SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

DETERMINING THE SETTLING VELOCITY BASED ON SIZE AND SHAPE OF GOLD PARTICLE TO IMPROVE THE DESIGN OF SLUICE BOX

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled **"Determining the Settling Velocity Based on Size and Shape of Gold Particle to Improve the Design of Sluice Box"**. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any further examining body or university.

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MENYELESAIKAN HALAJU PENGENAPAN BERDASARKAN UKURAN DAN BENTUK ZARAH EMAS UNTUK MENINGKATKAN REKA BENTUK KOTAK SLUIS (PALONG)

ABSTRAK

Penggunaan merkuri yang bertumpu kepada pelombong tradisional berskala kecil membawa kepada masalah pencemaran global. Dalam kajian ini,masalah yang dihadapi dalam kotak sluis atau palong telah disiasat dan data yang diperolehi adalah daripada kajian literatur. Daripada kajian, pengiraan akan dijalankan daripada dapatan kajian literatur berdasarkan undang-undang Stokes, dan Newton. Seterusnya, keputusan pengiraan yang diperolehi, halaju pengenapan akan memberi maklumat mengenai perilaku zarah berdasarkan saiz dan bentuk. Berdasarkan keputusan, masalah saiz zarah yang terlalu halus dan bentuk yang tidak teratur atau bentuk penyerpihan boleh memberi kesan kepada zarah untuk menetap. Di samping itu, kesan darjah kecondongan kotak sluis, dan nilai yang berbeza daripada kadar aliran juga sedang menjalankan dengan pengiraan justifikasi. Walau bagaimanapun, reka bentuk ini tidak cukup untuk membuktikan sama ada ia berjaya atau tidak hanya dengan menggunakan kaedah pengiraan. Reka bentuk yang dicadangkan perlu menjadi ujian dengan kaedah lagi eksperimen dan simulasi.

DETERMINING THE SETTLING VELOCITY BASED ON SIZE AND SHAPE OF GOLD PARTICLE TO IMPROVE THE DESIGN OF SLUICE BOX

ABSTRACT

The use of mercury in Artisanal Small Scale Mining (ASGM) has led to the global problem. In this study, the problem faced in sluice box had been investigated and the data involved was obtained from the literature study. The calculation was justified from the literature study based on Stokes' and Newton's law. Next, the result obtained that influencing the settling velocity gave information about the behaviour of the particles sizes and shape. Based on the result, the problem of too fine particle size and irregular or flakiness shape can affect the particle to settle. In addition, the effect of degree of inclination of sluice box, and different value of flow rate also being carried out by calculation justification. However, this design is not enough to prove whether it is successful or not just by using calculation method. The proposed design need to be tested by further experimental and simulation method.

CHAPTER 1

INTRODUCTION

1.1 Artisanal Small-scale Gold Mining (ASGM)

Artisanal and small-scale mining (ASM) is an important activity in many developing countries particularly in rural regions where economic agriculture are limited as it provides a primary and additional source of income. It has been reported that more than 30 different minerals substances are extracted by ASM operations worldwide (Priester M, 1993).

Artisanal and Small Scale Mining (ASM) is emerging as an important socio-economic sector for the rural poor in many developing nations. An artisanal miner or small-scale miner is, in effect, a subsistence miner. They are not officially employed by a mining company, but rather work independently, mining or panning for gold using their own resources. Small-scale mining includes enterprises or individuals that employ workers for mining, but generally working with hand tools.

Artisanal mining can include activities as simple as panning for gold in rivers, to as complex as development of underground workings and small-scale processing plants. In any of these circumstances, issues can stem from difficulties in achieving regulatory oversight of a large number of small operations (including issues such as security of land tenure for artisanal miners, to enforcement of environment, safety standards, and labour standards).

Artisanal Small Scale Gold Mining (ASGM) accounted for approximately 25% of the estimated 3000 tons of annual global gold production in 2002 (Spiegel and Veiga, 2010; MMSD, 2002). ASGM activities have dramatically increased in the recent years (Shandro et al., 2009) due to the global economic crisis and rising price of gold in 2011 (average of 1653 USD/troy ounce, www.lbma.org.uk).

1.2 Gold Description

Alluvial gold usually occurs in large, often visible nuggets and in unconsolidated materials makes alluvial gold are relatively easy to find and can be recovered by using inexpensive, simple technology. Gold is easy to transport across the borders and easily sold, and is by far the main metal being extracted.

Gold is resistant to most acids, though it does dissolve in aqua regia, a mixture of nitric acid and hydrochloric acid, which forms a soluble tetrachloroaurate anion. Gold is insoluble in nitric acid, which dissolves silver and base metals, a property that has long been used to refine gold and to confirm the presence of gold in metallic objects, giving rise to the term acid test. Gold also dissolves in alkaline solutions of cyanide, which are used in mining and electroplating. Gold dissolves in mercury, forming amalgam alloys, but this is not a chemical reaction.

Historically, the value of gold was rooted in its relative rarity, easy handling and minting, easy smelting and fabrication, resistance to corrosion and other chemical reactions (nobility) and its distinctive color (Anderson et al,2009). As a precious metal, gold has been used for coinage, jewelry, and other arts throughout recorded history. In the past, a gold standard was often implemented as a monetary policy, but gold coins ceased to be minted as a circulating currency in the 1930s, and the world gold standard was abandoned for a fiat currency system after 1976.

A total of 186,700 tonnes of gold is in existence above ground, as of 2015 (supply, 2016). The world consumption of new gold produced is about 50% in jewelry, 40% in investments, and 10% in industry (Soos, Andy, 2011). As at December 2015, gold is valued at around $39 per gram ($1,200 per troy ounce).

Like other precious metals, gold is measured by troy weight and by grams. The proportion of gold in the alloy is measured by karat (k), with 24 karat (24k) being pure gold, and lower karat numbers proportionally less. The purity of a gold bar or coin can also be expressed as a decimal figure ranging from 0 to 1, known as the millesimal fineness, such as 0.995 being nearly pure.

1.3 Mercury Description

Mercury is an extremely rare element in Earth's crust, having an average crustal abundance by mass of only 0.08 parts per million (ppm) (Ehrlich, H.L, 2008). Because it does not blend geochemically with those elements that constitute the majority of the crustal mass, mercury ores can be extraordinarily concentrated considering the element's abundance in ordinary rock.

The richest mercury ores contain up to 2.5% mercury by mass, and even the leanest concentrated deposits are at least 0.1% mercury (12,000 times average crustal abundance). It is found either as a native metal (rare) or in cinnabar, corderoite, livingstonite and other minerals, with cinnabar (HgS) being the most common ore (Rytuba, James J.,2000).

Mercury ores usually occur in very young orogenic belts where rocks of high density are forced to the crust of Earth, often in hot springs or other volcanic regions

(USGS, 2009). Mercury dissolves many other metals such as gold and silver to form amalgams. Iron is an exception, and iron flasks have traditionally been used to trade mercury. Several other first row transition metals with the exception of manganese, copper and zinc are reluctant to form amalgams. Other elements that do not readily form amalgams with mercury include platinum.[12][13] Sodium amalgam is a common reducing agent in organic synthesis, and is also used in high-pressure sodium lamps.

Mercury readily combines with aluminium to form a mercury-aluminium amalgam when the two pure metals come into contact. Since the amalgam destroys the aluminium oxide layer which protects metallic aluminium from oxidizing in-depth (as in iron rusting), even small amounts of mercury can seriously corrode aluminium. For this reason, mercury is not allowed aboard an aircraft under most circumstances because of the risk of it forming an amalgam with exposed aluminium parts in the aircraft (Vargel. C, 2004).

1.4 The using of Mercury in Extracting Gold in ASGM

In artisanal small-scale gold mining, ASGM miners do not have to blast or break the hard rock as the alluvial gold occurs as free gold, which are not bonded with other materials chemically or physically, and today, they mostly use mercury as a method to extract gold from its gangue. The use of mercury in mineral processing still remains as a preferred method employed by ASM to extract gold in mercury amalgamation although it is illegal in most countries. Some of artisanal miners think only of immediate benefits regardless of the hazards of their activities to themselves and the environment.

Figure 1.1: Mercury that used in traditional mining to extract gold without using a proper tools to handle it (Chandal, 2013)

When mercury is brought into contact with gold particles in sediments or crushed ore, it forms “amalgam” - a soft mixture of roughly 50% mercury and 50% gold. To recover gold from the amalgam, it is heated to evaporate the mercury, leaving the gold behind. Mercury is released into air, water, and soil in several of the steps of this process. Millions of miners, infants, children, women of child bearing age (potentially pregnant), and breast-feeding women, work or live in ASGM communities and are at risk of mercury exposure.

Mercury vapors in the air around amalgam burning sites can be alarmingly high and almost always exceed the WHO limit for public exposure of 1,000 nanogram/cubic meter1. This risks the health of workers but also those in the communities surrounding the processing centers. Exposure to levels of mercury vapors above 1,200,000 nanogram/cubic meter can be fatal.

The excessive use of mercury within ASGM has resulted in the sector becoming the number one global mercury polluter (Telmer and Viega, 2009). Mercury contamination in and around ASGM settlement is now widely acknowledged and reported, but there is no indication that the research has facilitated significant mercury abatement. The usage of this hazardous materials during gold extraction can lead to global problem affecting not only to human but also to the ecosystem which lead to the largest contributor of mercury emission in the world today.

Figure 1.2 shows the method that used to extracting gold with mercury and the process that involved in order to get the pure gold.

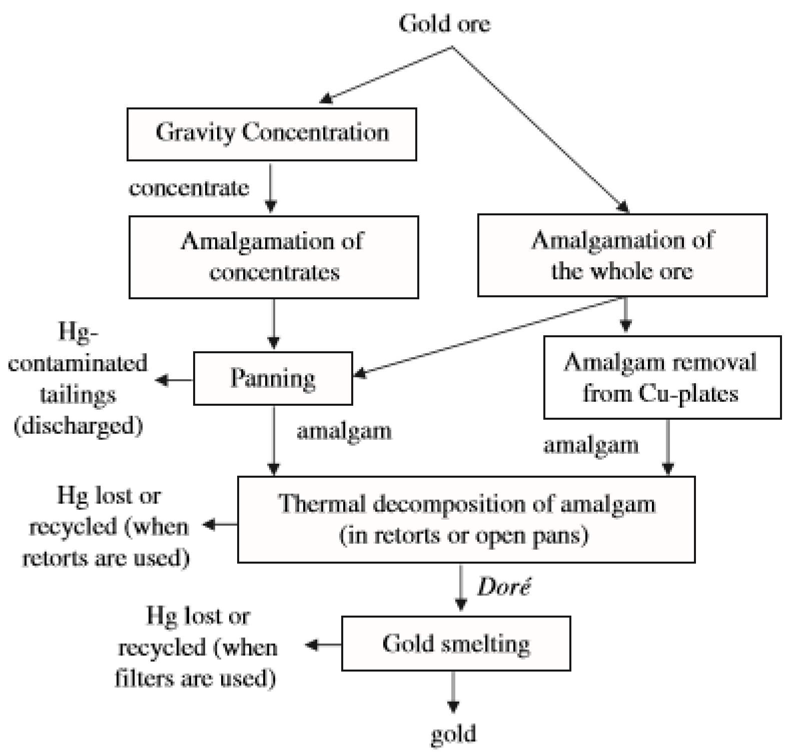

Figure 1.2: Methods used in artisanal mining operation to extract gold with mercury (Veiga et al, 2006)

Figure 1.3: Gold amalgam after the mercury mixed with gold concentrate (Saulo, 2004).

Hence, in order to reduce the using mercury to extract gold, this research will study the gravity concentrator that specifically on sluice box gravity separation on the designing of sluice boxes which the aim is to improve the performance and efficiency of sluice boxes that involving parameter such as slopes, width and length, and type of riffles incorporated. This research will focusing more on the relationshiip settling velocity of particles and the flow velocity that happens in the sluice box.

1.5 Problem Statement

The use of mercury in ASGM activity to extract gold have serious effect not only to human but also to environment. The main reasons that mercury is so widely used by ASM gold miners are that mercury are easy to use, available, inexpensive and miners are choose to ignore, the health risk that they will encounter when using the mercury.

In order to replace or reduce the usage of mercury in ASGM activity, gravity separators can be use and one of the method in gravity separators is by using sluice boxes. Sluice boxes is a box like a long tray which is open at both ends, which most commonly used for concentrating gold from alluvial gravels.

Sluice boxes recover the gold effectively with particle size from 25 mm to 100 µm. However, their performance becomes less effective when it comes to fine gold recovery. Recovery has always been a problem which in mostly in a standard of sluice box, it barely capture fine gold. This problem might be related to the settling rate of particles because coarse gold particle are quicker to settle down as gravity high effect on them compared to fine gold particles.

Most of sluice box have riffles along the bottom that are used to trap heavier mineral particles where in this case, to trap gold particle as water wash them and other materials along the box. The riffles cause small barriers to the water flow which creates eddies in the water, which makes the heavier materials such as gold and iron drop to the bottom, behind the riffles.

1.6 Objectives

In investigating the problem faced by sluice boxes to improve the performance and efficiency by calculation justification, the objective specifically targeting as below:

1. To determine the settling velocity for fine and coarse particles
2. To determine the settling velocity for particles based on their shape
3. To evaluate the settling velocity of particles and the flow velocity as well as proposed the design for the sluice box

1.7 Scope of Research

The data was collected from the literature study in order to analyse the relationship between recovery of concentrate and sluice box by comparing the sluice box gravity separation with the other gravity separator technologies.

The problems that occur will be studied in order to improve the efficiency of sluice box to recover fine gold by designing sluice box with few parameters involve including determining the settling velocity of particles based on size and shape which hopefully can overcome the problem in sluice box performance. The drawing of sluice box will use AutoCAD as a design software.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Gold is a chemical element with an atomic of 79 and known with symbol of Au (aurum), usually occurs in native form which are not combined with other elements. Gold has metallic luster with sun yellow colour in its pure form, however, when they are combine with the other metals such as platinum, nickel, silver copper and iron, the colour created from the combination of those metals comes in various colour hues ranging from silver to white to green and orange-red.

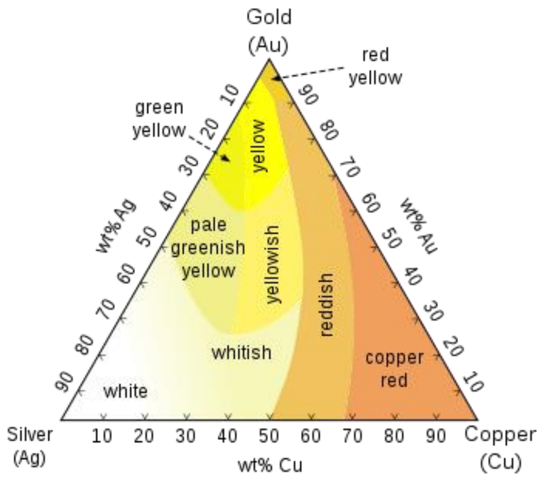

Figure 2.1: Gradation of colour of gold-copper-silver alloys (McDonald, 1978).

Gold is a heavy, precious metals with high density of 19.3 g/cm^3 which present at appreciable amount throughout the world. An impure gold that has density ranging from 15 to 19 g/cm^3,usually associated with gangue mineral that has lower density than the gold itself which enables the gold to be concentrated by gravity method. These method can separate clay, silt, sand and gravel from the gold by using various agitating and collecting devices such as sluice box and gold panning.

In the periodic table, gold is one of the least reactive chemical solid element under standard conditions which often occurs in native elements such as grains or nuggets in rocks, veins and alluvial deposits. In Malaysia, gold has been mined from both alluvial and hard rock mining. Gold has been used mostly as a jewellery which consume half of the new gold produced, 40% in investment and another 10% in industry. Gold can be found in ore in rock form, as nuggets or grains, in veins, alluvial deposits and placer deposits.

2.2 Main Method of Gold Extraction and Their Application

2.2.1 Main method of gold extraction

In gold processing, there are many ways to separate gold and one of the method that have been used for centuries are gravity separation. The main methods that always been used in industry are gravity separation, gold cyanidation and amalgamation.

a) Gravity separation

Separation by density difference is a process that is as old as recorded history. The principle employed in gravity separation goes back further in time to the formation and weathering of the rocks and the releasing of the minerals they contain and the transport of the mineral grains by heavy rains. It is the driving force for the formation of the alluvial deposits of precious metals and gemstones that have been worked since beyond recorded history as they still are today. Archaeological excavations have discovered mineral concentration activities such as the lead-silver concentrating plant in Attica, Greece, dating from 300-400 BC. So gravity separation has a long history as a mineral concentration process. Not all mineral combinations are amenable to this type of concentration technique.

Gravity separation is a method that used gravity to separate two or more minerals that basically have different specific gravity that separate the minerals by their relative movement in response to gravity that resist motion offered by viscous fluid. The difference in density between the minerals and the gangue are essential in order to get an effective separation. The type of separation possible can be gained from the Concentration Criterion,

$$Concentration\ criterion = \frac{D_h - D_f}{D_l - D_f} \tag{2.1}$$

Where

D_h = specific gravity for heavy mineral

D_f =specific gravity for fluid medium

D_l =specific gravity for light mineral

Based on the concentration criterion, if the value are more than 2.5, either in positive or negative, the gravity separation are easy to do, which the efficiency of separation decrease as the value of concentration criterion decrease.

Table 2.1: Concentration Criterion guide for gravity separation Source: Aplan 1985)

Values of Concentration	Significant for separation
> 2.50	Effective down to -75 µm
2.50 - 1.75	Effective down to -150 µm
1.75 - 1.50	Possible to 2 mm
1.50 - 1.25	Possible to 6mm
<1.25	Relative separation impractical (impossible at any size)

b) Gold cyanidation

Other methods used in gold extraction are gold cyanidation which is a metallurgical technique to extract gold by converting the gold to a water soluble coordination complex. Gold cyanidation (also known as the cyanide process or the MacArthur-Forrest process) is a hydrometallurgical technique for extracting gold from low-grade ore by converting the gold to a water-soluble coordination complex. It is the most commonly used leaching process for gold extraction. The main chemical reaction thats take place in gold cyanidation is the Elsner Equation:-

$$4Au + 8NaCN + O_2 + 2H_2O \Rightarrow 4Na\,[Au\,(CN)_2] + 4NaOH$$

The ore that has been ground will be leached in agitated tank and acid will be added to make sure that the gold is separated from its gangue. The extraction of gold from the cyanide leach solution is done by introducing the activated carbon to the tank and these carbon recovery system offers high recovery rates and lower capital and operating costs. These carbon recovery techniques include:

- Carbon-in-pulp :

  In order to form a slurry in an agitation tank, the ore is crushed, finely ground and mixed with the cyanide leach solution. The activated carbon is introduced into the slurry and then removed by screening once it is fully loaded or “pregnant” with gold.

- Carbon-in-leach :

  The process of CIL is very similar to the CIP process. The differences between these two processes are the way the slurry being prepared and the method to remove the gold from the leachate. The carbon is mixed with the leachate solution in CIL process whereas the carbon in CIP process is mixed with pulp. This less abrasive system make the carbon lasts much longer than in CIP process.

- Carbon-in-columns :

  This process in very effective to remove the gold from the low grade ore and during this process, the columns is filled with ore and the cyanide leaching solution passes through these columns. The using of resins replacing the carbon as the gold recovery substrate of choice has been started in few years back. Basically, the process used in resin recovery is quite similar to carbon, which the gold is adsorbed onto solid spherical polystyrene resin beads rather than activated carbon grains.

Despite being used in 90% of gold production, gold cyanidation is controversial due to the toxic nature of cyanide. Although aqueous solutions of cyanide degrade rapidly in sunlight, the less-toxic products, such as cyanates and thiocyanates, may persist for some years.

c) Amalgamation

Another method to extract gold are amalgamation which involved the use of mercury. There are two main ways that mercury can be used in ASGM:-

i. Whole ore amalgamation:

Whole ore amalgamation involving a process of mercury in direct contact with 100% of the material that has being mined. Mercury use ranges from high (4 parts mercury for each part gold recovered) to very high (20 parts mercury for every part gold or higher). In extreme cases, for example where ore is rich in silver, the ratio can be 50:1.

It is considered as poor practices due to its inefficient because it rarely captures more than 30% of the gold and results in major losses of mercury to tailings (waste material). Furthermore, large amounts of mercury are lost to the tailing because the mechanical process produces tiny mercury droplets that are too dispersed to capture. The result is mercury contaminated sites that are very difficult to clean up.

ii. Concentrate amalgamation:

Gravity method is a method that usually used to concentrate the gold into a smaller portion before the process of amalgamation. The concentrate contain the heaviest minerals including gold and mercury are used only on the concentrate. The difference of concentrate amalgamation and whole ore amalgamation is the amount of the mercury that are used to produce the gold. Whole ore amalgamation use more mercury compared to concentrate amalgamation which release only little or no mercury to tailing.Despite releasing less mercury to the environment than WOA concentrate amalgamation can still result in significant human exposure through inhalation of mercury vapor when safety equipment like retorts or fume hoods are not used.

Many artisanal miners extract gold by mercury because it is the quickest and the easiest way to extract gold, unlike the other manual gravity method, which consume more time to extract the gold. Furthermore, mercury is very effective in capturing gold under condition found in ASGM sites and the whole mining process can be done by one person.

However, the use of mercury in ASGM are dangerous due to its powerful neurotoxin that is harmful not only to people, but also to the environment. Totalling of 37% of inorganic mercury emissions in the world today, ASGM activities contribute the largest source of anthropogenic mercury emissions and the percentage increased steadily since 1995 (Veiga et al., 2014).

Based on the record in 2010, 1,960 tonnes of mercury estimated that emitted annually into the air from all human activities and from this estimated amount, 727 tonnes are from ASGM activity (UNEP, 2013; Veiga et al., 2014). As the operation rise, the abandoned facilities that mostly contaminated with hazardous substance such as mercury, cyanide and other chemicals used in the process of extraction, will also increase. (Veiga & Hinton, 2002).

Once the mercury is released, it can travel in a great distance through the atmosphere, causing contamination of ecosystems and human food chain. Mercury (2012) estimates the annual mercury consumption from ASGM in Tanzania to be as much as 45 t indicating the magnitude of the ‘mercury problem’. During gold extraction with mercury, miners typically mix the mineral concentrates with mercury with their bare hands, after which they heat the gold– mercury amalgam resulting in the mercury evaporating. The vapours pose an immediate health threat to people close to the extraction site. The mercury vapour gradually condenses on the ground and enters the drainage system and subsequently the food chain, where it eventually causes damage to humans. Mercury is harmful to the central nervous system and may eventually cause irreparable brain damage (e.g., Appleton et al., 2004; Chibunda, 2008; Tomicic et al., 2011).

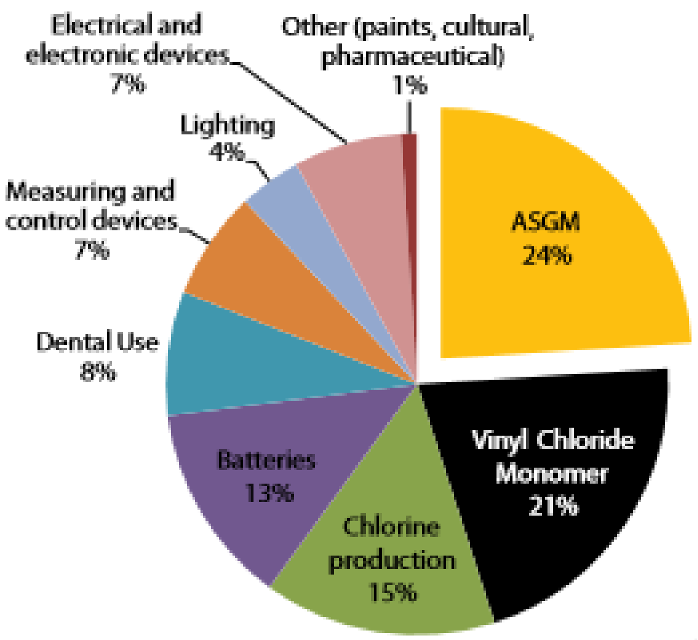

Figure 2.2: Mercury demand (annual consumption) in 2011 (UNEP, 2013).

Based on Figure 2.2, the mercury demand for annual consumption in 2011, artisanal small-scale gold mining took over 24 out of 100 percent which proved that most of mercury demand were from the ASGM industry (UNEP, 2013; Veiga, 2014). An estimated 1400 tonnes of mercury were used by ASGM miners globally in 2011 (www.mercurywatch.org).

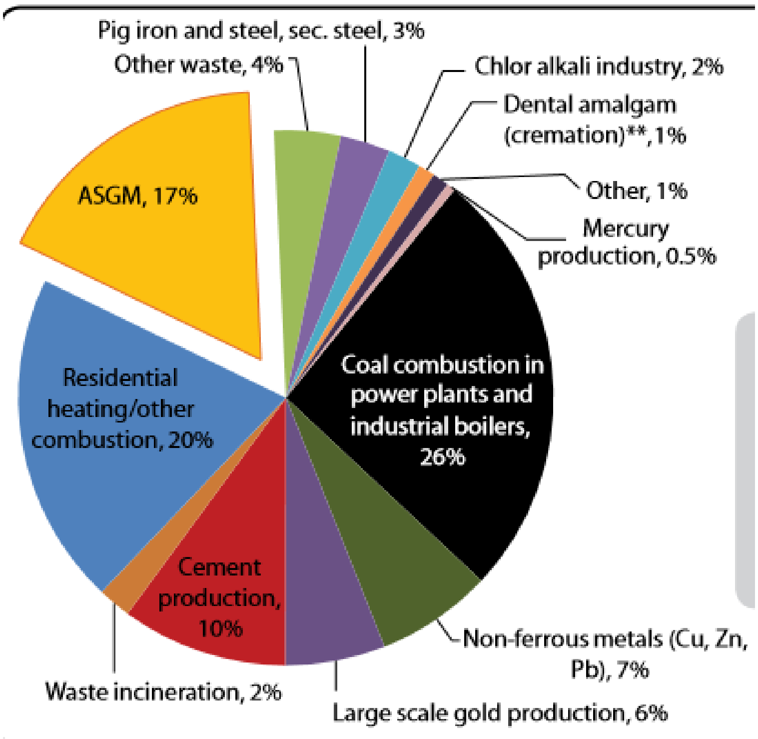

Figure 2.3: Mercury emission to the atmosphere (UNEP, 2013)

2.2.2 Uses and Applications of Gold

Gold has a long and fascinating history of their uses in various range of industries. Due to its factors of low contact resistance, high electrical conductivity, excellent reflectivity, corrosion resistance, ductility, stability and wear resistance, it is use in wide range of application for examples:

i. Jewellery and financial gold:

   For thousands of years, gold has been used as an ornament and jewellery due to its special properties that makes it perfect for manufacturing jewellery. In order to increase its durability, gold are alloyed with other metals such as copper and silver because pure gold are too soft to stand up to the stresses applied to many jewellery items. Gold has long been used as a medium of exchange or money which usually held in bars, known as gold bullion are used as financial backing currency.

ii. Electric and electronics:

In every sophisticated electronic device such as cell phones and global positioning system (GPS) units, small amount of gold is inserted in the devices to avoid interruption of the tiny currents used by these devices and remain free from corrosion.

iii. Dentistry and medical purposes:

In dentistry industry, due to its superior performance and aesthetic appeal, gold is used as a dental filling even it is expensive. In medical industry, gold is used as a drug to treat small number of medical conditions, radioactive gold is used in diagnosis and surgical instruments also contain small amount of gold which are highly reliable in electronic equipment and life-support devices.

iv. Automotive industry:

In build an airplane, gold alloy are used to join the parts of airplane engine safely and the windscreen are coated with thin gold in order to reflect the infrared radiation. In modern car today, gold are implemented as a microchips and sensors which control the anti-locked brakes chips or in sensors for inflating safety air bags.

v. Computers:

The rapid and accurate transmission of digital information through the computer and from one component to another requires an efficient and reliable conductor. Gold meets these requirements better than any other metal. The importance of high quality and reliable performance justifies the high cost. Edge connectors used to mount microprocessor and memory chips onto the motherboard and the plug-and-socket connectors used to attach cables all contain gold.

vi. Glassmaking

Gold has many uses in the production of glass. The most basic use in glassmaking is that of a pigment. A small amount of gold, if suspended in the glass when it is annealed, will produce a rich ruby color. Gold is also used when making specialty glass for climate-controlled buildings and cases. A small amount of gold dispersed within the glass or coated onto the glass surface will reflect solar radiation outward, helping the buildings stay cool in the summer, and reflect internal heat inward, helping them stay warm in winter.

2.3 General Description of Sluice Box in Gold Processing

Sluicing is a method or a way to separate and recover gold by using running water and have been used for over a thousand years which are still being used in small scale gold mining operation. Sluice box is a box like a long tray which is open at both ends, which most commonly used for concentrating gold from alluvial gravels. A wide sluice box are more suitable in the recovery of fine heavy minerals because it produces a thinner film of water with a given fluid flow. As for a narrower sluice box, it is more convenient for larger particles and transport the coarse gangue mineral throughout the sluice box. One of the oldest gravity separators used are sluice box with riffles. These riffles or carpeted sluice box are angled in order to settle down the heavy particles of gold behind the riffles or carpet fibres.

The primary difference of the old and new ones today is the construction and the materials use to build the sluice box. Previously, sluice box were made by heavy wood planks which are cheap and easily found. Now, sluice box are made by lightweight aluminium and steel. Depending on the complexity of the design, sluices can be expensive or affordable price.

2.3.1 Characteristic of Sluice Box.

A simple sluice box that consist of a wooden box with rectangular cross section of 1-2 m long, 0.3-0.5 m wide and 0.2-0.3 height are usually inclined at 5 to 15 degrees to the horizontal. Most gold is captured and sink easily at the beginning of the sluice as the moving water travels down the sluice which generates greater force. Removable carpet or other capturing device is placed at the bottom of the sluice and can be washed to remove the captured dense material.

The function of sluice box is to separate the gold and other materials that are usually found in the river. Sluices work on the principle that heavy particles sink to the bottom of a stream of water while lighter particles tend to be carried downstream and discharged. A rough surface, typically carpets, can trap the gold and other heavy particles. The riffles, which spaced evenly along the length of the sluice, act as a large boulders, small stones and river gravels which commonly trap the gold beneath or around them. It depends on the density and size of particle with the quantity of water and length of the sluice to achieve the completeness of the separation.

2.3.2 Characteristics of Other Gravity Separator

Concentration methods can reduced the use of mercury in small scale mining, if worked in effective way. Many machines and equipment that has been invented in order to separate the minerals in term of gravity. Gravity concentrating operation are characterized by process which allow particles to separate into layers of dense and light minerals. Concentration greatly reduces the mass of material that must be processed to separate the gold. Concentrating eliminates the need for whole-ore amalgamation, and reduces the amount of mercury required for amalgamation to roughly 1 part mercury per part of gold recovered.

Choosing a technology (or technologies over several stages of concentration) to produce a concentrate depends on the type of ore, grain size and mineralogy of the gold, access to capital and know-how with which to acquire and operate processing equipment. The technologies are divided into three groups which are jigging, shaking concentrators and flowing film concentrators.

Jigging uses an essentially vertical expansions and contraction of bed of particles by a pulse of fluid whereas shaking concentrator employ a horizontal motion to the solid-fluid stream to effectively fluidise the particles causing segregation of light and heavy particles. Flowing film concentrators initiates particle separation by a layer of slurry flowing down an inclined surface under the influence of gravity.

The presence of slimes can affect the gravity separator performance as it can increase the viscosity of slurry which make the sharpness of separation reduced. The gravity separator performance in term of size range applicability are shown at Table 2.2.

Table 2.2: Commercial separation equipment with size range applicability

Equipment	Feed Particles Size (m)								
	10	20	50	100	200	500	1000	10000	100000
JIGGING									
Inline Pressure jig									
Conventional jig									
Kelsey jig									
SHAKING CONCETRATORS									
Shaking table									
Gemini Gold Table									
FLOWING FILM CONCENTRATORS									
Sluice									
Spiral									
Knelson									
Falcon									
Reichert cone									

Flowing Film Concentrator

The velocity gradient across the film thickness is approximately parabolic when a film of water flows down a smooth surface under laminar flow condition when there is an increasing in velocity at position close to the slope surface but decreasing when located close to the water or air surface that due to friction with the surface and friction with the air as shown on Figure 2.4.

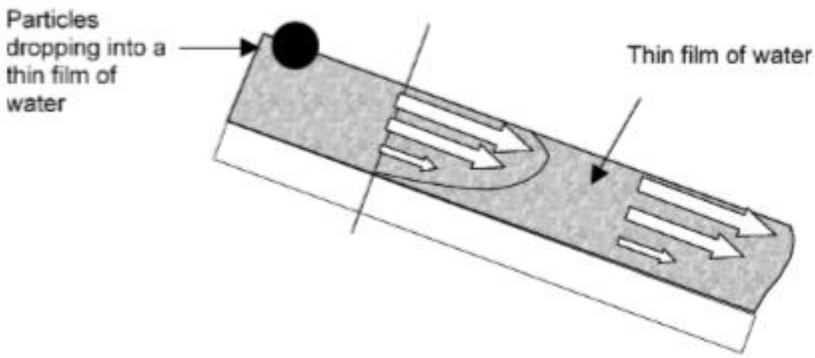

Figure 2.4: Velocity profile in a flowing film of water (Veiga, 2013)

Below are the description of some flowing film concentrators.

- Spiral concentrator

In spiral concentrator, in order to bring about segregation of light from heavy minerals, the length of the slicing surface is required and is done by taking a curved trough, it is compressed into a smaller floor which is then forming into a spiral about a vertical axis.

The working principle of spiral concentrator are when the slurry is being fed into the trough at the top of the spiral, the slurry will flow down to the spiral by