INDONESIAN MINING JOURNAL Vol. 15, No. 3, October 2012 : 146 - 158

IMPACTS OF ARTISANAL GOLD MINING AND EFFORTS TO MINIMIZE NEGATIVE IMPACTS TO THE ENVIRONMENT

DAMPAK PERTAMBANGAN EMAS RAKYAT DAN UPAYA MENGURANGI DAMPAK NEGATIF TERHADAP LINGKUNGAN

HUSAINI, LILI TAHLI and MUTA'ALIM
R & D Centre for Mineral and Coal Technology
Jalan Jenderal Sudirman 623 Bandung 40211,
Ph. 022 6030483, fax. 022 6003373
e-mail: husaini@tekmira.esdm.go.id; lili@tekmira.esdm.go.id

ABSTRACT

Indonesia has extensive primary and secondary gold ore deposits that are scattered at several islands. The processing method for gold includes cyanidation, amalgamation and gravity concentration. Amalgamation is one of the most dangerous methods that pollutes the environment. The process is conducted by artisanal gold mining extensively throughout the country and involving around 100.000 miners. The process is started by crushing the ore up to 2-3 cm, then put in the trommel along with Hg and water. The trommel is then rotated for 4-5 hours to produce amalgam (Au-Hg) to be separated from its tailing by panning. The clean Au-Hg, mixed with liquid Hg, is then squeezed to separate the Hg excess. The Au-Hg, mixed with borax is then burnt in a crucible to evaporate its Hg and get the golds bullion (Au-Ag metal). The gold is obtained after the silver within the bullion is leached by HNO_3 equipment used for burning the Au-Hg is an open vessel that is operated in the kitchen at which the people also cook the food. This condition is very dangerous for the miner and their families as the Hg vapor is very toxic and can damage human lung. Another problem is that Hg-containing fine tailings are directly discharged to the river. This mercury can pollute the aquatic system and become dangerous for human through food chain. The efforts decreasing the negative effect of artisanal mining employ a retort to burn the amalgam, centralize the trommels; concentrate the gold ores prior to amalgamation. Jig, shaking table, sluice box can be used for upgrading the gold. If tailing with relatively high gold content would be processed by gravity concentration or cyanidation, the location for tailing gold processing should be safe and far from the river and houses.

Keywords: artisanal gold mining, small scale mining, amalgamation, retort, impact, environment, concentration

SARI

Indonesia memiliki endapan bijih emas primer dan sekunder relatif besar yang tersebar di beberapa kepulauan. Cara pemrosesan bijih emas yang digunakan adalah sianidasi, amalgamasi, atau konsentrasi graviti. Amalgamasi adalah salah satu cara sangat berbahaya yang mencemari lingkungan. Cara amalgamasi diterapkan oleh pertambangan emas rakyat di berbagai wilayah di Indonesia yang melibatkan sekitar 100.000 penambang. Prosesnya dimulai dari peremukan sampai berukuran 2-3 cm, kemudian dimasukkan ke dalam gelundung bersama-sama air raksa dan air. Gelundung selanjutnya diputar selama 4-5 jam menghasilkan amalgam (Au-Hg). Amalgam dipisahkan dari ampasnya dengan cara digoyang-goyang sambil diputar (panning) dalam air. Hasil amalgam yang tercampur air raksa disaring dan diperas untuk memisahkan air raksa berlebih. Amalgam selanjutnya dicampur dengan boraks dan dibakar dalam krusibel untuk menguapkan air raksa dan menghasilkan bullion (logam Au-Ag). Logam emas diperoleh setelah Ag dalam bullion dilarutkan dengan asam nitrat. Peralatan yang digunakan untuk membakar amalgam berupa cawan dari tanah liat yang dioperasikan secara terbuka di dalam dapur tempat memasak makanan. Kondisi ini sangat berbahaya bagi para penambang maupun keluarga mer-

Received : 11 January 2012, first revision : 03 April 2012, second revision : 29 May 2012, accepted : October 2012

eka, karena uap air raksa adalah bahan sangat beracun yang dapat merusak paru-paru. Masalah lain adalah ampas berukuran sangat halus yang mengandung air raksa yang dibuang langsung ke sungai. Air raksa dalam sistem perairan dapat berubah menjadi metil air raksa (metil-merkuri) dan sangat berbahaya terhadap manusia melalui rantai makanan. Upaya yang dapat diterapkan untuk mengurangi dampak negatif dari pertambangan emas rakyat adalah menggunakan alat pembakar amalgam secara tertutup (retort), memusatkan gelundung, atau meningkatkan kadar bijih emas sebelum diamalgamasi. Jig, meja goyang, dan palong dapat digunakan untuk peningkatan kadar emas dari bijihnya. Apabila ampas yang masih mengandung emas cukup tinggi akan diproses secara graviti atau sianidasi, lokasi pemrosesan harus aman dan jauh dari sungai serta pemukiman penduduk.

Kata kunci: pertambangan emas rakyat, tambang skala kecil, amalgamasi, retort, dampak, lingkungan, peningkatan kadar

INTRODUCTION

Indonesia has extensive gold ore deposits that are scattered in several regions such as Lampung, South Sumatera, Aceh, North Sulawesi, Central Kalimantan, West Kalimantan, Central Kalimantan, West Java, East Java, Lombok, and Irian Jaya. There are two types of gold ores, namely primary and secondary (alluvial) gold ores. There are various gold processing methods implemented such as cyanidation, amalgamation, or gravity concentration by panning, sluice box, etc. that are usually selected based on the characteristic of the gold ores (Tahli, 2009). One of the gold processing methods that endanger the environment is amalgamation. The process is conducted by artisanal gold mining (gold small scale mining) widespreadly throughout the country. It is estimated that approximately 100.000 people are involved in gold small scale mining in Indonesia. The equipment used for burning the amalgam is an open vessel that is operated in the kitchen where the people are cooking food. This condition is very dangerous for the people who are working in this gold processing including their families. The very toxic mercury vapor and can directly inhaled by human reults in damaging human lung. Another problem which endangers the people is the mercury-containing fine tailings that discharged directly to the waters (river, ocean etc.). The mercury losses from amalgamation process is prominent namely between 1-2.5 times of the yielder gold metal. For example, Hg losses in Galangan area is between 1-2 tons and in Talawaan area is between 20-90 tons annually. A study of small-scale mining in Peru estimated that for every gram of gold produced, one or two grams of mercury was being released into the surrounding, as much as 95% of all mercury used in artisanal gold mining is released into the environment (Veiga, et al., 2006). This mercury could be methylating in the aquatic system. Through food chain, the metal which might be eaten by fish, will be poisoned the people who eats mercury-contaminated fish.

Mercury is a powerful neurotoxin and causes severe damage to the brain and kidneys. Inhalation of mercury can also cause lung, stomach, and intestinal damage, and even death due to respiratory failure. Mercury is one of the top six toxic pollutants that threats public health in 2010 in addition to heavy metals (lead, chromium, arsenic), pesticides and radionuclides. Approximately more than 100 million people in the world are at risk from toxic pollution at levels above international health standards (McCartor and Becker, 2010). Referring to Mukono in Sumual, 2009, there were several diseases caused by mercury pollution such as mercurialism, Minamata disease, mad hatter' disease.

Using mercury in the amalgamation process also allows small amounts of the heavy metal to contaminate soil and local waters through discarded tailings and sediments. The mercury-contaminated soil will affect the food sources. A study of a small-scale gold mining site in China found that the total elemental mercury concentrations in consumed vegetable and wheat samples significantly exceeded the Chinese-safety threshold (Veiga, et al., 2006).

METHODOLOGY

The method for decreasing mercury losses in this research is upgrading the gold content prior to using sluice box processing. The ore was ground to desired in term of size gold particles to achieveing high degree of liberation. To evaluate the success level for decreasing amount of mercury released into the environment, the research results were compared to the artisanal gold processing.

AMALGAMATION IN INDONESIA

Artisanal Gold Processing

Location of amalgamation process conducted by artisanal gold mining in Indonesia are scattered in several regions such as in Lampung, Central Java, West Kalimantan, Central Kalimantan, and North Sulawesi. The number of miners is estimated approximately 100,000 people, including those who work in Village Cooperative Unit-*Koperasi Unit Desa* (KUD) and *Wilayah Pertambangan Rakyat* (WPR) or Artisanal Mining Region. For example, the number of the miners at Talawaan and Galangan regions are about 3,000 and 2,500 people respectively. The miners at Galangan work in a group 4 – 6 people. Each group is responsible for ore extraction, processing, amalgamation process etc. Whereas the number of miners at Poboya, Palu is more than 10,000 people. They work in a group that contains 3-5 people up to 6-8 people.

There are 3 locations of gold ore amalgamation, Poboya, Kawatuna, and Lasoani. The number of trommels around 1,000 units (19,178 trommels), 940 stamp mills, and 229 units of cyanidation tanks (Table 1). Mining production ranges 3,000-3,600 tons of gold ores for month or 33,000-39,600 tons annually. The method of gold processing at Poboyo is amalgamation followed by cyanidation for its tailing. Recovery for amalgamation for 50 kg gold ore in the form of bullion was between 1-5 or 3 gs in average performing the gold content of 60-65% (Husaini, et al., 2010).

Cyanidation for tailing amalgamation processed 600 bags (30,000 kg) tailing followed, by adsorption and smelting and produced 2 kg gold within 18-22% purity. After purifying using sulphuric acid, the produced gold was 3 oz performing 90-95% purity. It can be referred that leaching process for 50 kg tailing amalgamation produces about 0.5 g gold within 90-95% purity. Total production is between 1,980-2,376 kg (60-65% purity) from amalgamation and 198-237.6 kg gold metal (90-95% purity) from cyanidation annually (Husaini, 2010). In general, the produced amalgam by Artisanal Gold Mining contains 50-60% Au (Veiga, et al., 2006).

In amalgamation process, the ore is sun-dried and manually crushed using a hammer or other traditional tools (stamp mill) up to 2-3 cm. Prior to crushing, the ore is usually burnt to make easy to crush. Burning the ore also increase the slurry pH from 5 to 6.5. This can improve the process. In general, the pH 7.0 is needed for amalgamation. Around 70 kg crushed ore along with water is fed into a tromel (size 50 cm x 70 cm) equipped by stone/rods/balls as grinding media. The tromels are then rotated using 60 rpm for 4-5 hours until 6-12 hours to produce fine particles and liberate the gold (Husaini, et al., 2010). After that, 1.5 – 2.5 kg of mercury is added to the tromels and the tromels are rotated again for half an hour to get the amalgam (Au-Hg).

The amalgam is then separated from the slurry (tailing) through the panning process and then is collected and placed in a cotton cloth to be squeezed for separating the mercury excess. The amalgam is then burnt in a clay crucible to evaporate the mercury and get the gold bullion. Sometimes, borax is added to remove the impurities within the bullion. The gold is obtained after

Table 1. The number of unit amalgamation, tromel, stamp mill, cyanidation tank at Gold Mining Area in Poboya, Palu

NO.	Location	Number of Units	Number of trommels	Number of Stamp Mill	Number of Cyanidation Tanks
1	Poboya	762	15.175	723	229
2	Kawatuna	159	2.877	108	-
3	Lasoani	79	1.146	109	-
	JUMLAH	1.000	19.178	940	229

Source : Regional Mining Office, Palu City, 2010 leaching the bullion using nitric or sulphuric acid to separate the silver. In Poboya, the leaching solution for dissolving silver (Figure 1). Silver sulphate is precipitated by copper metal to get silver and copper sulphate.

Risks of Hg to human health include consumption of contaminated fish, improper handling of contaminated sediments, and inhalation of mercury vapors. Mercury can be inhaled and absorbed through the skin and mucous membranes.

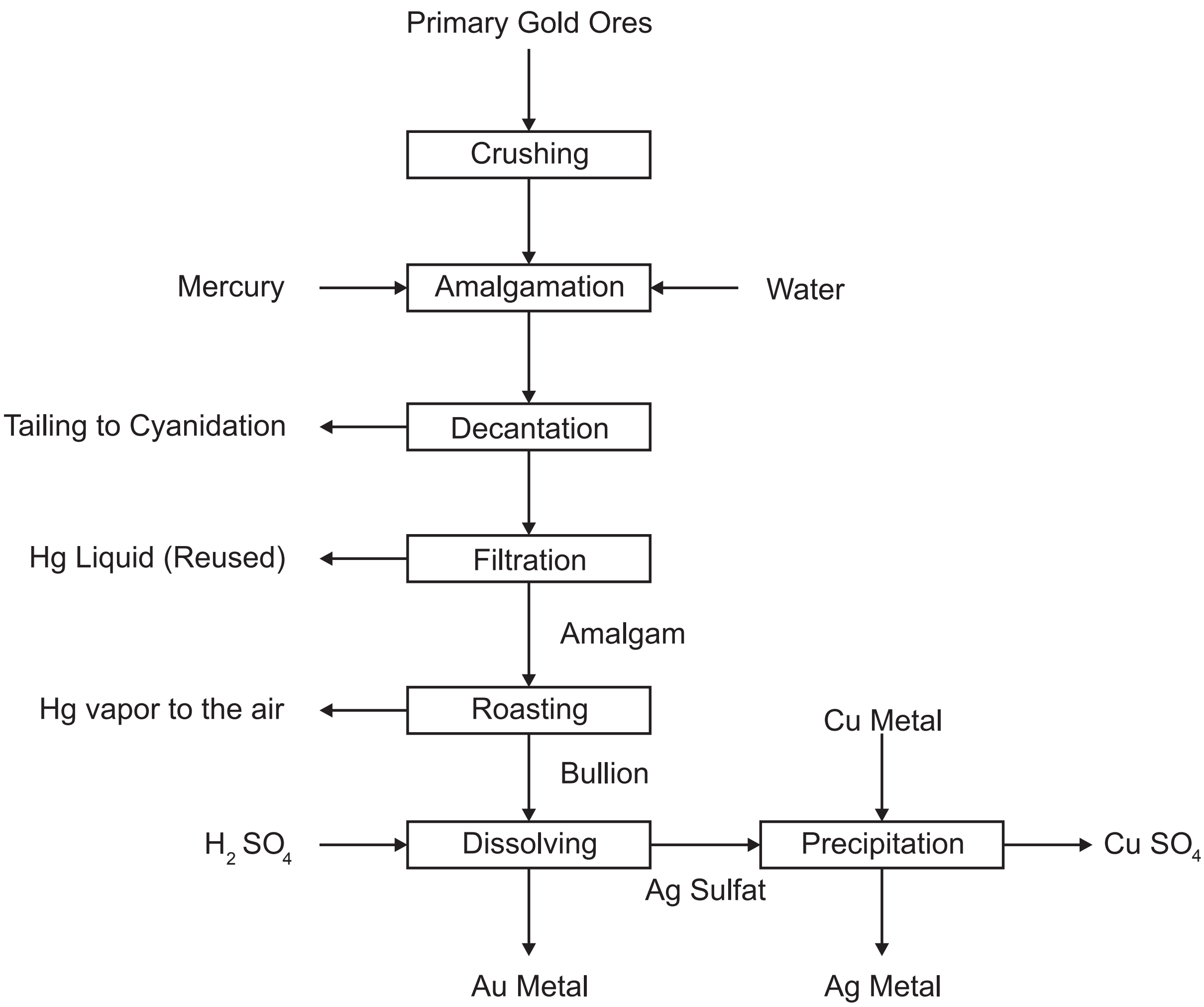

Figure 1. Amalgamation practice in Poyobo (Husaini et al., 2010)

Impacts of Artisanal Gold Mining

Naturally, mercury in the form of methylmercury – a highly toxic organic compound of mercury- tends to be accumulated in the body of fish and shellfish. The level of mercury will increase when the fishes are consumed by a predator. Increasing concentration of a substance in the tissues of organisms at successively higher levels in a food chain is called biomagnification. Minamata disease, occurred in Minamata, Japan, was a result of the biomagnification.

Therefore, when heating mercury or mercury compounds that may decompose when heated should always use adequate ventilation in order to avoid exposure to mercury vapor. The most toxic forms of mercury are their organic compounds, such as dimethylmercury and methylmercury. Methylmercury (CH_3Hg^+) is a potential neurotoxin that impairs the nervous system causes many problems to children such as damages to the brain and nervous system, mental impairment, seizures, abnormal muscle tone, problems in coordination, asthma, pneumonia, skin diseases and upper respiratory infectious (Darmutji, 2003).

Several ways of mercury released from artisanal gold mining are directly entered into water bodies as elemental mercury droplets and sediment as coatings after amalgamation process. Mercury vapor will be emitted to the atmosphere when the amalgam is heated. When a combination of cyanide and mercury is used, the formation of cyano-mercuric complexes enhances its transport. In general, around 95% of all mercury used in artisanal gold mining is discharged into the environment and causes negative impact. In Indonesia, mercury-containing ball mills provides over 50-60% Hg (Veiga, et al., 2006).

Around 1,994 trommels were operated using 1-2 kg of mercury everyday or approximately 200 ton mercury used annually in Dimembe area (North Sulawesi). Mercury losses were between 11.23-14.04 tons annually. These cause mercury accumulation in sediments and bioaccumulation in fish and molusca in Talawaan River. The mercury content in molusca and fish was about 0.5 and 0.5 mg/kg, respectively. The data shows that the pollution extremely dangerous and deeds to be managed properly.

The wastes of the artisanal gold amalgamation process in Talawaan contains pollutants of heavy metals as follows: Hg 9.03 ppm, As 0.09 ppm and Pb 0.06 ppm. Those concentrations are above the environment threshold (Sumual, 2009). In Galangan area, the lost of mercury is estimated about 1 – 2 tons of mercury released annually in this area, while in Talawaan area is estimated to be between 20 – 90 tons annually (Darmutji, 2003, Beinhoff, 2007).

The amount of mercury lost during amalgamation depends on the employed amalgamation method. In cases where the whole ore is amalgamated, the mercury losses can achieve up to 20 g for each gram of produced gold. Of the 20 g mercury, 19 g are directly to river and 1 g to the air. However, the mercury losses are normally 1.3 g; 0.3 g discharged to the river and 1 g emitted. No mercury losses, if the roasting uses a retort as the evaporated mercury condensed to the liquid one (Beinhoff, 2007).

The number of trommels for gold amalgamation at Central Kalimantan tends to increase every year during period of 1992-2007 (Table 2). As a consequence, the need of mercury for gold processing increases. Table 2 shows that total consumption of mercury for that period was 92.7 tons. The ratio of Hg to gold across Central Kalimantan is about 1.3 and the amount of the mercury lost to the tailing was between 28.00-33.33%.

The negative impact of amalgamation in Central Kalimantan are high mercury level and turbidity of several rivers. Bulk sediments concentration in the rivers are 250 ppb at Kapuas River, 300 ppb at Katingan, Tumbangnusa, and Barito Rivers, 400 ppb at Kahayan River and 1,650 ppb at Kalanaman River. Concentrations for the finest sediment fraction (less than 63 micrometer grain size) were three to ten times higher than that or the bulk concentration.

Mercury contents of suspended river sediments collected from Katingan, Tumbangnusa, Kapuas, Kahayan, Kalanaman, and Barito Rivers, and several mining ponds were considerably high. The mercury level of suspended sediments for an amalgamation pond in Galangan was 10 to 40 times higher than suspended sediments from regional rivers that was 10,000 ppb (dry weight) comparing to 250 to 900 ppb. The cause of high level of mercury level was dredging activities in the rivers that mobilizing huge volume of fine sediments which suspended and transported mercury to downstream (Telmer and Stapper, 2007). In Palu, based on the report of Palu Health Institution, the level of mercury in the river was about 0.01 ppm and this value was above the accepted standard for mercury (0.001-0.005 ppm).

RESULTS AND DISCUSSION

Several efforts can be implemented to minimize the impacts. Those are:

a. Gold and silver contents within the ores
   To evaluate effect of gold grade on the amalgamation process, it had been conducted amalgamation process using Lampung low and high grade ores. Each experiment used 50 kg and 500 g mercury. The average gold and silver of the low grade were contents of 13.19 g/t and 19.80 g/t, respectively. The average recovery of gold and silver was 53.20% and 27.68%, respectively and mercury losses to the tailing were between 1.8-4.8% or 3.69% in average. The weight of evaporated mercury during amalgam roasting depends on the amalgam weight. The average weight of

evaporated mercury was 46.55 g for the average amalgam weight of 58.18 g . The ratio of Hg evaporated to bullion recovered was 4.0 in average (Table 3).

A high grade retains gold and silver contents of 25.10-135.97 g/t and 400.16-5860 g/t, respectively. The highest recovery of amalgamation process was 94.04% for gold and 4.87% for silver. It was achieved using feed of 114.09 g/t gold and 1632.76 g/t silver. Gold recovery of amalgamation for the high grade was higher than that of the low grade one, but the silver recovery was lower (Table 3). It might be caused by very small silver particle size. The weight of evaporated mercury during roasting the amalgam depends on the weight of the amalgam. The weight of evaporated mercury was 2,209.48 g for 2,917 g amalgam weight, and about 78.75 g for 110.25 g amalgam weight. Whereas the ratio of evaporated Hg to bullion recovered were 3.12 and 2.50, respectively (Table 4).

b. Upgrading the ores before amalgamation
Study the effect of pre-concentration of the gold ore on the amalgamation process had been conducted by upgrading the ore using a sluice box. The ores were ground to liberate the gold and silver particles from its gangue minerals. The purposed is to make gravity separation easier. In addition, the contact between gold particle surfaces with mercury in the tromels will work properly and will result in higher gold recovery in the form of amalgam (Au-Hg);

Due to inadequate liberation of gold particle, the amalgamation process is unefficient. Size of gold in the ore can affect amalgamation recovery; the coarser the gold size, the higher the gold recovery. According to Veiga, et al. (2006), mercury efficiently captures gold particles that are coarser than 0.074 mm (200 mesh) and the dold content within concentrate should be more than 20 g/t. The concentrate obtained from the researchperformed19.6-234.06 g/t Au and 556.04-10782.59 g/t Ag (Table 5). The concentrate were then amalgamated. The results were shown in Table 5. It can be seen that the higher the gold content within feed, the higher the gold recovery. Gold recovery was 95.72% for gold ore that had a content of 214.92 g/t Au, however the Au recovery was only 76.91% for the ore within19.06 g/t Au. A good contact between gold particle of high grade with the liquid mercury is supposed to be the reason. The ratio of mercury evaporated to the bullion recovered was in the range of 0.85-3.37. It can be inferred then increasing the gold content prior to amalgamation will decrease mercury losses and increase gold recovery;

c. The quality of mercury
The mercury for amalgamation should be clean and fresh. Amalgamation process could work optimally if there is a good contact between gold particles with liquid mercury. For that reason, the used mercury should be cleaned by washing out its impurities that are coated on the mercury surfaces. After several times usage, the liquid mercury will be contaminated by some impurities or its surface is oxidized. The liquid mercury is the inactive (weak). To reactivate the substance, it should be put in salty water and connect to a radio or car battery for about 10-20 minutes, then use within 1 hour (Veiga, et al., 2006). Another process could be carried out by destilation;

d. Improving process condition
The amount of the employed mercury must be balance with the gold content within the ore. Trommel revolution (amalgamator) should also be regulated to improve the contact between mercury and gold particles. Pulp pH should be maintained >7 (neutral) and duration of amalgamation process has to be handled properly. Solid percentage of the slurry should be less than 50% and along 1 part of Hg and 100 parts of water the slurry was slowly agitated slowly for less than one hour to minimize flouring of the mercury. Gold recovery was about 90% in practice and mercury loss can be minimized as low as 0.5%. The differences of this amalgamation condition might be due to the difference of gold ore characteristic.

From field observation at Bolaang Mongondow, North Sulawesi; the achieved gold recovery from artisanal gold mining varies from 19 to 60% (Table 6), while the avrage mercury losses is 42.6%. After improving the condition of amalgamation process, the gold recovery increased to 84.08% with average mercury loss around 5.60% for a process without a sluice box and 2.77% for that within a sluice box (Table 7). These results were achieved by

Table 2. Estimation of mercury emissions and gold from Artisanal Mining Activities, Central Kalimantan (Telmer and Stapper, 2007)

Period	Number of Unit	Hg Consumed (ton/year)	Hg in amalgam (ton/year)	Hg in tailing (ton/year)	Hg consumed for period (ton)	Gold produced for period (ton)	Ratio of Hg consumed/ Gold produced for period	Hg losses in tailing (%)
2005-2007	2535	12.4	8.7	3.7	37.1	28.5	1.30	29.84
2001-2004	2028	9.9	6.9	3.0	29.7	22.8	1.30	30.30
1998-2000	1014	4.9	3.5	1.5	14.8	11.4	1.30	30.61
1995-1997	507	2.5	1.7	0.7	7.4	5.7	1.30	28.00
1992-1994	254	1.2	0.9	0.4	3.7	2.9	1.28	33.33
Total					92.7	71.3		

Table 3. Amalgamation low grade ore from DU238 location, Lampung (without pre-concentration)

No	Number of tromels	Total of Feed (kg)	Grade		Recovery	Recovery	Used Hg/ tromels (g)	Remained Hg in each tromel (g)	Hg losses to the tail-ing (%)	Amalgam weight (g)	Bullion weight (g)	Evaporated Hg (g)	Ratio evapo-rated Hg/ recovered bullion
			Au (g/t)	Ag (g/t)	Au (%)	Ag (%)							
1	30	1,600	5.10	8.17	36.76	24.64	500	477	4.6	31.10	6.22	24.88	4
2	40	2,000	7.22	10.41	39.13	25.69	500	480	4	55	11	44	4
3	48	2,400	6.33	13.05	73	25.22	500	475	5	67.60	13.52	54.08	4
4	16	800	16.01	22.54	61.52	25.24	500	478	4.4	56.75	11.35	45.40	4
5	24	1,200	12.75	19.19	44.12	26	500	485	3	63.65	12.73	50.92	4
6	32	1,600	10.16	20.61	43.54	26.40	500	491	1.8	69.75	13.95	55.80	4
7	8	400	22.18	31.15	67.08	34.19	500	482	3.6	51.05	10.21	40.84	4
8	11	550	18.37	36.31	52.96	32.66	500	476	4.8	60.45	12	48.45	4
9	16	800	20.55	16.78	60.71	29.08	500	490	2	68.25	13.65	54.60	4
Average	25	1,262	13.19	19.80	53.20	27.68	500.00	481.56	3.69	58.18	11.63	46.55	4.00

Table 4. Amalgamation of Lampung gold ore (high grade) in DU238 location, Lampung (without pre-concentration using a Sluice Box)

No	Grade		Amalgam weight (g)	Bullion weight (g)	Recovery		evaporated Hg (g)	Ratio evaporated Hg/ recovered bullion
	Au (g/t)	Ag (g/t)			Au (%)	Ag (%)		
1	114.09	1,632.76	1870	186.80	94.04	4.87	1,683.20	9.01
2	135.97	5,860.35	2917	707.52	89.85	9.99	2,209.48	3.12
3	95.48	4,797.85	2000	720.33	91.62	13.19	1,279.67	1.78
4	25.1	400.16	110.25	31.50	50.20	26.78	78.75	2.50

Table 5. Amalgamation of the concentrate obtained from a sluice box

No	Feed (kg)	Au grade (g/t)	Ag grade (g/t)	Amalgam weight (g)	Bullion weight (g)	Au recovery (%)	Ag recovery (%)	The weight of Hg evaporated (g)	Ratio of Hg evaporated/ bullion recovered
1	325.7	234.06	10782.59	7121	1630.65	90.86	13.15	5490.35	3.37
2	268.6	156.22	6350.53	3765	1214.75	91.63	16.87	2550.25	2.10
3	274.1	214.92	3150.34	1430	611.46	95.72	12.88	818.54	1.34
4	233.8	22.05	1257.42	90	48.67	75.51	2.55	41.33	0.85
5	145.2	19.06	556.04	200	51.7	76.91	6.66	148.3	2.87

Table 6. Criteria and research result of gold amalgamation (Bolaang Mongondow, North Sulawesi)

Criteria of amalgamation	The result of artisanal gold amalgamation	The research result of gold amalgamation
Particle size (mesh)	200	170
Solid percentage (%)	> 70 or uncertain	50
Revolution of trommel (rpm)	uncertain	Based on critical speed 40 - 50 rpm (for tromel with size 50cmx70cm)
Mercury condition	Weak	Fresh and clean
The amount of mercury	Excess or uncertain	800 g (for ore 50 kg and Au 25 g/t)
Revolution time (hour)	Uncertain	7
pH	5 - 6.5	7
Recovery of Au (%)	19 - 60	84
Losses of Hg (%)	42.6	5.6

Table 7a. Amalgamation and sluicing processes to minimize mercury loss at Bolaang Mongondow, North Sulawesi

				Amalgamation Process					
No	Feed Weight (kg)	Au grade in feed (g/t)	Au weight in feed (g)	Hg consumption (g)	Hg losses in trommels (g)	Bullion weight (g)	Au recovery in trommels (%)	Hg losses in good amalgamation (%)	Hg losses in artisanal gold amalgamation (%)
1	48	9	0.432	500	22	0.31	73	4.4	50
2	48	11	0.528	500	30	0.35	65	6	50
3	48	13	0.624	500	26	0.48	77	5.2	50
4	48	12	0.576	500	38	-	78	7.6	50
5	48	14	0.672	500	32	-	84	6.4	50
6	48	9	0.432	500	20	-	71	4	50
Average	48	11.33	0.54	500	28	0.19	74.67	5.60	50

Source : Mutaalim, 2006

Table 7b. Amalgamation and sluicing processes to minimize mercury loss at Bolaang Mongondow, North Sulawesi

Sluicing Process (Solid percentage=40%; Slope for no 1-3 = 2o and no 4-6=4o)										
No	Feed Weight (kg)	Au grade in feed (g/t)	Au weight in feed (g)	Hg recovery in sluice box (g)	Weight of con-centrate (g)	Au grade in concen-trate (g/t)	Hg recovery by using sluice box (%)	Au recovery (%)	Hg losses from sluice ox (g)	Hg losses from Hg used in tromels
1	48125	2.4	0.12	(%)	4,125	14	70	50	6.6	1.32
2	47992	3.8	0.18	17.4	5,994	14.3	58	47	12.6	2.52
3	48072	3	0.14	10.4	4,006	14.4	40	40	15.6	3.12
4	48068	2.7	0.13	19	3,980	15	50	46	19	3.8
5	48087	2.2	0.11	14.4	3,556	11.9	45	40	17.6	3.52
6	47828	2.6	0.12	8.4	3,886	12.8	42	40	11.6	2.32
Average	48028	2.78	0.13	14.17	4,257	13.73	50.83	43.83	13.83	2.77

Source : Mutaalim, 2006

considering several factors that affected the amalgamation such as fineness of the ore, solid percentage of the slurry, rotation of the trommel, quality of the mercury, duration of the tromels rotation, and acidity of the slurry. On the other hand, gold recovery > 60% can be achieved by KUD Selogiri, artisanal gold mining in Central Java, for gold ore with grade > 20 g/t. Au recovery from direct amalgamation with Au content between 10-16 g/t) was between 56,61-60,34%, while by gravity concentration, the Au grade could be increased from 4 to 526.5 g/t with Au recovering $\geq$ 80%. The Hg loss in direct amalgamation is 3-5 % for each process (Tahli, et al., 2009). Gold processing by gravity concentration at pilot scale in Wonogiri, Central Java showed that the greater the gold grade the higher the gold recovery.

Efforts that should be conducted to handle amalgamation product are as follows:

- using a retort
  The best technique to recover the gold from the amalgam is using a retort for burning the amalgam and evaporating the mercury. The process is then followed by condensation using a condenser to get the mercury liquid. This mercury could be recycled to the amalgamation process (Hinton, et al., 2003). Heat for burning the amalgam must be proper (around 350°C). Insufficient heat will leave more than 20% mercury within gold. Retort is a simple and highly cost-effective method to controll mercury release into the environment. Over 95% of mercury vapor can be captured. Types of the retort vary. There are bowl retort, pipe retort, hood, filter, etc. Typical retort cost is approximately between US$5 and US$20;

- using a sluice box and mixer
  Discharge amalgamation tailing should be carefully handled. Liquid mercury in amalgamation tailings should be recovered by a mixing method. Solid percentage in this method is less than 30% (Veiga, et al., 2006). It will settle the mercury to the bottom of the tank. The upper part of the slurry is discharged into a sluice box to capture mercury liquid before discharging it to tailing pond.

- if amalgamation tailing with a relatively high gold content will be processed by either using gravity concentration or cyanidation, location for equipment to recovery gold from tailing should be safe and far from the river and houses. The waste of cyanidation process that is discharged to the tailing pond should satisfy the standard. Cyanidation of amalgamation tailing should be carried out using 0.1% NaCN solution to extract the gold within the tailing. Condition for the process is determind at pH 11, 20% solid percentage and the NaCN doses suitable to the amount of the tailing;

- centralizing the tromels is necessary to handle the tailing. This is implemented interms of increasing gold recovery and reducing Hg release. This method has been constructed in Venezuela;

- Trained operator must be handle the amalgamation, retorting and smelting processes. Usually, miners at North Sulawesi take their gravity concentrates to private or state-owned centers to be amalgamated, retorted and smelted by trained operators. Mercury should be stored safely when it is not used in safe containers that are covered with a thin (1 cm) layer of water to prevent mercury evaporation;

- Education is the largest barrier to adopt such a technology for artisanal gold mining. Education and technology should be provided to the artisanal gold miners as their knowledge regard minimizing the exposure into the environment. The limit of mercury vapor for public exposure is 1.0 μg/m³. When burning the amalgam in open air, miners can be exposed to the Hg around 60,000 μg/m³. Acute Hg poisoning, results from inhalating 1,200 to 8,500 μg/m³ Hg vapor (Veiga, et al., 2006).

CONCLUSIONS AND SUGESTIONS

Conclusions

- The amalgamation process conducted by the artisanal gold mining in Indonesia shows the mercury loss in tailings between 19-60%. To decrease the loss, pre-concentration of the ore should be conducted.

- To protect the environment, gold amalgamation should be conducted within a 100 m from any waters. Its waste should be passed through a sluice box to catch mercury liquid prior to discharging to the ponds.

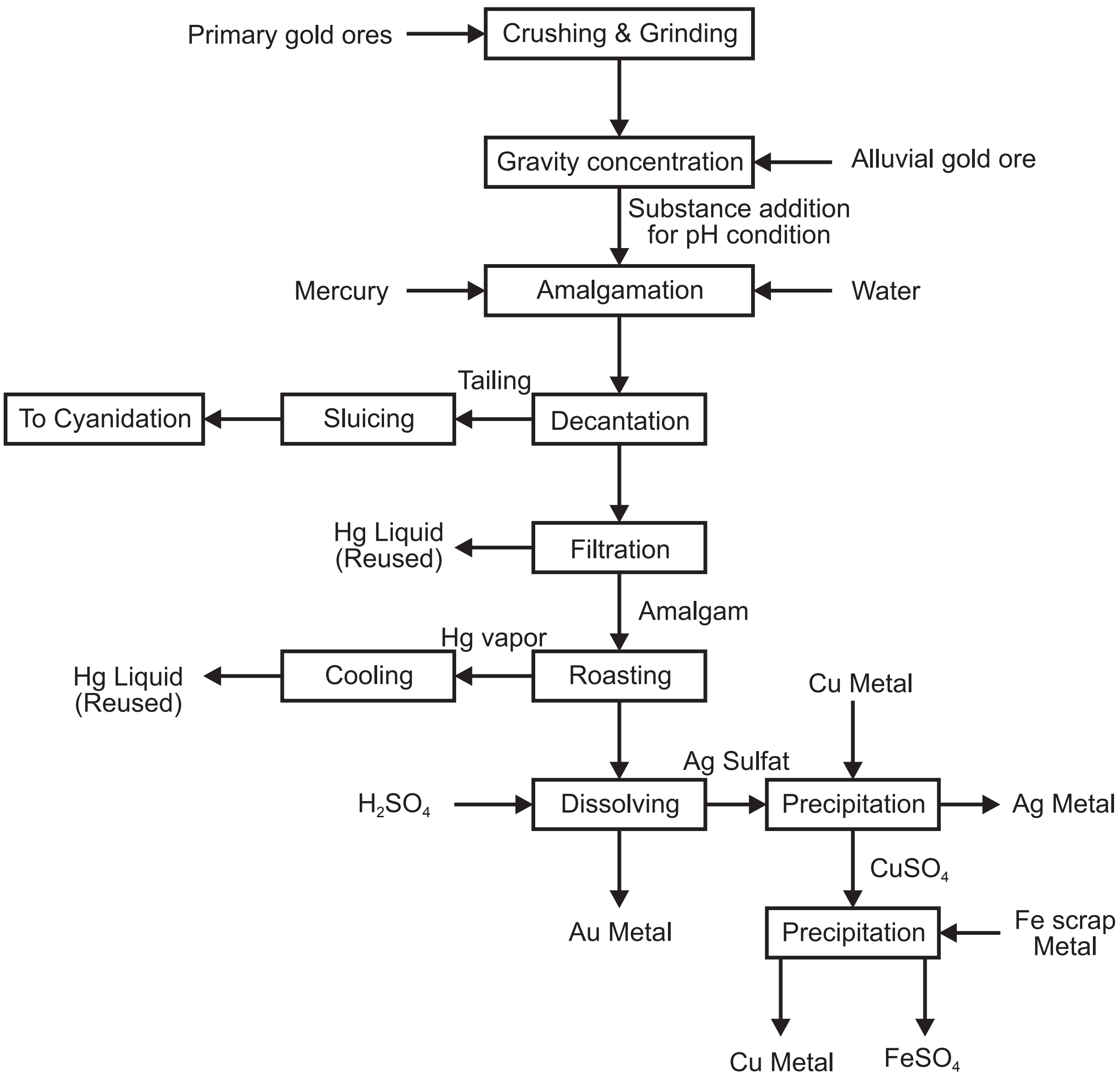

Figure 2. Modification of gold amalgamation to minimize mercury losses (Source : Husaini, et al., 2010)

- Liquid mercury should be stored in safe containers.
- A retort should be used to recover the gold from the amalgam in order to protect the environment.
- Each miner should follow standard requirement proposed by a regional government official including mining expert.

Sugestions

- Governments should provide education on environmental management and a technological assistance in areas of high concentration of the artisanal gold miners.
- The artisanal gold mining in the form of the Village Cooperative Unit should be centralized to the tailing and obtain amalgamation license.

REFERENCES

Beinhoff, C., 2007, Removal of barriers to the abatement of global mercury pollution from artisanal gold mining, *Global Mercury Project, United Nations Industrial Development Organization (UNIDO)*, Vienna/Austria, p. 1-4.

Darmutji, S.T. 2003, Overview of project site in Indonesia Talawaan and Galangan areas, *Global Mercury Project*, December 2003, p. 7-17.

Hinton, J. J., Veiga, M. M.. and Veiga, T.C. 2003, Clean artisanal gold mining: a utopian approach?, *Journal of Cleaner Production 11 (2003)*, p. 99–115.

Husaini, Yunianto B., dan Sujarwanto, 2010, Investigation of mining and processing of gold ores in Poboya, Palu, September 2010 (unpublished material).

McCartor, Andrew J.D. and Becker, Dan B.A. , 2010, Top six toxic threats six pollutants that jeopardize the health of tens of millions of people lead, mercury, chromium, arsenic, pesticides, radionuclides, *World´s Worst Pollution Problems Report 2010*, Blacksmith Institute in partnership with Green Cross Switzerland, p.19-55.

Mutaalim, 2006, The amalgamation and sluicing processes to minimize mercury losses in Bolaang Mongondow, North Sulawesi (unpublished material).

Sumual, Herry, 2009, Characterization of the traditional gold mining in Dimembe, North Minahasa, *Agritek Vol. 17, No. 5*, September (2009), p. 164-168.

Tahli, L., 2009, *Teknologi pengolahan emas*, Puslitbang Teknologi Mineral dan Batubara, Bandung, p.10-60.

Telmer, T. and Stapper, D., 2007, Evaluating and monitoring small scale gold mining and mercury use: building a knowledge-base with satellite imagery and field work UNIDO PROJECT EG/GLO/01/G34, *FINAL REPORT November 2007 Aqueous Geochemistry Laboratory*, School of Earth and Ocean Sciences, University of Victoria, p.19-30.

Veiga, M. M., Baker, R.F, 2006, Removal of barriers to introduction of cleaner artisanal gold mining and extraction technologies, Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners, *Project EG/GLO/01/G34, Global Mercury Project*, Coordination Unit, Vienna, UNIDO, p.6-26.

Veiga, M. M., Baker, R.F., Metcalf, S. M., Klein, B., Davis, G., Bamber, A., Singo, P., 2006, Removal of barriers to introduction of cleaner artisanal gold mining and extraction technologies, manual for training artisanal and small-scale gold miners, Project EG/GLO/01/G34, Global Mercury Project, Coordination Unit, Vienna, UNIDO, p.16-50.