MERCURY DISCHARGES FROM SMALL SCALE GOLD MINES IN NORTH SULAWESI, INDONESIA: MANAGING A CHANGE FROM MERCURY TO CYANIDE[1]

Alfred E. Whitehouse, Harry H. Posey, Tom D. Gillis, Michael B. Long, and Asep Atju S. Mulyana[2]

Abstract. Mercury amalgamation is the predominant gold processing method used in North Sulawesi and elsewhere in Indonesia. Only a portion of the mercury used in the process is recovered because floured mercury is discharged directly to upland disposal sites and streams with the tailings and Hg vapor are released when amalgam is heated without retorts to recover gold from amalgam. Cyanide (CN) processing was introduced to recover gold from the tailings so additional Hg vapor is released as the loaded charcoal is burned, breaking the Hg-CN complexes. Small scale gold mines in North Sulawesi alone emit approximately 64 tons of Hg per year to the environment, exceeding the 40 tons per year emitted from coal-fired power plants in the United States.

Replacing Hg-amalgamation with gravity separation followed by vat cyanidation would bring about significant environmental benefits. In this paper we examine some of the more prevalent gold recovery practices in Indonesia, and propose management and beneficiation improvements. We believe these changes would yield higher recovery rates, and would eliminate the environmental damage caused by mercury losses that follow the current processes.

Additional Key Words: mercury amalgamation, cyanidation, mine management

---

[1] Paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

[2] Alfred Whitehouse is Director of International Projects Office, USDOI Office of Surface Mining Reclamation and Enforcement, 1951 Constitution Ave., NW, Washington, DC 20240; Harry Posey is Senior Environmental Specialist with the Colorado Division of Minerals and Geology, 1313 Sherman St, Denver, CO 80203; Tom Gillis is Senior Environmental Specialist with the Division of Minerals and Geology, 701 Camino Del Rio, Durango CO; Mike Long is Senior Environmental Engineer with Shell Exploration and Production Company, Denver CO; Asep AS Mulyana is a Geologist with USAID Environmental Services Program, Ratu Plaza Building, 17th Floor, Jln. Jend. Sudirman No. 9 Jakarta 10270, Indonesia.

7th International Conference on Acid Rock Drainage, 2006 pp 2354-2368
DOI: 10.21000/JASMR06022354

https://doi.org/10.21000/JASMR06022354

Background

Uncontrolled use of mercury is the common practice in small scale Au mines worldwide, whether in alluvial or hard rock deposits. Most small scale Au mines are in 33 countries:

Latin America: Honduras, Nicaragua, Colombia, Ecuador, Peru, Bolivia, Chile, Brazil, Surinam, Venezuela, and The Republic of Dominica.
Africa: Ghana, Kenya, Tanzania, Zambia, Zimbabwe, Ethiopia, Guinea, Liberia, Nigeria, Gabon, Republic of Central Africa, Burundi, and Madagascar.
Asia: India, China, Philippines, Papua New Guinea, Malaysia, and Indonesia. (Wotruba, et al, 1998).

The US Department of the Interior's Office of Surface Mining Reclamation and Enforcement (OSM) has been providing technical assistance to the Indonesian Ministry of Energy and Mineral Resources (MEMR) since 1995 under grants from the US Agency for International Development (USAID). The broad objectives of the project were to increase the capacity of MEMR and provincial and local governments to manage the mineral sector while ensuring that effective, economic recovery of minerals was balanced with environmental protection. Assistance was directed initially towards the central government, which managed all mineral resource activities. Support later shifted to provincial and county governments following passage of two decentralization laws, Law 22/1999 and Law 25/1999, which shifted responsibility to manage mineral resources and regulatory programs to the regions.

Straddling the equator between Indochina and Australia, Indonesia (Fig. 1) is one of the most mineral-rich countries in the world, hosting significant deposits of coal, Sn, Cu, Au, Ag, Ni, Al, and quarry minerals. Minerals are considered the "wealth of the Indonesian people" and are controlled and regulated by the State as a vital part of its economic development strategy. The mining industry contributes nearly $3.2 billion ($US) and is a prime mover for Indonesian economic development in the provinces of Papua, Bangka-Belitung, NTB, and East Kalimantan. The formal mining sector directly employs over 35,000 people and indirectly another 120,000 in contracted support services. Annual revenues paid directly to the government through various taxes and royalties are about $917 million ($US). The informal mining sector employs many more but contributes little in the way of taxes or royalties.

Usually one thinks of small scale miners working placer deposits of Au, platinum, gemstones, or other minerals with a high value and low bulk. Indonesia's small scale miners are active in most all minerals including coal, Sn and construction minerals. Indonesia's "informal" mining sector is comprised of a broad range of individuals, cooperatives, and companies varying from single persons and family units working part-time to well-organized small to medium sized operations. Small scale miners are also a mixture of legal and illegal operators working where opportunity presents itself. They often are supported by people with money and political power who stifle attempts of provincial and county governments to dislodge them. Government efforts to regulate existing operations have proven difficult due to problems associated with rapid decentralization. Agencies given primacy by decentralization are faced with very limited resources, lack of technical expertise, unclear jurisdictional boundaries and levels of authority, inadequate cooperation and coordination with other agencies, and inadequate knowledge of existing laws and regulations.

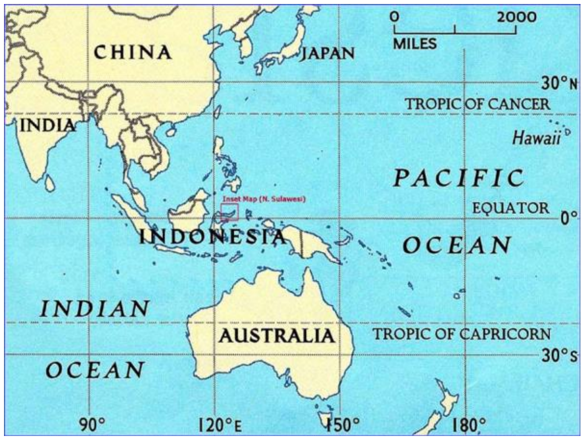
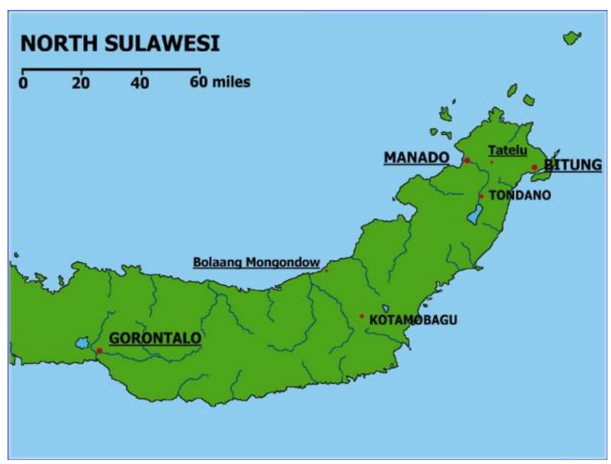


Figure 1. Regional Map: Indonesia is an archipelago of 17,508 islands (6,000 inhabited) [CIA World Fact Book- Indonesia 2005] and is part of the notorious Pacific "Ring of Fire." It has the world's largest number of active volcanoes of which 80 of 129 active volcanoes have erupted since 1600. [Directorate of Vulcanology and Hazard Mitigation, Ministry of Energy and Mineral Resources, Indonesia]

Introduction

Indonesia has a large number of small scale Au mining areas on its islands of Java, Sumatra, Borneo and Sulawesi (Fig. 2). These include areas around Tasikmalaya and Pongkor in West Java; the Sumatran Provinces of Lampung, Bengkulu, West Sumatra, and North Sumatra; East, West, and Central Kalimantan (Borneo); and Bolaang Mongondow County, and Dimembe and Ratatotok Districts in North Sulawesi (Fig 2, Fig. 3). Gold deposits mined by Indonesian small scale miners include both alluvial and vein deposits, and all of these operations use Hg amalgamation to recover the Au.



Figures 2 and 3. Regional maps of Indonesia

Mercury amalgamation likely dates to Roman times and is one of the oldest methods of extracting Au from its ores. Amalgamation of Au ores described by Georgius Agricola in *De Re Metallica* in 1556 is essentially the same as present day practices. Use of wooden water wheels in Pasaman, West Sumatra, to power small mills would be very familiar to Au miners of the 1500's (Fig. 4).

Figure 4. Water powered trommels, Pasaman, West Sumatra. A water wheel is used to turn two trommels in this set up.

When clean Hg is brought into contact with clean Au, the Au is "wetted" and "drawn into" the Hg resulting in a solution of Au in Hg, an alloy, or amalgam. Excess Hg, once strained through a dense material such as umbrella cloth, leaves a Hg amalgam (Fig. 5). Mercury can be removed from the amalgam by dissolving it in HNO_3 or by heating to drive it off as a vapor leaving the Au behind.

After extensive use or excess grinding, Hg may not wet or take up Au or coalesce into larger globules, and is said to be "sick" or to have undergone "flouring." Sickening is caused by impurities in or on the surface of the Hg, the most common being oil, grease, clay, Mn, Fe sulfates, and metal sulfides. Flouring occurs when Hg breaks down into extremely small globules giving it a white, flour-like appearance. Flouring occurs when Hg is subjected to extreme levels of grinding through multiple passes with ores during amalgamation. Once it flours, the Hg will not coalesce into manageable globules, but stays in a floured condition and is usually lost to tails. Any Au this HG takes up before becoming sickened is also lost to tails (see, for instance, Beard, 1987). Sickening is probably the major process that leaves Hg in tails.

Figure 5. Gold-mercury amalgam after excess mercury and water has been squeezed through a dense cloth. This amalgam will be heated to drive off the mercury, leaving a button of Au.

Description of the Problem

In the Dimembe District, 25 km north of Manado (Fig. 3), small scale Au mining is reported as early as 1950 but began in earnest in 1998 and 1999. Dimembe is a political subdivision of Minahasa Utara County, North Sulawesi Province, where much of the Au mining in that county is taking place. An assessment of small scale mining in North Sulawesi in 2001 reported mercury losses to the environment between 35 and 104 tons/year (Dames and Moore Woodward Clyde, 2001). They reported 270 Au amalgamation units (trommels) employing between 2,700 and 3,000 people. Stream water testing in the Talawaan and Tatelu sub-districts of Dimembe showed Hg levels between 200% and 7,950% above applicable drinking water or aquatic life standards for Hg. Process wastewater was 1,950% above the Indonesian Hg standard of 0.005 mg/L.

Human urine was tested from 63 processing plant workers, miners and nearby residents. Concentrations were highest in the processing plant workers (up to 202.65 μg/L), followed by miners (up to 182.64 μg/L) and nearby residents (up to 34.55 μg/L). The USEPA has set the maximum safe level of occupational exposure at 50 μg/L. Unfortunately, there are no clinical observations for the above individuals to correlate the high urine level with clinical signs of Hg poisoning.

In December 2001 when an OSM team visited Dimembe, small scale mining was a major concern of the North Sulawesi provincial government agencies, Dinas Pertambangan (mining) and BAPEDALDA (environment). Dinas Pertambangan was firm in their position that these were illegal mines and that the agency had no jurisdiction over illegal mines. Dinas Pertambangan said illegal miners were a police responsibility and they should be evicted. It was unclear, however, what the police felt about this issue. BAPEDALDA had no permitting or regulatory authority over these mines but were very concerned about the high Hg levels found in the areas around the Au camps.

Property rights, i.e. access to and control of the land and mineral resources, seemed to be the key issue in addressing problems of small scale miners and Hg in the environment in Dimembe District. Small scale Au mining and processing operations are held within land areas that belong to Tanah Passini. These lands bear customary ownership and use rights under local *adat* law, a long-standing traditional community or village-based system of laws in Indonesia for dealing with land use and other community issues. When mining activities began in 1998, small scale mining and processing entrepreneurs and operators came mostly from Kabupaten Bolaang Mangondow/Kotamobagu, which is another Au area in North Sulawesi about four hours drive from Manado. As capital and knowledge accumulated in Dimembe, ownership shifted toward local people. By the end of 2001, about 80% of the mining and processing facilities in Talawaan and Tatelu areas in Dimembe (Fig. 2) were owned by local individuals. Local community leaders and provincial government officers confirmed this shift in ownership so local governments have been much more inclined to protect the land tenure of "their people." The central government made several weak attempts to remove the small scale miners from Dimembe but none were successful. With increasing political support from provincial and local governments, these efforts from the central (national) government have ceased.

In December 2001, when the OSM team visited Dimembe, there was one CN vat leach operation under construction by a local businessman, Ferry Moningkei, who had been a Au worker in Davo, Philippines where he learned the CN processing technology. He planned to buy tailings from trommel owners after they had processed the ore several times with Hg (up to 5 times in some cases). He expected to recover more than 6 grams Au /tonne. Moningkei had a letter of permission from the North Sulawesi Governor's office and the Provincial BAPEDALDA Director to construct and use this "experimental practice" in hopes this would be a demonstration to other processors to use less Hg or eliminate it entirely. This was an unusually bold action by a government agency as it provided permission to an activity considered illegal by another agency, Dinas Pertambangan, that had primary authority over mining operations. It demonstrated they were so concerned over the health impacts from Hg that they were willing to try something as radically different as Moningkei's CN vat leach system, even if on an experimental basis.

In February 2002, Ferry Moningkei's CN leach operation was operating. Recovery rates were better than predicted and he was actively buying tailings for reprocessing. He also said that tailings prices were starting to increase and that some trommel owners were refusing to sell their tailings. However, visits to several trommel owners and mine sites revealed they still had little knowledge about Moningkei's vat leach process or his success. Table 1 compares processing statistics in the region in 2002.

Table 1. Mining and processing statistics, February 2002. (Reported by Dinas Pertambangan and BAPEDALDA for Dimembe.) This table reflects some increases from 2001.

Active Mine Shafts	300
Active Trommel Units	400 (Units have 10 to 12 drums each)
Active Au Buyers	60
Workers in Dimembe:	
Miners	2,000 to 2,500
Trommel Workers	2,000 to 3,000
Ore Transporters	250 (Horse or ox carts and jeeps)
Manual Ore Crushers	600 (Men, women, children breaking ore with hammers)
Motorcycle Taxis	200
Security and Others	100

Trommel Operations

Gold ore is hauled in 40 kg sacks (Fig. 6) to local trommel operations where it is crushed and processed. Smaller operations employ families to manually crush the ore; these crushers place cobs of uncrushed ore within a circle of rubberized material secured with to a wooden handle, and hammer it to coarse sand (Fig. 7; Fig. 8). Larger operations use a primary jaw crusher and a stamp mill (Fig. 9).

Figure 6. Oxen transporting sacks of ore to processing operation. Tatelu District.

Figure 7. Community of workers using hammers to crush ore; Tatelu district.

Figure 8. Ore is held inside a ring of conveyor belt material attached to a handle and crushed by hand with a hammer.

Figure 9. Atop each rod, or stamp, is an eccentric wheel that raises then drops the stamp to crush the ore in bins beneath.

Crushed ore and river rocks are added to trommel drums and tumbled to further reduce particle size. Trommels are small ball mills or autogenous grinders. Each trommel unit contains 10 or 12 rotating drums (trommel), each with a capacity of about 130 liters (35 gallon) (Fig. 10). The drums are laid sideways and rotated with belts connected to a central motor. A single motor may run several trommel units. Each drum is charged with about 20 kg of crushed ore, washed rounded river rocks about softball size for milling balls, and water. This mixture is rotated for 3 to 4 hours, which crushes the ore to sub-sand sized particles releasing much of the free Au and associated metal oxides. Following this grinding step, ½ liter of Hg or more is added to each drum and the rotation continues for an additional half hour to create an amalgam of Hg and Au.

Figure 10. Trommel bank. Each drum, or trommel, holding about 20kg of ore is tumbled with river rocks for several hours. This autogenous grinding process is followed by further grinding with Hg to contact the Au with Hg to form an amalgam.

Figure 11. A worker loads ore for a second (or more) pass at crushing. If the crushed ore contains Hg, the workers' skin is exposed to it, especially through cuts or abrasions.

When a number of trommel owners were asked how much Hg they needed to buy each month, their consistent reply was, "about one liter." Their monthly purchase can be directly correlated to monthly losses so each month there are 400 liters or 5412 kg (1 L Hg = 13.53 kg) of Hg being lost to the environment. This yearly loss of 63.92 tons compares with 40 tpy that lost in the U.S. by all coal-fired power plants combined (see for instance, USEPA, 1997).

After ½ hour in the trommels, some of the Hg is pounded into tiny droplets or floured and is lost when the amalgam is separated from the tailings. This appears to account for the majority of the Hg losses. Additional Hg is lost to the atmosphere during the heating of the amalgam and, certainly, from the occasional spill. These losses are consistent with results from earlier studies (Dames & Moore/Woodward Clyde, 2001).

Following amalgamation in the trommel, each drum is flooded with water to remove the clay and fine rock particles (Fig. 11) and the Hg / Au amalgam is recovered. The amalgam is then squeezed through a piece of umbrella cloth to separate the excess Hg, which is reused in other trommel batches. The remaining amalgam is then heated (ordinarily in an uncovered metal crucible in a non-vented area) using a blowtorch (Fig. 12) and Au is recovered (Fig. 13). Several small retorts were observed but all were unusable due to warping from overheating.

Figure 12. Amalgamated Au is heated with fluxes in an open clay or metal pot. The amalgam at this stage is unprotected, and Hg escapes to the open air.

Figure 13. Gold button recovered after heating. Workers in this setting have the maximum contact with Hg vapors, and thus are most susceptible to Hg poisoning.

Initial tailings management was good at most trommel sites because they were collected and put into bags for reprocessing (Fig. 14). Final tailings disposal was not managed so well and many tailings found their way into the adjacent streams and rivers along resulting in substantial amounts of Hg there (Fig. 15).

Dimembe was a successful agricultural area, producing bananas, coconuts, papaya, rice, a variety of vegetables and freshwater fish, which were sold at the nearby markets in Manado. As results from a number of studies on the impacts of small scale mining and Hg were made public, the demand for Dimembe's fish and produce were greatly reduced due to market fears of Hg contamination. These market reductions even impacted the tuna industry in Manado Bay as Japanese buyers began to refuse fish from that area. Today, not even the sellers of fried bananas on Manado's streets will buy bananas from Dimembe. Sadly, a long-term sustainable agricultural economy was replaced by a relatively short-term mining economy.

Figure 14. Bagging Hg-bearing tails.

Figure 15. Tailings ponds by a stream.

Other Gold-Producing Operations

While this paper focuses primarily on Hg processing at vein Au deposits in North Sulawesi, it seems useful to record what we know about Au production in other areas of Indonesia. Mercury amalgamation is apparently in common use to recover Au from alluvial placers (Fig. 16) and colluvial placers (Figs. 17, 18) particularly in central Kalimantan (Borneo). In addition, there are significant sized trommel operations on Sumatra, some containing up to 75 trommel units. While we know little about the degree of environmental releases from these operations, it seems clear that Hg amalgamation is practiced and that environmental releases probably are similar in magnitude to those in North Sulawesi.

Figure 16. A suction dredge and sluice (tilted portions) recover free Au by gravity separation. Gold and other heavy minerals will be amalgamated and roasted to free the Hg. Barito River, Central Kalimantan.

Figure 17. Gold is recovered from colluvium or paleo placers using hydraulic mining techniques. This technique releases massive amounts of sediment to streams and causes erosion and mass wasting.

Figure 18. Hydraulic mining. A jet of water is sprayed at the loose sediment to expose Au bearing units. Valuable units will be run through sluice boxes to recover Au and heavy minerals.

Alternative Process to Replace Mercury Amalgamation

Gold produced from Hg amalgamation provides immediately saleable goods and provides significant economic benefit to large numbers of workers (see Table 1). Yet, given the way Hg is almost completely wasted to the environment, the current Hg use practices are environmentally insensitive, more dangerous to human health and the ecology, more expensive, and less efficient than other methods. In this section we discuss how modifications in current practices and the abandonment of Hg use altogether could overcome much or all of the shortcomings of Hg use.

Mercury retorts when used properly can recover virtually all Hg from Hg amalgam. Yet of all the mining and processing camps that were observed using Hg, none were using Hg retorts. In 2001 in recognition of the problem, USAID workers provided Hg retorts to local processors in Sulawesi. However, in camps where they were provided, the retorts appear to have been ruined by heating with acetylene torches. Acetylene produces temperatures far in excess of the 356º C needed to volatilize Hg, so the retorts warped then leaked and became useless.

Because it volatilizes slowly at room temperature, as long as Hg is employed in milling, total control of it lies beyond expectations. Proper retort use would significantly reduce the discharge of Hg to the atmosphere but, unless mill workers revise their use of Hg in the trommels to prevent sickening, large Hg losses to the tailings will continue. Currently, mill workers handle Hg in the crushed ore using little if any dermal and lung protection. Mill workers routinely contact Hg when they scrape the amalgam-laden crushed ore from the trommels after grinding. They also wade barefoot in the trough at the trommel's end when they bag Hg-laden tails by hand for re-processing (Fig. 19). Unless these practices change, a reduction in mill workers' dermal contact cannot be expected to decrease, potentially limiting their health or life span significantly. After multiple iterations of the milling process the tailings are finally disposed of in uncontained dumps and ultimately find their way to the soil, plants and streams. In addition to the health and environmental benefits, these changes would also reduce reagent costs.

Figure 19. Recovering Hg-treated tails for Hg re-processing or cyanidation. Protective equipment is rarely available. Workers who are exposed to Hg contact in settings like these may limit their health or life span significantly through dermal contact alone.

Mercury amalgamation at North Sulawesi operations not only has significant environmental impacts and human exposure risks, but it is also inefficient. Owing to the lack of fire assay procedures in the area, ores are treated several times with Hg and, depending on whether the successive batch produces Au or not, each batch may be re-handled several times until the ore is spent. Even at that point, a certain amount of Au will be washed away as fine amalgam, and some fine residual Au will remain in the tails.

Vat leach, carbon in pulp (CIP) cyanidation of the Hg-treated tails has been successful at removing extra Au (and Ag) (Fig. 20) from the ores.[1] Once the ore is leached, the loaded carbon is segregated and burned to produce a gold-Ag residue. The loaded carbon also contains other metal-CN complexes, including HgCN, so that Hg is volatilized in the process.

Both Hg amalgamation and cyanidation work most efficiently within a limited range of grain sizes. Larger Au particles require longer contact time than smaller ones, although the ability for Hg to contact small Au particles is much more limited than CN as the Hg is a viscous liquid whereas the CN solution is not. A CN solution is able to penetrate into cracks and cleavage planes whereas Hg will contact only particles exposed at the surface of the crushed minerals.

[1] Based on the appearance of the buttons and conversations with gold producers, Hg amalgamation appears to remove less silver than cyanidation.

However, beneficiation efficiency is greater when particle sizes are below a certain threshold diameter, approximately 0.15 mm.

Figure 20. The yellow-gold buttons contain mostly Au, according to the Au buyers. The black buttons contain high Ag in addition to Au. The more valuable Au buttons were produced directly from Hg amalgamation. The Ag- Au buttons were produced by cyanidation. Because cyanidation recovers both Au and Ag more efficiently than amalgamation, it maximizes resource recovery. However, Au buttons command a higher price and thus may inhibit the switch from Hg amalgamation to cyanidation alone.

To attain such size segregation requires that ores having relatively large free Au particles be first crushed then washed and subjected to gravity separation (Table 2). Gravity separation can produce a high grade segregate that could be refined by direct smelting, eliminating Hg. The tails from such a separation can then be treated with CN solution, one time, for a period of several hours to days, depending on the ore characteristics, to produce a pregnant solution for further refining.

The advantages of cyanidation in this setting may be extremely significant for environmental protection, protection of worker health, and health of local people. It may also be more cost effective considering the additional metal that will be recovered.

Table 2. Proposed processing steps for an alternative method that would abandon Hg amalgamation. The process presumes that assay techniques would not be employed.

Processing step.	Comment
Primary crushing	Retain primary crushing techniques, including hand crushing as applicable.
Secondary crushing: autogenous grinding in trommels	No change in process. Retain existing equipment.
Washing	Ore washing currently is not practiced. A washing step would require techniques and land to settle fine particles and recover coarse particles for CN leaching.
Cyanide vat leaching	Vats exist at some operations, and would be retained. Carbon in pulp (CIP) or carbon in leach (CIL) circuitry could be employed.
Tailings deposition	Existing tailings ponds could be used, but should be upgraded. Tailings management problems will grow as tailings from processed ores increase in volume. Current observations indicate that major improvements in tailings management will be needed, whether the processing steps are changed or not.
Tailings detoxification	This is not a current practice as far as observed. However, detoxification of CN tailings would not need to consider Hg issues if the tails were derives from cyanidation alone.

Regulatory & Permitting Alternatives

A change to cyanidation will still require effective regulation of mining activities by provincial and county governments in order to ensure adequate protection of health, safety, and environmental resources. To increase technical expertise amongst local agencies, training programs can be developed by Indonesia's Ministry of Energy and Mineral Resources, Agency for Education and Training Center in Bandung, West Java and presented to agency staffs in the form of 2-4 day short courses. Course topics should include health effects of Hg, techniques for CN and tailings management, mechanisms for building cooperation and coordination between agencies, and health and environmental monitoring. In addition, a simplified permitting process can be developed specifically for small scale mining operations that are beneficial to both the government and operators. It should be low cost, be easily understood, be capable of being implemented, and produce measurable results. This type of permitting process is often referred to as "permit by rule," "rule authorization," or "permit by agreement," and basically consists of an authorization to conduct an activity whereby the operator agrees to conduct operations in accordance with a set of general conditions or performance standards. Under this approach, operators do not need to develop an individual permit for their specific operation, and the agency only needs to develop a set of generic performance standards. Examples of this type of permitting process are the U.S. Clean Water Act – storm water permits for construction activities, and the U.S. Clean Air Act – operating permits for small emissions sources.

Conclusions

A successful shift from Hg amalgamation to gravity separation plus cyanidation in North Sulawesi could be accomplished with relatively small capital investment and continued use of existing processing equipment. Primary jaw crushers and stamp mills used for secondary crushing should continue in use to produce feed for trommels. Trommels appear to be the most significant capital expenditure and should continue in use for autogenous grinding. Operators could construct simple, water-intensive gravity separation and washing units from local materials, much in the way trommels have been fabricated locally. Vats to leach the ore with a CN solution can also be constructed locally and should be sized for daily trommel production.

A complicated feature of CN processing, which apparently has not yet been introduced into the region, is electrowinning. This will likely require additional outside expertise and equipment but should be well received, as it will reduce carbon costs.

Government control should include a form of permitting and oversight that assures better environmental protection, particularly protection from the long-term adverse effects of Hg pollution already measured in this area. A more effective tailings management system needs to be developed and enforced. Tailings already contaminated with Hg that are to be re-processed with CN should be stored locally after treatment, to retain the Hg in soils rather than releasing it to groundwater or to the air. Lined facilities should be considered to contain existing Hg tails until the need for more advanced cleanup techniques is realized.

Acknowledgements

The authors would like to acknowledge assistance and reviews by David Bird, Allen Sorenson and Dick Barnhisel, plus session organizers, Don Ranville and Kathy Smith.

References

Agricola, Georgius, 1556, De Re Metallica, Translated from the First Latin Edition of 1556 in 1950 by Herbert Clark Hoover and Lou Henry Hoover, Dover Publications, Inc., New York, 638 pp.

Beard, Richard R., 1987, Treating Gold Ores by Amalgamation, *Circular No. 27, March, 1987;* Presentation given at an Ehrenberg, Arizona miner's seminar.

Dames & Moore/Woodward Clyde, 2001.

USEPA, 1997, Mercury Study Report to Congress, EPA-452/R-97-004, December.

Wotruba, Hermann, et al, 1998, Environmental Management for Small Scale Gold Mining, International Development Agency for Swiss (CONSUDE), La Pas, Bolivia.