SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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PROCESSING OF GALENA FROM AIR PIAU, KELANTAN

By

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled: **"Processing of Galena from Air Piau, Kelantan"**. 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 other examining body or university.

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LIST OF ABBREVIATION

cm	Centimetre
mm	Millimetre
sg	Specific gravity
SEM	Scanning electron microscope
EDX	Energy-dispersive X-ray spectroscopy
XRF	X-ray fluorescence
rpm	Rotation per minute
g	Gram
XRD	X-ray diffraction

LIST OF SYMBOL

μ	Micron
°C	Degree Celcius
Al	Aluminium
Pb	Plumbum
Fe	Iron
Na	Sodium
S	Sulphur
Si	Silicon
Zn	Zinc
Cd	Cadmium

PEMPROSESAN GALENA DARI AIR PIAU, KELANTAN

ABSTRAK

Dalam kerja penyelidikan ini, satu sampel pukal galena yang diperolehi daripada Air Piau, Kelantan digunakan untuk pencirian dan pemprosesan. Projek ini dibahagikan kepada dua bahagian kaedah iaitu pencirian dan pemprosesan. Kaedah pencirian telah dilakukan untuk sampel mentah, sampel selepas pemisahan dan sampel selepas pemprosesan. Kaedah pencirian yang digunakan adalah analisis XRF untuk mendapatkan komposisi kimia didalam sampel wakil, sampel sebelum pemprosesan dan sampel selepas pemprosesan. Kajian mikroskopi menggunakan mikroskop Kunah Robo dan SEM / EDX adalah untuk mengenal pasti dan memerhatikan ciri pembebasan mineral galena daripada sampel asal. Analisis taburan saiz zarah telah dilakukan untuk menentukan saiz dan mineralogi sampel mentah selepas menjalani proses pelbagai peringkat proses analisis. Untuk kaedah pemprosesan, sampel galena telah menjalani proses komunisi untuk membebaskan mineral sebelum ia boleh diproses menggunakan kaedah Buih pengapungan. Dari pencirian sampel mentah, gred galena adalah rendah keran kadar pembebasan dan saling diantara mineral galena dengan mineral sphalerite, mineral pirit dan mineral kuarza. Gred galena perlu dioptimumkan supaya ia boleh diproses secara ekonomi di industri. Untuk mengatasi masalah tersebut, proses penumbukan menggunakan penghancur kon dan pengisaran menggunakan kilang cincin telah dipilih supaya pembebaskan mineral beleh berlaku sebelum ia boleh ditumpukan oleh buih pengapungan. Data yang diambil daripada parameter yang berbeza semasa menjalankan proses buih pengapungan telah dibandingkan dan ia menunjukkan bahawa pengumpul dos 250 g / tan dengan 6 minit masa pendingin dan saiz pecahan di bawah 106 mikron mempunyai kadar pemulihan tertinggi iaitu 98.94%.

PROCESSING OF GALENA FROM AIR PIAU, KELANTAN

ABSTRACT

In this research work, a bulk sample of galena bearing ore for characterization and processing was obtained from Air Piau, Kelantan. The research work has been divided into two parts of method, characterization and processing. Characterization was performed for raw sample, after comminution and after processed. Characterization method used were XRF analyses to obtain chemical composition in the representative samples before processing and after being processed. Microscopy study using Kunah Robo Microscope and SEM/EDX are to identify and observe the liberation characteristic of galena minerals in the sample. Particle size distribution analyses were perform to determine the size and mineralogy of raw sample after undergo various stage of analyses process. For the processing, galena sample was undergo comminution process to liberate the minerals before it can be process using Froth Flotation method. From the characterization of raw sample, the grade of galena was low due to rate of liberation and interlocking of galena mineral with sphalerite, pyrite and quartz minerals. The grade of galena need to be optimized so that it can be economically processed in the industrial. To overcome the problem, comminution process using cone crusher and ring mill was choose to liberate the minerals before being concentrated by froth flotation. Data taken from different parameters that have been used for froth flotation were compared and it is shown that collector dosage 250 g/ton with conditioning time of 6 minutes and below 106 μm size fraction having the highest recovery rate of 98.94 %.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The gold-lead bearing rich prospect of PMBK AZ – ZAHAB Sdn. Bhd is significant lead mineral (galena) occurances located in the North part of Kelantan from Air Piau and Air Legong site. From the geological data reported, its shows that galena concentration was high from Air Piau site. This company was interested to recover galena for plumbum (Pb) instead treating this valuable mineral as waste.

Formation of gold shows that in hydrothermal deposits, gold usually formed associated silver and base metals, copper, lead and zinc (Ariffin and Hewson, 2007). Lead (Pb) is a soft , malleable, ductile and heavy metal. It is corrosion resistant and when melted into a liquid it has shinny chrome-silver look. Because of these characteristics, lead usage was demanded especially for lead-acid car batteries which equal to one half of the lead produced. Other than that, galena were also used in the construction industry for roofing, cladding, gutters, and glazing bars for stained glass. Due to its high density and resistance to corrosion, lead become useful for ballast keel of sailboats and as scuba diving weight belts. For military usage, lead is used to make bullet and radiation shields around X-ray equipment.

The main lead mineral that produce Pb metal is Galena (PbS), Cerussite ($PbCO_3$) and Angelsite ($PbSO_4$). The hardness of galena is 2.5 and the specific gravity is 6.7 which also the most abundant and widely distributed sulphide mineral (Julius, 2015). Galena often found in the cubic crystal form due to alternating structure of lead and sulphur atom that packed in cubes. Due to hydrothermal environment, galena usually associate with sphalerite (zinc sulphide, ZnS).

The major lead producer in the world are from China with 53.8 thousand tons followed by Australian on 11.8 thousand tons, U.S. on 6.5 thousand tons, Peru on 4.7 thousand tons, Mexico 4.5 thousand tons, Russia 2.6 thousand tons, India 2.2 thousand tons, Bolivia 1.8 thousand tons, Sweden 1.2 thousand tons and Canada on 1.0 thousand tons as reported by asianmetal.com. In Malaysia, lead resources were in the form of by-product to concentrate. Means that there are no lead mine in Malaysia.

The present price for lead ore was 2308.02 USD/ton reported by Infomine.com. Lead price are in a bullish pattern from 2015 to present and now reaching the previous high price on 2013 which are 2400 USD/ton. The increasing of lead price is due to high demand for lead mainly in the acid-lead batteries production shows that this element are worth to be exploit.

Galena processing in the world such as America Silver Corporation use cut and fill mining method to recover the galena minerals. The galena minerals then skipped to the surface using galena hoist and introduce to the processing plant. In the processing plant, the galena mineral then crushed and screened. Minerals that passing the screen size then grind and the grind product size was separated by cyclone. Next, undersize cyclone particle then being float by flotation concentrate. This concentrate are then undergo dewatering process while tailing was pumped for sand fill and Osburn Tailing Storage Facilities (Atkinson, 2016).

1.2 Problem Statement

PMBK AZ – ZAHAB Sdn. Bhd. discover a significant amount of galena mineral on Air Piau site. Based on the high demand and price this mineral are worth to be exploit as a side income for the company. However, mineral that are associated with galena mineral need to know before any processing stage can be apply.

1.3 Study Area

The sample in this study is a bulk galena sample approximately size of 18 x 18 x 15 centimetres. The sample was grabbed at Air Piau site belongs to PMBK AZ – ZAHAB Sdn. Bhd which located at Lot 179 Jalan Dewan Beta Hilir, Kg Gaung Belukar, 15100 Kota Bharu, Kelantan, Malaysia (GPS location of 6°02'03.3"N 102°12'55.4"E). The mining site is accessible by land and will takes around one hour of driving from Kg Gaung Belukar and around 5 hours of driving with the distance of 346 km from Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang to arrive Kg Gaung Belukar. The grabbed sample taken brought to USM pilot laboratory to be characterize and process using froth flotation method.

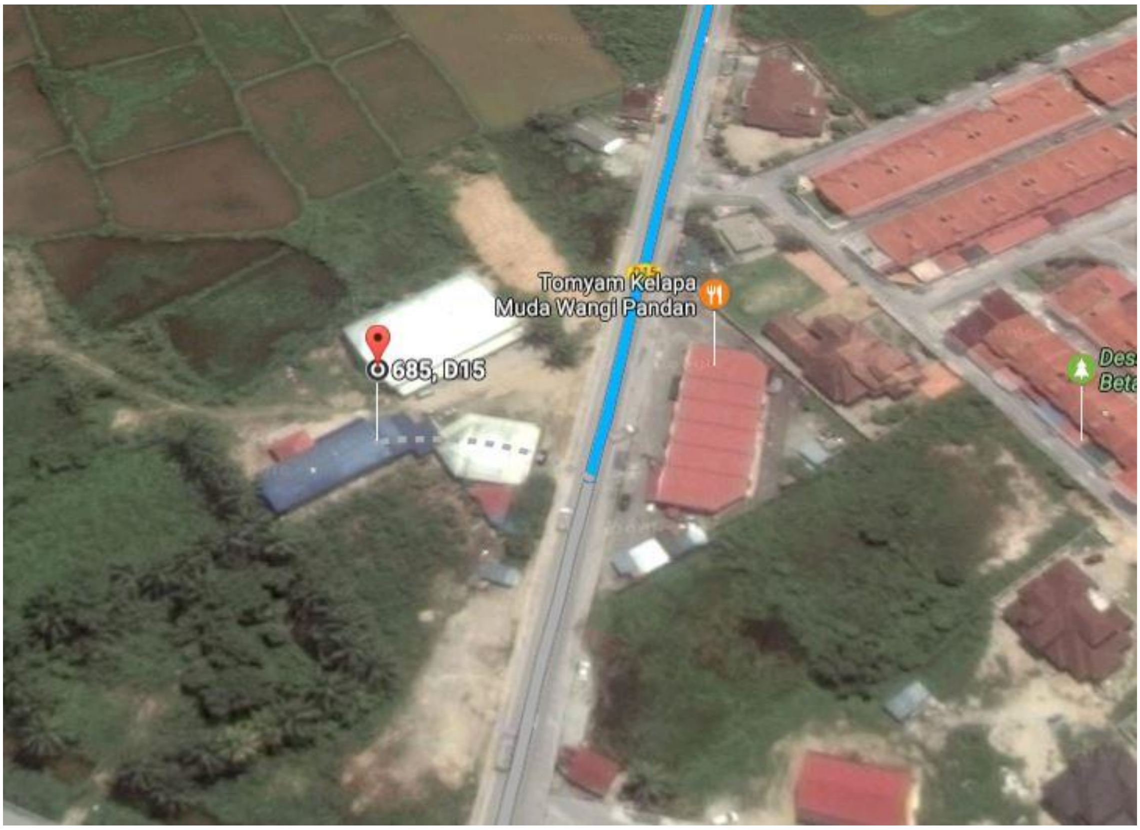

Figure 1.1 : Satellite image of PMBK AZ-ZAHAB operation office.

1.4 Research Objectives

The purpose of this research is to study the composition that exist within galena bulk sample received and to concentrate the galena mineral from the galena bulk sample received. Therefore the objectives of this research are:

- To characterize the galena samples from Air Piau, Kelantan.
- To recover lead from galena samples by using froth flotation method.

1.5 Scope of Research

Scope of work for this experiment is to characterize the galena bearing samples by using crusher and grinder. Than the samples are analyse by using scanning electron microscopy (SEM), Kunah Robo Microscope, X-ray Fluoresence (XRF), and X-ray Diffraction (XRD) for mineralogical and chemical composition studies including grade analysis and process selection later.

The galena minerals are then choose to be concentrated by using froth flotation method. Different size, collector dosage and conditioning time were tested to find the most efficient flotation collector dosage. Recovery calculated for each dosage were analysed and a suggestion for the most efficient dosage are reported to the company.

1.6 Thesis Outline

The thesis contain five chapters, Chapter 1, Chapter 2, Chapter 3, Chapter 4 and Chapter 5. Chapter 1, an introduction towards the research which includes the objectives and problems related to this research. Chapter 2 is the literature review on the galena ore properties, including the characterization method used and the physical processing methods used. Chapter 3 explains about all the experimental work including the way of sample sampling, characterization the samples and physical process that involve. Chapter 4 was discuss on the results obtained from the characterization and the physical processing. Chapter 5 is the conclusion of this research and suggestion to improve this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Galena (lead sulphide, PbS) is the primary metal mineral of lead which found through the world. Its frequently occurs with other metal, particularly silver, zinc, copper and sometimes gold. Thus lead is also a co-product of zinc, copper and silver production making the extraction of lead more economic than if it occurred in isolation. Lead utilization in lead-corrosive batteries that are utilized to begin cars is the fundamental purpose behind lead request. It use about twenty pounds of lead for each batteries which need to changes every four or five years (Council, 2003).

Galena is easily to recognise as it broken pieces exhibit perfect cleavage in three directions that intersect 90 degrees and has a distinct silver color and metallic luster. However, treatment methods are employed for separation of galena and sphalerite, which includes selective flotation of galena and depression of sphalerite, and selective floatation of sphalerite and depression of galena (Li *et al.*, 2017). Sphalerite can become activated by heavy metal ions in solution, which replace metallic zinc on the mineral surfaces by a process of ion exchange (Wills, 2006).

The recovery of lead and zinc bearing minerals as well as the selectivity of separation are greatly influenced by the mineralogical characteristics of the ore and the various process parameters (Singh, 2004). Therefore the best parameter need to be choose by the suitable of the ore grade to make it efficient and profitability for the company. Grade of the ore can be determined by characterization and using XRF analysis as in Chapter 3.

2.2 Galena Mineral

Galena which opaque are lead grey and silver in colour has cubic and octahedral shape. The main lead mineral is galena (PbS), cerussite ($PbCO_3$) and angelsite ($PbSO_4$). The hardness of galena is 2.5 and the specific gravity is 6.7 which also the most abundant and widely distributed sulfide mineral (Julius, 2015).

Galena is found in igneous and metamorphic rock in medium to low-temperature hydrothermal. In sedimentary rock it occurs as veins, breccia cements, isolated grains and as replacements of limestone and dolomite. The lead element is toxic but while bound in crystal structure, it is safe to handle. However, prolonged exposure to the pulverized dust in the form of inhalation or ingestion, it is hazardous to human health (Julius, 2015).

A study on assessment of environmental health impacts of galena mining at New Zurak in central Nigeria that have been done shows a most devastating Pb poisoning episode occurred recently (June, 2010) in Zamfara, northwestern Nigeria. Ingestion of Pb released from gold mining activities caused the death of at least 400 people, mostly children between the ages of 5 and 11 years (Lar, Ngozi-Chika and Ashano, 2013).

Regarding to the harmness of lead to the human health, a legislation have been made in different country concerning the lead product as shown in the table 2.1.

Table 2.1 : Legislation addressing lead or lead compound in different country (Council, 2003)

Country/countries	Legislation
European Union*	Ban on the use of lead carbonates and lead sulphate in paint. Ban on lead foil wine wrappers. Ban on lead in cosmetics. Limit values for the concentration of lead in gasoline. Total phase-out of lead in gasoline is planned to take place by 2005.

	Restrictions on the content of lead in packaging materials. Limits on the release of lead from toys and ceramic articles intended to be in contact with foodstuffs. A general ban on the use of lead in new electrical and electronic equipment is taking effect as of 1 July 2006 /EU 2000a/. A ban on lead in vehicles with certain exemptions is going to take effect as of 1.July 2003. /EU 2000b/.
Denmark*	General ban on most uses of lead compounds not covered by EU-legislation. Also ban on many uses of metallic lead including lead flashing, fishing weights, lead solder in cans, lead shot and lead pipes and lead solders for drinking-water installations, etc. A special tax exists on new lead-acid batteries aimed at financing collection and recycling.
Belgium*, Canada, Finland*, Netherlands*, Norway, Sweden* and UK*	Ban on lead shot for wetland hunting. Sweden and Norway has notified regulation banning all lead ammunition for hunting. Canada has extended the ban to cover most game birds throughout the country.
Canada, Finland*, Germany*, Hungary, Norway, Sweden*, Switzerland	Tax, deposit or other arrangements linked to lead-acid batteries aimed at support collection and recycling.
UK*	Ban on lead fishing weights
USA	Ban on lead solder in cans for food packaging and lead foil capsules on wine bottles. Limits on the release of lead from ceramic articles. Ban on lead solder for household plumbing. Ban on lead in house paint.
Mexico	Ban on lead for pottery
Canada	Lead fishing weights less than 50 grams is banned in national wildlife areas and national parks.

Australia, Austria*, Canada, Finland*, Germany*, Iceland, Netherlands*, New Zealand, Norway, Sweden*, Switzerland, UK*, US, Mexico	Restrictions on lead in paint
Australia, Canada, Iceland, Japan, New Zealand, Norway, Switzerland, US and Mexico	Restrictions on lead in gasoline
Austria*, Belgium*, Germany	Ban on lead in pesticides
Canada, France*, Netherlands*	Restrictions on lead solder in cans for food packaging
Australia	Limits on the release of lead from ceramic articles. Restictions on the content of lead in toys, pencils, crayons etc. In Queensland limit on the content of lead in materials used as fuel.
Austria*	Ban on lead in chain saw oils
France*	Ban on lead salts in imitation pearls in jewellery
New Zealand	Limit on the content of lead in toys and materials for writing, drawing, marking or painting
Switzerland	Ban on use of lead in clothing dyes
Norway	Restrictions on lead in packaging

* Regarding individual Member States and applicant countries of the European Union, these countries are only mentioned specifically if more restricted legislation than EU-legislation is in force.

The lead product such as batteries, cable sheeting, rolled/extruded lead, ammunition, alloys, lead compound, petrol additives and miscellaneous are an important need in a daily life. Therefore the production of lead is still continue to fulfill the demand of it. Sample from Malaysia are only by product of other heavy metal so there is no specific lead mine that operate in this country. In Malaysia, galena was found from Sabah, Serawak, Kelantan, Pahang and Perak.

In Australia, almost all of the lead-zinc mine are underground mining and highly mechanised. Firstly the ore are drilled and blasted before transferred to underground rock crusher and hoisted to the surface. At the surface, the ore then subjected to additional crusher and fine grinding before undergo flotation stage which float lead sulphide mineral and sink zinc sulphide mineral. The concentrate then sintered to combine fine particles into lump and removed some sulphur as sulphur dioxide. The sintered lead then smelted followed by refining.

2.3 Mineralogical and Geochemical Analysis

Hydrothermal deposit that was grabbed from the mid-Okinawa Trough, belongs to Zn-Cu-rich type, consisting predominantly of sphalerite, chalcopyrite, pyrite with lesser galena and amorphous silica. According to the mineral particle size and the idiomorphic degree, two generations of pyrite have been distinguished. The first generation pyrite (PyI) is mostly euhedral cubic crystal with a size up to 0.5 mm, while the particle size of second generation pyrite (PyII) is much smaller. Most of the first generation pyrite particles (PyI) are surrounded by sphalerite and chalcopyrite, which indicates that pyrite crystalized earlier than sphalerite and chalcopyrite. The crystal shape of pyrite reflects its crystalizing condition, when the crystallization temperature is higher than 300 °C or lower than 200 °C, pyrite crystalizes as a cubic shape (Zhang *et al.*, 2016).

Most of pyrite particles (PyI) in the sample are cubic crystal and the crystal size is nearly uniform which indicates that the fluid temperature and mineralization condition are stable during the period of pyrite crystallization. Combine with pyrite closely intergrow with chalcopyrite, it is plausible to infer that the crystallization temperature of pyrite is higher than 300 °C. Chalcopyrite occurs occasionally as tiny blebs or foliated microcrystals scattered in sphalerite forming so-called "chalcopyrite disease" (Zhang *et al.*, 2016).

There is few of anhedral galena existed in the sample, filling the interspace of sphalerite and chalcopyrite demonstrating that crystal of galena is later than sphalerite and chalcopyrite. Amorphous silica is the dominant gangue mineral, cementing the initially crystalized sulfide minerals through fissures forming network structure. Amorphous silica is typical low temperature hydrothermal mineral, precipitation of which suggests that the temperature of hydrothermal fluid has decreased apparently. Few amount of subhedral to anhedral pyrite particles were enclosed in Amorphous silica, in size of < 100 μm, which are the second generation pyrite (Zhang *et al.*, 2016).

2.4 Particle Size Analysis

Size analysis is a fundamental part of labaratory testing procedure. It is to determine the quality of grinding and in establishing the degree of liberation of the values and the gangue mineral at various particle sizes. The optimum size range for the feed of the process can be determine so the process can has high efficiency and any losses occured in the plant can be reduced (Wills & Napier-Munn, 2006).

The method of size analysis must be accurate and reliable because the plant operation changes depending on the labaratory results. A small quatity of sample that is representative of the bulk material are required for this test (Wills, 2006).

Particle size analysis primary function is to obtain the quantitative data about the size and the size distribution of the particles in materials. This analysis cannot be measured for the exact size of the irregular particle (Wills, 2006).

For separation of diaspore and kolinite, the particle size has a significannt influence on the flotation parameters. The favorable particle size fraction for direct flotation were -38+20 μm and -54+38 μm and the adverse particle size fraction were -10 μm and -20+10 μm. While for reverse flotation, the favourable particle size were -74+54 μm and -10 μm and the adverse particle size fractions were-38+20 μm and that for unfavorable size fraction (Zhang *et al.*, 2017).

In other research on particle size against flotation performance, it said that the destruction of froth by hydrophobis particles is size-dependent, and there seems to be an optimum size range for particles to stabilizes or destabilize the froth. With fine size fraction, froth stability was higher and froth volume is high. A vise-versa result are reported for coarse size fraction while medium size particle fraction resulted in better flotation performence (Feng and Aldrich, 1999).

2.5 Comminution

The objective of comminution process is to liberate the valueable minerals from the associated gangue in order to obtain a good yield at the further concentration step (Bérubé & Marchand, 1984). For high grade solid, good liberation is important to expose the required mineral for processing it efficiently.

In order to separate the minerals from gangue, it is necessary to crush and grind the rock to liberate valueable minerals so that they are partially or fully exposed. This process of size reduction is called comminuition. The crushing and grinding process will produce a range of particles with varying degrees of liberation as shown in the Figure 2.1. For particle that exceed a target size required for physical separation or chemical extraction are returned to the crushing or the grinding circuit (Grewal, 2012).

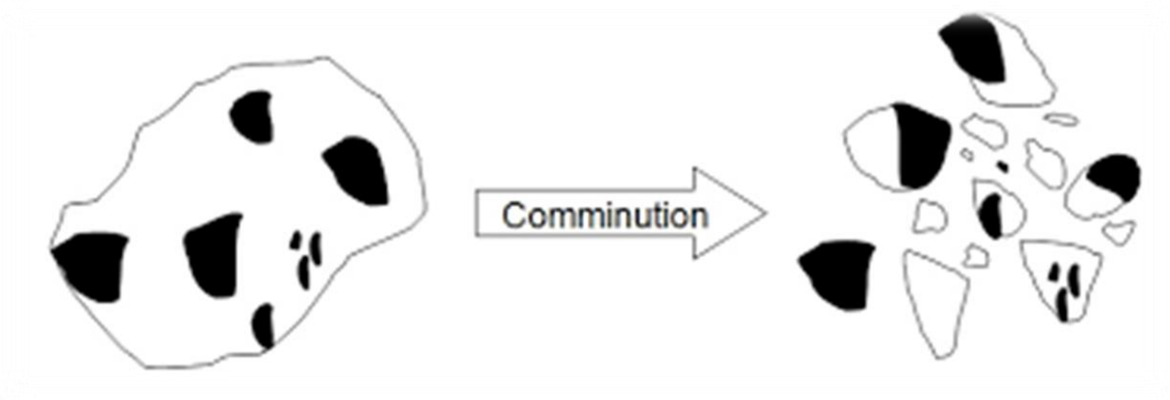

Figure 2.1 : Comminution of larger material result in particles with varying degrees of liberation. The darker reqions represent the valueable mineral (Grewal, 2012)

Liberation process using grinding is one of the greatest energy consumers in the processing plant. It is known as the key to good mineral processing because the target of liberation process is to separate the values from gangue minerals. Consequences from fine grinding is it will also increase energy costs and can lead to the production of very fine untreatable slime particles, which may lost into tailings (Wills, 2006).

If the ore is low grade and the minerals have very small grain size, it will consumes high energy cost for grinding and due to fine particle size, the losses while processing may be high. Hence, results from grinding the ore is a compromise between high grade concentrates, operating costs and losses of fine minerals (Wills, 2006).

The comminution process can be devided into two which are crushing and grinding. Crushing process usually carried out by jaw crusher, gyaratory crusher and roll crusher where ae grinding can be perform by using ball mill. (Reddy, 2001)

2.5.1 Jaw Crusher

Crushing is the first mechanical stage in the process of comminution in which the main objective is the liberation of the valueable minerals from the gangue. It is generally run in a dry condition and usually apply in two or three stages. The maximum size of run-of-mine ore can be as large as 1.5 m across and can be reduced to 10-20 cm in heavy-duty crushing machines (Wills & Napier-Munn, 2006).

Jaw crusher consists of a heavy frame which carries a fixed jaw and another movable jaw. The jaw plates which are made of chilled cast iron or manganese steel.are set inclined at an angle of about 24° angle of nip to one another. The ore particles are fed down between the jaws and nipped and crush by them as the moveable jaw closes. In order to get the required size, the clearance between the jaws can be adjusted (Reddy, 2001).

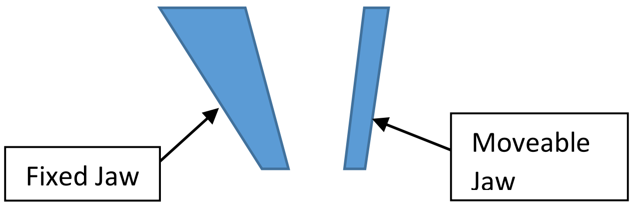

Figure 2.2 : Jaw Crusher

2.5.2 Cone Crusher

The use of compression crusher, such as gyratory, cone, and jaw crushers, is common in the mining and aggregate industries. The raw material handling in these industries including drilling, blasting, and crushing, sometimes it need to be repeated, before a final product or a product ready for the next stage of the process emerges (Lee & Evertsson, 2011).

Cone crusher and gyratory crusher on the same principle. Both have the same operatiom. Cone crusher has a less steep crushing chamber and more parallel zone between crushing zones. Broken pieces of rocks fall down and the next position where it is broken again. Same process continues until the broken pieces become small enough so that it can pass through the narrow opening that is at the bottom of the cone crusher (Asfar, 2012).

A cone crusher is comparable in operation to a gyratory crusher, with less steepness in the devastating chamber and to a greater degree a parallel zone between smashing zones. A cone crusher breaks the rock by pressing the rock between an whimsically revolving splinde , which is secured by a wear resistance mantle, and the enclosing concave hopper, secured by a manganese curved or a bowl liner. As rock enters the top of the cone crusher, it become wedged squeezed between the mantle and the bowl line or concave as in Figure 2.3. Large pieces of ore are broken once, and then fall to a lower position (because they are now smaller) where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

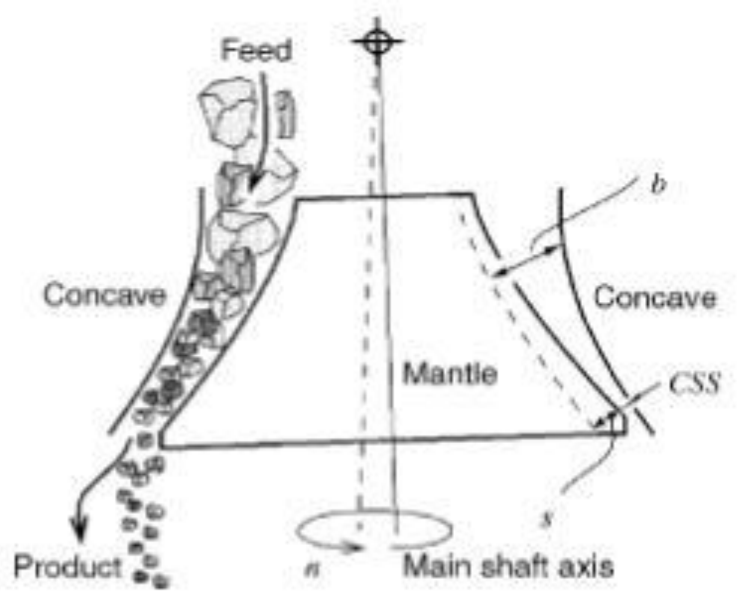

Figure 2.3 : Cross section view of a cone crusher. (Evertsson, 2003) .

A cone crusher is suitable for crushing a variety of mid-hard and above mid-hard ores and rocks. It has the benefit of dependable development, high profitibility, simple alteration and lower operational expenses. The spring release system of a cone crusher acts an overload protection that allows tramp to through the crushing chamber without damage to the crusher.

A study on the active use of crushers to control product requirement shown that the dynamic parts of pulverizing must be considered all together to process plants to accomplish their objectives and goals in a proficient and savvy way. Active crushing involves the consideration of time-dependent effects which differs from consider the whole process to be in a steady state condition. Key aspects of active crushing include crusher process strategies, crusher design strategies and circuit operation (Bearman and Briggs, 1998)

Cone crusher had been choosen due to the product from the crushing will produce particle size below 3.35mm. For the physical processing used in methodology, if the sized of mineral was large, the liberation between the minerals were low and it may still interlocks with each other. This may cause lower concentrate while processing it. The suitable size choose was below 3.35 mm and not too fine in size to avoid the sample becoming slime while undergo wet processing.

2.5.3 Rod Mill

Rod mill may be considered as either fine crusher or coarse grinding machines. They are capable of taking feed as large as 50 mm and making a product as fine as 300 μm. The rods that are only a few centimeters shorter that the length of the shell must be prevented from turning so that they become wedged across the diameter of the cylinder. The grinding action results from line contact of the rods on the ore particles; the rods tumble in essentially a parallel alignment, and also spin, thus acting rather like a series of crushing rolls. The coarse feed tends to spread the rods at the feed end, so producing a wedge or cone shape array. This increase the tendency for grinding to take place preferentially on the larger particles, thereby producing a minimum amount of extremely fine material (Wills, 2006).

2.5.4 Ball Mill

Ball mills is the final stages of comminution that are perform by using steel balls as the grinding medium and so designated ball mills. They are better suited for fine finishing since ball have greater surface area per unit weight than rods. The efficiency of grinding depends on the surface area of the grinding medium. Means that the ball should be as small as possible and the charge should be graded such that the largest balls are just heavy enough to grind the largest and hardest particle in the feed (Wills, 2006).

A study on control of grinding conditions in the flotation of galena and its separation from pyrite shown that there are high iron content in the sample after the flotation process. The sample was ground with 4 kg of balls in the specialised mill for 30 minutes with 90 wt.% of the particles present were less than 53 μm in diameter. The recovery of lead were studied and shows that grinding conditions requiring lower amount of sodium hydroxide to maintain the grinding pH at 9.0 that resulted in higher galena recovery (Peng *et al.*, 2003).

2.6 Physical Processing of Galena Ore

Physical processing of the ore is the process to prepare for extraction process between valuable and gangue minerals. Industrial processing for galena ore start with comminution process which are crushing and grinding, before ground ore are mixed together with water and special chemical in flotation cell that constantly agitated. The objective of the physical processing is to concentrate an ore economically.

There are two fundamental operation in mineral processing which are liberation of valueable minerals from their gangue minerals and separation of these values from the gangue known as concentration (Wills & Napier-Munn, 2006).

For separation of valueable mineral from the gangue gravity concentration methods can be used. The process is using the differences in specific gravity of the mineral to seperate it from concentrate and tailing. Separation is often assisted by application of one or more forces, such as vertical, horizontal, or centrifugal by viscous fluid media such as water (Wills & Napier-Munn, 2006).

Gravity concentration methods separate minerals of different specific gravity by their relative movement in response to gravity and one or more other forces, the latter often being the resistance to motion offered by a viscous fluid,such as water or air(Wills & Napier-Munn, 2006).

For effective separation, it is essential that a marked density difference exists between the mineral and the gangue. Type of separation possible can be gained from the concentration criterion (Eq. 2.1).

$$Cc = \frac{(Dh - Df)}{(Dl - Df)} \qquad \text{(Eq. 2.1)}$$

where D_h is the specific gravity of the heavy mineral, D_l is the specific gravity of the light mineral, and D_f is the specific gravity of the fluid medium.

Based on B.A Wills (2006), when the quotient is greater than 2.5, whether it is positive or negative, the process for gravity separation is relatively easy, the efficiency of separation decreasing as the value of the quotient decreases.

Separation process in a fluid is dependent not only on its specific gravity, but also on its size. Large particles will affected more than smaller ones. The efficiency of gravity processes therefore increases with particle size and the particle should be sufficiently coarse to move in accordance with Newton’s law (Wills & Napier-Munn, 2006).

Gravity separator are extremely sensitive to the presence of slimes (ultra-fine particles), which increase the viscosity of the slurry and hence reduce the sharpness of separation, and obscure visual cut-points. Therefore the particles sized below 10 µm is removed from the feed before any gravity concentration. There are many different type of gravity separators and machine have been designed and built. The most commonly used in mineral processing industries are Jigs, Spirals, Shaking Table and Mozely Table (Wills & Napier-Munn, 2006).

Physico-chemical separation process known as froth flotation is the most widely used to treat low-grade and complex ore bodies which would have otherwise been regarded as uneconomic. Flotation is a selective process and can be used to achieve specific separations from complex ores such as lead-zinc, copper zinc, etc. (Wills & Napier-Munn, 2006).

2.6.1. Jigs

Jigging is one of the oldest methods of gravity concentration uses in the industry. It is normally used to concentrate the coarse material around 3 to 10 mm size. If the difference in specific gravityis large, good concentration is possible with the wider size range. Fine sand and slime should be controled to provide optimum bed conditions (Wills & Napier-Munn, 2006).

The separation of minerals of different specific gravity using jigging process is proficient in a bed which is rendered fluid by a throbbing current of water so as to create stratification. Objective of this is to widen the bed of material being dealt with and to control the dilation so that the heavier, smaller particles penetrate the interstices of bed and the larger high specific gravity perticles fall under a condition presunably like to hindered settling (Wills & Napier-Munn, 2006).

The initial acceleration of the mineral grains is thus independant of size and dependant only on the densities of the solid and the fluid. To separate small heavy mineral particles from large light particles a short jigging cycle is necessary. Although relatively short fast large light particles a short jigging cycle is necessary. Although relatively short fast strokes are used to separate fine minerals, more control and better stratification can be achieved by using longer, slower strokes, especially with the coarser particles sizes. Therefore, it is a good practice to screen the fed to jigs into different size ranges and treat these separately. The effect of differential initial acceleration is shown in Figure 2.4.

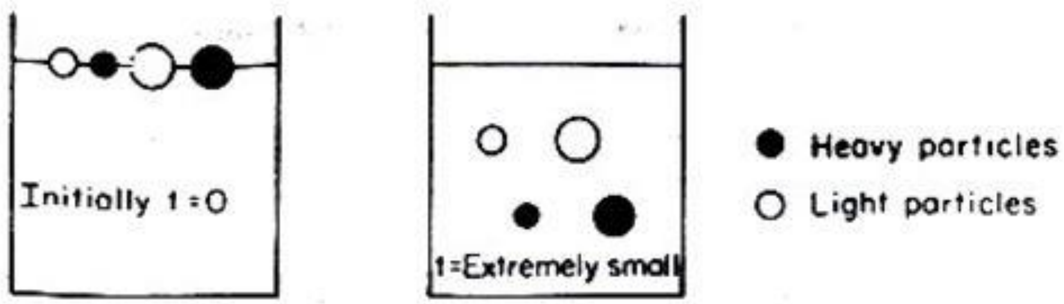

Figure 2.4 : Differential initial acceleration (Wills & Napier-Munn, 2006).

At the end of a pulsion stroke, as the bed begins to compact, the larger particles interlock, allowing the smaller grains to move downwards through the interstices under the influenced of gravity. The fine grains may not settle as rapidly during this consolidation trickling phase (Figure 2.5) as during the initial acceleration or suspension, but if consolidation trickling can be made to last long enough, the effect, especially in the recovery of the fine heavy minerals, can be considerable (Wills & Napier-Munn, 2006).

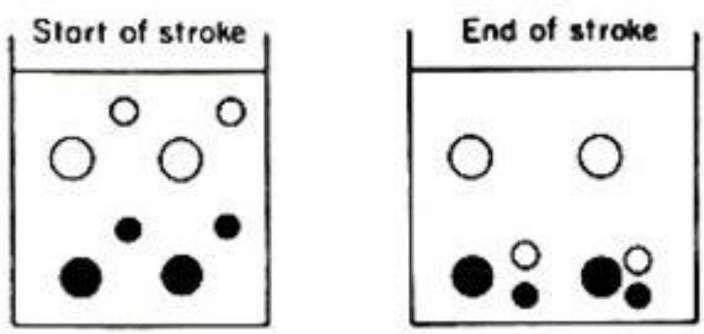

Figure 2.5 : Consolidation trickling (Wills & Napier-Munn, 2006).

By reffering research by Wills & Napier-Munn, 2006 an idealized jigging process is shown as the Figure 2.6 below.

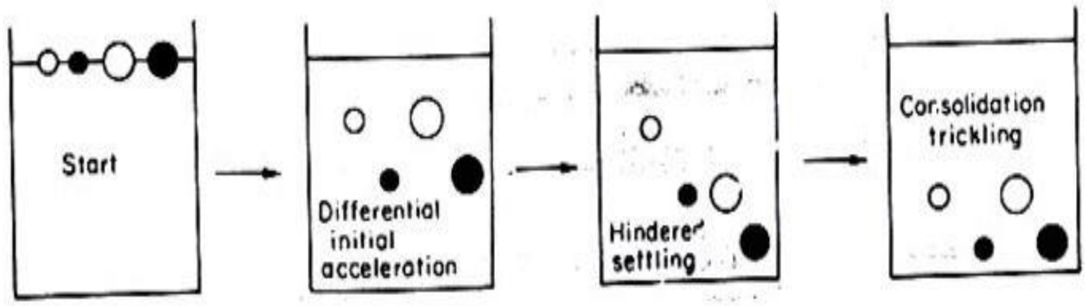

Figure 2.6 : Ideal jigging process (Wills & Napier-Munn, 2006).

Two basic methods are used for the removal of dense particles from the jig (Wills, 1988; Weiss, 1985; Schubert, 1986). On-screen jigging is applied to larger particles; both, the dense and the light particles, remain on the screen, which has a smaller aperture than the smallest particle in the mixture. The dense particles are removed by means of a controllable gate or a variable-speed star valve. Through-screen jigging, also known as hutching or the English method, is applied to smaller particles. The dense particles pass through the screen, which has a larger aperture than the diameter of the largest dense particles. Subsequently, they are removed from the hutch by means of a mechanical discharge. A layer of large particles, a ragging, with diameters substantially larger than the screen aperture, is kept on top of the screen. The dense particles percolate through this ragging. The ragging often consist of materials such as hematite, steel shot, galena or feldspar (Jong, 1996).

2.6.2 Magnetic Separator

The objective of magnetic separator is to exploit difference in magnetics properties between minerals. Minerals have properties of ferromagnetic, paramagnetic and diamagnetic. Ferromagnetic properties defined as very high susceptibility to magnetic forces and the mineral may retain some magnetism when remove it from the field. This type of mineral can be concentrated using low intensity magnetic separator. Paramagnetic is the properties of mineral which attracted along the lines of magnetic force to point of high intensity magnetic separators. While the diamagnetic is the minerals will be repelled along the lines of magnetic force to a point the intensity is smaller. The diamagnetic substances cannot be concentrates using the magnetic separator (Wills & Napier-Munn, 2006).

For magnetic to lift particular mineral is not only depended on the value of the field intensity, but also the field gradient. The higher the magnetic susceptibility, the higher is the field density in the particle. Paramagnetic minerals havr higher magnetic permeabilities than the surrounding media. Diamagnetic minerals have lower magnetic susceptibility than their surrounding medium. Based on Cohen in 1996, negative diamagnetic effect is usually orders of magnitude smaller than the positive paramagnetic attraction.

There are two type of magnetic separator used in industry. It can be classified into low and high intensity machines. Low intensity separators (Figure 2.7) used to treat ferromagnetic and can be used also to treat paramagnetic minerals. High intensity magnetic separator (Figure 2.7) is used to treat paramagnetic minerals. Until the 1960s, high intensity separation was confined solely to dye ore, and it has been commercially since about 1908. These separators also focus on the separation of very fines particles that are paramagnetic.

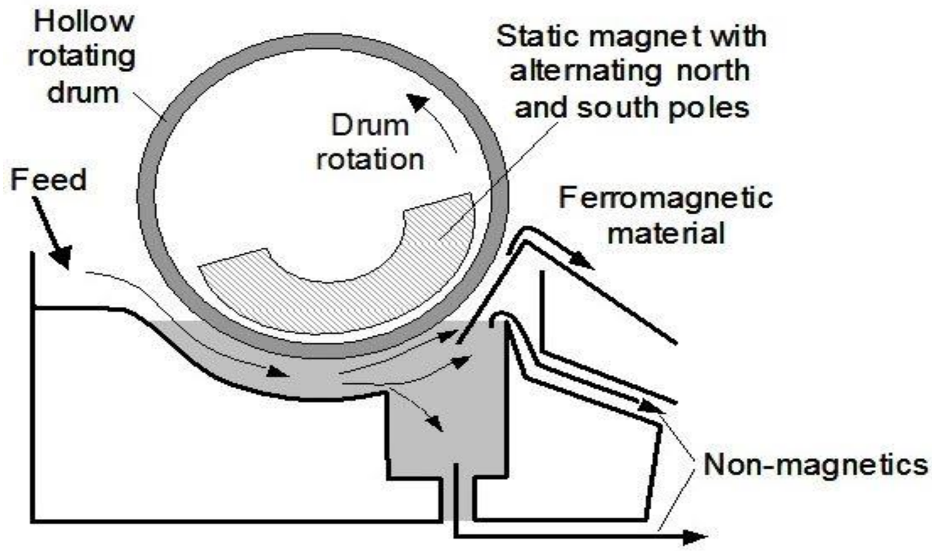

Figure 2.7 : Overview of wet low intensity magnetic separator (Grewel, 2012)

Based on the exploration and transformation of galena that associate with sphalerite, chalcopyrite and barite in the Linares district (NE Andalucia, Spain), waste produce from mining and mineral extraction exposed local people to a heavy atmospheric dust load and contaminated extensive areas used for corp cultivation. From the study its conclude that magnetic properties of lead slag heap mainly correspond to a para and/or antiferromagnetic material while galena and sphalerite did not show clear tendency as they presence in the non-magnatically trapped friction (Sierra *et al.*, 2013)

2.6.3 Shaking Table

Shaking table otherwise called wet table. It is consist of a slanting deck with a riffled surface. An engine drives a little arm that shakes the table along its length, parallel to the riffle and rifle design. This longitudinal shaking movement comprises of a moderate forward stroke followed by quick return strike. The riffles are arranged in such a manner that heavy material is trapped and conveyed parallel to the direction of the oscillation as in Figure 2.8. water is added to the top of the table perpendicular to the table motion. The heaviest and coarsest particles move to one end of the table while the lightest and finest particles tend to wash over the riffles and to the bottom edge.

Shaking tables are often used downstream of other gravity concentration equipment such as spirals, jigs and centrifugal gravity concentrators for final cleaning prior to refining or sale of product (Grewel, 2012).

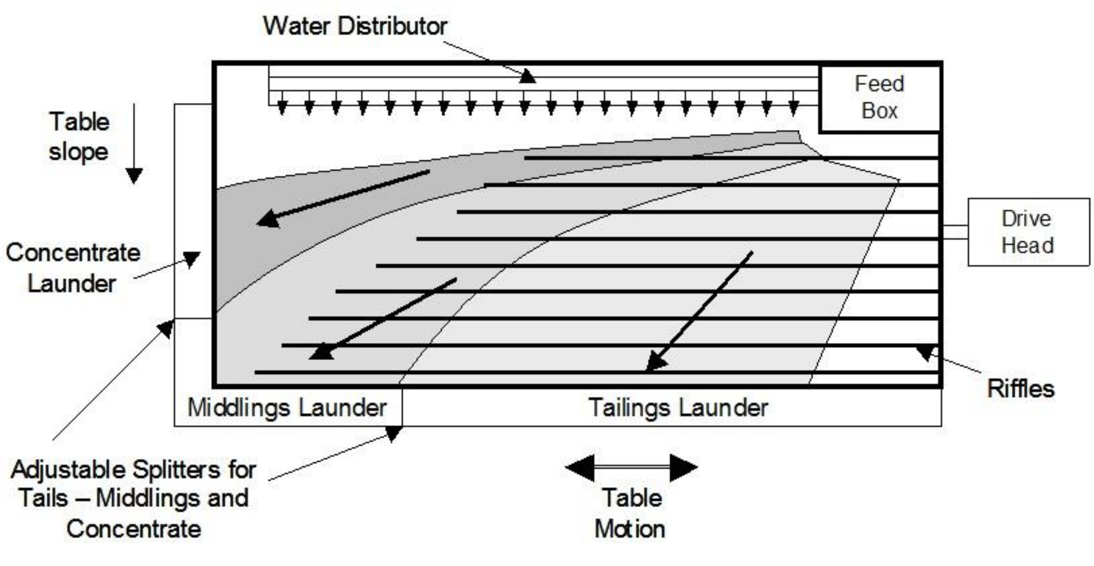

Figure 2.8 : Shaking table top view (Grewel, 2012)

A flowing film of water flows over a flat, inclined surface the water closet to the surface is retarded by the friction of water absorbed on the surface. The velocity is