slurry rates between 250kg/min and 1400kg/min can provide high recoveries in the finer size range once the sluice has sufficient length.

3. By reducing the feed top size, the flow rate required to transport larger gangue particles out of the sluice could be effectively used to sort the minerals based on their specific gravity since the effects of particle size would be minimal.

4. Multi-stage sluice boxes Figure 9 should be designed and fitted accordingly to capture the various gold particle size ranges that are common in placer deposits.

Figure 9: Multi Stage Sluice box

5. The Nomad matting proved to be a very effective gold trap to hold large amounts of gold and prevent its migration down the sluice.

6. Cleanup periods should be designed to avoid the riffles from being packed, which may result in gold migration and possible losses. Once there is a presence of angular or blocky gravel or high clay content, the cycle time should be reduced since these materials have the tendency to pack the riffles and would affect the performance of the sluice.

These simple practices could be implemented to improve sluice box efficiency.

The cleanup process can be performed without using mercury. The rougher concentrate can be upgraded to a final concentrate by simple hand screening Figure 10 and sorting to remove course gold particles following panning to recover finer particles. Although this is time- consuming, it is cleaner and has been undertaken by various mine operators in French Guiana. The final concentrate is smelted directly to produce gold ingots.

Figure 10: Mercury Free Cleanup

Cleangold Sluice

An interesting sluice box (Figure 11) was invented by Dave Plath and manufactured by Cleangold, a company based in Lincoln City, Oregon. The Cleangold sluice uses magnetic sheets inserted aluminum sluice boxes. Magnetite, a mineral usually found in placer gold-ore deposits, forms a corduroy-like bed on the sluice floor and is effective at recovering fine gold. A cleanup sluice box is available in size of 2ft x 6in (60 x 15 cm), the prospecting sluice, that is handy for preliminary deposit evaluations, and sluice inserts . The costs of these Cleangold sluices are minimal and the main advantage of these sluices are their high concentration ratios. Gold becomes trapped below magnetite layer and the sluices can be scraped and washed into a pan. Using a magnet, the magnetite is removed and a high grade of gold concentrate is obtained. Mercury is not required for the final cleanup. This technology was field tested and demonstrated to miners in Suriname, Guyana and French Guyana during June 2004, and the results indicated that it can be used as a potential replacement for mercury during cleanup.

Figure 11: Clean gold sluice box

Gemini Table

This type of shaking table (Figure 12) is very common in French Guiana. The table deck is made of fiberglass, and is supported by a steel frame. It has a longitudinal adjustable tilt and just one-direction shaking movement with variable speed. The final concentrate is extremely rich and does not require mercury.

The Gemini Tables are specialized, low capacity finishing devices for application where pre-concentrated material is supplied as feed to the tables. Gemini Tables are capable of producing a very clean gold concentrate from gold-bearing black-sand concentrates when fed minus 20-mesh material. In many cases, the Gemini concentrate is suitable for direct smelting.

Figure 12: Gemini Table

Recovery efficiencies are excellent down to approximately 325 mesh size, which is about the finest particle size that can be observed with the human eye. Since control of mineral separations is by visual means, recovery is generally limited to particles that can be seen. It must also be recognized that the size and quantity of free gold present in the Gemini table feed depends upon the efficiency of the recovery and concentrating devices that are used ahead (sluice boxes in the Guianas scenario) of the Gemini table circuit. Feed rates and processing capacities depend upon characteristics of the feed material such as mineral composition, size distribution and shape factors. The most common table is the Gemini model GT60 Mk2, designed to process up to 60 lb. (27 Kg) per hour. The water supply to the table must be provided from a clean independent (steady-head) source, which will assure constant feed pressure to the water manifold. The water volume is the most important control variable when operating the Gemini Tables. The price of the table is US$8,000.

Centrifuges

The treatment of gold in the Guianas has experienced a promising advance with research and the introduction of centrifugal concentrators in the gold mining industry. Such concentrators include the Knelson, Falcon and Knudsen centrifuges [6]. The Knelson is most popular in the Guianas, with various replicas of Knudsen also being developed. These centrifuges enhance separation by increasing the gravitational force.

Figure 13: Knelson 7.5 Centrifuge

The Knelson Figure 13 comprises a ribbed rotating cone, into which a pulp of 20-40% solids by weight is fed. The concentrate is accumulated in the ribs, and compaction of the bed is prevented by the injection of water in a counter flow. A fluidized bed is created, which allows gold particles to penetrate into the concentrate layer[8]. The penetration rate is enhanced by the rotating vessel.

As the volume between the ribs is constant, the concentrate volume collected after any operating time will also be constant.

The Falcon is essentially a rotating bowl, into which slurry feed from a central well. Upon initial feeding, a bed is quickly developed until a final profile is achieved. Material is then recovered selectively in a mode that is size- and density- dependent.

The most suitable models for the small-scale gold mining industry in the Guianas are the Knelson 7.5 inches and the Falcon B6, which are essential batch equipment capable of processing 0.64tph and 0.5tph, respectively[8]. Centrifuges are very expensive, and require skilled labor and the availability of clean water to achieve desired separation. Many local replicas of the Knelson are now available in Brazil, and there are at least four manufacturers of cheap centrifuges (costing 10% of the value of a real Knelson). The bowls of these machines are not made of polyethylene like the ones of Knelson concentrator but of carbon steel.

Processing with chlorine

The chlorination process was first used in 1848 to treat arsenic gold ores in Silesia. The halogen/halide system predates cyanidation for the treatment of ores containing fine gold particles and gold sulfides ores not amenable to treatment by gravity concentration and amalgamation. The method lost popularity with the discovery of cyanidation, which proved cheaper and technically easier for the common miner.

However, there has been a renewed interest in chlorination because of recent negative experiences with cyanidation (Omai, Guyana and Ok Tedi, Papa New Guinea) and the potential environmental consequences of mercury uses. The concentrate is leached in hydrochloric acid, which is common in swimming pool acid (30% HCl) and chlorine common in bleach (required strength 14-16% sodium hypochlorate), to dissolve the gold particles. The leach residue, which consists mainly of silica, together with insoluble silver and sodium chloride and small amounts of occluded gold, is retained and reused.

After leaching is completed, the filtrate is treated with one of the following agents to precipitate the gold.

a. Sodium metabisulfate;

b. Oxalic acid;

c. Ferrosulfate;

d. Sodium nitrate; and

e. Zinc (chunks, bars or powder)

The chemical reactions for the process are as follows:

<u>Leaching</u>

$Gold_{(s)}$ + Sodium $hypochlorite_{(aq)}$ + Hydrochloric $acid_{(aq)}$ = Gold $Chloride_{(aq)}$ + Sodium $Chloride_{(s)}$ + $Water_{(l)}$

<u>Precipitation</u>

Sodium $metabisulphate_{(s)}$ + Gold $chloride_{(aq)}$ + $Water_{(l)}$ = $Gold_{(s)}$ + Hydrochloric $acid_{(aq)}$

WWF– Guianas coordinated a preliminary laboratory test in Guyana with the Guyana Geology and Mines Commission and the Geology and Mines Department of Suriname during August 2004. The results indicated that recoveries were greater than 93% In the finer size ranges (-300 microns).

Several other processes have been derived from this process, including the CETEM-saltem process developed in Brazil and the Halox process, which generates chlorine by electrolysis. Generation of chlorine actually takes place quite naturally when sodium chloride (cooking salt) and hydrochloric acid occur together in water, where all the oxygen and hydrogen required for the creation of gold chloride is available. More on this technology can be found at web site http://www.goldmineworld.net, including steps to carry out the leaching process.

Conclusion

Very often small scale mining in the Guianas is done with little regards for the environment. Tailings are disposed of however deemed suitable for the operators without cosidering the consequences and subsequent damage to the environment**.** Mercury continues to be the preferred treatment of placer gold ores. Amalgamation techniques would have severe impacts on the aquatic environment of the Guianas if the current practices continue. Aquatic biota is the main contamination pathway for mercury, which bioaccumulates throughout the food chain, occurring in its highest concentrations within higher-level organisms such as carnivorous fishes. The river-based communities in the Guianas use fish as their primary source of protein, and are therefore at risk of mercury poisoning. Recently concluded tests indicated that several persons had elevated mercury levels in hair samples, including babies and small children. In contrast to other chemicals that cause spectacular accidents when released, mercury has a long-term, time-delayed impact and is commonly referred to by many experts as a “chemical time bomb”.

Small to medium scale mining need not to strife with

environmental degradation. A fundamental need in the Guianas is the dissemination of information and the promotion of improved mining techniques, the regulations and strict monitoring of the gold mining sector. Many of the small-scale miners do not know the rudimentary technique of prospecting book keeping. They cannot determine if their investment will be profitable. Mining continues to be done as a gamble that somehow luck is going to strike. When it is done in this manner, financial losses and environmental costs are high.

Figure 13: Mercury Free Gold

This paper is the first in a series to promote environmentally friendlier mining techniques and has provided an overview of mercury-free alternatives that have been tested and/or promoted by some innovators in the goldmining sector. Continued testing of some of them and aggressive promotion of others are important and should be utilized to alleviate mercury pollution in the small-scale gold mining sector of the Guianas.

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