Global Mercury Project

Project EG/GLO/01/G34:
Removal of Barriers to Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies

Equipment Specification for the Demonstration Units in Zimbabwe

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Table of Contents

1. Background

1.1. Number of Miners

In Zimbabwe, it is estimated that there are between 300,000 and 400,000 artisanal gold miners sustaining the livelihood of at least 2 million people. There are 200 registered “formal” large to medium-scale gold mines and thousands of small-scale gold operations producing, according to the official statistics, up to 5 tonnes of gold annually. This production from a large contingent of miners seems to be underestimated and most gold must be smuggled out of the country where prices are more attractive. About 20,000 to 30,000 people are directly involved in gold extraction in the Kadoma-Chakari region selected by the Global Mercury Project to implement demonstration units.

There are 3 categories of people in the artisanal gold mining operations in the region:

1. **miners** who excavate and extract semi-weathered gold ore and take this for processing at custom milling centers. There are about 3,000 to 5,000 people involved in this activity.
2. **millers** who work in the milling centers where the ore is milled and concentrated for the miners. There are probably about 1,000 to 2,000 people in 70 milling centers.
3. **panners,** individuals who concentrate alluvial gold by panning the gravels in creeks and rivers or re-processing tailings from former industrial mining operations. They represent the majority of individuals extracting gold. They are nomads and can represent a contingent of 15,000 to 25,000 people in the region.

1.2. Processing Methods Used

Ore extracted by miners is transported to the custom milling centers to be ground and concentrated by operators. The custom milling centers are a desirable solution as this organizes the activity and avoids the use of mercury in different places. However, the millers allow miners (customers) to use their own mercury at any step of the process.

The technology employed by the custom milling centers varies. For crushing and grinding, some of them use wet stamp mills (3 or 5 stamps) with capacity of 0.2 to 0.5 tonne/h and some use jaw crushers followed by grinding with ball mills (capacity of 0.7 to 2 tonnes/h). For mineral concentration, the most popular methods are centrifuges and copper-amalgamation plates.

The centers charge between Z$ 10,000 (US$ 2.86)[1] to Z$ 14,000 (US$ 4) per hour of grinding and concentration depending on the hardness of the ore. Using stamp mills, hard rocks take 5 hours/tonne to be ground and concentrated, whereas soft ores take 1.8 hours/tonne.

Miners prefer milling centers with stamp mills, as they believe that ball mills retain part of the gold in the internal liners. The lack of gold liberation is an evident problem when using stamp mills and this is the main reason why miners recover less than 30% of the total gold by gravity separation followed by amalgamation. Stamp mills operate with water and the pulp is discharged through a 0.6 to 0.8 mm screen into a local-made centrifuge or on copper-amalgam plates.

The concentrates from the centrifuges are given to the miners and they perform their own amalgamation. The millers provide the miners with amalgamation barrels and they do not charge extra for this service. Miners can add whatever they want into the amalgamation barrels, including soap, acids, and sodium cyanide tablets. The material discharged from amalgamation barrels is concentrated by panning in a plastic bowl and the tailings pass through an amalgamating copper plate. Some miners take home the amalgamation tailings. They re-grind, sometimes add more

[1] Auction rate: 1US$ = Z$ 3500; official rate is 1 US$ = Z$ 824

mercury, pan them at their backyards and roast them in kitchens. The fate of these Hg-contaminated amalgamation tailings is unknown.

It is common to see miners adding three teaspoons (150 g) of mercury in the centrifuges used for gravity concentration of gold. This “flours” part of the mercury that is lost with the tailings. The use of copper-amalgam plates is also very popular in the centers and to amalgamate the whole ore.

The great majority of miners in the region do not use retorts as they claim that the process is time-consuming as they use low-temperature bonfires. Instead they put the amalgam in a tin to be burned in a wood fire without any protection. The burning process is done either under supervision of a large number of people or furtively in the bush. At low temperature, the retorting process is very incomplete. Retorted gold beads with more than 20% of residual mercury are usual.

Most of the gold is left in the primary tailings and the millers apply vat-cyanidation to extract this remaining gold. Miners receive no compensation for the extra gold extracted by cyanidation. This is a source of conflict between miners and millers. Most milling centers have 5 to 10 cyanidation tanks to extract residual gold using vat-leaching but some millers have as many as 27 tanks. About 20 to 70 tonnes of tailings from the gravity circuit and from the amalgamation process are added to cement each tank to be leached with 18 kg NaCN/tank.

Panners in Kadoma-Chakari are isolated individuals either working in local rivers and streams, especially the Muzvezve River, or panning tailings from former mining company operations (sometimes with their authorization). Panners are from remote areas, some of them from neighboring countries and they are frequently harassed by local police while working in illegal areas. In the dry season, they divert the river and excavate the gravels to concentrate gold in improvised sluice boxes (known as James Tables). They process from 1.5 to 2 tonnes of material per day recovering 0.2 to 0.4 g Au and losing equal quantities of mercury (50g per 4 months).

The amount of Hg lost in the milling centers is equivalent to the amount of gold being produced which is between 2 and 3 kg/month. When copper plates are used to amalgamate the whole ground ore, the miners estimate that they lose twice as much mercury. Assuming that all 70 milling centers in the region are losing between 2 and 4 kg of Hg /mo, something around 1.7 to 3.4 tonnes of Hg is being emitted to the environment in the Kadoma-Chakari region just from the milling operations. Considering the use of Hg by panners, the **Hg losses in the region must be between 3 and 5 tonnes/a.**

2. Proposed Solution

It is clear that knowledge is badly needed to improve the working conditions of the artisanal and small-scale miners (ASM) in the Kadoma-Chakari region. The level of education of miners and millers is higher than in other African countries facing similar problem. Zimbabwe has a long tradition in mining. Local equipment manufacturers have very good technical capacity to develop any type of equipment suitable for small-scale miners. They do not downscale conventional processing equipment but in fact, they actually have developed appropriate technology for the needs and production scale of the small miners. The Zimbabwean centrifuge is an example of the creativity of the manufacturers. However, these solutions must be brought to the miners and millers’ attention. An option is to create a demonstration site to provide fair access to all people involved in the mining activities within the region. As there is a clear conflict of interest between miners and millers, the ownership of the demonstration facilities is a problem. Some pieces of equipment can be assembled to teach miners, panners and millers how to process ore with less environmental and health impact. The focus of the initiative should be on TRAINING not custom processing services.

2.1. Transportable Demonstration Units (TDU)

The ASM activity in Zimbabwe is extremely widespread across the entire country. Fortunately in Zimbabwe the bulk of the activity tends to be concentrated within country's greenstone belts, which nevertheless extends over about 600 km in length and up to 100 km wide, from Northeast to Southwest Zimbabwe. There is a need to introduce the GMP initiative and technological demonstration of appropriate equipment throughout the mining area, and it is easier to bring a transportable demonstration unit to several thousand people than to bring several thousand (or even tens and hundreds of thousands) of people to a static demonstration unit. Beyond the reaches of the Great Dyke and up to 300 km from it, there are numerous satellite gold mines and ASMs; for example on the eastern border near Mutare, and around Masvingo in the South. A static GMP demo unit located on the Great Dyke would be very far from these areas.

Most of the hard-rock ores extracted by ASMs in Zimbabwe are processed in the facilities of custom milling plants. Perhaps there are hundreds of these mills all over Zimbabwe. The custom mills tend to be located in those areas with historical production records or where significant mining is taking place, and the more outlying ASMs have to transport ore for several kilometers to those plants. This introduces further problems:

- A static GMP demonstration unit would logically be located in a high-producing area, amongst existing custom mills. The miners would utilize the custom mills, where they need to witness the processing of their ore, and would return immediately to their mine sites to avoid lost production time. They would be unlikely to take the time to visit a demonstration unit. If on the other hand the unit came to the vicinity of their mine sites it would create interest and patronization.
- A centrally-located, static GMP demo unit in the vicinity of custom mills would tend to be viewed as a production facility by ASMs rather than a learning facility.
- The custom mills frequently abuse mercury, both of which are sometimes intentional at the expense of their customers. There would have strong resistance to educate their customers in enhanced and improved processing techniques, and ultimately to make them independent of the custom mills.
- Problems of land tenure, services, mineral rights, etc., would be involved with a central static demo unit. Ownership of the unit (government, NGO, mining association, etc.) might also become an issue.
- The ASMs tend in many instances to be semi-nomadic by their very nature. It would be logical to have a demo unit that moves with the people and the gold strikes.

As discussed above, for these and many other reasons it would be beneficial to have a mobile or easily trans-locatable demo facility. In addition to overcoming certain of the problems listed above, this facility would provide the following advantages:

1. easier to implement than fixed demonstration/training centers;
2. a transportable training unit would prolong the demonstration effect beyond the project lifetime;
3. as artisanal miners have nomadic characteristics, the training units go after them and not vice-versa;
4. a variety of technical options for gold concentration, amalgamation and retorting can be demonstrated to miners and millers; it is up to them to select what is affordable, appropriate and durable according to their convenience;
5. easy to change and adapt new pieces of equipment used for demonstration without the need for concrete foundations, etc.;

6. more miners and public can be outreached than in fixed demonstration/training units; more people will receive brochures and other educational material;
7. a continuous "supply" of new ASMs to educate, rather than the same handful who would be visiting custom mills close to a static demo unit.
8. the ownership of the training units is easy to decide (Government, University, NGO, etc); no land or mineral title is required;
9. Miners' Association can embrace this idea without having conflict of interest; the directors will not be the only ones to have benefits;
10. the units have high flexibility in terms of the subjects to be presented to the miners; the ability to add "peripheral" education, for example, health & sanitation, bookkeeping, legal issues, etc);
11. geochemical and medical teams can make use of the units to assess environmental impacts and neuro-toxicological effects of mercury;
12. it is possible to demonstrate the use of safety equipment (e.g. different types of masks for dust, Hg vapour, chemicals);
13. it is easy to incorporate shows (as in a "circus") to attract miners and public to watch skits and movies about environmental impacts and mercury pollution; this theatrical performances must be designed to be played with the mining communities highlighting local aspects and incorporating concepts of environmental and health protection;
14. the technical demonstration and classes can be conducted either at the mine sites or at populated centers (awareness campaign);
15. it is possible to set up portable classrooms to teach some basic technical concepts;
16. ease of adding space for further infrastructure or equipment by simple addition of a trailer to the primary mobile carrier (truck);
17. the units can bring ideas to improve the livelihood of different mining communities such as suggesting economic diversification activities or value-adding techniques (e.g. handcraft, fish farming, agriculture, brick making using tailings, etc);

One of the main drawbacks of this initiative is the fact that miners may have the impression that the transportable demonstration units is a solution for processing ore in many different sites, which is consistent with their nomadic nature. In fact, mobile processing plants are useful to increase gold production but, as a side effect, they disperse even more mercury pollution and environmental degradation. The training units should be assembled to accommodate different types of equipment not necessarily connected to each other. These units must work as <u>pilot plants</u> only for TRAINING purposes.

2.2. Implementation Process

The steps to implement the transportable demonstration unit (TDU) in Zimbabwe are:

1. selection of the local institution that will own and look after these units;
2. discussion of the concept and detailed plan with stakeholders;
3. decision about who will operate the TDU and its sustainability;
4. selection of trainers and elaboration of training material (and eventually awareness campaign movies, brochures, posters, etc.)
5. operating plan and schedules for training are established;
6. contract an engineering company to manufacture, install and start-up the TDU;
7. contract trainers and unit operators.

A clear letter of understanding should be established between UNIDO and the institution that will own the TDU to guarantee that the objective and mandate of the training units will not be diverted (for example to be used as a production unit). In Zimbabwe it was identified that the IMR (Institute of Mining and Research) has all technical attributes and personnel to be in charge of such TDU.

The concept and design of the TDU must be thoroughly discussed with the Zimbabwean stakeholders including Government agencies, miners and millers' representatives, equipment manufacturers, academics, NGOs, etc. Details of the design and operation of the units must be discussed and suggestions to improve the design must be incorporated.

The idea of implementing the TDU in Zimbabwe was discussed with Government representatives and other mining experts in Zimbabwe in February 2004 and it was a consensus to focus the training on miners in existing facilities (milling centers). Millers will also have benefits of the suggested improvements and they can easily acquire some pieces of equipment. This can sound paradoxical since millers extract gold from the tailings, but this can be resolved by adjusting the milling rates charged to miners.

2.3. Components of a TDU

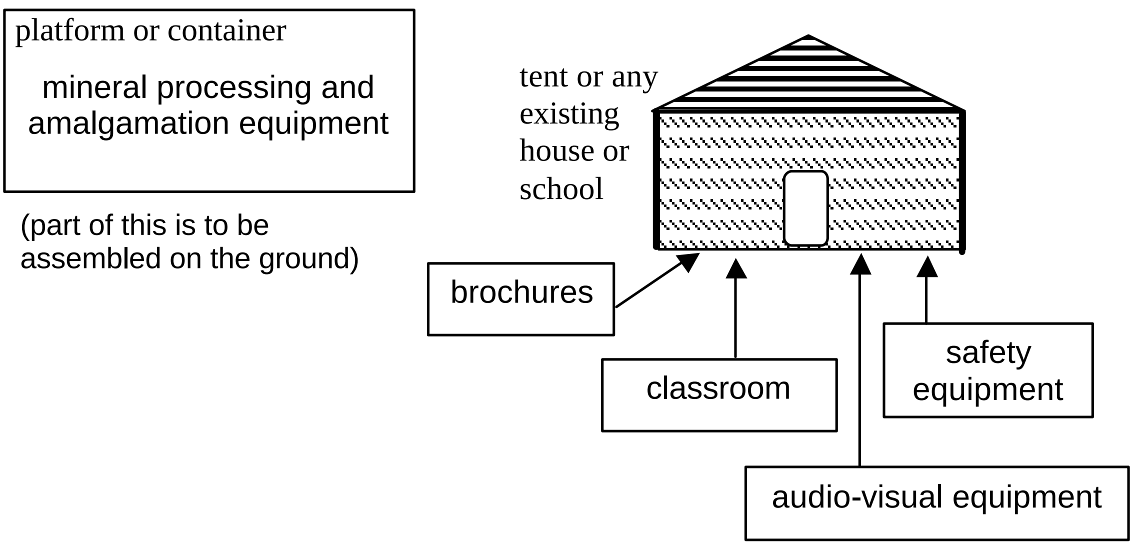
In order to design the transportable demonstration units, the main components of the units must be studied. The main components of the TDU are:

- a platform (or container) to transport and secure all pieces of equipment
- a tent or any type of structure to be used as a portable classroom
- a generator

The main pieces of equipment can be assembled on a fixed wooden platform and other machines, the heaviest ones can be settled on the ground. A heavy truck, preferably of 7 tonne capacity, can move the pieces of equipment from one site to another. The demonstration plant is mounted in one site for example for 2 or 3 months, then everything is dismounted and transported to another site where it is assembled again on the ground. The processing/amalgamation equipment would be removed from the truck and easily erected at each site, where the unit would remain before moving on. It is seems cheaper to rent a truck to move the unit from one site to another than to purchase a vehicle.

The main pieces of equipment to demonstrate gold processing and amalgamation techniques are not connected. The trainers use them to demonstrate the principles and advantages of each machine and it is up to the miners to up-scale, modify, improve or purchase the machines from a local supplier. A tent made of parachute or a local simple structure made of wood and straw or an existing classroom is used as a classroom, office, and laboratory (e.g. health assessment and Hg analysis using portable Hg analyzer or colorimetric semi-quantitative techniques).

The main components of a transportable unit is shown in the diagram below:



In a meeting with some stakeholders in Zimbabwe in February 2004, it was advised to adopt a "bottom-to-top" approach for the demonstration plants and a "top-to-bottom" approach for the instruction of trainers and training of Government representatives. In this case, the trainers and local leaders will be trained in practical and theoretical subjects related to ASM. The implementation of the demonstration units will be done in existing milling centers (paying normal operating fees to the millers) and using tailings as the initial material to be treated. As long as gold is recovered from tailings , this should bring more credibility to the trainers. Subsequently, primary ore can be used in the demonstration units comparing the performance of different types of equipment.

3. Selection of Processing/Amalgamation Equipment

The pieces of equipment to be demonstrated to the miners must follow some criteria:

1. must not be very complex (technical knowledge)
2. must be easily accessible (preferentially locally manufactured)
3. must be inexpensive and locally maintained

In order to organize the rationale behind the decisions on equipment selection, some pieces of equipment popular among ASM either in Zimbabwe or elsewhere in Africa were evaluated. The main pieces of equipment should demonstrate all steps of a simple mineral processing cycle normally used by artisanal miners. This includes:

1. Comminution/Classification
2. Gravity Concentration
3. Amalgamation
4. Retorting

3.1. Comminution/Classification

It is not trivial to suggest simple comminution equipment, as there is no universal recipe for the most expensive unit operation in mineral processing. Comminution in conventional mining operations is usually conducted in closed systems with classification (e.g. screens or hydrocyclones). This is a way to control overgrinding as well as to achieve the gold liberation size. As no information is available about the **gold liberation** grain size, the principle of testing different grinding times is the only one available to evaluate liberation. Concepts like this can be passed to the miners, who can use a small ball mill and a gravity separation equipment to test their ores. This will definitely improve their gold recovery by gravity concentration. In order to reach the liberation size, comminution equipment must work in closed circuit with classification (e.g. screening) processes. Unfortunately most of the ASM operations conduct their comminution process in open circuit, without any classification. When using sluice boxes, the only classification observed is a rudimentary screening process to eliminate coarse pieces of gravel. These concepts must be discussed with miners in order to implement more efficient techniques. The most popular mills used by ASM are discussed as follows.

3.1.1. Crusher

The main process used by artisanal and small scale miners (ASM) to crush big blocks of primary ore is a manual hammer. Pounding the blocks with a metallic hammer against a heavy metal plate or a rock monolith, miners can reduce big block to a size of below 50 mm to feed the fragments into a small laboratory jaw crusher. A small crusher handling 500 kg/h of material to reduce it to –1/4"(6.5 mm) it is enough to show the concept of mechanical crushing. This is an important part of the comminution step and must be part of the demonstration unit.

Table 3.1 – Technical Data of a Small Jaw Crusher (Clarson 6”x 3”)

Specification	**Characteristics**
Jaw Opening	6” wide x 3”gap
Max Capacity	0.5 tph
Max Feed Size	2”(50 mm)
Jaws	Ni-hard steel
Jaw Profile	Ribbed
Product Size	nominal 100% passing –9mm
Drive	V-belt drive, 275 rpm
Power	2.2 kW
Extent of Mechanization	Fully mechanized
Shipping Weight	220kg
Price	US$ 5000

3.1.2. Stamp Mills

The usual method of grinding that has been adopted by ASM in Zimbabwe is stamp milling. Zimbabwe is perhaps the only country where outdated but appropriate stamp mills are in common use. Despite of being less efficient than ball mills, stamp milling is an accepted technology in Zimbabwe as the entire process is VISIBLE and TRANSPARENT. Stamp mills have the advantages of not requiring prior crushing beyond what can be achieved manually with sledgehammers, of being relatively easily cleaned out between ore batches and of being robust and simple to operate. On the other hand "traditional" stamp mills are large devices, slow to erect (requiring cranes, etc), relatively high capital and relatively inefficient.

These mills are made by a number of Zimbabwean companies, but cost and size dictates that they are normally owned and operated as "custom" mills, where several artisanal miners will use a single mill, owned normally by an entrepreneur, the miller. The mill mortar box – generally of deep, rectangular cast iron construction - must be cleaned out between ore batches. Cleaning is easy but not quick, and usually involves manually digging out all the accumulation in the mortar box between the stamp dies. The mill owners normally also extract heavy fees from the ASMs.

Katanka stamp mill

The Small Mining Supplies developed a much smaller, single-stamp mill - the "Katanka" (so named because of the noise it makes) which is intended to provide one mill per miner, or per co-operative (Fig. 1). The mill frame is of flanged pipe construction rather than heavy, single wooden beams, and is designed to be transportable by small truck when disassembled. Assembly is possible using shears legs and a shuttering kit is provided to enable casting of foundations, or even supply of pre-cast block foundations which simply require setting and leveling.

The Katanka has a cylindrical mortar box that provides the advantage of more useful (multi-directional) splash-back of ore onto the stamp die. The mortar box is of steel-lined with a bolted front face that is easily removed for cleaning. Production rate, while lower than the big 3 or 5 stamp mills, will be more suitable, for demonstration and even for the scale of ASM operations.

The discharge screen size is altered easily by changing the mesh in the discharge splash box. Typical size is about 0.6-0.8mm aperture, at which P80 is probably about 0.3-0.4mm.

The specific benefit of the Katanka is the fact that it is small enough as a single stamp to warrant one-man-one-mill. "Normal" stamp mills have 3 or 5 stamp, and a Katanka 3 or 5 stamp mill would not offer any benefit over the mills currently available in Zimbabwe. These are very large and well beyond the means of most ASMs, and also need very much bigger foundations and frames as a result of the odd numbers of stamps, compression strokes, etc. The Katanka has pre-cast foundation blocks. At each site the ground needs minor excavation, leveling and compaction, placement of the pre-cast foundation blocks and erection of mill. Casting of cement foundations is NOT necessary.

Table 3.2 – Technical Data of the SMS Katanka Single Stamp Mill

Specification	Characteristics
Capacity	0.3 tph, dependent on ore hardness & outlet screen
Feed Size	80mm max.
Product Size	Nominal 100% passing 1.2mm, 80% passing 0.5mm
Water Use	1500 Liters/hour approx
Extent of Mechanization	Fully mechanized
Mode of Operation	Continuous
Power	7.5kW
Drive	Pulley & V belt, flat belt final drive
Stamp Weight	660kg
Shipping Weight	1540kg; with pre-cast foundation = 2500 kg
Construction	Flanged & welded mill frame, cast iron, tappet, shoe & die
Optional	Pre-cast concrete foundation blocks
Price	US$ 12000

In spite of being an interesting option for individual miners, using existing milling center facilities in Zimbabwe, a stamp mill is not quite necessary for the Demonstration Unit. The high price and low mobility of the Katanka mill are also factors to leave this piece of equipment out of the selection list, at least for a while.

3.1.3. Hammer Mill

Hammer mills are very popular among ASM in many operations in Africa, Asia and Latin America, but not specifically in Kadoma, Zimbabwe. Very few operations are using hammer mills in the project area. These mills provide fast grinding and consequently higher throughput. The main problem related to hammer mills is the high wearing rate of the structure and hammers, usually made of cast iron. In operations with hard-rock ores, rich in quartz, the hammers must be changed every 2 tonnes of material processed when the discharge grid is 1mm. The miners must have a narrow contact with local equipment supplier as well as welding facilities to change hammers constantly. In the case of milling weathering (softer) ores, hammer mills are very durable and an appropriate method for ASM. However, even working with lateritic and saprolitic ores, miners do excavate eroded layers of quartz-gold-veins which have high Bond Index.

In Venezuela, all milling centers use hammer mills, however their employees do not receive salaries, but they are paid with the gold retained in the mill liners. In the past, the hammer mill technology was demonstrated for the Zimbabwean ASM and they reacted strongly against this type of equipment, specially because a long time of cleaning is needed and gold is definitely trapped inside the machine. Despite the high output rate of these machines, it seems not adequate to recommend hammer mills for the Zimbabwe as they are not easily accepted by ASM.

Table 3.3 – Technical Data of a Clarson Hammer Mill

Specification	Characteristics
Capacity	Dependent upon ore hardness & particle size. Maximum 6 tph at 70mm feed size, 19mm product size
Feed Size	70mm max
Product Size	1 to 6mm depending on the discharge screen
Water Use (optional)	1500 Litres/hour approx
Extent of Mechanization	Fully mechanized
Mode of Operation	Continuous
Power	10kW
Speed	900 – 1270 rpm
Drive	Pulley & V belt,
Price	US$ 12000.00

3.1.4. Impact Mill

An impact mill usually uses rock-to-rock impacts to crush the ore. The most successful mill using this principle is the Barmac, manufactured by Metso. The transference of energy from the spinning rotor to the particles is very efficient, resulting in high reduction and the production of large quantities of fine particles. The percentage of fines required can be altered by changing the rotor tip speed, chamber configuration, rotor size, cascade ratio and feed gradation The residence time of particles in the crushing chamber range from between 5 to 20 seconds. During this time each particle is subjected to hundreds of particle interactions from both coarse and fine particles resulting in cleavage, impact, abrasion and attrition of the particles. The crushing action of the Barmac allows it to liberate minerals, or preferentially crush deleterious material, without over crushing the valuable minerals. Barmac mills require high power and they are usually expensive units, rarely recommended to artisanal miners. However, other impact mills using similar concept were developed. One example is the Clarson Impact mill. The rapid comminution is obtained at the expense of high abrasion of the mill walls. Although it probably has a small degree of material-on-material action, it is very much a hammer mill and wears quickly. In high energy milling process, it is typical to observe consumption of about 1.5 kilograms of steel per tonne of quartz-rich ore milled. The use and promotion of impact mills face the same problems as hammer mills. For soft ores this can be a nice solution, but for hard ore this incurs in high cost of maintenance. For the specific project site, it seems not appropriate to demonstrate such a equipment to miners.

Table 3.4 – Technical Data of a Clarson Vertical Impact Mill

Specification	Characteristics
Capacity	Dependent upon ore hardness & particle size. Maximum 2 tph at 20mm feed size, 1.5mm product size
Feed Size	20mm max
Product Size	P80 1.5mm
Extent of Mechanization	Fully mechanized
Mode of Operation	Continuous
Power	5.5kW
Speed	3000 rpm (max)
Drive	Pulley & V belt,
Price	US$ 6000.00

3.1.5. Ball Mill

Tumbling mills, such as ball or rod mills, are the most efficient grinding equipment but they are expensive and demand skill to work correctly. An efficient grinding needs control of critical speed, number of balls, ball sizes, pulp density, power draw, foundation, etc. They also need material previously crushed and the fact that emptying and cleaning out the mill between ore batches is slow and difficult. Ball mills are being used in a few custom-milling centers in Kadoma. Many customers (miners) do not like to use ball mils as they claim that gold becomes retained inside the liner. In fact, the millers clean out once per month the ball mills and the gold from the clean-up are split pro-rata between the ASMs according to the their individual ore tonnages and recoveries for the month. This is not a trivial job. There are at least 2 manufacturers of small (3'x6' and 4'x8') production ball mills used in the Zimbabwean milling centers (see table below from ABJ manufacturer). The size of these ball mills is still large for a demonstration unit (as well as the cost) and it seems not adequate for the demonstration purpose of the transportable units. A smaller device should be manufactured to demonstrate the principle of tumbling mills and to introduce the concept of gold liberation size. This can be easily appreciated by ASM applying different grinding times and screening the ground products. This is more discussed ahead in this document.

Table 3.5 – Technical Data of an ABJ Ball Mill

Specification	**Characteristics**
Size	∅3 ft (90cm) x 6ft (1.8) long
Critical Speed	Nc = 76.63 $D^{-0.5}$ (in ft) = 44.2 rpm
Feed Rate	1 to 1.7 tonnes/h
Feed Size	20mm max
Product Size	P80 1.5mm
Ball Charge	1333 kg
Ball Charge Volume	40% of the mill volume
Ball Size for First Charge	75% of 76mm and 25% of 50mm
∅ Of Ball Renewals	76mm
Liner Weight full Set	2702Kg
Liner Material	Ni Hard
Liner Type	Wave
Mill Weight	6000 Kg for 3/6ft and 4500 for (3x4ft)
Water Required	1260 Litres per tonne of ore milled
Extent of Mechanization	Fully mechanized
Mode of Operation	Continuous
Power Installed	22.5kW
Power Consumed	16 kW
Discharge	Trommel screen fitted with discharge box
Drive	Girth and pinion gear drive and SPB V-belt drive
Price	US$ 34000.00

In order to demonstrate the principles and advantages of a ball mill, a simple steel drum with lateral discharge can be used instead of a continuous production ball mill. In Indonesia, artisanal miners produce gold working with a set of 12 to 48 small batch ball mills (∅48 x 60 cm) to grind primary gold ore. Each mill grinds 40 to 50 kg of material per batch. The grinding time in Indonesia is too long (3 hours) as miners use excess water and wrong milling media (gravels and rods). Similar mills are used in Tanzania but miners do not use water as they need to transfer the ground product in bags to another group of workers who charges for the concentration step. This is a matter of organization of the work and it can be changed.

Despite the low production rate of these portable mills, the concept of having many small-batch-ball mills instead of large ones seems interesting. Miners and millers can follow a step-by-step approach acquiring one mill after another and then increasing their milling capacity. This is not the best solution in terms of energy consumption, but definitely is adequate for the financial capacity of the miners, employs more people and it is a fully accepted concept in many ASM regions. The specifications of a similar ball mill with this capacity are given below.

Table 3.6 – Technical Data of a Small Batch Ball Mill

Specification	**Characteristics**
Size	∅0.48 (1.6 ft) x 0.6 m (2ft) long (internal)
Lining	25mm thick steel shell and ends, unlined
Critical Speed	Nc = 42.3 $D^{-0.5}$ (in m) = 61 rpm
Operating Speed	70 - 75% of critical speed; 45 rpm
Feed Capacity	40-50 kg/batch
Feed Size	12mm max
Water required	for 70% solids at 40kg load = 17 – 18 L for 70% solids at 50 kg load = 21 – 22 L
Product Size	Time dependent; typically P80 = 100 mesh (0.150 mm)
Ball Charge Volume	40% of the mill volume
Ball Charge	350kg
∅ max of ball	44mm (see below)
Ball Size for First Charge	50% of 40mm and 50% of 25mm
Type of Ball	Cast or forged steel (0.9 C, 0.85 Mn, 0.2 Si, 0.5 Cr, 0.1 Mo)
Ball Hardness	63-65 Rockwell
Shipping Weight	280kg
Extent of Mechanization	Partially mechanized; batch manual discharge
Mode of Operation	Batch
Discharge	Lateral door
Drive	Torque arm gearbox and Vee Belt
Installed Power	2.2 kW
Price	US$ 8340

Note: Calculation of the largest ball (B) diameter (in mm)

$$B = \sqrt{\frac{F}{K}} \cdot \sqrt[3]{\frac{Sg \cdot Wi}{100\ Cs \cdot \sqrt{3.281\ D}}} \cdot 25.4$$ ....B= 44 mm

K = constant for closed wet grinding systems = 350
F = feed P80 in µm = 2 mm = 2000 µm
Sg = specific gravity of the mineral = 2.7
Wi = Work Index = 10
Cs = fraction of the critical speed = 0.70
D = mill internal diameter (in meter) = 0.48

3.1.6. Size Classification

Size classification is extensively used associated with grinding circuits to prevent the entry of undersize particles into the grinding machines, to prevent oversize material from passing to the concentration stage and to prepare a closely sized feed that improve the gravity concentration process[2]. Screening is the simplest and cheapest process for industrial sizing but is generally limited to material coarser than 100 mesh (0.15 mm). Spiral classifiers and hydrocyclones are widely used to classify fine particles. As gold liberation is the main factor to obtain high gold recoveries, size particle classification provides control on the gold liberation of the ground product. Unfortunately, very few artisanal miners appreciate this simple control principle and operate their grinding systems in open-circuit, i.e. no classification is used. Rudimentary wood or metal-framed screens can be locally manufactured for wet screens but the screens are not easily available. These can be made of brass or stainless steel or eventually, improvised with nylon screens. A spiral classifier is fed with the grinding product and the pulp is diluted to 50% solids. It uses a continuously revolving spiral to move sands up the slope, while fine flow down with water. The overflow becomes coarser with increasing dilution and pulp density control is the main problem of the spiral classifiers. Mechanical classifiers like this could be demonstrated to miners but it is an expensive piece of equipment and some skills are needed to operate it. A rudimentary but yet useful mechanical classifier has been

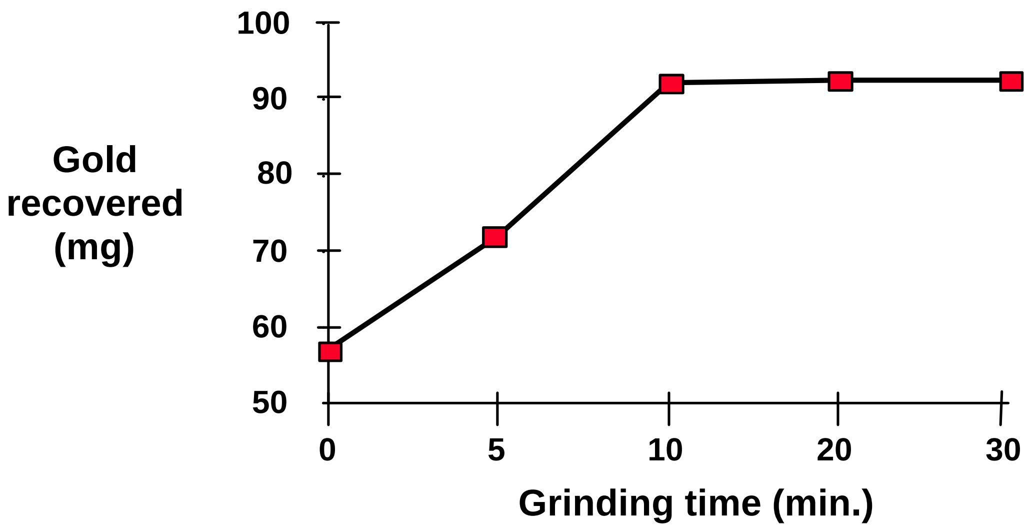
[2] Wills, B.A., 1988. Mineral Processing Technology. Oxford, UK, Pergamon Press, 785 p.

used by some millers in Kadoma. The pulp from concentrators or amalgamating-copper plates is added to a small cemented tank and the coarse material is scooped out to the top of an inclined wall by a belt with pieces of rubber paddles. This is similar to a bucket classifier, but buckets bring the advantage of dragging more material than paddles. Hydrocyclones are very efficient for desliming and not very complicated to be manufactured. However, the principle of hydrocycloning is complex and a proper design requires skills. An elutriator can also be used as a hydraulic size classifier. Controlling the water speed, the rising flow carries fine particles. Other designs with different diameters and conic shapes can be easily manufactured using garden and kitchen materials.

For the demonstration unit it is suggested to manufacture a 3-deck-portable screening set in which sieves can be replaced at any moment. The deck should be 0.6m long, 0.4m wide and 0.2m high. This will provide more control to the ball-milling process. The first screen is a robust grizzly, with large opening (12 mm) to support the weight of the balls being removed from the mill. The balls are washed on this screen. The second screen has opening of 1 or 2 mm to protect the finest screen in the third deck. In the third deck, screens with 0.5mm and 0.2mm (or finer) can be used. The undersize material is collected in a 200 or 300L plastic container where the pulp (20-30% solids) is pumped by a treadle pump to the concentrators.

3.1.7. Checking Gold Liberation

The classical procedure of using microscopy to check liberation size of the mineral of interest does not work properly for gold, as its concentration is usually very low. There are a series of techniques to evaluate gold liberation using screened factions. During the training, miners and trainers can run a sequence of tests with tailings or ore to determine the gold size liberation. A homogenized pile of tailings or crushed material (about 1000 kg) is formed and thoroughly mixed. About 100 kg of material is ground at a specific time. As the ball mill has maximum capacity of 50 kg, the material has to be ground twice. After grinding each 50 kg, the interior of the mill is washed and the material is discharged on the screening deck. The undersize fraction (pulp of 20-30% solids) of the ground material is pumped, concentrated using one of the gravity concentration equipment and the concentrate is subsequently amalgamated-retorted. Increasing the grinding times, for example 0 (no grinding), 5, 10, 20 and 30 minutes, it is possible to observe that more gold has been recovered, if the original pile is well homogenized. The amount of gold obtained when grinding and processing each 100 kg of material is registered. The oversize fractions retained in screen 2 and 3 are dried and weighed. A curve of the amount of gold recovered by gravity concentration and amalgamation versus grinding time or grain size (e.g. P80 in screens 2 or 3) provides a clear visualization of gold liberation. An example of this procedure can be seen below, when a tailing was used to check gold liberation. In this case, it is clear that the recommended (re)grinding time of this tailing is 10 minutes; consequently the liberation grinding size is also obtained.



3.2. Gravity Concentration

Often gravity separation methods are confused with size classification as coarse particles of light minerals can behave like a small particle of a heavy mineral. The most effective gravity separation processes occur when applied to narrow grain size. The most important factor for a successful gravity separation is liberation of the gold from the gangue minerals. It is not trivial to establish the degree of liberation of low-grade minerals such as gold. The classical microscopy procedure of screened fractions to establish mineral liberation rarely applies to gold ores, as no reliable results are obtained. In this case the most recommended method to establish the gold liberation size is grinding at different times (or grain size distributions) and applying gravity concentration to the ground products. This is a classical and important procedure to recommend any type of gravity concentration process. As most artisanal miners do not classify the crushed/ground material, i.e. work in open circuit, the chances to improve gold recovery are very limited but yet possible.

The main advantages of gravity concentrators over hydrometallurgical methods are:

- relatively simple pieces of equipment (low capital and operating costs)
- little or no reagent required
- can be applied from relatively coarse particles to fine size materials

Some of the most popular gravity concentration pieces of equipment used by ASM in Africa are discussed as follows.

3.2.1. Sluices

Sluice boxes are the most popular gravity separation process used by artisanal gold miners worldwide as they can be locally manufactured, they do not require power, and provide high enrichment ratio. They are of simple construction and easy operation. The principle of operation of a sluice box is simple: heavy particles in a water stream settle and become trapped by riffles or mates. A very comprehensive report on sluice boxes is provided by British Geological Survey (BGS, 2002)[3]. For an efficient separation, BGS (2002) lists the main parameters and recommends the following:

- ore slurry: steady and pre-screened slurries (screen <25 mm, ideally 5mm))
- pulp density: <15% solids (weight/volume), e.g. 15g of solids in 100mL of water; pulp density depends on grain size; for fine fractions or clayey ore, 3 to 5% solids is used
- flow velocity: depends on box width and slope: if speed is too slow, the sluice box becomes blocked; if it is too fast, gold is washed away; recommended flow speed is 1 to 2 m/sec
- stream depth: 20 to 30 mm
- sluice slope: 10 to 15 degrees
- sluice length: 2 to 5 m
- width: depends on desired flow speed; usually it is between 0.5 and 2 m
- water need: 30 to 70 m^3/h/m of width; then a 1m wide sluice box working with a 5% w/v pulp can process from 1.5 t/h to 3.5 to/h of material.

Miners believe that the long sluice boxes improve gold recovery. However it is observed in long sluices that most gold is recovered on the first 2 or 3 meters where the flow speed is slower than at the sluice end. This is the main reason why Brazilian "garimpeiros" (ASM) devised the 2 or 3-deck sluice boxes. Each deck is approximately 2.8 to 3 m long, 1.5 to 2 m wide and placed in zigzag. The top box discharges the pulp on the second box. This breaks the flow direction and reduces the water speed, promoting additional gold recovery at the beginning of the second (and third) deck. It is also possible to have different lining materials in each deck. These 2-deck sluices are common in Brazil, Suriname and Guyana. They operate with hydraulic monitors of 4, 6 or 10 inches and the 5% solid

[3] BGS – British Geological Survey, 2002. Good Practice in the Design and Use of Large Sluice Boxes. Booklet prepared by Styles, Simpson and Steadman. Report CR/02/029N. 39 p.

ore pulp is pumped to the sluice boxes at a rate of 4 to 5 m^3 ore/h (6-inch pump) to 7 to 9 m^3/h (10-inch pump). This means that up to 24 tonnes/h of material can be processed.

The width of a sluice box is a much more critical parameter than the length. Narrow-width sluice boxes promote high-speed flows and this consequently affects gold recovery. Pinched sluice boxes (variable width) is used for pre-concentration. The height of the sluice box usually respects the riffle height: sluice width ratio of 0.3. This means that, for a sluice box 1.2 m wide, the sluice height must be around 0.36m. In Zimbabwe is common to see panners using “ground sluices” which are made excavating the ground, setting a bed with rocks and lining it with sisal.

The choice of the adequate trapping mechanism is key for an efficient gold concentration. Sluices using riffles (1 to 3 cm high) are usually appropriate for coarse gold (> 0.4 mm). As the riffles create turbulence, this reduces the chances of trapping fine gold. For fine gold particles, the shape of gold particle and quality of the matting material has great influence on the gold recovery. Priester and Hentchel (1992)[4] list the lining materials used by ASM in different parts of the world:

- rubber matting
- sisal mats
- fine and coarse fabric e.g. corduroy, cord velvet
- carpets
- meshed hemp or grass cords
- metal grid
- split bamboo

Gold recovery can be increased by frequent clean-ups of the sluice box. In this case rubber liners are more practical to clean and so not need rifles to fix them to the box bottom. MINTEK (South Africa) devised interesting sluice boxes (strake) with rubber-mat glued to it. Black ribbed vinyl mats are also useful to recover gold and easy to clean but it costs in USA, about US$15/$m^2$.

In terms of mats, it is interested to demonstrate to miners different types of sisal clothes and carpets. The most adequate carpet used in ASM operations is the 3M Nomad Dirt Scraper Matting in particular the type 8100 which consist of a coiled vinyl structure. This is usually recommended for relatively coarse gold. The price of this carpet in ASM sites can reach up to US$ 40/m^2. The Brazilian company Sommer (subsidiary of the German company Tarkett Sommer) sells 2 types of carpets widely used by Brazilian ASM: “Multiouro tariscado” (which is good for gold speck of rice-medium size) and “Multiouro liso” (which is good for 100 mesh-fine gold). These carpets can cost around US$ 10 to 15/m^2 which is cheaper than the 3 M carpets. However these carpets are not easily accessible to ASM in Africa. Sisal clothes can cost as low as US$ 3/m^2, are available in most African countries, and, depending of the type, they can be used for coarse, medium and fine gold recovery. It is a matter of trying different types. Raffia mats seem to be used in the past in Zimbabwe for fine gold concentration. This definitely must be further investigated and tests can be done together with the miners to establish the ideal type of sisal cloth.

The American company **Keene Engineering** offers a large variety of riffled sluice boxes made of aluminum with rubber ribbed matting and vinyl carpets. The A52 Keene 10”x 51” (25 x 129 cm) seems an interesting alternative to be demonstrated to ASM. The cost in USA of this sluice is around US$100. The company also provides pumps (3 to 8 inches) and a large variety of accessories. This small portable sluice (weighing 5kg) had capacity of processing up to 5 tonnes/h of ore. Keene sluices were very popular in Zimbabwe some years ago but the company representative left the country. A copy of the Keene sluice was widely promoted in Zimbabwe as the Bambazonke. Local supplying (and eventually manufacturing) of these sluices must bring a lot of benefits for miners and, in particular, for the river panners.

[4] Priester, M & Hentshcel, T., 1992. Small-scale Gold Mining. Published by GATE/GTZ. Vieweg, Germany. 96p.

It is suggested to manufacture some aluminum sluice boxes or simply use the Keene's boxes without riffles but with different types of mats. The demonstration unit should be able to show the advantages of different types of lining (sisal cloth, carpets, rubber, etc.) to miners and especially to panners.

Another interesting sluice box is the one manufactured by **Cleangold,** a company based in Lincoln City, Oregon. The Cleangold sluice uses polymeric magnetic sheets, with the magnetic poles aliened normal to the direction of the flow, inserted into a simple aluminum sluice box. Magnetite, a mineral usually found in gold-ore deposits, forms a corduroy-like bed on the sluice floor, which appears effective at recovering fine gold. This sluice box can be available in any size and a 2ft x 6in (60 x 15 cm) sluice costs US$ 75 in USA. The main advantage of this sluice is the high concentration ratio. Gold becomes trapped in a magnetite layer and the sluice can be scrapped and washed into a pan. Using a magnet, the magnetite is removed and a high grade of gold concentrate is obtained. In many cases the use of mercury to amalgamate the concentrate is not necessary. However, as the magnetic separation of the concentrate can carry some gold, amalgamation or even leaching of the concentrates is recommended. In one test comparing the Cleangold sluice with a Knelson concentrator, the sluice obtained slightly better gold recoveries than the centrifuge. In a recent field test in Venezuela conducted by UNIDO, tailings from hammer mills and Cu-amalgamating plates were re-passed in a 2ft long Cleangold sluice box without re-grinding. About 11% of gold was recovered and the concentrate analyzed 2850 ppm Au. The company representative mentioned that they can manufacture a 60 x 50 cm Cleangold sluice box and it would cost around US$ 165 (in USA).

Cleangold Sluice box (60 x 15 cm)

It is suggested for the TDU a static set of 2 Cleangold 60x50 cm sluices (making a 1.2 m long sluice) with a steel structure to allow slope adjustment. This structure can easily be locally manufactured.

3.2.2. Gemini Table

This Australian type of shaking table was basically devised to treat high grade concentrates to produce a product to be melted. It has been used by large mining companies to treat centrifuge concentrates. The table deck is made of fiberglass supported by a steel frame. It has a longitudinal adjustable tilt and just one-direction shaking movement with variable speed. The impact of this equipment in the demonstration unit is the possibility of observing a yellow gold layer on the table. The final concentrate is extremely rich and does not require the use of mercury. The main problem of using Gemini table is the fact that the middling product, which sometimes consists of unliberated gold particles, is not easily visually identified. In this case, the middling must be re-circulated to the table, preferentially after re-grinding. In Venezuela, some Processing (Amalgamation) Centers have adopted the Gemini table obtaining a clear gold concentrate that is melted. However the Venezuelan Centers use to amalgamate the middlings. This was not very effective in eliminating amalgamation but it has reduced the amount of mercury introduced in the process.

Table 3.7 – Technical Data of a Gemini 60 Table

Specification	**Characteristics**
Feed Rate – Nominal	60 lb/h (27 kg/h)
Feed Rate – Maximum	100 lb/h (45 kg/h)
Feed Size – Recommended	Minus 20mesh (0.833mm)
Feed Size – Maximum	Minus 14mesh (1.17mm)
Water Usage – Maximum	3 US GPM (0.7 m^3/h)
Extent of Mechanization	Fully mechanized
Mode of Operation	Continuous
Power	0.75kW
Shipping Weight	300 lb (136 kg)
Dimension	0.83m wide, 1.3m long and 0.8m high
Feed Height	1.1 m
Drive	Pulley & V belt,
Price	US$ 6000.00

3.2.3. Centrifugal Concentrators

Centrifuges operate applying a centrifugal force on the ore particles, in such a way that this force is 60 (in the case of Knelson) to 300 (in the case of Falcon) times higher than the gravitational force. The two main manufacturers of centrifugal concentrators are: Knelson and Falcon, both from British Columbia, Canada. Both concentrators have a ribbed rotating cone into which the pulp of 20 to 40% solids is fed and the concentrate is accumulated in the riffles. The compaction of the concentrate layer is avoided by injection of water in counter flow. This water fluidizes the concentrate bed and allows fine gold particles penetrating into the concentrate layer. The main problems for introducing these centrifuges in ASM operations are:

- high cost
- lack of skilled operators
- lack of clean water and controlled pressure for counter flow

Many copies of the classical Canadian centrifuge Knelson are available in ASM sites. In Brazil there are at least 4 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. In the ASM operations in Poconé, Brazil, these cheap centrifuges work for 8 hours with nominal capacity of 24 tonnes/h resulting a concentration ratio of 1000 to 1 or higher. It is common to observe concentrates with more than 1000 g/t of Au. The volume of concentrates is fixed, limited by the volume of the riffles; then the weight of concentrate is almost constant.

The "ABJ Bowl", which in effect is a copy of a Knudsen Concentrator out of California, has been extensively used in Kadoma, Zimbabwe. The conic centrifuge does not have counter-flow water. The centrifuge has 3 transversal pieces of steel that promotes turbulence on the flow, facilitating the mineral exchanging process. When the concentrate bed is scratched, this improves particle exchange and consequently opens sites on the bed for gold concentration. Adapting a rake on the center of the ABJ centrifuges, can improve gold concentration. About 30 to 33kg of gravity concentrate is obtained. One of the main problems observed in Zimbabwe ASM operations is the use of mercury in the ABJ concentrators. Mercury flours in the process, and it is lost to the tailings. Very little has been done to change this bad practice.

Table 3.8 - Technical Specification for ABJ Centrifuge Concentrator

Specification	**Characteristics**
Size	∅0.78 m
Operation	Unfluidized centrifuge, ribbed cone
Cone Material	Moulded butyl rubber
Operating Speed	102 rpm
Feed Capacity	Up to 3 tph in slurry at 30% solids
Feed Size	-4mm max
Shipping Weight	130kg
Extent of Mechanization	Partially mechanized; batch discharge of concentrates
Mode of Operation	Batch
Discharge	from bottom
Drive	Bevel gear and Vee Belt
Installed Power	0.7 kW
Price	US$ 2760

3.3. Amalgamation

Zimbabwe is relatively high on technical process expertise, even at ASM level, and appreciation of correct use of mercury is possibly better than a lot of other countries, but mercury is nevertheless a problem as it tends to be overused. In some cases mill owners are persuaded by their customers (miners) to do incorrect things. For example, very often in milling centers, miners add mercury into the ABJ centrifuges or use Cu-amalgamating plates at the discharge of the stamp mills. Amalgamation of the whole ore is usually the main cause of high mercury losses and the Hg_{lost}:$Au_{production}$ ratio can be higher than 3. Manual amalgamation of concentrates using pans is environmentally better than the amalgamation of the whole ore. Amalgamation barrel is adequate equipment to amalgamate gravity concentrates but the use of many iron balls and long amalgamation time, as seen in Zimbabwe, promotes mercury flouring and consequent loss. As such some re-education of millers and miners is required.

Ideally the best situation is where mercury is avoided all together by alternative processes such as MINTEK – iGoli or CETEM- Saltem processes where gravity concentrates are leached with chlorine solutions. However these options are not as simple and inexpensive as amalgamation. The best practice would be the establishment of a processing center, like in Venezuela, where gravity concentrates are amalgamated by skilled operators. Concentrates could also be leached in these centers using chlorine, or even cyanide. This seems a natural evolution of the artisanal mining processing system when the miners and millers become more educated and organized. Meanwhile the training efforts must be concentrated on reducing mercury losses and occupational exposure. In this case, the elimination of whole ore amalgamation (e.g. stamp mill discharges over copper plate) is imperative. Any process to be introduced must also bring a financial gain to the miners and mill owners otherwise they will not accept the technical innovations.

Assuming that amalgamation is still the most accepted gold extraction process in the ASM regions, the initial approach should be the reduction of the mercury emissions. Some pieces of equipment capable to improve the amalgamation step are described as follows.

3.3.1. Amalgamation Barrels

Barrel is the most efficient amalgamation process. They are used to amalgamate gravity concentrates. Recovery of gold from heavy mineral concentrates can be higher than 90%. Amalgamation barrels with capacity to amalgamate up to 30 kg of concentrate per batch are adequate to the demonstration units. It is very important to avoid the impression that these barrels can be used for grinding primary ores. This incorrect practice has been responsible for large mercury losses in Indonesia, where miners add iron rods and balls into the barrels to grind 40 to 50 kg of primary ore for 4 hours with 1 kg of mercury. This has been resulting in $Hg_{lost}:Au_{production}$ ratio of 100. It has been demonstrated how grinding reduces the ability of gold to be amalgamated. In these cases, mercury loses coalescence, i.e. breaks down in droplets ("flouring effect") and mercury is lost. The action in amalgamation should be attrition of mercury with gold rather than impact. In Zimbabwe is common to see miners grinding gravity concentrates in amalgamation barrels and sometimes using a tablet of 250 g of sodium cyanide.

The suggested elliptical amalgamation barrel has a "pelletizing" disk format and promotes high contact of mercury with gold particles.

Table 3.9 – Technical Data of a SMS Elliptical Amalgamation Barrel

Specification	**Characteristics**
Size	∅0.66m x 0.30m wide
Lining	8mm thick steel shell, rubberized
Max Speed	30 rpm
Max Feed capacity	35 kg concentrate/batch
Ball Material	Rubber
Ball Size	100 mm
Number of Balls	5 to 8
Amalgam Trap	Adjustable discharge tray with mercury trap and adjustable copper plate
Extent of Mechanization	Partially mechanized, batch manual discharge
Mode of Operation	Batch
Discharge Type	150mm oval lateral door
Installed Power	2.2kW
Drive	Vee Belt
Shipping Weight	180kg with frame and access ladderway
Price	US$ 4000

Amalgamation barrels can also be made of plastic PVC but in some African countries this can be more difficult to find and costly than steel. This is definitely very beneficial as no iron balls can be introduced in the barrels and the mercury flouring is avoided.

The recommended barrel volume is about 2 Litres/kg of concentrate. In order to amalgamate 30 kg of concentrate, a 60 L drum is needed (approximately ∅0.35 x 0.6 m). The pulp of concentrate with 50 to 60% solids should not exceed half the barrel volume.

The amount of mercury used for amalgamation is usually a function of the gold grade in the gravity concentrate. As this information is usually not available a common addition of 10 to 20g Hg per kg of concentrate (1:100 to 1:50 Hg:concentrate ratio) is sufficient to promote good amalgamation. Amalgamation time above 40 min usually promotes mercury flouring.

The main inconvenient of amalgamation barrels is the relatively high concentration of Hg in the tailings. Amalgamation tailings from barrels, as observed in Poconé, Brazil, have from 80 to 200 mg/kg of Hg[5]. It is also common to find amalgamation tailings with 500mg/kg (ppm) of Hg. This is a result of mercury flouring, i.e. loss of mercury coalescence. A restrict control to avoid mercury flouring is needed when operating barrels. This is done adjusting amalgamation time, adding reagents and reducing stress on the concentrate pulp.

[5] Farid, L.H.; Machado, J.E.B.; Silva, O.A. (1991). Emission Control and Mercury Recovery from Garimpo Tailing. In: *Poconé: Um Campo de Estudos do Impacto Ambiental do Garimpo*, Ed. M.M.Veiga and F.R.C. Fernandes, CETEM/CNPq, Rio de Janeiro, Brazil, p. 27-44. - in Portuguese

Use of chemicals such as potassium permanganate or even sodium cyanide (as seen in Zimbabwe) to reduce mercury surface tension and clean gold particles surface may improve the amalgamation process, but the benefits for gold extraction do not take into consideration the occupational risks and the environmental effects. One gram of NaOH per kg of heavy mineral concentrate to be amalgamate is an efficient method to improve amalgamation without solubilizing mercury.

3.3.2. Amalgamation Plates

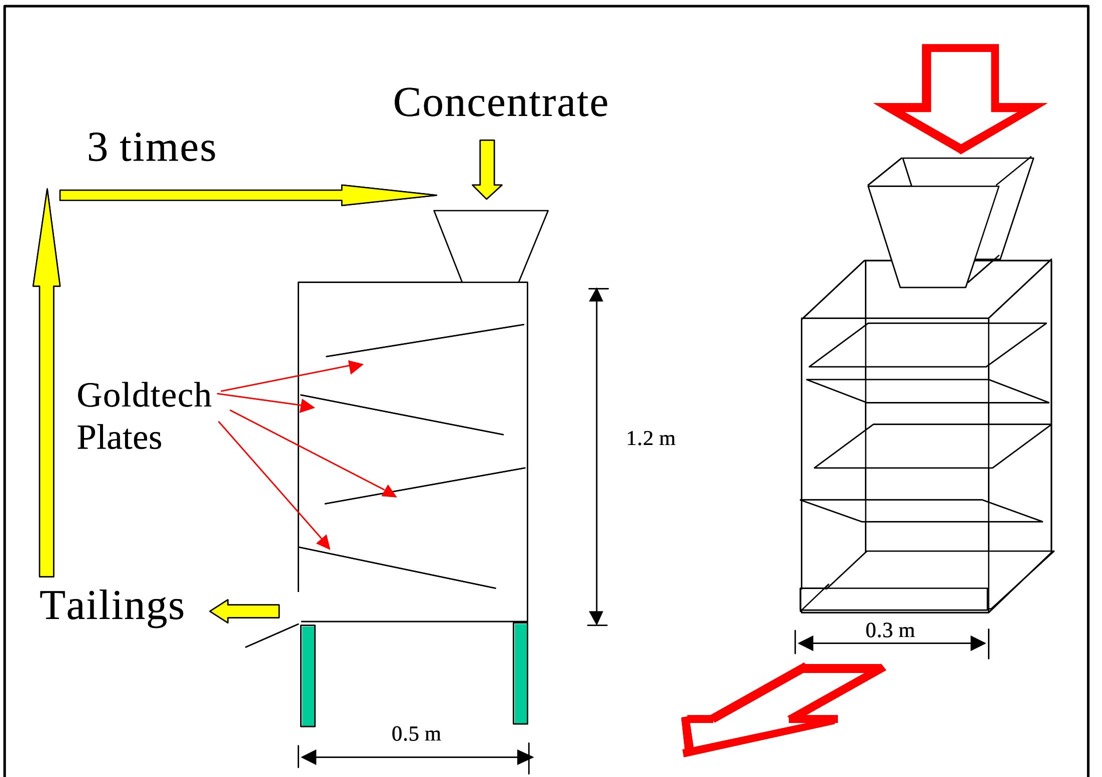
Amalgamation Plates are stationary metallic sheets usually dressed with a thin layer of mercury (usually 150g Hg/m² of plate) use to amalgamate free gold particles in ores ground coarser than 1.5 mm. Working with 10% of slope these plates receive pulp of auriferous ore (10 to 20 % of solids) and the amalgamation takes place when gold particles contact the plate surface. The velocity of flow has to be sufficiently low that the precious metal particles can sink to the plate surface and yet high enough that other mineral constituents of the concentrate do not remain on the plate. The most common plates used in ASM operations in Zimbabwe and elsewhere are made of copper. The efficiency of the process depends on the operator ability, but usually is low due to the short time of ore-mercury contact. The method works better for alluvial gold but it is very limited for primary ore in which quite often gold is not completely liberated from the gangue minerals. About 0.3 m^2 of plate is required to treat 1 tonne of ore/24 h for pulps with 20% solids. Amalgam is removed (scraping) periodically interrupting the process. Abrasion of the mercury surface releases droplets that go out with the pulp. Acidic water may also cause brown or green spots on the copper plate and mercury is also lost. A large majority of artisanal miners do not use a mercury trap at the end of the plates. In Venezuela, tailings from amalgamation Cu-plates typically contain 60 to 80 ppm Hg.

A new technology was developed in Brazil and commercialized by two manufacturers: Goldtech and Rio-Sul. A thin coating of Hg and Ag is electrolytically deposited onto a metallic plate (brass, galvanized steel, copper, etc.). About 80 g Hg/m² of plate is added to the plates to amalgamate gravity concentrates. Gold is captured and firmly fixed to the plate surface. Hg losses are minimized. When the plates are fully loaded, amalgam is removed by washing with a plastic scraper. This kind of plates has been successfully tested in Brazil to remove Hg from contaminated tailing. In recent test in Venezuela, tailings from ordinary Cu-plates containing in average 62.2 ppm were submitted to a cascade system with four special-plates. More than 95% of Hg was removed from tailings. Those plates are <u>not</u> indicated to capture gold from the whole ore but only to amalgamate gravity concentrates or to clean contaminated tailings. A wood structure was built to hold 4 Goldtech 40 x 30 cm plates placed in zigzag, as seen in the diagram below. About 10 g of mercury per plate is added. About 10 kg concentrate from carpet sluice boxes was passed 3 times in less than 10 minutes. Then, the plates are removed from the wood structure and the amalgam was scrapped off.

The main advantages of using the special-plates to amalgamate gravity concentrates are:

1. amalgamation process is faster
2. no heavy mineral-amalgam separation
3. minimum Hg loss in the amalgamation tailings

The process of manufacturing these special plates in Zimbabwe should be investigated as the price CIF per plate in Brazil is still expensive: US$ 200 (Goldtech plate 40 x 30 cm) and US$ 600 (Rio-Sul plate 60 x 40 cm). In any case, this is the best system to promote clean and fast amalgamation of gravity concentrates.



Special Amalgamation Plates in Zigzag

Table 3.10 – Technical Data of a Box with Special Amalgamation Plates in Zigzag

Specification	Characteristics
Box Size	1.2 x 0.5 x 0.3 m (internal)
Box Material	Naval Plywood (2cm thick) or C-Steel
Type of Plate	Goldtech 40 x 30 cm (or Rio-Sul 60 x 40 cm)
Number of Plates	4
Arrangement of Plates	Zigzag and cascade
Plate Slope	10°
Max Feed Capacity	100 kg concentrate
Pulp Density	<10%
Extent of Mechanization	Manual
Mode of Operation	Batch
Discharge	Frontal
Price	US$ 1500

3.3.3. Comparing Barrels with Special-Amalgamating Plates

The advantages and disadvantages of using barrels or special amalgamating plates to extract gold from gravity concentrates are shown in the Table below. The main problem is to restrict the use of these special plates to amalgamate just concentrates. As ordinary copper-amalgamating plates are widely used to amalgamate the whole ore, miners can have the impression that these special plates can be used in the same way. This is a mistake as the intense attrition of tonnes of ore pulp on top of the special plates will degenerate the superficial silver amalgam and release mercury to the tailings. Miners can also misuse the amalgamation barrels as ball mills, adding iron balls while amalgamating concentrates or, even worse, the whole ore. This, as seen above, causes huge mercury losses.

Table 3.11 – Comparing Special Amalgamating Plates with Barrels to Amalgamate 100 kg of Gravity Concentrate

	Zigzag Box with 4-Special Amalgamating Plates (40x30cm)	**Amalgamation Barrel + Elutriator (or Spiral-pan)**
Amount of Hg needed (g)	40	1600
Typical Hg conc. in tailings (mg/kg)	<1	200 – 500
Amalgamation time required (min)	10	40
Time to obtain amalgam (min)	20 (scrapping the plate)	20 (using spiral pan)
Need to squeeze amalgam to remove excess Hg	yes	yes
Relative amount of excess Hg	low	high
Dangerous misuse	use the plates to amalgamate the whole ore	use the barrels to grind ore together with Hg
Main problem	occupational exposure of operators to Hg vapor	mercury flouring
Skill needed	low	medium/high
Price (US$)	1500	4500 (including spiral pan)

3.3.4. Separation of Heavy-minerals from Amalgam

When amalgamation of gravity concentrate is conducted in a barrel, the heavy minerals must be separated from the amalgam (+ excess Hg). When amalgam-heavy mineral separation is made by panning at the creeks margins, mineral portion with residual mercury overflows to the watercourses creating "hotspots" which are highly contaminated sites. Mercury from these sites can react with organic matter and be methylated by a biotic process. The tailing generated in the amalgam-heavy mineral separation may contain as much as 500 mg/kg (ppm) Hg. Infrequently amalgamation tailings are properly stored in plastic lined pools or waterboxes. Miners usually store it in open pools near watercourses or reprocess it in the same primary circuit. In Zimbabwe the amalgamation tailings (contaminated with Hg) are mixed with primary tailings to be submitted to cyanidation. This leaching process is very effective and relatively rapid to dissolve gold, but a much slower to dissolve mercury. This leaves soluble mercury species in the final tailing.

The main techniques to separate the amalgam from the heavy minerals are described below:

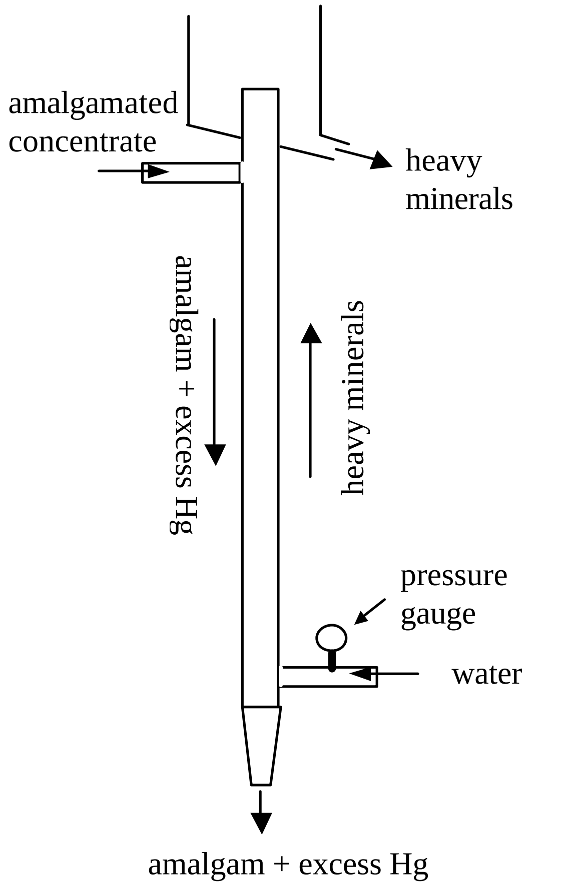
Panning
Panning in the water box is one of the most adopted method to separate amalgam (with excess mercury) from heavy minerals concentrate. The methodology is not very efficient but simple and inexpensive. This however promotes long contact of the operator's hands with mercury. When panning is conducted in a water box or cemented tanks (as observed in Tanzania), the amalgamation tailings are temporarily stored. The extraction of mercury from contaminated tailings is usually not practiced by ASM. The main option for cleaning mercury from tailings is the use of special-amalgamating plates described above. In this case, it is much better to use the special plates to amalgamate concentrates in first place.

Elutriator
Elutriator is a vertical pipe (diameter of 4 to 10 cm and 0.5 to 2m high) in which the amalgamated concentrate is fed on the top and a fast flow of water cause the heavy minerals to overflow while the amalgam with excess mercury sinks. The process is fast but it is not 100% efficient and fine mercury droplets can also be dragged to the top with the heavy minerals. The pipe can be made of steel (as in Venezuela), plastic or acrylic. This latter bring the advantage of visual control of the water flow. Elutriators are easy to be locally manufactured and the cost ranges from US$ 50 to 300 depending on the type of material used. Acrylic tube is more expensive than steel. A PVC-water pipe is an affordable option to build an elutriator. For the demonstration unit, it is recommended to

install a small (∅4cm and 0.5m long) acrylic elutriator at the discharge of the amalgamation barrel. Eventually elutriators with different diameters can also be built to be used as hydraulic classifiers to demonstrate to miners how to classify by particle sizes.

Spiral Pan

Spiral Pan is a tilted plate with a spiral riffle on the surface of the pan which moves the amalgam and excess mercury into the center of the wheel where it is collected. The heavy-mineral portion is discharged at the edge of the wheel. It is fully mechanized and the pan angle controls the efficiency of the separation. A water pipe with thin holes crosses part of the spiral section to wash the minerals down. The simplest pans are made of polypropylene plastic with diameter ranging from 30 to 50 cm. The wheel rotation speed is controllable (from 15 to 22 rpm) thanks to a 12 V motor (adaptable to car battery). The feed capacity is around 30 kg per hour. There are many spiral pan manufacturers in USA, many of them can be found in the Internet. The prices of these spirals range from US$ 300 to 500 depending on the level of accessories. The weight of the whole setting is less than 10 kg. In terms of heavy-mineral-amalgam separation, the spiral pans provide better control than an elutriator and the final amalgamation tailing contains less mercury. Both techniques are worthwhile to be demonstrated to miners.



Scheme of an elutriator

Spiral Pan

3.3.5. Removing Excess Mercury

The universal process used by most artisanal miners to remove excess mercury from amalgam is filtration squeezing the amalgam in a piece of cloth. The cloth retains the amalgam (paste) and permits mercury to flow through the fabric or chamois pores. Despite the low absorption of mercury through the miner's hand, it is always advisable to wear gloves during this artisanal procedure. This process usually results in amalgam with 40 to 50% Hg.

A creative solution to remove excess Hg from amalgam without using the hand squeezing process was developed in a Processing Center in Venezuela. The amalgam with excess mercury is transferred to a porcelain crucible, covered with a piece of fabric on top and placed in a centrifuge. The centrifuge runs for 1 or 2 min. and the resulting amalgam has less than 20% Hg.

This can be brought to the miners' attention in the demonstration units. This can be built adapting a domestic food processor.

3.4. Retorting

An efficient method to separate mercury and gold from amalgams is by heating above 350 °C. Mercury becomes volatile leaving gold behind in solid state. A retort is a container in which the gold-mercury amalgam is placed and heated; volatile mercury travels up through a tube and condenses in an adjacent cooler chamber. With retorts, mercury recovery is usually higher than 95%. Substantial reduction in air pollution is obtained. There are a large variety of retorts. Some of them are made with stainless steel while others use inexpensive cast iron. Mercury losses during retorting are usually less than 5%, but this depends on the type of connections or clamps used.

This operation unfortunately in most artisanal mining sites around the world is usually conducted burning amalgams in pans or metallic trays using a blowtorch or bonfire. In Zimbabwe it is very popular the use of bonfires to burn amalgam. The miners place the amalgam on a steel plate or shoe-polishing tin to be burned in a bonfire. As the temperature is not high enough and the time of burning is too short (miners leave the amalgam for 10 minutes), the final gold *doré* contains up to 20% of residual mercury. The only control of the burning is visual. As long as the amalgam ball becomes superficially yellow, the miners remove the *doré* from the fire. Inside the bead it is possible to see residual mercury. As most gold buyers know this fact, they reduce the *doré* purchase price. When better retorting techniques are introduced, the gold price must be negotiated with dealers, showing that less mercury has been retained in the *doré*.

As occupational exposure is the main pathway in which mercury enters the human body in artisanal gold mining areas, it is suggested to demonstrate the advantages of using different retorting processes. In places such as Lao PDR, where mercury in mining areas is purchased by US$ 80/kg it makes sense to use the economic argument to convince miners to recycle mercury. In Zimbabwe, like in many other African countries the price of one kilogram of mercury is around US$ 12 to 20/kg. In spite of being three to four times higher than the international mercury price, this is still cheap, i.e. equivalent to one gram of gold. So, the economic argument should be replaced with other strategy. Despite the introduction of retorts through many programs (CETEM, UNIDO, Projekt-Consult GmbH, ITDG, Organization of American States, etc) and obvious benefits associated with their use, artisanal miners are reluctant, primarily due to a lack of concern for environmental and health impacts relative to other issues. The most effective argument to convince miners to use retort is using social and cultural issues. For example, in 1985, the Secretary of Mining of Goiás State, Brazil, started a campaign promoting retorts that included a brochure illustrating the effects of mercurialism. Impotence was stressed as one of the initial symptoms, which is somewhat inaccurate and therefore questionable from an ethical standpoint, but was extremely effective in capturing the attention of miners.

It is important to understand the main reasons by which miners do not use retorts. Engineers tend to look for the efficiency of the retorting process, when in many cases, efficiency is not the dominant factor to introduce a cleaner technology. The arguments are site-specific and sometimes fraught with misperception. However in some cases there are actual reasons that must be considered when introducing retorts in a mining site. Some of the most common arguments used by miners for not using retorts are listed below. All these factors must be taken into consideration in order to recommend the adequate type of retort in a specific mining region. In some cases gold buyers use the miner's perception to lower the purchase price. This is common when miners sell brown retorted gold.

The *doré* volume after retorting usually has the same volume as the amalgam. The amount of mercury in the *doré* depends on the retorting temperature. A well-done retorting would result in a *doré* with 1 to 2% Hg. Using blowtorches, the retorting time ranges from 10 to 20 minutes, in a 1 or 1½"crucible retort. Shorter time provides *doré* with high content of Hg. Usually this is not seen by miners, as the surface color is yellow. When using blowtorches, it is possible to melt gold in the retort crucible. Brazilian miners use to add some borax and a little dash of potassium nitrate to melt gold and remove impurities. This operation must be conducted in a fume hood equipped with filters. Activated carbon soaked with potassium iodide makes a very efficient filter to retain residual mercury vapor.

Table 3.12 – Arguments Used by Miners for Not Using Retorts

Arguments	Reasons	Possible solution
it takes time (sometimes miners become vulnerable to bandits attack when retorting)	low temperature	use air blower in bonfires or blowtorch; avoid crucible made of refractory material such as clay
it needs practice to operate	heating process must be uniform when using blowtorch	training
gold is lost during retorting	iron retorts: amalgam is not visible; bad perceived by miners	glass retorts can demonstrate that gold will not evaporate together with Hg or be trapped
gold sticks in the retort crucible	sometimes gold adhere to crucible bottom	• crucible must be filled with soot, or baby powder or a thin layer of clay; • avoid overheating (beyond red color)
Hg loses coalescence	sometimes condensed Hg disintegrates in fine droplets	NaCl and radio battery to re-activate Hg
gold becomes brown	unknown; probably due to a superficial reaction with iron	• still not well studied; • oxidizing atmosphere or use of stainless steel crucibles; • melt gold; • hammer gold *doré*

Air blower used in Tanzania increase the temperature of a bonfire

Regarding the type of retort to be demonstrated to miners the strategy must be: ANY RETORT IS BETTER THAN NOTHING. Even a crude method of retorting described in the "Gold Panner's Manual", a favorite of North American weekend prospectors, is better than burning amalgam in open pans or kitchen ovens. This simply involves "baking" the amalgam in the scooped out cavity of a potato. Readers are advised not eating the potato after processing.

The best retorts to be advised to miners are those made of local and easily accessible materials, non-expensive and easy to demonstrate. Durability can be a factor, but as long as the retorts are cheap and accessible, this becomes less relevant for miners.

In the demonstration unit it is suggested to have a large variety of retorts, from the simple to the most sophisticated one, to provide options to miners. It is definitely up to the miners to choose the most convenient and affordable type of retort for him/her.

3.4.1. Increasing Temperature

Another important factor to be considered when suggesting a retort, is the source of heat. Using blowtorches with propane gas (as in most Latin American countries) or with gasoline-air (as in Indonesia), the temperature on the amalgam can easily go above 400 °C promoting efficient mercury elimination from amalgam in less than 20 minutes. In a bonfire, more than one hour is needed to remove more than 90% of mercury from a 5 g-amalgam. When a bonfire is used, an air-bower is needed to speed up the process and to justify the use of retorts. Manual or foot-operated blowers have been used in Tanzania to forge mining equipment. These blowers can easily be locally manufactured. In Zimbabwe, manual air-blowers were produced in the past using an efficient system of gears to promote high ventilation to a coal or wood bed. This was extensively used by steel forgers. Air-blowers are definitely needed to be included in the demonstration units in particular in most African countries where most miners use wood as the main heating source. Burners using gasoline or liquid propane should also brought to miner's attention. In Zimbabwe it is common to use paraffin burners (Primus) for cooking and lightning. This can be included in the demonstration unit.

Indonesian gasoline-air blowtorch

3.4.2. Home-made Retorts

Home-made retorts are not very efficient but are easy to be manufactured with local materials. One option is the use of standard plumbing pipes and connections to make retorts with crucibles (end plug of plumbing pipes) from ¾"to 2". Smaller crucibles promote faster retorting. For those miners retorting more than 5 grams of amalgam per batch, retorts with crucible of 1½" are advisable. This costs less than US$15. This idea, devised by prof. Raphael Hypolito[6] from Brazil, has been adopted by many organizations and different designs of the RHYP retorts are available. The main drawback is that the pipes are made of galvanized steel and when mercury condenses, it sticks to the cooling pipe creating an amalgam with zinc. With the use of the retort, eventually, the accumulate mercury comes off, but this can bring a bad impression for the miners. In a brochure made by the British NGO, Intermediate Technology Development Group (ITDG)[7], there is the following note: *Do not worry if, the first time you use the retort, only a small part of the expected amount of mercury is recovered. Most of the mercury is normally trapped in the retort, and will be recovered in second and subsequent uses*.

For an adequate operation, the zinc from all plumbing parts must be burned off. Zinc fumes are relatively toxic. This initial operation must be done in a fume hood. Mercury can also leak through the connections. For a better operation it is advisable to heat the entire retort body in a charcoal bed and preferentially using an air-blower to speed up the operation.

Home-made retorts can also be made of steel tins. An inexpensive option for retorting has been applied in Papua New Guinea and China. The Chinese two-bucket retort consists of a metallic bucket and a bowl filled with water. A larger bucket covers the first bucket containing the amalgam. The PNG "tin-fish-tin" retort employs the same concept, but uses fish tins and wet sand instead of water. In both cases, the amalgam is heated using wood, charcoal or electric element and mercury vapors condense on the cover-bucket walls.

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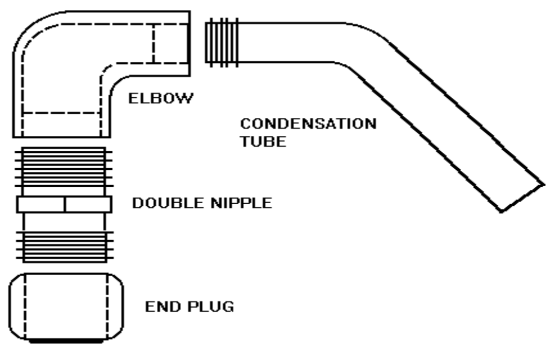
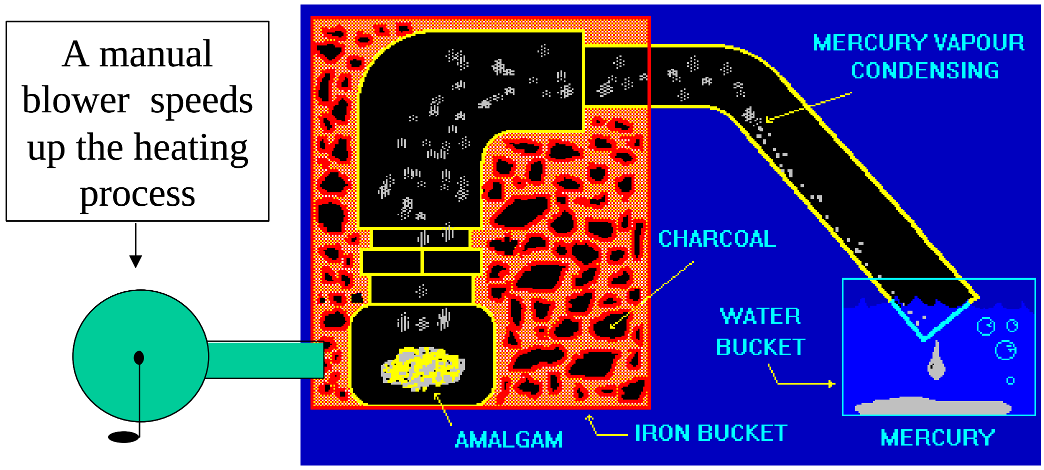
[6] Veiga, M.M.; Meech, J.A.; Hypolito, R., 1995. Educational measures to address Hg pollution from gold mining activities in the Amazon. Ambio, v. 24, p.216-220, 1995. Royal Swedish Academy.

[7] ITDG. A Simple Retort. www.itdg.org/html/technical_enquiries/ docs/mercury_retort.pdf

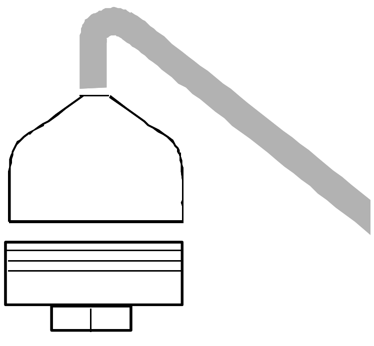


RHYP Retort

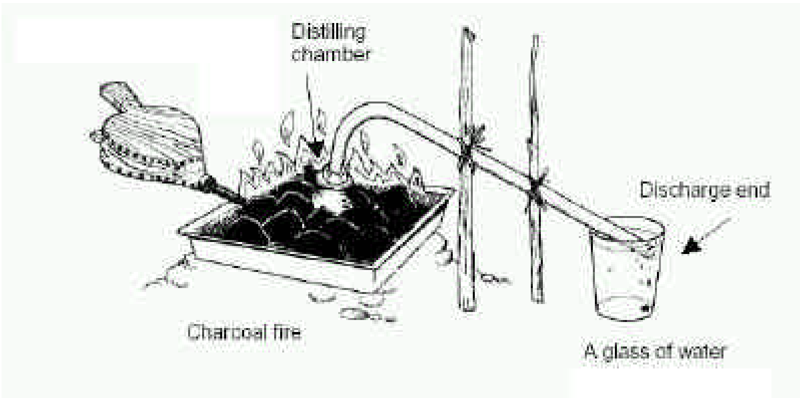
RHYP Retort



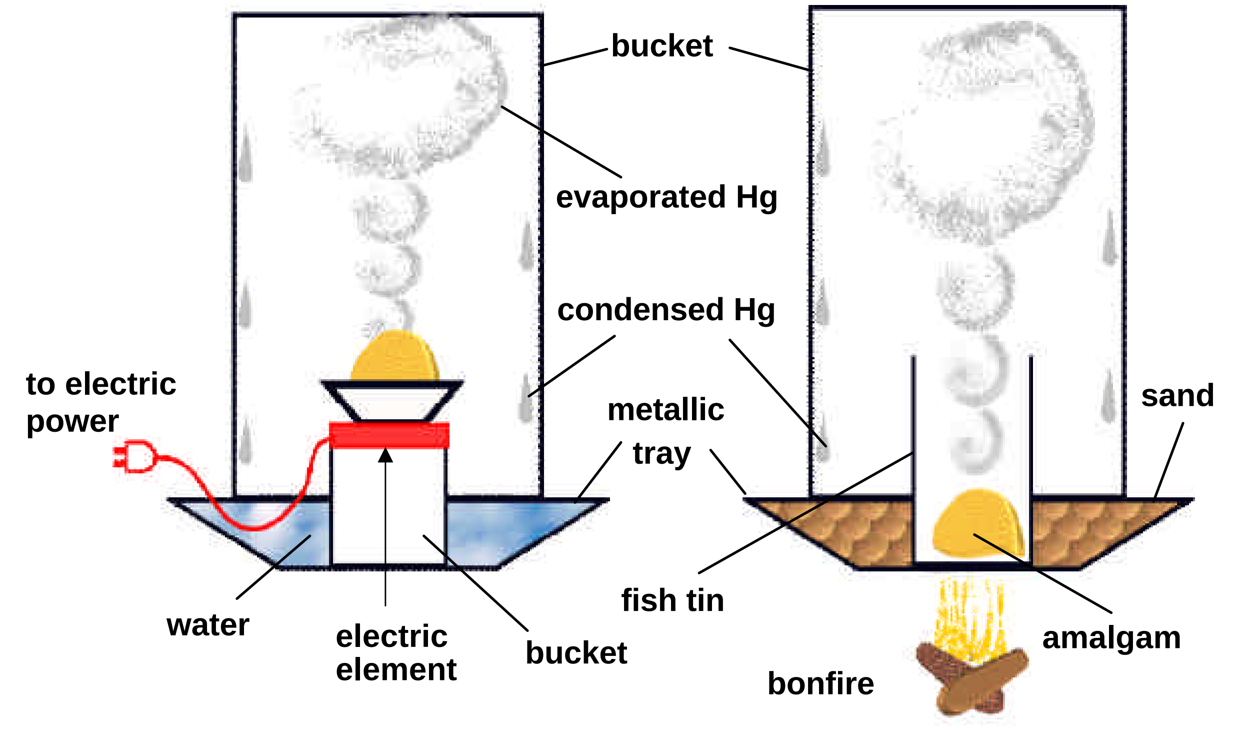
For an appropriate operation, all retort body must be heated



Alternative Design for RHYP retort

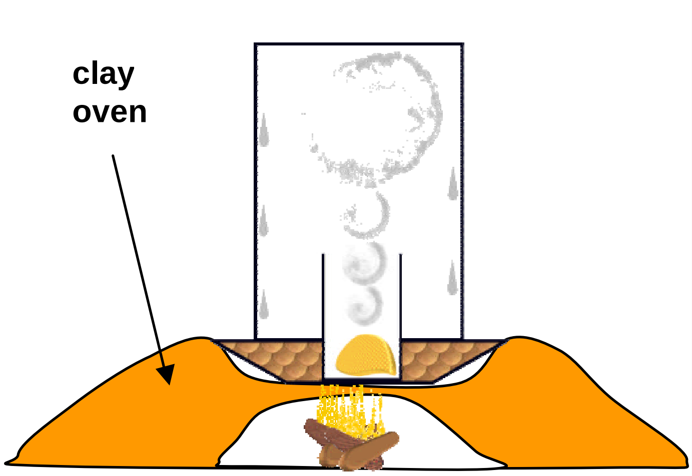


RHYP in use, as promoted by ITDG



Other types of home made retorts used in China (left) and Papua New Guinea (right)

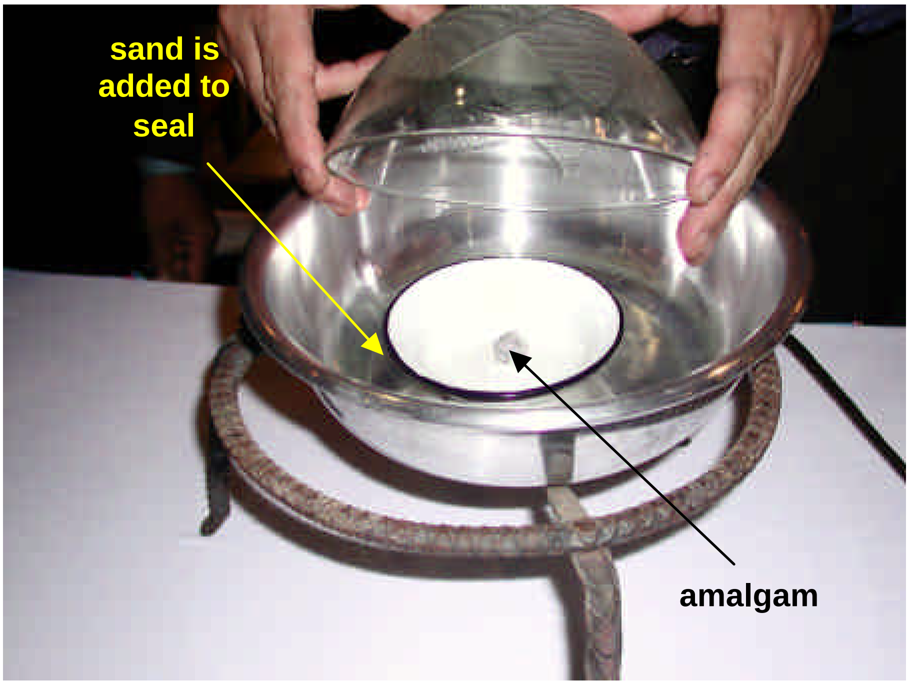
Using the same principle of the Papua New Guinea ("PNG retort") fish-tin retort, UNIDO built a retort using kitchen material for the ASM in the Mekong River in Lao PDR. On a metallic support (locally used for cooking on bonfires), a small enameled steel tray with amalgam is placed inside another larger steel bowl, covered with a glass bowl and sealed with sand. The glass bowl allows the miners to see the amalgam decomposition, but this can be replaced with a metallic bowl. Mercury condenses on the bowl walls and drops into the sand. This retort cost less than US$ 10 to be built. Miners can recover the condensed mercury panning the sand placed around the small tray.



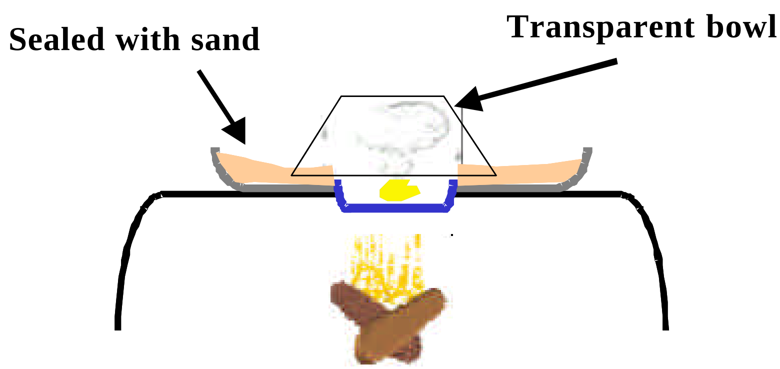
A clay oven increases retorting temperature

Using a glazed-steel (enameled) bowl as crucible, yellow gold is obtained, increasing the acceptability of miners to the retorting process. The firing structure can also be built in clay as used in Western Africa for cooking. This process increases the temperature of the bonfire and concentrates the flames under the bowl.

The idea of using kitchen crucibles covered with a bucket was also used by UNIDO to fabricate a retort in El Callao, Venezuela. This was a more elaborated retort built on a steel table but also using a stainless steel salad bowl as crucible. The table was filled with water and the amalgam burned with a blowtorch from the bottom. As the crucible was thin, the retorting time was short (10 min). Mercury condensed on the wall of the cover and dripped into the water. This retort took 10 to 15 minutes to eliminate most mercury from amalgam using a propane blowtorch. A serious inconvenient of this, and other retorts, is that sometimes miners remove the cover (bucket) from the crucible while the retort is hot. When this occurs, miners are exposed to mercury vapor.



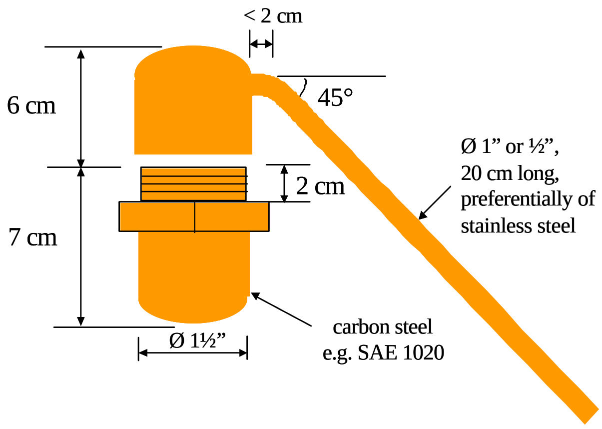
The "PNG Retort" made in Lao PDR



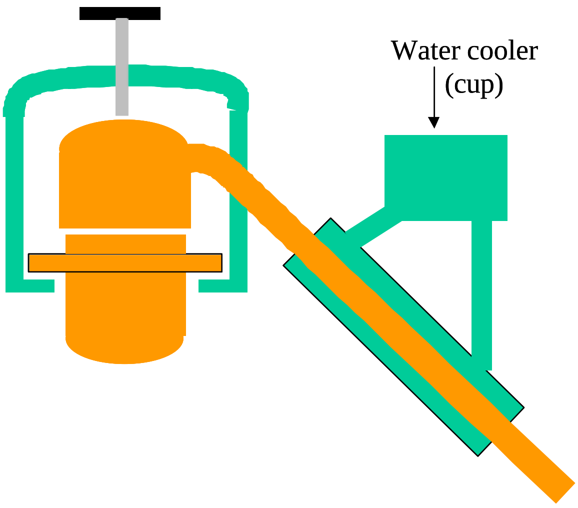
Scheme of the PNG Retort operating

"Venezuelan Retort"

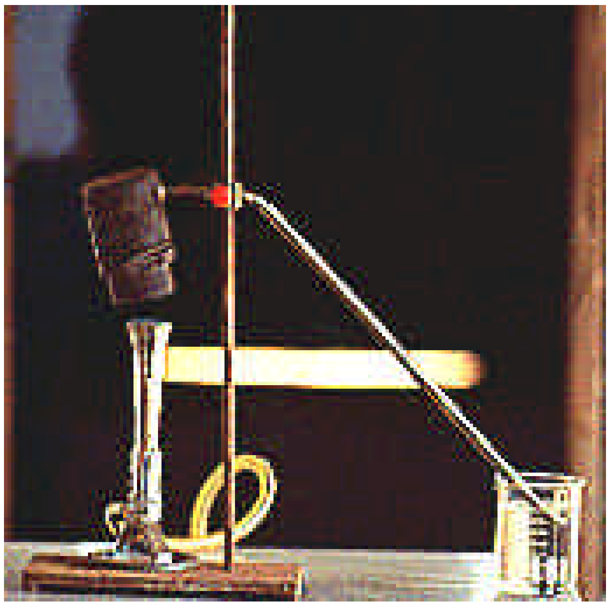

"Venezuelan Retort" in operation



Retort devised by CETEM, Brazil (air-cooled)



Retort devised by GTZ in Indonesia (water cooled) made of stainless steel


CETEM retort operating

3.4.3. Conventional Retorts

As mercury forms amalgam with almost all metals except iron and platinum, ordinary retorts are made of steel. Durable retorts can be made of steels that resist to corrosion and creep. Other characteristics to be observed are resistance to thermal expansion, structural stability and resistance to fatigue. In applications where the environment is not corrosive and the piece is not subjected to mechanical strength, carbon steels with low content of carbon (0.2 to 0.4%) work well. The strength of a low-carbon steel reduces from 43 kg/mm² (ambient temperature) to 25 kg/mm² at 540 °C. A simple and cheap air-cooled retort made of low-steel carbon was devised by CETEM (see diagram below). In order to increase the mechanical properties at temperatures above 500 °C addition of 0.45 to 0.65% Mo and 0.3 to 0.6% Mn to a 0.2%C steel increases its strength at 540 °C to 35 kg/mm². Creep resistance doubles with small amounts of Mo and Mn in the steel. Addition of 5 to 6% Cr increases two or three fold the strength of low carbon steels. The main commercial Cr steel is the 410 AISI with 0.15%C.

Retorts can also be made of Cr-Ni austenitic steels such as AISI 304 (0.08% C, 18-20% Cr, 8-11%Ni) or 310 (0.25%C, 24-25% Cr, 19-22%Ni). These steels combine high heat resistance with corrosion resistance up to temperatures around 900 °C. Stainless steels are much more costly than C-steels but the retorts are more durable. The aspect of durability must be discussed and cost/benefits must be presented to miners for their decision.

The advantage of having stainless steel cooling pipes is that mercury does not stick on the pipe wall when it cools down. Water-cooled retorts are slightly more efficient in Hg condensation than air-cooled. GTZ designed a 1½” water-cooled retort, used in Indonesia, in which no water circulation is needed. The price of these retorts made in Indonesia of stainless steel was around US$ 100 to 120.

A creative idea used in Colombia[8] is the encapsulation of a stainless steel (AISI 304) retort using a cylindrical refractory cement, like a furnace. The capacity of this retort (known as “still”), as originally designed, is for as much as 400 g of amalgam. The cooling pipe is steep to minimize mercury sticking on the pipe walls and it crosses a 7.8 water-tank. With liquid-propane gas burner about 95% of mercury was recovered in 8 minutes of operation and 9 g of gas was burned per minute. While using gasoline burners, the burning time increases to 20 min consuming 0.015 L/min. The same heating system is used to melt gold in a graphite crucible. This retort can be manufactured in Zimbabwe using a propane-gas burner. The retort can be made using either CETEM’s or GTZ’s retorts designs but in stainless steel. The idea of having a refractory insulation around a retort heating unit is very good and a clay-made oven can be tested for this purpose.

3.4.4. Glass Retort

A glass retort (Thermex) has been manufactured by the Munich-based company Metall-Technic. The high-silica-containing crucible resists up to 700 °C. The cooling pipe and connections are made of stainless steel. A water glass cools down the recipient receiving the condensed mercury. Miners can inspect the condensation process. This innovative approach has been very useful to demonstrate to miners the entire amalgam retorting cycle. As miners can observe mercury being released from the amalgam and condensed, they trust that all gold is recovered in the process.

[8] Pinzón, J.M.; Contreas, R.; Bernardy, C., 2003. A new still for the prevention of mercury poisoning in small-scale gold mining by amalgam extraction. *Geofísica International*, v.42, n.4, p.641-644.

Glass retort is useful to demonstrate the retorting principle

UNIDO has distributed a number of these Germany-manufactured glass retorts in Africa and the Philippines. Due to the low capacity (<30 g of amalgam), high cost (~ 1 oz gold), breakability and lack of spare parts, this cannot be used as a permanent retort but for demonstration purpose only. The refractory character of the silica crucible also makes the retorting time longer than when a steel retort is used but the amalgam color transformation, from silvery to golden, is quickly observed on the amalgam surface in less than 5 minutes of retorting with a blowtorch. With longer use, the crucible becomes opaque (silicon oxide formation) and becomes difficult to see the amalgam inside. It is important to demonstrate together with Themex that steel retorts employ the same principle and work similarly.

3.4.5. Comparing Retorts

It is recommended to demonstrate as many different types of retorts as possible and build some along with the miners during the training step. This will be useful to highlight the cost and benefit of the various types of retorts. It is also important to work with miners to develop "new" types of retorts. This will make them more comfortable with their own inventions.

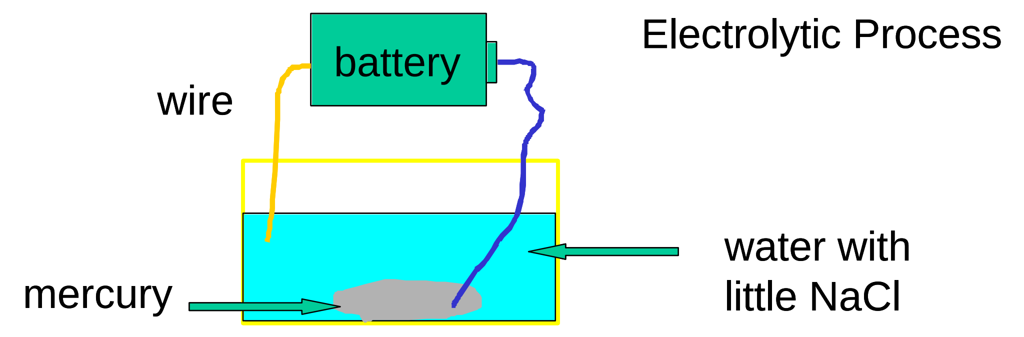
Table 3.13 – Different Types of Retorts to be Demonstrated to Miners

	RHYP	PNG	CETEM	Venez.	Colombian	GTZ	Thermex
crucible material	Galvanized steel	C-steel	Low C-steel	Stainless steel	Stainless steel	Stainless steel	High silica glass
durability	Low	Low	Medium	Medium	High	High	Low
price (US$)	5-20	5-20	20-50	10-40	80-90	100-200	400-500
possibility of local (Africa) manufacturing	High	High	Medium	High	Medium	Medium	None
retorting time (min) with blowtorch	15-20	10-15	15-20	10-15	10-20	15-20	20-30

3.4.6. Recovering Mercury Coalescence

Mercury recovered by retorting often does not have the same amalgamating properties as new mercury. In many South America countries, miners simply discharge retorted mercury. The most efficient way to reactivate the surface of mercury is by using an ultrasonic bath, such those used by dentists, wherein mercury droplets coalesce in seconds. However this is an expensive equipment (~US$400) and not frequently accessible to miners. A much less expensive method[9] involves electrolytic activation using table salt and a simple battery to clean mercury surface. A process to retain the contaminated liquid effluent should accompany any activation method. For example, the effluent can be filtered through a pipe filled with lateritic material or activated charcoal. Despite the small amount of effluent, some soluble mercury could be transformed into more toxic forms once discharged into the environment. This equipment should definitely be demonstrated to miners using a simple steel or glass can and a radio battery with some copper wires.

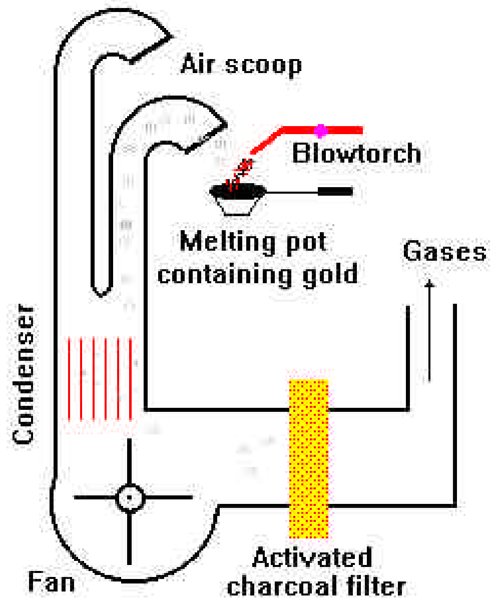
[9] Pantoja, F. and Alvarez, R., 2001, Techniques to Reduce Mercury Emissions in Gold Mining in Latin America, Book of Abstracts from the 6th International Conference on Mercury as a Global Pollutant, Minimata, Japan, October, 2001, p. 215.



Simple procedure to re-activate Hg surface

3.4.7. Filter for Gold Shops

Usually gold *doré* is sold to gold shops in the villages or to dealers who come to the mines. The buyers often pay less for the bullion according to the quality of the gold from each region. Gold *doré* is then melted with some amount of borax and nitro to remove impurities and, sometimes, to make jewelry. As the *doré* still has residual mercury this is released during the melting operation. The residual mercury ranges from 1%, when retorting is well done to 20%, when amalgam is roughly burned in bonfires, as in Zimbabwe. The fume hoods used by gold shops are usually very rudimentary comprising just a fan that blows out the mercury vapor into the urban atmosphere. In the interior of these shops Hg levels in air can reach 300 µg/m³. The residual mercury is lost. Gold shop employees and citizens living around the shops are exposed to high levels of mercury vapor and develop neurological problems. The most dramatic case was documented in the BBC movie “Price of Gold”. A citizen in Brazil lost his walking and speech abilities after living for eight years above a gold shop.



Special fume hood developed by the company Apliquim in Brazil

In 1989, a Brazilian company, Apliquim, developed a mercury condensing fume-hood consisting of a series of condensing plates coupled with iodide impregnated activated charcoal filters. This equipment reduces mercury emissions by more than 99.9%. Less than 1 µg/m³ (WHO limit for public exposure) of mercury was detected in the exhausting gases of this fume hood.

Gold buyers are usually much more capitalized than miners and millers, but the demonstration of a whole special fume hood for gold melting is very expensive to be included as a major component of the demonstration unit. It is suggested to include in the unit some components of an air filtering system to demonstrate to gold dealers the environmental and health benefits of using condensers (even a simple water trap) and activated charcoals (impregnated with potassium iodide) filters.

4. Capital Cost of a Demonstration Unit

The capital cost for manufacture the Transportable Demonstration Unit (TDU) includes the costs of equipment, supporting structure (truck bed or container), all ancillaries (wires, pipes, etc.), the tent to be used as classroom and dormitory, power generator, and all labour, supervision and field expenses for first transportation, installation, start-up and short training.

There are a number of tents in the American market that are used as portable classrooms. Shelter Systems offer a dome-tent with diameter of 30' (9m) and it is 11' (3.3.m) high weighing 190lb (86 kg) 706 square feet (65.6 m²). According to the manufacturer, the tent can be set up by one person in 30 minutes without tools and taken down in 5 minutes. The price is around $2000. The tent is to be used as classroom as well as to show videos and slides to miners. In Zimbabwe, Taylors Canvas offers a 6x6m tent with galvanized steel and PVC cover that can easily accommodate 30 people in 3-seat benches. The walls roll up and more people can attend the lecture.

Audio-visual equipment for training and awareness campaign is also considered. This consists of a lap-top computer plus a data projector and a screen. A turn-key contract with an engineering company is recommended to manufacture, install and start-up the unit. Some pieces of equipment do not necessarily operate on the truck bed. They must be installed on the ground in a way to be easily dismounted and removed. A drop-side container is much more secure than a flat bed platform.

Table 4.1 – Capital Cost of a Transportable Demonstration Unit

Equipment	**# units**	**Price US$ (Harare)**
Small jaw crusher (6”x3”)	1	5000
Small ball mill (∅48 x 60 cm)	1	8340
3-set portable screening system with 200l plastic container and replaceable screens	1	500
Sluice boxes: A52 Keene (25 x 129cm)	2	400
Carpets and vinyl mats for sluice boxes	2	100
Cleangold (60x50cm) and structure	4	2000
ABJ centrifuge concentrator	1	2760
Gemini table 60	1	6000
SMS elliptical amalgamation barrel (∅66 cm)	1	4000
Special amalgamating plates (40x30cm) Goldtech (with box)	4	1500
Acrylic elutriator (∅4 x 120 cm)	1	300
Spiral pan (∅40 cm)	1	500
Centrifuge to remove excess Hg	1	1000
Stand with clamps to support retorts	3	150
Retorts: RHYP	10	200
Retorts: PNG retort	10	400
Retorts: CETEM retort (c-steel)	5	400
Retort: Colombian still (stainless steel) with burner	1	500
Retorts: Thermex retort	3	1500
Paraffin burner (Primus)	2	100
Air blower	1	400
Filter for gold shops (activated charcoal with KI)	1	300
Water pump (2”) + flexible rubber pipes	1	800
Treadle pulp pump	1	300
Pulp scale	1	300
200-kg scale	1	100

Gold scale (20 g to 1 mg), portable and battery operated: PP-2060-D Digital Acculab Pocket Scales	1	400
Platform/container to transport all pieces of equipment	1	1800
A&V equipment (computer + beamer + screen)	1	5000
Power generator (27 kVA)	1	8000
Canvas tent (6x6 m)	1	2000
Portable folding plastic chairs	30	850
SUBTOTAL		55900
Miscellaneous (gloves, masks, safety equipment, glassware, bowls, buckets, small instruments, etc.) + spare parts (10%)		5590
Contingencies (10%)		5590
Transportation + installation + start-up + training (10 days)		5000
TOTAL		**72080**

5. Operating Cost of a Demonstration Unit

The TDU must be operated by trainers which include a local mining and mineral processing expert and a technician. It is also recommended to hire one or two local miners to help the unit operation and promote the training activities. These trainers must be trained and this cost is not included herein. Eventually, some other experts (see invited experts) in a specific field related to mercury pollution (e.g. health) can be invited to go the TDU for a sequence of lectures. In principle, the TDU will move just three times per annum, staying in each site for 4 months. The truck to transport the unit must be rented. The platform or container containing all pieces of equipment to be transported can have some legs to facilitate the loading process.

The Government must be committed with the operation of this demonstration unit and keep it working at different sites after the UNIDO project life.

A mechanic and/or an electrician are listed as an expected expense to repair any type of equipment in the unit.

The operating time of the demonstration plant is calculated based on a use of 50% of the demonstration plant, since other 50% of the operators' time is used for classes, training, analysis, maintenance, etc. The operating hours of the plant is calculated as follow:
8 hours/day x 22 days/month x 12 months/annum x 50% of operation = 1056 hours/a

The cost of power was estimated using a power generator but when electric power is locally available, this can be rented from the milling center. In this case, a power meter must be installed on the line in order to pay the right energy cost to the miller. When using a diesel generator it is estimated the use of 0.2 L of diesel/HP-hour or 0.27 L/kWh. Considering a total power of 15 kW and an operating time of 1056 hours/a then the total energy consumed by the unit is around 15840 kWh/a or 4277 L of diesel per annum or 356 L/month. Considering the cost of US$ 0.85/L, then about US$ 303/month of diesel is expected.

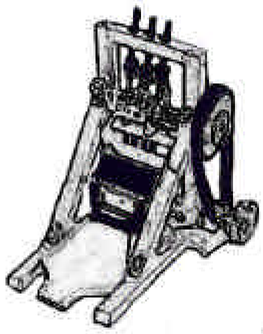
The tailings generated by the demonstration unit must be safely disposed before the unit moves to another site. This must be done by hiring a truck and disposing the tailings in a landfill, preferentially re-vegetating the site. Water to be used in the TDU comes from local suppliers that in many cases are the milling centers. The use of water from natural streams should not be the first option. The water management item includes the cost in reclaim the water from the ponds an/or any type of expense related to fees to be paid to millers.

The most feasible way to operate the demonstration unit is through a sub-contract with a local institution (e.g. IMR) that provides trainers and technicians, and it will be in charge of the unit maintenance. Ideally this institution should own the TDU.

Table 5.1 – Operating Cost of a Transportable Demonstration Unit

Item	**US$ (monthly)**	**US$ (annually)**
Direct Labor		
• local expert (6 months)	1000	6000
• technician (12 months)	500	6000
• one miner (helper) (12 months)	250	3000
• invited expert (lump sum) (2 month/a)	2000	4000
Mechanic + electrician		1000
Repair parts (5% of the capital cost)		3500
Lubricants (1% capital cost)		700
Power (diesel oil) or electric power when available	303	3632
Power generator maintenance (20% of the generator price/a)		1600
Truck rental (3 times/a): 3 x 700		2100
Rental of the Custom Milling (50% of the time)	385	4620
Water management	100	1200
Tailing management	100	1200
Carpets replacement		200
Retort replacements	100	1200
Reagents (NaOH, Hg, etc.)	50	600
Living expenses for 3 people	3 x 400	14400
Meals + coffee for the course attendants (10 days/month)	450	5400
Travel expenses for 3 people	100	1200
Office and promotional material	100	1200
Subtotal		**62752**
Contingencies + administration (10%)		6275
TOTAL		**69027**

Small Mining Supplies (Pvt) Ltd



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3 November 2003

Dr. Marcello Veiga,
UNIDO
Global Mercury Project
Vienna International Centre

Per email: M.Veiga@unido.org

GLOBAL MERCURY PROJECT – DEMONSTRATION UNIT – ZIMBABWE

Dear Dr Veiga,

We would like to thank you for consulting our company in respect of the above, and for the useful discussions we held in Zimbabwe and Ghana.

To refresh your memory, I shall start with a brief outline of our company, and then move on to how we believe we can be of assistance to you:

SMS Company Outline

Small Mining Supplies (Pvt) Ltd (SMS) was formed 2 years ago with the express intent of providing expertise and equipment to the Zimbabwean artisanal and small mining community, which as you have seen is relatively sophisticated. Despite this sophistication, this sector suffers from a lack of finance, and thus inability to establish privately-owned process plants. As such the artisanal sector is at the mercy of custom mill operators, and the small-worker sector, whilst frequently operating privately-owned mills, often suffers from a lack of cutting-edge technology and finance to make technological capital improvements.

At SMS we felt that there was an opportunity here to provide both expertise and equipment, on a scale and cost level suitable for the ASM sector. Expertise is borrowed largely from the experience and ongoing R&D programs of our sister company, Peacocke, Simpson & Associates (Pvt) Ltd (PS&A). This company has provided extensive minerals dressing services to the region and internationally since 1985, and relies upon the skills of a number of Zimbabwean key players:

Kevin Peacocke, BSc, C Eng – Director

Peter Simpson, BSc, C Eng – Director

Barnabas Moyo, C Eng – R&D Manager

Stanley Makonde, Dip Acc – Sales & Procurement Manager

Patrick Chiropa – Laboratory Manager

The staff of Peacocke, Simpson & Associates (Pvt) Ltd have combined experience in excess of 100 years, heavily biased towards the Zimbabwean small mining sector, which is a model industry in Africa. Messrs Peacocke & Simpson sit on the board of SMS, which also draws upon the skills of the other key players in the company. Both Messrs Peacocke & Simpson are strongly associated to Knelson Concentrators and have traveled extensively for this company in Africa and beyond. Their particular forté is gravity processing and optimizing of processes and recoveries without the need for chemicals.

The third board member of the SMS board is Mr Kevin Woods, also a Zimbabwean by birth, who has some 20 years of experience in the Zimbabwean mining industry. Mr Woods' background has been predominantly in the sourcing, refurbishment and supply of used or new small mining equipment in Zimbabwe. Over the years, Mr Woods has dealt with nearly all of the more important players in the Zimbabwean industry, as well as numerous lesser players, and he has very strong relationships with various indigenous small-mining associations.

Although SMS is only 2 years old, therefore, it draws upon a huge expertise &experience resource, and has made significant strides in the industry. The company has developed a small single-stamp mill aimed at artisanal and cooperative miners, rubble scrubbers, amalgam barrels, etc., and is presently developing a low-priced centrifugal concentrator. The bias here is towards providing medium/high technology which is both appropriate in terms of both price and operator skill level. All internal equipment lines are continuously improved and updated with feedback from the industry and according to R&D investigations at PS&A.

Moving beyond the borders of Zimbabwe, SMS has an existing joint venture with Mulittech Services of Ghana for small mining equipment supply in West Africa, and is actively seeking JV partners in other African countries. Outside the continent, we have excellent relations worldwide with a number of mining equipment supply companies, generally through the worldwide Knelson network. Most of these companies have been allied to Knelson for many years, and have tried-and-tested track records.

K H Woods, P T Simpson, K G Peacocke
Directors of SMS