ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMICAL & BIO ENGINEERING

CENTER FOR ETHIO-MINES DEVELOPMENT

FLOWSHEET DEVELOPMENT STUDIES FOR LEGA DEMBI GOLD PROCESS PLANT

A PROJECT SUBMITTED TO THE DEPARTMENT OF MINERAL ENGINEERING SCHOOL OF CHEMICAL & BIO ENGINEERING

PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER IN MINERAL ENGINEERING

By: Adinew Abebe Tumoro

Id. No- GSR/4622/14

Advisor:- Dr. Eng. Abubeker Yimam (Associate Professor)

Sep, 2023

Addis Ababa

Ethiopia

APPROVAL

A: Candidate

Adinew Abebe ____________ ____________

Student Signature Date

B: Approved By:

1. Dr. Eng. Abubeker Yimam (Associate Professor) _____________ ____________

Advisor Signature Date

2. _____________ ____________ ____________

Co-Advisor Signature Date

3. Dr. Eng. Berhanu Assefa _____________ ____________

Program Chairperson Signature Date

4. Dr. Zekarias Gebreyesus ____________ ____________

Examiner Signature Date

Table of Contents

List of Figure

List of Table

List of Acronym

AG	Autogenous Grinding
AGEP	Adola Gold Exploration Project
B1-B7	Conveyor belt number
CIC	Carbon - in column
CIL	Carbon in leach
CIP	Carbon in pulp
CIS	Carbon-in solution
CSS	Closed side setting
C1-C11	Conveyor belt number
DDS	Double deck screen
EMRDC	Ethiopian Mineral Resources Development Corporation (EMRDC).
FAG	Fully autogenous grinding
GC	Gyratory crusher
HCC	Hydro cone crusher
KG	Kilogram
KW	Kilo watt
MM	Mili meter
NaCN	Sodium cyanide
PS	Pregnant solution
ROM	Run of mine
RPM	Revolution per minutes
SG	Specific gravity
SSP	Secondary stock pile

UFG	Ultrafine grinding
VF	Vibrating feeder

List of Mineral Formulae

AuCu	Aurocupride
Au_2Bi	Maldonite
$AuSb_2$	Aurostibite
$Ca(OCL)_2$	Calcium hypochlorite
CuS	Covellite
$CuFeS_2$	Chalcopyrite
Cu_2S	Chalcocite
$Cu_2Co_3(OH)_2))$	Malachite
$Cu_3(Co_3)_2(OH)_2)$	Azurite
Cu_2O	Cuprite
Cu_9S_5	Digenite
FeS_2	Pyrite
FeAsS	Arsenopyrite
$Fe(1_{ex})S$	Pyrrhotite
SAG	Semi-Autogenous Grinding (SAG)
PbS	Galena
Sb_2S_3	Stibnite
ZnS	Zincblende

ABSTRACT

This flowsheet advancement of Legadambi processes for gold plant contain different unit operation and unit process. Legadambi gold process plant use different beneficiation mechanism to extract and recover the valuable metal or element of interst from associated mineral or gangue. The process consists seven consecutive and interdependent but segregated unit operating process and unit process. Process those implmented in Legadembi were comminution (crushing and grinding), Thickening and reagent leaching (Extraction), both adsorption and Desorption (stripping), Electrowinninng and gold Smelting,Tailing dam and Detoxification plant.

The flowsheet consists two crushing circuits each consists a primary, secondary and tertiary stage crusher that produces a crushed ore product, which is then conveyed to feed the grinding unit. Grinding unit is configured in two single stage mills with cyclone classification to confine the particle size reduction within requirement range. Grinding unit consist circuit discharges ore slurry through desanding screen to thickening unit; screen removes trash material from overflow slurry. Flowsheet of thickener and reagent unit utilizes flocculent chemicals to increase/enhances settling rate of solid in grounded ore slurry for gold and silver leaching process. Leaching circuit uses sodium cyanide to extract gold. In the pulp procedure, activated carbon and gold from the ore are utilized to adsorb the recovered gold from solution in carbon. The carbon is gathered and processed in the elution circuit, which separates the carbon and gold, after the CIP circuit. While the gold is extracted from solution during the electrowinning process, the carbon is renewed and utilized again in the CIP circuit. To create gold Dore bars, the stripped and electrowonted gold is melted in a gold chamber. For the purposes of final deposition, recovering decant water, and the detoxifying process, process tailg ravitate to a tailing storage facility. Process tails solution detoxified in cyanide destruction plant before being discharged to the environment.

Finally, Production process of each unit described with block and process flowsheet.

Keywords: *Flowsheet development; Comminution; beneficiation mechanism*

ACKNOWLEDGMENT

First and foremost, I want to sincerely gratitude to almighty God for sending me with the water, strength, and purification procedure and good health that allow for me to finish this project. I want to convey my appreciation to my advisors Dr. Eng. Abubeker Yimam (Associate Professor) and Bogale Tadesse (Ph.D.), for all of their help, advice, insightful critiques, inspiration, and never-ending support.

I would like to thank Midroc Legadembi Gold Mine, particularly Metallurgy Department for their countless support. I am also appreciative of the Ministry of Mines, for providing of second degree chance.

In closing, I am deeply grateful to my family for their supportive comments.

1. Introduction

1.1 Background

Gold is the metal that exudes romance the most. It is showered with love and care to the point of near-worship. Gold has a great mystique. There seems to be a deep-rooted need for gold in human nature [1]. Because of its brilliant hue and resistance to tarnish, gold has long been prized by humans and utilized in jewelry and unique decorative accents. Due to the ancients' reverence for gold, holy items made of the metal have been used for many millennia. Gold is frequently hammered into foil to create funeral masks or cast as idols. Gold is extensively utilized as currency after being used for barter. The majority of gold is found naturally, almost entirely alloyed with different proportions of silver to form the mineral electrum, but not with copper. Pyrite [FeS2], galena [PbS], zincblende [ZnS], arsenopyrite [FeAsS], stibnite [Sb2S3], pyrrhotite [Fe(1ex)S], and chalcopyrite [CuFeS2] are the most significant minerals that are typically associated with gold. Metallurgists frequently divide gold ores into three categories: free milling, complicated, and refractor.y (in order of increasing processing complexity) [2].

The processing of gold ores, specifically the several competing methods and the respective benefits and economics, has become a primary concern in the sector. Gold ore is the most important minerals in Ethiopia, mainly Lega Dembi in Southern Ethiopia with significant deposit. The development of optimum flowsheet for beneficiation of gold ore in these areas is essential to achieve the greatest gold recovery at the lowest cost. One of the potential options to solve the project economy, to achieve the most gold recovery at the least expensive and to minimize environmental problems is the use of alternative flowsheet.

To extract and recover the valuable metal or element of interest from related minerals or gangue, Legadambi Process Plant uses a variety of mechanisms. Seven sequential, interrelated, but distinct unit processes and unit operations make up the process. Many processes, such as comminution (crushing and grinding), thickening and reagent; leaching (extraction), adsorption and desorption (stripping), electrowinning and gold smelting, tailing dam, and detoxification plant, are used in the building of flowsheets for the beneficiation of gold ore. The primary, secondary, and tertiary stage crushers in each of the two crushing circuits used by the Legadembi process plant create crushed ore output, which is subsequently transported to feed the grinding unit. The grinding unit is set up with two single-stage mills and cyclone classification to limit the reduction of particle size to the required range. The desanding screen, which separates debris from the overflow slurry, is used to discharge ore slurry from the grinding circuit to the thickening unit. For the purpose of improving the settling rate of solid in the grounded ore slurry for the gold and silver leaching process, a thickener and reagent unit uses flocculent chemicals[3]. Activated carbon is used in the pulp procedure to adsorb the gold that has been recovered from solution using sodium cyanide in the leaching circuit[4].

1.2 Statement of the Problem

Currently, Earn profit by optimizing extraction process for a specific ore sample has always been a challenge for mining investors. For that reason, flowsheet development need to be maximize the gold recovery, increase the project economy and minimize the effluent environmental compliance. Less use of plant control and monitoring may cause inflation of cost by using unefficient plant design. To alleviate such problems, A good designed process flowsheet must be investigated. Selection of the optimum size to flowsheet development is arguably one of the most important challenge in gold processing [5].

Treatment of gold ore is the most predominant step, targeting to upgrade gold recovery by using flowsheet development need to be maximize the project economy. Additionally, as of right now, there isn't any harmonizing flowsheet development to develop all kinds of beneficiation and Selection of the optimum size depends entirely in a manual manner. But, the usage of flowsheet development strategy can extensively increase the performance of the plant and easy controling discipline.

The projecters are paying more attention to flowsheet development. They suggest continuously optimizing the process treatment for gold ore (which is not always adapted properly) for beneficiation methods which significantly influences gold recovery. Besides, very few studies have been achieve to recovery gold from gold ore, to increase project economy, i.e., flowsheet development, using diffirent treatment techniques. So, this study focused on flowsheet development of legadembi gold process plant using combined beneficiation methods like:- comminution (crushing and grinding), Thickening and reagent; Leaching (Extraction), Adsorption and Desorption (stripping), Electrowinninng and Gold Smelting to optimize the project economy and minimize the effluent environmental compliance.

1.3 Objectives

1.3.1 General Objectives

The overall goal of this project is to increase project economy. within the physical constraints of the deposit characteristics.

1.3.2 Specific Objectives

- To accomplish the most gold recovery at the lowest cost
- To minimize the effluent discharges from gold plant which cause impact on environment.
- To maintain a continuous plant operation flow control and operation performance assessment by monitoring the incoming ore and monitoring the parameters in order to ensure the quality of the output product.

1.4 Significance of the study

The importance of gold flowsheet development by using conventional methods is to optimize effective and safe project economy. This study also highly contributes to the growing awareness of the environment, and a need for mining sector for employment within the limitations that are imposed by the sustainable development. This project work will creat the concept of creating flowcharts for the processing of gold ores may seem to have been superseded, given the foregoing discussion of many unit operations and process configurations.

Generally, this work will provide efficient performance in order to save on investment and avoid risk on investment and provide a framework for plant control and monitoring to achieve the greatest gold recovery.

1.5 Scope of the study

The project's work scope inside the given time and resource consists of: -

- Study the unit process and unit operation of the plant
- Study appropriate flowsheet development to each unit
- Study framework for plant control and monitoring to achieve the largest recovery of gold

2. Literature review

2.1 Mineralogy of gold-bearing ores

Gold tellurides and goldesilver Less significant are tellurides and goldesilver tellurides, however they can occur in specific deposits [6].t with respect to a sizeable amount of the gold content. Maldonite [Au2Bi] and aurostibite [AuSb2] are uncommon minerals that can be found in some gold occurrences. Aurostibite [$AuSb_2$] and maldonite [Au_2Bi] are uncommon minerals, however some gold resources contain them. Certain primary copper ores include aurocupride [AuCu] [7]. Large nuggets of gold and smaller particles encased in the sulfide mineral crystal structure can both be found in an ore deposit. These sulfide minerals, often known as gold carrier minerals, have trace to very small concentrations of gold with respect to a sizeable amount of the gold content. Maldonite [Au2Bi] and aurostibite [AuSb2] are uncommon minerals that can be found in some gold occurrences. Aurostibite [$AuSb_2$] and maldonite [Au_2Bi] are uncommon minerals, however some gold resources contain them. Aurocupride [AuCu] is found in some primary copper ores [7]. Large nuggets of gold and smaller particles encased in the crystal lattice of sulfide minerals can both be found within an ore reserve. These sulfide minerals, often known carrying minerals for gold, have trace to very small concentrations of gold [8]. Because the gold particles in the sulfides are so minute, it is discovered that gold ores are refractory. In order to free the gold before flotation, roasting, bacterial leaching, or pressure leaching must be performed.

The study of minerals aids in resolving concerns and difficulties in the processing of gold ore. It offers helpful details on reagent consumption optimization, flowsheet building, recovery improvement, and process selection. The recovery procedure is determined by the mineral makeup of the ore. The crucial mineralogical factors are in particular the mineral assemblage (native gold, gold tellurides, auriferous sulphides; acid-generating and oxygen-consuming minerals such as pyrrhotite (Fe(1-x)S), marcasite (FeS_2), and melnicovite pyrite (FeS_2); cyanide-soluble copper minerals such as chalcocite (Cu2S), digenite (Cu_9S_5).

2.2 Comminution

Comminution is executed early in the mining process to produce satisfied with controlled particle count and to make it easier to transport newly extracted material using conveyors, scrapers, and ore transporters. Because of this, bulk mineral content is typically finely scattered and tightly connected to the gangue, so they have to be first unlocked or liberated before the separating process can begin. Comminution gradually reduces the ores particle size until the pure mineral particles can be separated using available technology. The mill or processing plant uses a series of grinding and crushing procedures occur in the mill or facility for processing minerals to achieve comminution.

2.2.1 Crushing

The primary comminution step's mechanical goal is to crush the precious metal gangue materials, which is typically an arid process. Crushing occurs in two to three stages. Through primary, secondary, and tertiary crushing, run-of-mine ore lumps of 10–20 cm in diameter and 15 m in width are lowered with the use of heavy gear. Instead of being recycled back into the feed, the crusher product from open-circuit crushing is combined with the undersized material from the screen and sent to the next step. Both the crusher product and the undersized material from the screen are sent to the next stage by closed-circuit crushing. When manufacturing a rod mill or ball mill, the crusher performs at its peak level [9].

2.2.1.1 Primary crusher

Heavy-duty equipment called primary crushers is used to reduce ROM ore down to an appropriate size for transport and for feeding the AG/SAG mills or secondary crushers. The units are always run on an open circuit, whether heavy scalping screens (grizzlies).

The main crushing timetable and the mining schedule coincide in the majority of operations. Typically, the ore is delivered to the crusher by the mining department and the mineral processing department handle and crush the ore from this point through the subsequent ore-processing stages when primary crushing is carried out at the surface. This is especially true when primary crushing is carried out underground. Due to mechanical delays and inadequate crusher feed, primary crushers are typically designed to run for 75% of the time that is available.

[10]. Principal crushers come in two principal varieties in metalliferous operations jaw and gyratory crushers.

Jaw Crushers

The owner of the blake crusher patent was [11], and the majority of jaw crusher in use today are variants on this basic design. The patent states that the stone breaker “consists the employing two jaws—one stationary and the other movable to hold the stones broken.” The jaws are positioned sharply with one jaw pivoting so as to swing in comparison with the other fixed jaw. The material fed into the jaws is repetitively pinched and let drop farther into the crushing cavity until the discharge aperture.

Gyratory Crushers

Surface crushing machines are the main use for gyratory crushers. Resembling a jaw crusher, the head moves most extensively close to the discharge. This typically alleviates the choking brought on by edema. An effective illustration of arrested crushing is the gyratory crusher. The eccentric sleeve allows the spindle to freely rotate around its axis, which causes the lumps to be squeezed during crushing between the spinning head and the top shell segments with minimal abrasive action in the horizontal direction.

2.2.1.2 Secondary/Tertiary Crushers

Compared to the strong, tough primary machinery, Back-up crushers are lightweight. Cone crusher handle the majority of the second and third-stage crushing of metalliferous ores. A feed's maximum size will generally be smaller than 15 cm in diameter since they use primary crushed ore as feed, and it is considerably simpler to manage because the majority of the dangerous components, such as tramp metal, wood, clays, and slimes, have already been eliminated.

Crushers, cone

Several of the same concepts, such as gape, place, and launch; use because the modified gyratory crusher is called a cone crusher. The main distinction is that beneath the gyratory cone crusher head or cone shorter a universal bearing that is curved supports the spindle rather than hung like it is in the gyratory.

Crushers, roll

Even though they are not frequently utilized in the mining sector, roll crushers can be useful for crushing less abrasive feeds like limestone, coal, chalk, and gypsum that are friable, sticky, or frozen.

2.2.2 Grinding

In the comminution process, grinding is the final step where particles are decreased in size.

2.2.2.1. Tumbling mills

The remaining two crushing stages (secondary and tertiary) and rod milling of the conventional circuit are typically replaced with AG/SAG mills. This has a few advantages over the conventional circuit, including lower capital costs, the ability to process a variety of ore types, including sticky and clayey feeds, relatively simple flowsheets, large equipment sizes, a reduction in the need for labor, and a decrease in the amount of steel used (it should be noted that these mills take the place of some crushing/rod milling stages). Since so many existing plants are retrofitting them due to the increased use of AG/SAG milling, few new facilities are designed without it [12].

Each type of mill has a horizontal cylindrical shell with replaceable wear liners and a charge of grinding medium inside it. The mill shell rotates in tumbling mills, imparting motion to the charge via the mill shell [13].

In the mineral sector, tumbling mills are frequently used for primary grinding, or the stage immediately following crushing, where particles between 5 and 250 mm are reduced in size to between 25 and 300 m [14]. Tumbling mills have been developed to a high degree of mechanical efficiency and dependability, yet there is still controversy over how well they convert the energy they give into shattered material. The main causes of ore breakage are repeated, random impact and abrasion, phenomena [15].

Types of Tumbling Mill

Rod Mills

Both fine crushers and coarse grinders can be thought of as these mills. They can process feed up to 50 mm in size and produce a product as fine as 300 m, with reduction ratios (F_{80}:P_{80}) often falling between 15:1 and 20:1. When the ore is "clayey" or moist, which tends to choke crushers, they are frequently preferable to fine crushing equipment. Although various theories have been put forth, there is no practical way that these impacts can be directed at the interfaces between the mineral grains, which would produce optimum liberation (liberation by detachment), so they are still present in older plants but are frequently replaced during modernization. Utilizing assisted breakage technologies like microwave heating and high voltage [16] and are now relatively rare [17].

Ball Mills

Because they provide a larger surface area per unit weight than rods, steel balls are employed as ball mill grinding media, which are tumble flours utilized in the latter stages of primary comminution. Ball miils, which have a maximum length to diameter percentage of 21, are an excellent option for pulverization machinery. Tube mills are ones having a ratio of three to five. the latter are commonly used in dry mode to grind concrete, clinker, gypsum, and phosphate; on occasion, they are divided into numerous longitudinal sections, each of which has a certain charge composition. Another form of mill are tube mills, which have a single chamber[18].

2.2.2.2. Stirred Mills

The notion of utilizing " spherical grinding media and an agitator" was irst proposed in [19], which is when the concept of agitated grinding first emerged. Pharmaceuticals to industrial minerals have all found uses for stirred milling in fine to ultrafine grinding. Agitated grinding has increased in the last few years, roughly coinciding with the processing of more complex fine-grained ores that require liberate grinds of 10 m and less [20].

Motionis what stirred mills do; Added by the turning to face the charge of a stirrer internal [21], which is stationary and placed either horizontally or vertically. The stirrer agitates or rotates the mill's grinding medium (25 mm or less) [22].

2.2.3 Comminution circuits design for gold ore processing

The definition of target product size (to maximize revenue), ore characteristics, and downstream processing will frequently narrow or refine the field of applicable comminution flowsheets. This design throughput is defined as is frequently dependent on infrastructure considerations, mine development, stripping, or mining order, or equipment sizes. A thorough description of the comminution circuit's design has been provided [23]. No decision had been reached about the choice of a circuit following the preliminary research, but a testwork program had gathered physical property data acceptable for conventional circuits and for a preliminary evaluation of SAG milling.

Historically, pulverizing and blending have been seen as distinct operations,A number of flowsheet options exists for the comminution of primary crushed ore, the most common of which are:

- Rod and/or ball milling is followed by staged crushing; Rod and/or ball milling is followed by staged crushing;
- Fully autogenous grinding (FAG) or single stage semi-autogenous grinding (SAG); and

Two-stage grinding that entails autogenous grinding entirely or in part, followed by ball milling or pebble milling. There are many other broad circuit kinds, and the list above is not all-inclusive. In modern times, staged crushing followed by rod and/or ball milling is usually only used in smaller plants (1.5 Mt/a) processing tougher, more capable ores. Because of the lower initial investment and easier operation, the industry is increasingly relying more and more SAGmilling and less on autogenous milling.

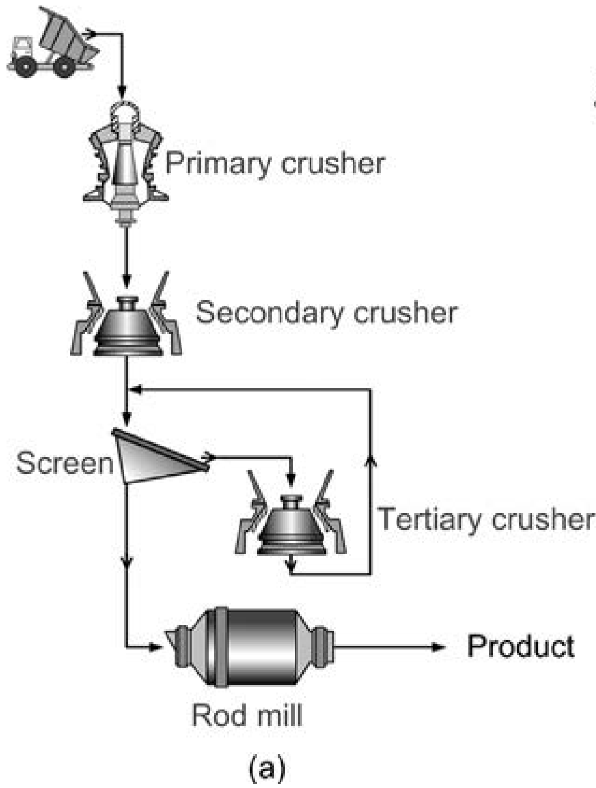


Figure1. Both a rod mill and a SAG mill with a "recycle" (pebble) crusher are fed by crushing flowsheets.

2.3 Beneficiation of gold

Depending on the ore's characteristics and financial factors, flotation, cyanide leach, and primary gravity concentration are among the processes for processing gold ore. Several techniques are used. In order to extract gold from its ores, one or more of the previously listed methods were applied.

2.3.1 Gravity Concentration

Fine free gold, which is too tiny to be recovered effectively, is dependent on the installed equipment and ranges from 500 m for sluices to 200 m for jigs to 50-100 m for spirals to 50 m for shaking tables [24]. The interaction of gold with other minerals, in particular the locking of fine gold grains in quartz and other "light" gangue minerals, reduces the average particle density. Because gold metal is so incredibly malleable and ductile, free gold grains flatten during grinding and milling as opposed to breaking apart. With larger gold grains, this effect is more pronounced. In table concentrators, flaky gold frequently aligns itself parallel to the water flow, and in centrifugal concentrators, it "surfs the bowl" like a sail in the wind, increasing the risk of rejection [25].

2.3.2 Leaching processes

One hydrometallurgical technique that allows for the beneficiation of gold ores from sources that would otherwise be unproductive because of their fine gold distribution or their relatively low gold grades. Although these are not the only ore types that can be leached, these ones can.

Cyanidation is one of the most widely used processes for processing gold ore. In order to extract precious metals from the ore, this method uses solutions of sodium or potassium cyanide as lixiviants (leaching agents). A variety of technica setups are feasible for cyanide leaching processes. Leaching with agitation is a practical method for high-grade gold ores that are highly leachable. This includes continuously stirring an ore pulp that is being leached in specialized tanks with particle sizes of less than 100 microns.

2.3.2.1 Gold recovery after cyanidation

Carbon processes

The best and most common way to extract gold using cyanide leachates is via adhesion to activation of carbon. Utilizing carbon to recover gold is frequently adjusted between pure CIP and CIL, thus there may be one or two leaching phases before the pulp comes into touch with carbon. [26]. Despite the fact that gold recovery onto carbon was first patented in [27] and after recovering the gold unit around 1950, there was no workable way to recycle the carbon[28].

Carbon in pulp (CIP)

Ore is dissolved into solution to produce gold via a progressive leaching process called carbon in pulp (CIP), which starts with special tanks or vats. CIP leaching systems are typically set up in circuits of 4-6 tanks or vats so that counter current decantation can be used in many phases of gold adsorption. After the initial leaching step, a filter stage separates and clarifies the pulp from the pregnant leach solution. The gold is then desorbed or "loaded" onto the activated carbon (AC) by passing through it or by submerging it in the pregnant solution. The gold is subsequently recovered by electrowinning after being removed from the loaded AC using a diluted cyanide solution in an elution circuit.

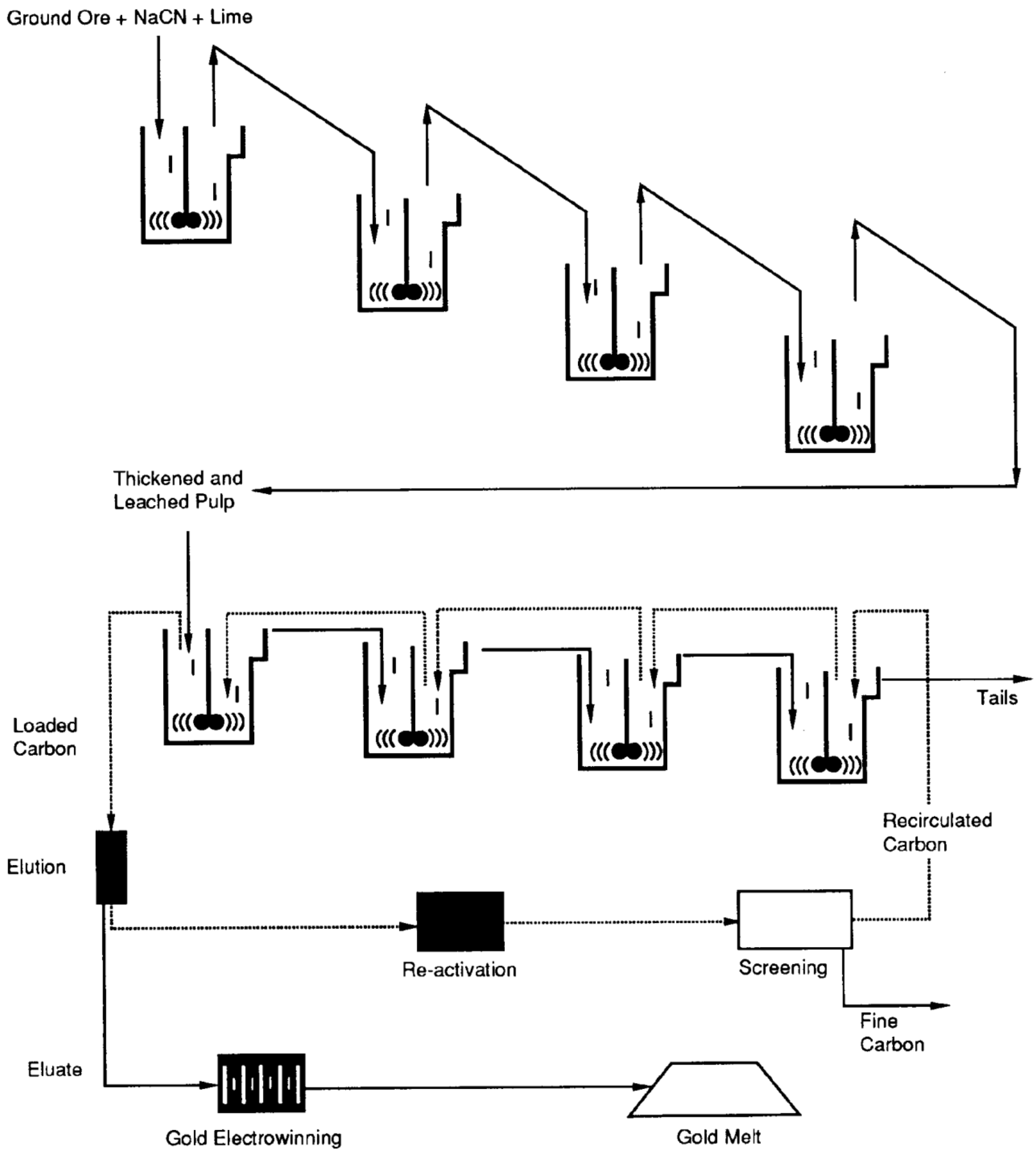


Figure2. A Typical flowsheet of Carbon-in-Pulp (CIP)

(Source: Calgon, Granular Carbon for Gold Recovery undated.)

Carbon in leach (CIL)

Simultaneous leach and adsorption processes, which take place as soon as metals dissolve in the leach slurry ac and are submerged in the agitated leaching tanks, may be more effective than cip when there are significant concentrations of silver, copper, or other ovulation-robbing elements like carbonaceous ores. After the leach cycle is finished, loaded carbon is screened to separate it from the pulp and then put through an elution process to extract the gold. Arsenic-containing ores and other ores that are not highly recoverable for the cyanide process can be separated from one another by a number of design aspects.

Not all ores are highly recoverable using the cyanide method. Ores containing arsenic and antimonial have historically caused problems[29].

Electrowinning

The process of electrowinning, also known as electroextraction, involves placing metal electrodes on their ore after it has been dissolved or liquefied [30]. Electrorefining uses a similar process to remove impurities from a metal. Both processes use electroplating on a large scale and are important techniques for the economical and straightforward purification of non-ferrous metals. The resulting metals are said to be electrowon. In electrowinning, a current is passed from an inert anode through a liquid leach solution containing the metal so that the metal is extracted as it is deposited in an electroplating process onto the cathode.

2.3.3 Flotation of Gold Ores

The basis for flotation is variations on the surface of physico-chemistry characteristics of mineral materials. Such characteristics are either inherent or are brought about by the suitable compounds. By adding chemicals, a single mineral or set of Particles of minerals are forced to attach preferentially to air bubbles during the floatation process. In order to prepare the ore for flotation, it is processed and sorted by size. The next step involves mixing the ore with chemicals from one of four primary groups: collectors (promoters), frothers, activators, and depressants. In a conditional cell, the ore slurry and chemicals are typically combined to coat the desired mineral. Pumped into a flotation cell with conditioned slurry, air is added. The target mineral is carried to the surface, away from the remaining gangue, by air bubbles that cling to the reagents and transport it there for collection[31].

The target material in the flotation procedure isn't always a precious metal or other valuable substance. The values may be retrieved from either the top or bottom of the flotation cell, depending on the specific gravity and the reagents used [32].

Pure gold metal surfaces are hydrophilic by nature, but because hydrocarbons can easily bind to them, they become somewhat hydrophobic, giving them some natural floatability. Matching collectors to the composition of free native gold can improve the efficiency of gold flotation [32].

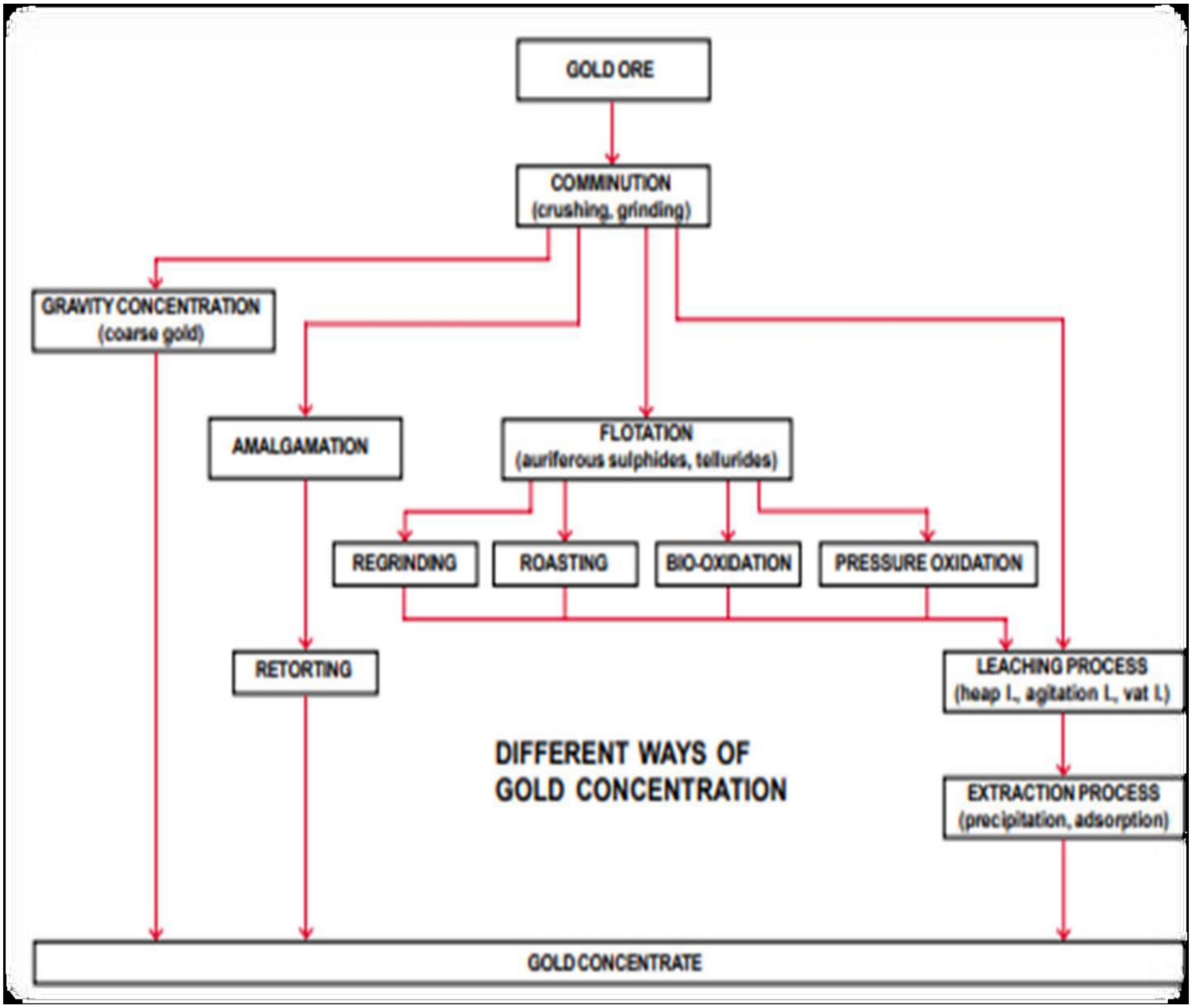


Figure 3: Generalized flowsheet for gold beneficiation.

2.3.3.1 Flotation Propertie of Gold Minerals

Although natural gold and its alloys are easily floatable for xanthate collectors due to their lack of surface impurities, gold surfaces are often tarnished or covered with various pollutants[33].

2.3.3.2 Flotation of Gold Containing Mercury/Antimony Ores

These ores often fall under the category of hard-to-treat ores, where cyanidation typically results in subpar extraction. Because mercury is somewhat soluble in cyanide , consumption rises and e xtraction falls [34].

2.3.3.3 Flotation of Gold From Base Metal Sulphide Ores

The typical range of gold recovery from base metal ores was 30% to 75%. Gold accumulates in the copper concentrate when the ore is a copper-zinc or copper-lead-zinc ore. Gold usually reports to the lead concentrate when lead-zinc ores are processed. Recent research [35] on a variety of base metal ores have uncovered some key characteristics of the gold flotation behavior of these ores. With the right choice of reagent schemes, gold recovery to the base metal concentrate can be significantly increased.

2.4 Flowsheet development for gold ore bodies

A wide range of basic metallurgical flowsheets with endless variants are used to process gold orebodies. The flowsheet that offers the highest gold recovery at the lowest cost is always the optimal flowsheet economically speaking. Given that these two frequently clash, some degree of accommodation is required. The industry gives processing gold ores a lot of attention, especially the competing technologies and their relative benefits and economics. One issue that keeps coming up is how difficult and refractory the ores are that need to be handled. The ideal flowsheet will be created by the process engineer using this as a starting point, albeit it does not pretend to be exhaustive. Despite the fact that the number and significance of the process selection alternatives have increased [36].

2.4.1 Flowsheet option for gold orebodies

In conclusion, the following headings will be used to assess gold flowsheet options:

- Free-milling ore processes
- Complex ore processes

➢ Refractory ore processes

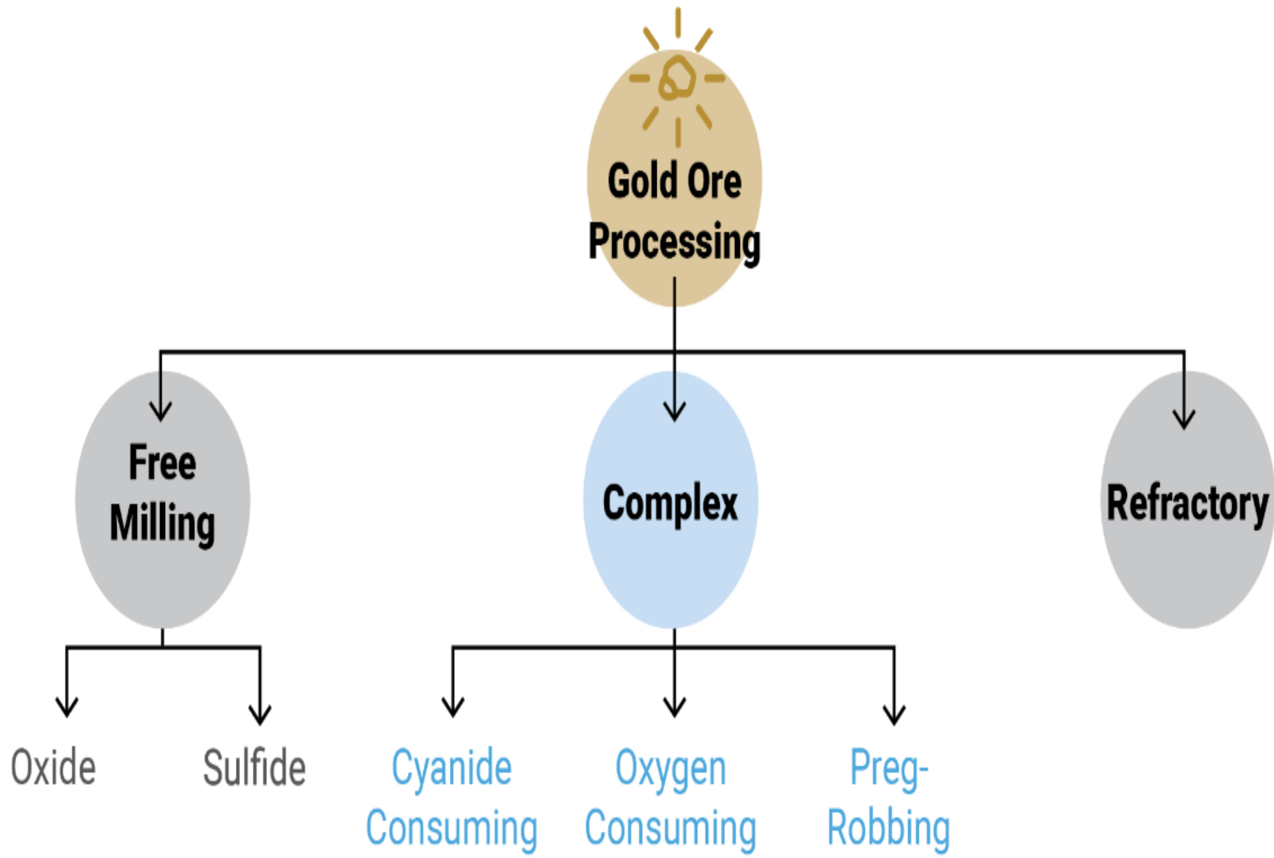


Figure 4. Gold ore characterization.

2.4.1.1 Free-milling ore processes

When referring to ore, the term "free milling ore" describes ore in which gold may be readily separated from other minerals by physical means (crushing and grinding), followed by gravity and direct cyanidation. Typically, free-milling ores are those from which customary cyanide leaching may recover more than 90% of the gold [36].

The selection of the flowsheet for free-milling ores can be very simple, with the main concerns focusing on the choice of the comminution circuit, the application of heap leaching, the handling of high silver ores, and the flotation alternatives for free-milling sulfides.

2.4.1.2 Complex ore processes

Complex ores are ores that can yield high gold recoveries but only when leaching conditions are changed or intensified. Pregnant-robbing and reactive ores are two subcategories of complex ores. Preg-robbing ores have components that can absorb gold-cyanide complexes during the leaching process. Any ore that has components that react with reagents is referred to as reactive ore [37]. Base-metal-related complex ores, such as copper-based ones, can consume cyanide and cause problems with carbon-in-pulp (CIP) and elution. Preg-robbing carbon will necessitate flowsheet inclusions in order to obtain an adequate recovery rate without suffering large gold losses to carbon-in-leach (CIL) tailings.

2.4.1.3 Refractory ore processes

The fact that gold ores are becoming more refractory as they are processed is a frequent subject. This is true even though ores like those at Kalgoorlie have needed roasting to be liberated for the past century. The features of refractory ores and the reasons for decreased recovery have been explored in papers on refractory gold treatment [36], the economics of the available technology and the choice of an appropriate process route [38].

The only refractory gold processes deemed to have reached a reasonable state of development in 1987, when GRD Minproc completed the feasibility assessment for the Bogosu project in Ghana, were pressure oxidation and concentrate roasting[39]. While it may not be necessary to undertake a detailed program exploring every option for all refractory gold projects, it is certainly important not to make an arbitrary selection based on preconceived ideas of process attributes or on generic comparisons of process effectiveness. Beyond 2000, the number of options has not increased to any significant extent[40], have released decision diagrams for the metallurgical testing of refractory gold ores, which are helpful tools for creating testing plans.

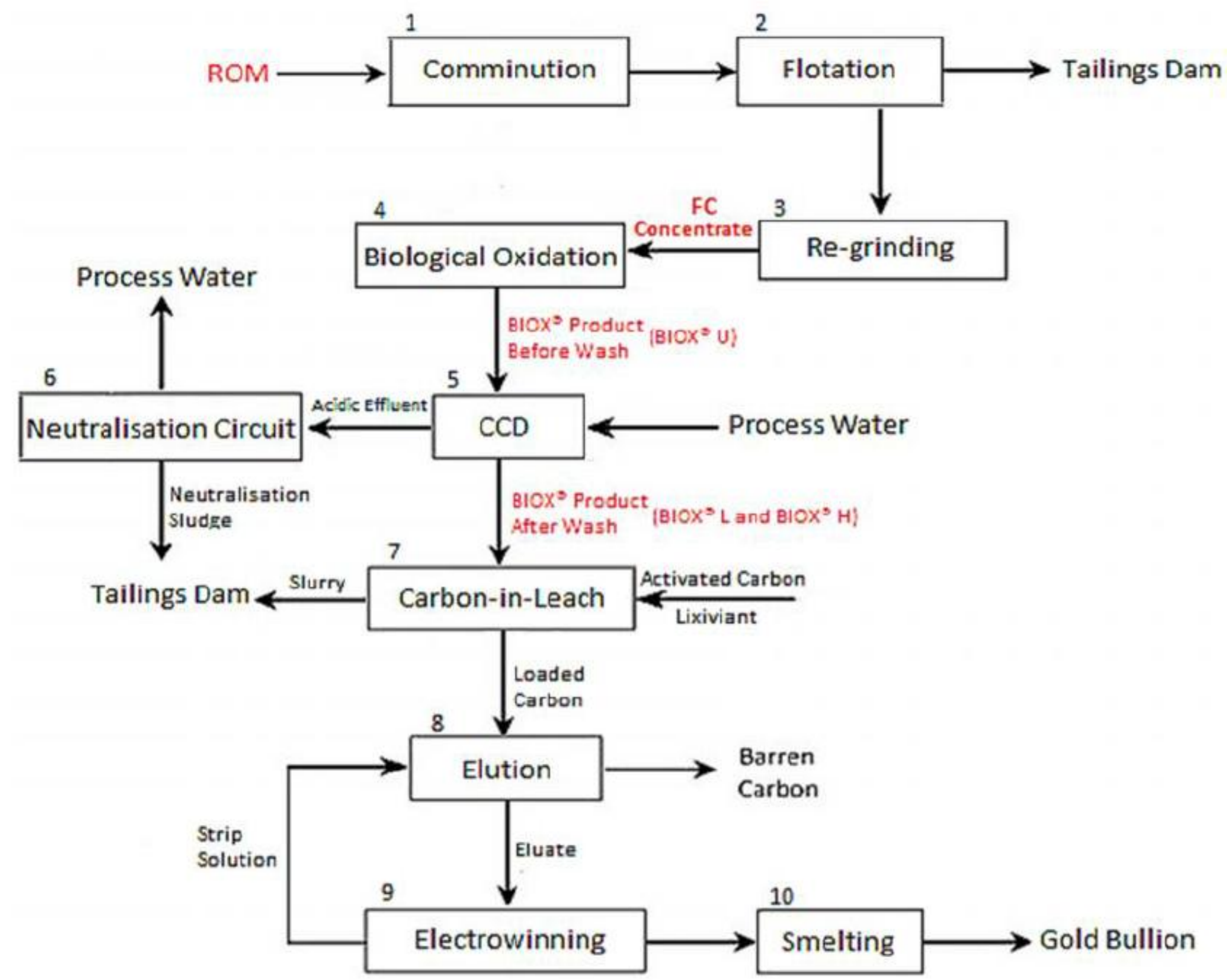


Figure 5. A typical flowsheet for processing refractory gold

2.5 Environmental Compliance

The cost of environmental compliance is a significant component that must be taken into account in the selection of a flowsheet and the economic assessment of a gold project. This can have a big impact and varies depending on the flowchart and the country. In most countries, cyanide must be destroyed before being released into a tailings pond, and it must always be destroyed before being released into the environment. The particular method chosen and the restrictions set by local authorities will affect the cost of cyanide destruction. This in turn depends on the concentrations of many other soluble species as well as the concentration of metal cyanide complexes and cyanide in the effluent. Alternatives have numerous drawbacks and are less effective than cyanide [41].

CHAPTER THREE

3. Materials and Methods

3.1 Chapter overview

This chapter mainly focuses on the equipment required, beneficiation methods, and chemicals that were employed for various work performed in this work.

3.2 Materials

Table 3.1 General Plant stage and respective materials

Objectives	**Equipment and materials**	**Chemicals**
Plant Procedure		
Crushing	• Jaw crusher • Gyratory crusher • Cone crusher • Double deck screen • Feeder • Conveyor belt • hopper •	No chemicals
Grinding	• Rod mill • Ball mill • Sum • Hydro cyclone • Desanding screen • Trommel screen	• Lime
Thickening	• Thickener	• Flocculant

	• De-aertion tank	
Leaching	• Leaching tank	• Sodium cyanide(NaCN)
Adsorption	• CIP tank	• Carbon
Elution	• Elution column	• Caustic soda (NaOH)
Acid wash	• Acid wash tank	• Hydrochloric Acid(HCl)
Electrowinning	• Electrolyte tank and pumps	
Gold Smelting	• Smelting Fluxes • Silica (SiO_2) • Borax	

	$(Na_2B4O_7.10H_2O)$ • Nitre (KNO_3)	

3.3 Methods

3.3.1 Size reduction (Comminution)

The size reduction of ore was performed by crushing unit and grinding unit.

3.3.1.1 Crushing unit

The crushing unit of legadembi plant was equipped with two independent Primary crushers (Original & Medina) to reduc size.The Crushing unit was performed by primary, secondary and tertiary based on the particle size.

Primary stage crusher (Jaw crusher)

Original crusher (Old crusher):- The crusher reduce a fed of 1200mm diameter lump to a product size 80% (P80) passing of 120mm.

The jaw crushed ore was sent to the secondary stockpile via a conveyor belt (C1&C2).The ore was then with draw from the bottom of stockpile facilitated by the vibrating feeder (VF3or VF2)to the corresponding conveyor belt (C3) which is equipped with a metallic detector to prevent any metal entering to the secondary superior crusher (CR2), where it was reduced to 45-50mm per the close side setting gap arrangement. Secondary crusher product conveyed by (C4& C5) to the double deck vibrating screen consisting of the upper deck rubber screen (40mm) size and the lower deck rubber screen (20mm).The undersize of the lower deck rubber screen conveyed to final stockpile by C9 and C10, but over size of the upper and lower deck is conveyed by C6 to the bin and then to the tertiary crusher(hydrocone) by C7. Secondary and tertiary crusher feed was regulated by installed photo cell in order to start or stop the corresponding conveyor belt per their crushing efficiency.

Medina crusher: Thecrusher reduces ore lump from 1200mm to an 80% passing size of 130mm. The Run of Mine(ROM) ore was fed to a 90 tonne capacity hopper by a front-end loader to 70mm aperture grizzly feeder that vibrates. Moving grizzly transfer the ore from the hopper compared with a single-toggle jaw crusher. The undersize ore from grizzly pass through 19mm mesh to B2, while over size Ore transferred into crusher chamber. The jaw crusher operates with a closed side setting (CSS) of 130-135mm.

Crushed and discharged ore from jaw crusher conveyed by B1 to secondary stockpile. Secondary stockpile underneath vibrating feeder transfers the ore onto B3 and discharge into secondary or superior crusher. The ore crushed and discharged from superior crusher conveyed by B4 into double deck vibrating screen. Screen were fitted with 20mm and 40mm lower and upper decks respectively. The over size from the upper deck and lower deck reports to surge bin conveyor B5 while under size from lower deck discharge onto B7 conveyor and then transfers to fine stock.
The oversize ore from surge bin transfers by variable vibrating feeder onto B6 and discharged into hydrocone crusher. The product of hydrocone crusher combined with superior crusher on B4 and then transfers to double deck vibrating screen.

Secondary stage crusher (Gyratory crusher)

Secondary crusher (gyratory)crusher maximum feed size of 130mm. The crusher were powered by an electric motor with a power on 160 kW and a maximum revolutionary speed of 1475rpm. Closed side setting of the main shaft assembly position of the crusher produce an 80% passing size of 50mm.

Tertiary crusher (Hydro cone crusher)

The crusher powered by an electric motor with 220kw at speed of 1470rpm. The main shaft assembly can be set between 8-41mm by hydro set. The crusher reduces ore particles from 50mm to an 80% passing size less than 20mm.

3.3.1.2 Grinding unit

The ore particles were ground in revolving steel containers with cylinder shapes that hold a charge of loose crushing bodies as the grinding medium, which is free to move inside the mill.

Lime

Lime was delivered to mill by fork and temporally placed on wood shit. The lime from surface lifted by overhead crane and placed on upper floor of grinding room nearby rod mill feed chute. Two sacks of lime 72kg each within two hour interval poured into rod mill.

Rod mill

Crushed ore with an 80% passing size of 20mm was fed directly into the rod mill fed chute by the mill feed conveyor C11. A rod mill shell was steel lined a 3400mm diameter by 5600mm effective grinding length. The mill overflow discharge unit fitted with a 6mm aperture trammel screen and powered by 800kw motor with 982 rpm.

Ball mill

Ball mill used a closed-circuit operation with a hydrocyclone. Cyclone Under flow process water, grinding media, and slurry added through the ball mill feed chute. Ore particle grinded from 80% passing size less than 600µm to 80% passing size less than 125µm. Ball mill overflow slurry passed through a 6mm trommel screen that attached at discharge end.

Hydrocyclone

Cyclone underflow or ore particles which have not reached the required liberation size are re-entered the ball mill for additional grinding. The ball mill received the cyclone underflow re-grinded and joined in sump with fresh rod mill discharge. The combined ball mill discharge and rod mill discharge is then cycloned again, with 55% solid.

The trash screen distributor is where the cyclone overflow slurry from the cyclone clusters gravitates, where it is distributed over the waste screen to remove any plastic, steel, wood ore foreign material coming from the mine.

Trommel screen

Undersize slurry from the rod and ball mill was sent to the cyclone feed using a trommel screen. sump pump, diluted to 55% solids with process water, and pumped to classification cyclones. The scalped off ore and grinding media were then collected and stored in the drum. Oversize ore transported to rod mill for regrinding while grinding media for other usage.

Desanding screen

Through a distributor, diluted slurry is introduced onto the moving cloth. Gravity causes the undersize to flow through the fabric and settle in the under pan. Any sticking material is washed from the screen cloth using water sprays, and any oversize material that was held on the screen was ejected at the driving pulley.

The pre-leach thickener receives the undersize from the screens using gravity, while oversize or trash material collected on screen before returned to grinding circuit with process water and discarded into drum.

3.3.2 Thickening and Reagent unit

3.3.2.1 Thickener

A specified velocity was used to discharge the de-aerated and flocculated feed into the thickener's main body through the annular space between the feed well and the deflector plate. The rake arms move the solids toward the underflow cone for extraction when they have settled.

3.3.2.2 Flocculant

Flocculent transported by loader and stored in preparation area for temporary usage. During flocculent preparation 25kg magnafloc poured into hopper manually at controlled rate; 6.25kg Consumption per shift.

3.3.2.3 Cyanide

2 ton of NaCN box daily transported from store by loader and placed nearby cyanide preparation tank. Wooden intermediate bulk container of sodium cyanide immediately lifted by overhead crane and poured into preparation tank. The preparation tank used to prepare 11.76% sodium cyanide solution weight by volume.

3.3.3 Leaching and Adsorption

3.3.3.1 Leaching

Thickener underflow was pumped to the leach feed distribution box and then gravitates to the first of six series connected leach tanks via a pulp sampler box where the feed is sampled by automatic sampler every 15 minute interval and combined to one sample lot every four hours. The solid sample sent to the laboratory for gold determination is used as a head grade. The tanks are mechanically agitated using twin hydrofoil type agitators. Sodium cyanide as a 10% solution is added to the leach feed distribution box at a rate necessary to give optimum gold dissolution in the leach tank train. The sampler box was also fitted with dart values to enable slurry to be fed to tank No. 2 bypassing tank No.1. Tanks 1 to 5 are fitted with dart valve controlled overflows to enable tanks to be bypassed for maintenance. Each tank was fitted with air sparge pipes delivering plant air underneath of the impeller. The air flow was manually controlled by a valve on each sparge line.

3.3.3.2 Adsorption

Adsorption could be accomplished by bio-sorption, sorption on ion exchange resins, extraction with organic solvents, and adsorption on activated charcoal.

3.3.4 Elution

Elution process was performed by elution tank, when 2.7 ton of loaded carbon passed a process of acid wash, acid flush, loaded carbon transfer and column flush. The Loaded carbon recovered from Adsorption circuit to harvesting screen gravitate to acid wash tank.

3.3.4.1 Acid wash process

Concentrated hydrochloric acid (32% concentration on weight basis) transported from store by fork lift to acid wash area in 210 L drum and placed near to acid make-up tank. Acid transferring process was performed by using acid drum pump (hose type pump) to dilute acid make-up tank to prepare 3% v/v diluted acid for acid wash process.

3.3.5 Electrowinning and Gold Smelting

3.3.5.1 Electrowinning

Eluant transferring and stripping process started based on the style parameter of the processing facility to maximize elution efficiency of silver and gold from loaded carbon and consequently to minimize the remaining concentration of gold in eluted carbon typically less than 50ppm.

3.3.5.2 Gold Smelting

Smelting of gold, silver loaded steel wool cathode and preparation of gold bullion.

CHAPTER FOUR

4. BENEFICIATION METHOD AND FLOWSHEET DEVELOPMENT FOR LEGA DEMBI GOLD PLANT

In this section, beneficiation and the flowsheet development study method of the ore by using comminution (crushing and grinding), thickening (by using Flocculant),leaching(by using Cyanide), Adsorption (by using carbon), elution(by using caustic soda (NaOH)), acid wash **(**by using hydrochloric acid**)** the treatment method use diffirent parameters like feed rate, feed size,product size, ore density,diameter, length,width, rotational speed and flowsheet development of each unit was discussed.

4.1 Comminution

4.1.1 Crushing unit

The crushing unit of legadembi plant was equipped with two independent crushers (Original & Medina) in both case size reduction is the ultimate goal and the final product with less than 80% passing size of 20mm particle subject to fine stockpile for Rod mill feed. The first original crushing plant was erected at very beginning of the establishment of the whole plant. However, major equipments have been changed by MIDROC Gold to boost the crushing capacity as required. The second Medina crusher was installed additionally to overcome the shortage of fine crushed ore to the processing plant. Entirely both plants have the same type of equipment for secondary superior gyratory crusher, model CS 430, and tertiary hydro cone crusher, model CH 440, but with different primary jaw structure consisting of double two-toggle jaw for original crusher and single toggle jaw structure for Medina crusher. Depending upon crushed ore requirement both plants work at the same time or one at a time as required.

4.1.2 Stage of crusher

Legadembi process plant performs a Tertiary stage crushing; classified as primary, secondary and tertiary based on the particle size. There are two independent tertiary stage crushing unit in the process plant. The crusher differentiates one from the other only on primary crusher design and number of conveyor belts.

4.1.2.1 Primary stage crusher (Jaw crusher)

Both Primary stage of crushing plant are Blake type jaw crushers. Old crusher is double toggle while medina is a single toggle the jaw crusher.

Original crusher (Old crusher):- Primary stage of old crusher is double toggle jaw crusher with the size of 1000 * 800mm.The crusher was powered by an electric motor with a power on 90Kw and a maximum revolution speed of 1000rpm. The crusher reduce a fed of 1200mm diameter lump to a product size 80% (P80) passing of 120mm.

Old crusher Processing System

The slot screen undersize directly goes to the final stockpile while the oversize with the jaw crushed ore was sent to the secondary stockpile via a conveyor belt (C1&C2).The ore is then with draw from the bottom of stockpile facilitated by the vibrating feeder (VF3or VF2)to the corresponding conveyor belt (C3) which is equipped with a metallic detector to prevent any metal entering to the secondary superior crusher (CR2), where it is reduced to 45-50mm per the close side setting gap arrangement. Secondary crusher product conveyed by (C4& C5) to the double deck vibrating screen consisting of the upper deck rubber screen (40mm) size and the lower deck rubber screen(20mm).The undersize of the lower deck rubber screen conveyed to final stockpile by C9 and C10, but over size of the upper and lower deck is conveyed by C6 to the bin and then to the tertiary crusher(hydrocone) by C7.Secondary and tertiary crusher feed is regulated by installed photo cell in order to start or stop the corresponding conveyor belt per their crushing efficiency.

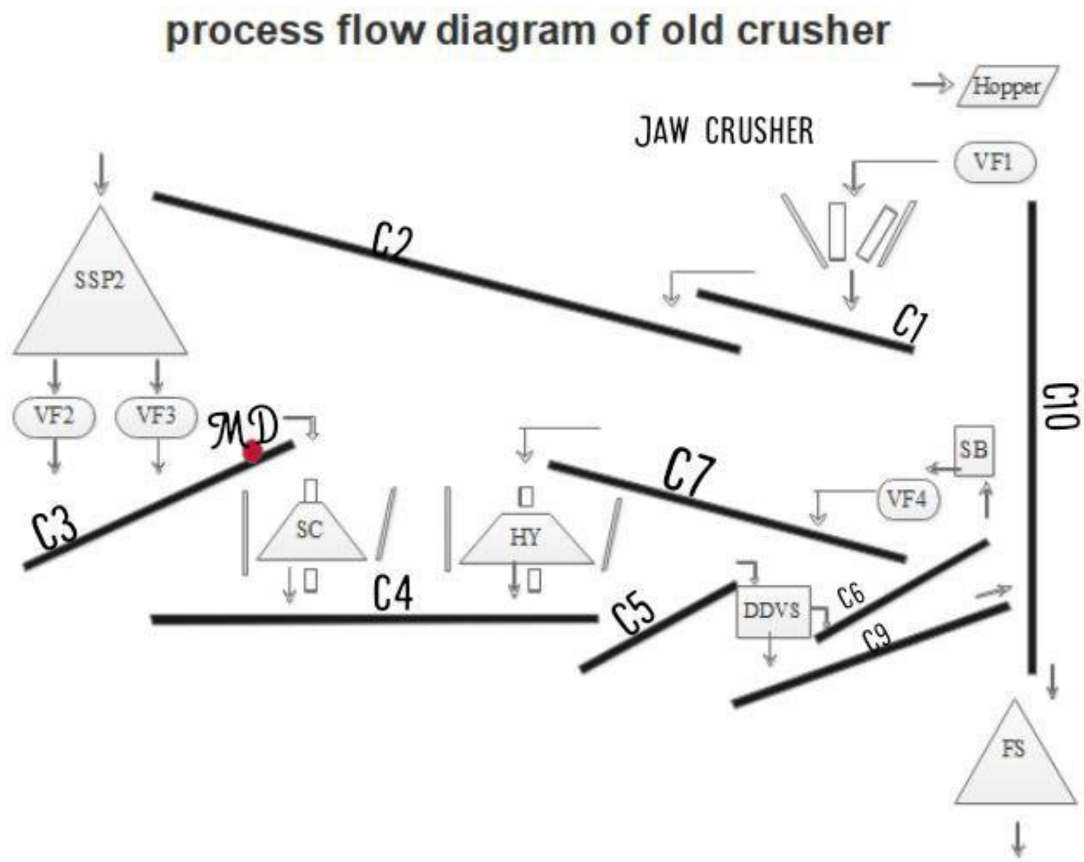


Figure 6. Process flowsheet of old crusher

Medina crusher: -Medina crusher is single toggle jaw crusher with maximum feed opening of 1200*1100. The crusher powered by 160kw electric motor and with 1475rpm.The crusher reduces ore lump from 1200mm to an 80% passing size of 130mm.

Medina Processing System

The undersize ore from grizzly pass through 19mm mesh to B2, while over size Ore transferred into crusher chamber. The jaw crusher operates with a closed side setting (CSS) of 130-135mm and is powered by a 160kw motor.

Crushed and discharged ore from jaw crusher conveyed by B1 to secondary stockpile. Secondary stockpile underneath vibrating feeder transfers the ore onto B3 and discharge into secondary or superior crusher. The ore crushed and discharged from superior crusher conveyed by B4 into double deck vibrating screen. Screen is fitted with 20mm and 40mm lower and upper decks respectively. The over size from the upper deck and lower deck reports to surge bin conveyor B5 while under size from lower deck discharge onto B7 conveyor and then transfers to fine stock.

The oversize ore from surge bin transfers by variable vibrating feeder onto B6 and discharged into hydrocone crusher. The product of hydrocone crusher combined with superior crusher on B4 and then transfers to double deck vibrating screen.

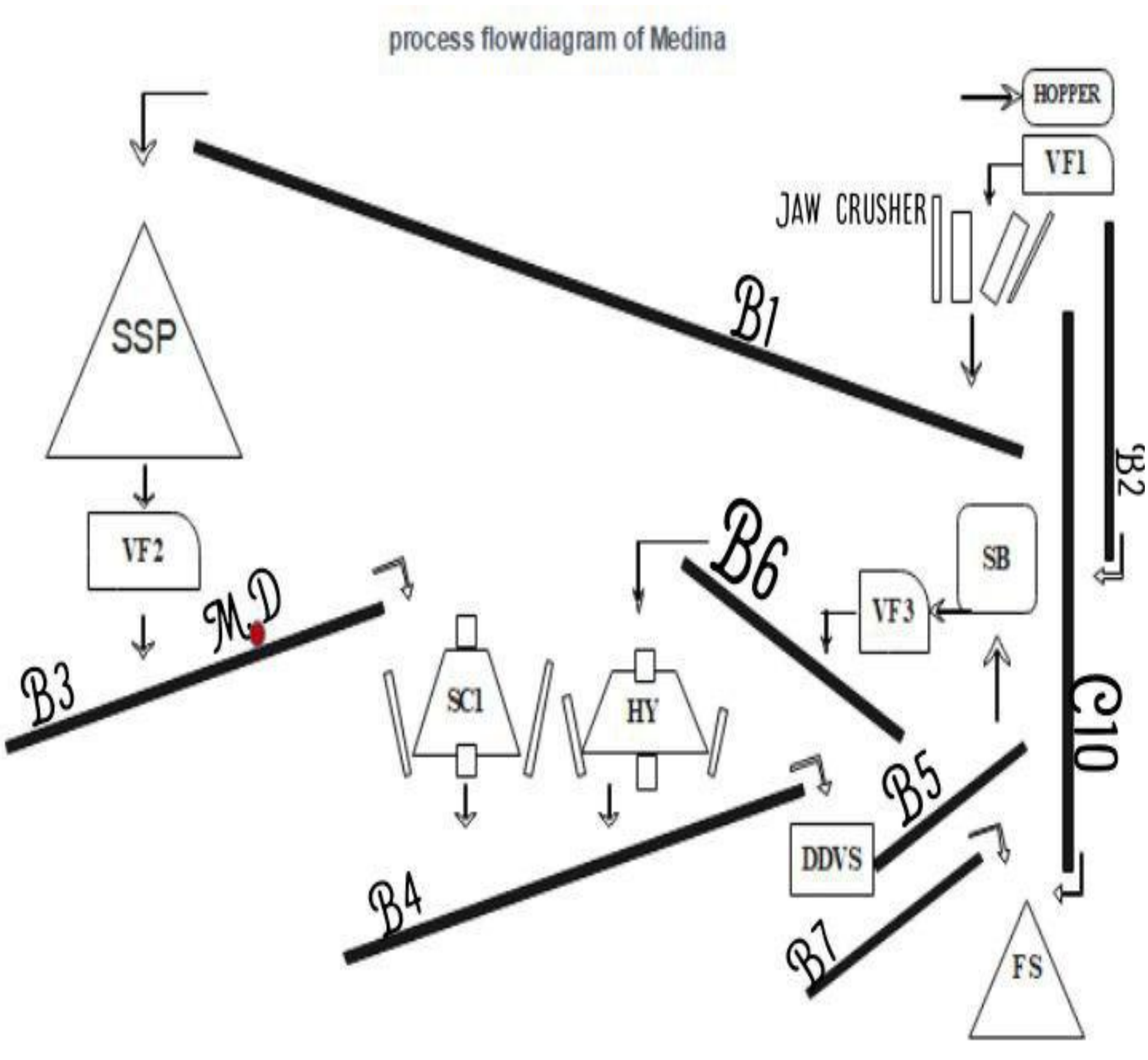


Figure 7. Process flowsheet of Medina crusher

4.1.2.2 Secondary stage crusher (Gyratory crusher)

Secondary crusher is reduction gyratory crusher maximum feed size of 130mm. The driven by an electric motor for the crusher with a power on 160 kW and a maximum revolutionary speed of 1475rpm.Closed side setting of the main shaft assembly position of the crusher produce an 80% passing size of 50mm.

4.1.2.3 Tertiary crusher (Hydro cone crusher)

Tertiary crusher is a short head Hydro cone crusher a maximum feed size 50mm.The crusher powered by an electric motor with 220kw at speed of 1470rpm. The main shaft assembly can be set between 8-41mm by hydro set. The crusher reduces ore particles from 50mm to an 80% passing size less than20mm.

Componets of Crushing circuit

The crushing circuit at Legadembi crushing plant typically was a tertiary stage operation that utilises an initial jaw crusher, an additional gyratory crusher, an ultimate hydrocone crusher, and Double deck vibrating screen. Primary, Secondary and DDVS configured in open, while tertiary and double deck vibrating screen in closed circuit.

1. Vibrating grizzly feeder

Usually, very coarse material is screened on an inclined screen called a grizzly screen. Grizzlies are defined by parallel steel bars or rails placed along the ore flow and separated by a predetermined amount. The bars are often made of wear-resistant manganese steel and are tapered to create gaps that widen toward the screen's discharge end in order to keep rocks from being lodged between them. [42].

2. Vibrating Feeder

In order to regulate the flow of bulk materials out of a bin, a feeder is utilized. Any feeder must be chosen to suit a certain bulk solid and the needed range of feed rates. Uniform flow is provided along a short slot opening using vibratory feeders. Material is thrown up and forward on a vibratory feeder so that it will surface at a location further down the tray [43].

3. Conveyor Belts

Different types of bulk solids are moved via belt conveyors over distances ranging from meters to kilometers. As a result, the belt and its load must be supported on idlers on both the conveying and return portions [43].

Table4 .1 Belt conveyors specification of old crusher

No	Belt Name	L(in meter)	W(in meter)	Thick(in mm)	Belt motor
1	C1	18.1	1.00	10	7.5kw ✕ 1460rpm
2	C2	101.1	0.80	10	15kw ✕ 1460rpm
3	C3	53.5	0.80	10	15kw ✕ 1460rpm
4	C4	20.3	0.80	12	7.5kw ✕ 1460rpm
5	C5	47.1	0.80	12	15kw ✕ 1460rpm
6	C6	53.5	0.80	12	15kw ✕ 1460rpm
7	C7	38.1	0.80	10	15kw ✕ 1460rpm
8	C8	38.1	0.80	10	15kw ✕ 1460rpm
9	C9	15.9	0.80	10	7.5kw ✕ 1460rpm
10	C10	101.1	0.80	12	15kw ✕ 1460rpm

Table 4.2 Belt conveyors specification of Medina(New) crusher

No	Belt Name	L(in meter)	W(in meter)	Thick(in mm)	Belt motor
1	B1	81.2	1.00	12	15kw ✕ 1445rpm
2	B2	-	0.65	10	-
3	B3	94.36	1.00	12	11kw ✕ 1730rpm
4	B4	61.55	0.80	12	11kw ✕ 1730rpm
5	B5	43.5	1.00	12	11kw ✕ 1730rpm
6	B6	47.5	0.80	12	11kw ✕ 1730rpm
7	B7	45	1.00	12	18.5kw

4. Double deck vibrating screen

The upper deck have rectangular and square opening randomly at apertures size of 40mm and lower deck 20mm.The oversize from screen lower aperture circulated thorough belt and bin arrangement for further crushing by tertiary crusher until the required specification while undersize transfers to fines stock[44].

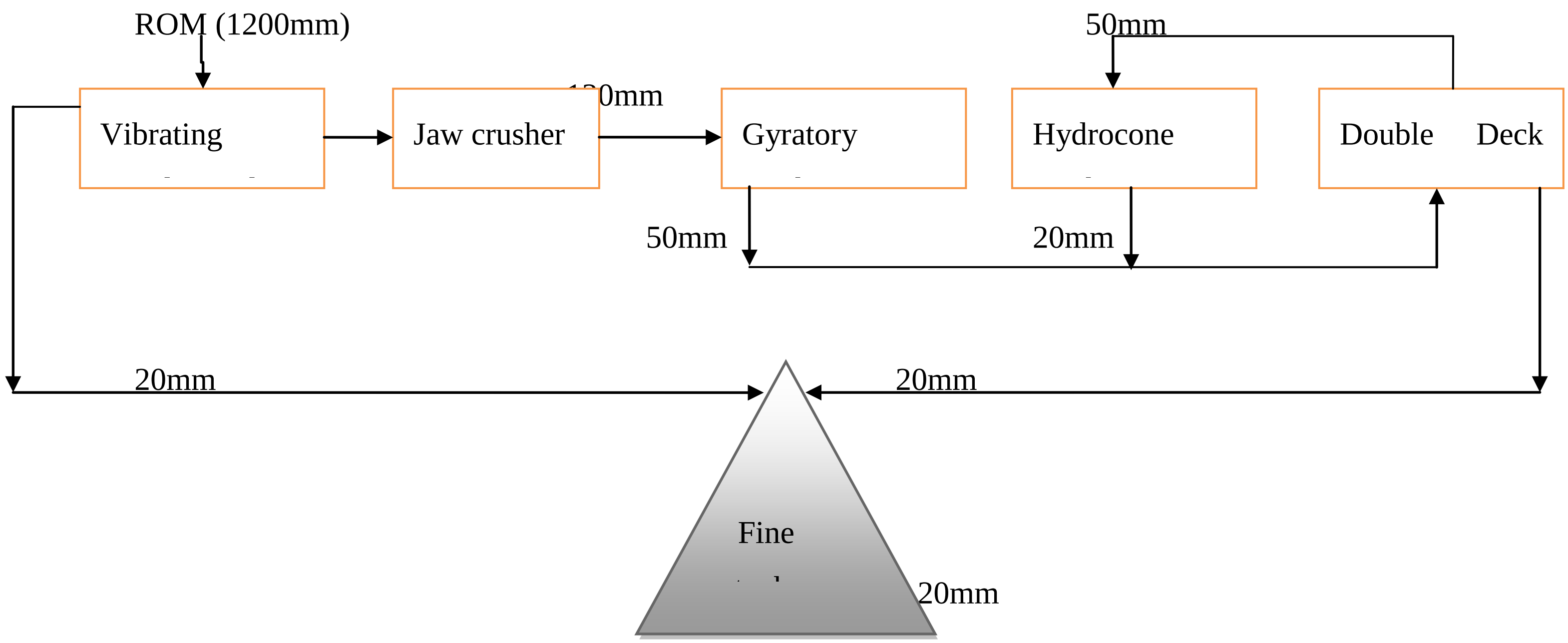


Figure 8. Process flowsheet of crusher circuit

4.1.3. Grinding unit

To separate the valuable metal from the gangue material, the fine material was processed further. Legadembi process plant grinding unit averagely ground 3120 tons per day in current feed rate of 120-140t/hr. The grinding circuit can operate at a full capacity greater than 200 t/h (fresh feed), and produce a final particle size P_{80} of 120-130µm.

4.1.2.1 Grinding circuit

Legadembi process plant grinding unit implement different mill type according to grinding media with classification and separation equipment. Grinding circuit basically intended to keep and control process variables these include; feed rate, media charge, percent of solid or density and product particle size. Major equipment and components of Legadembi process plant grinding circuit described as follow:

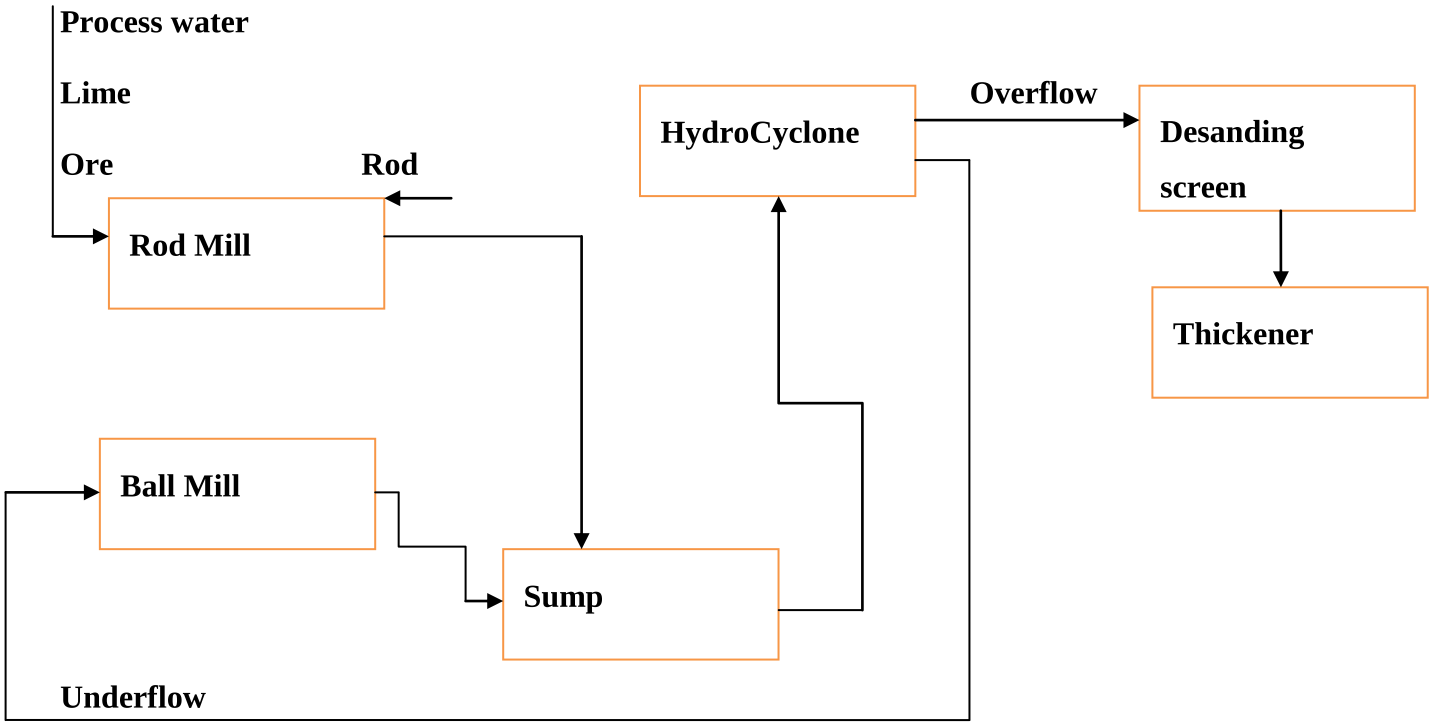


Figure 9. Process flowsheet of grinding unit

Rod mill

Crushed ore with an 80% passing size of 20mm is fed directly into the rod mill fed chute by the mill feed conveyor C11.A rod mill shell is steel lined a 3400mm diameter by 5600mm effective grinding length. Rod mill is wet overflow discharge type, which is operated at 65% of the critical speed and with a normal operating rod mill charge of 45% on a volumetric basis.

Ball mill

Cyclone under flow slurry, grinding media and process water added through the ball mill feed chute. Ore particle grinded from 80% passing size less than 600µm to 80% passing size less than 125µm. Ball mill overflow slurry passed through a 6mm trommel screen that attached at discharge end. Water will be added to the ball mill to maintain slurry density of 72-74% of solid.

Hydrocyclone

The coarse particles spiral downhill before exiting the hydrocyclone through the spigot in the underflow stream. The tiny particles ascend and exit through the vortex finder in the overflow [45].

Desanding screen

Gravity causes the undersize to flow through the fabric and settle in the under pan. Any sticking material is washed from the screen cloth using water spray, and any oversize material that was kept on the screen is discharged at the driving pulley[46].

The desanding screen has a 6m2 surface area and a 0.7mm screen opening.For the purpose of removing trash, hydrocyclone overflow is gravity-fed to a desanding screen or trash screen.

Mill discharge pump Mill discharge pump which have a capacity of 837.5m^3/h with speed of 1450rpm operated in standby mode to transfer or pump slurry from discharge sump to hydrocyclone classification circuit.

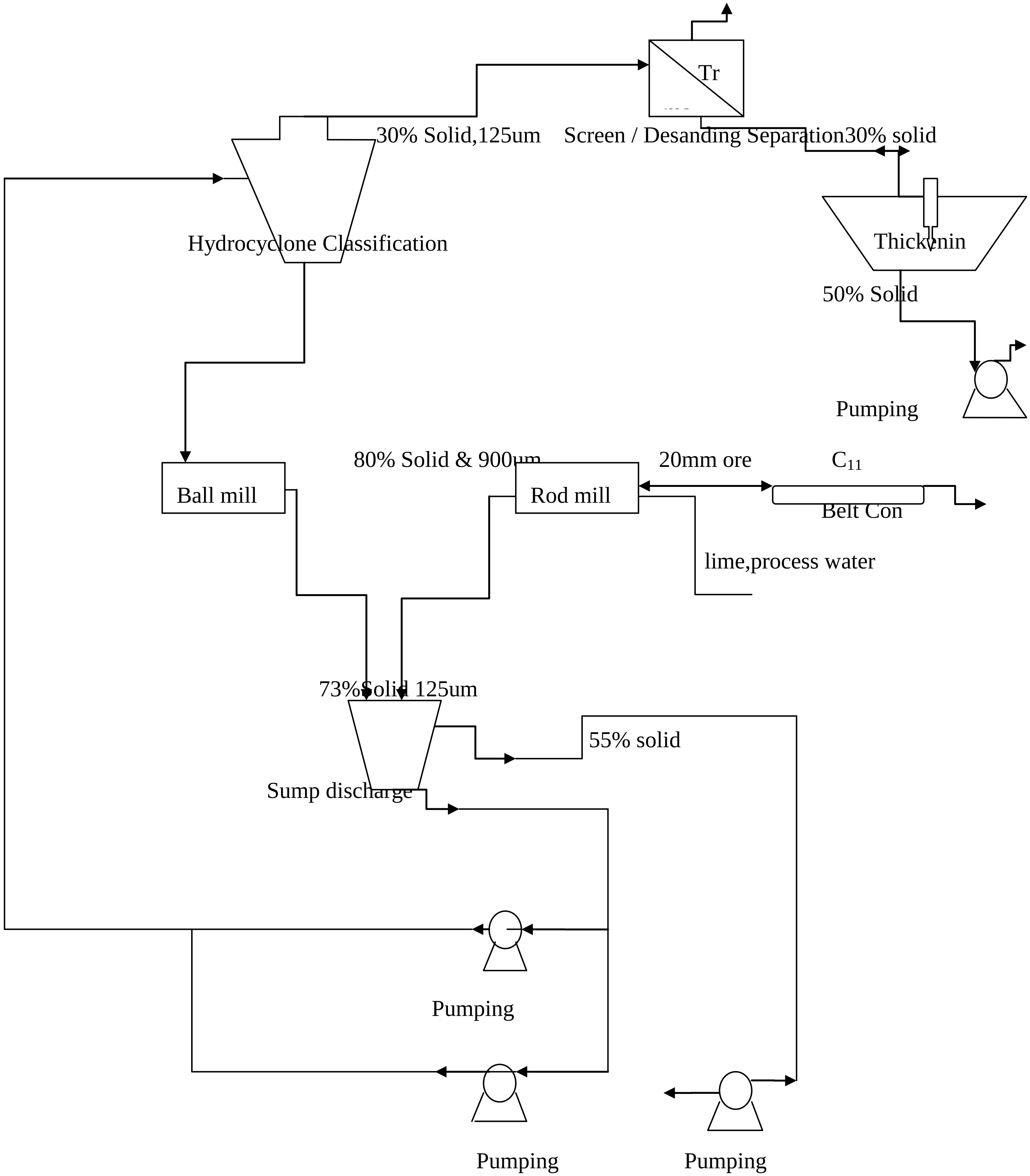


Figure 10. Process flowsheet of grinding circuit

4.1.2.2 Grinding unit Utility and consumption

Water

There two basic source of water for plant operation are process water from Awata river and underground water from tailing recycle.

Process water

Process water from Awata River pumped to the intermediate dam. Water from intermediate dam pumped to reservoir which is sufficient for 2-3hr of normal operation.

Underground water

Underground water recovered from tailing recycle used as dilution water for grinding unit, thickener overflow tank makeup, spray water for safety screen and cooling for Air compressor. Process water sourced from reservoir and thickener overflow with additional make-up from the incoming tailing recycle makes enough to utilize the sources efficiently.

Grinding Media

The grinding media of the mill is steel rod with 5.2m length, 90mm diameter and 272kg weight. The mill charging takes place in 15 day or twice per month a total of 60 rods per charge. The grinding media of the ball mill is a 50mm diameter steel ball charged 3-4 drums per day according to power consumption and ore type or work index.

2. Lime

Lime is used in gold mine for three purpose, one is to control P^H of a solution,secondly it use as an aid for settling and also for the detoxification of residual cyanide in tailing dam overflow water. The lime from surface lifted by overhead crane and placed on upper floor of grinding room nearby rod mill feed chute. Two sacks of lime 72kg each within two hour interval poured into rod mill feed chute manually on controlled manner to prevent blockage, basically to control or stabilize leach feed alkalinity in the design range.

Table 4.3 Grinding unit consumption optional

Type	Consumption	Amount kg	Kg/t
Ball grinding media	3-4 drum per day	925.926 kg each	0.73
Rod grinding media	120 per month	275.74 kg each	0.37
Lime	18-24 sacks per day	72kg	0.47

4.2 Thickening and Reagent unit

The fine grinding mill product classified by hydrocyclone; cyclone overflow product flows using gravity to transport waste to a desanding or trash screen. Gravity causes the undersize from screens to fall into the pre-leach thickening. To encourage the settling of fine solids, flocculant (anionic polyacrylamide) solution is introduced to the thickening feed through deaeration tank. For the leach circuit, the pre-leach thickener creates a thickened product with 45–50% solids. The thickened slurry is continually pumped from the thickener underflow pump to the leach circuit for gold cyanidation.

4.2.1 Thickener

In many instances, adding modest amounts of a flocculant chemical can artificially enhance the rate of sedimentation. A tank to hold the slurry, feed piping and a feed well to let the feed stream into the tank, a rotating rake mechanism to help move the concentrated solids to the withdrawal points, an underflow solids with drawal system, and an overflow launder are the basic parts of a thickener.

Thickener circuit Process

Legadembi gold process plant implements a high rate or high capacity Delkor enviroclear Thickener, which have 13.7m diameter with rake driving mechanism, powered by 11kw an electrical motor and the thickener area of $147m^2$. The slurry discharged from milling circuit through hydrocyclone overflow at 27-30% of solid de-aerated and flocculated before entering into thickening and dewatering process in de-aeration tank. The slurry additionally flocculated by top entry pipes on two places in the thickener. The slurry on continuous process flocculated and thickened between 45-50% of solid before discharged to leach circuit by underflow pump. Supernatant or clear water recovered through overflow launder and pumped from thickener overflow sump to grinding unit for further process water consumption. A level sensing device is used to detect the interface between the sludge bed and clarified liquid. The signal from the sensing device is used to regulate underflow removal so the sludge bed level is maintained at a normal operating level. The clarified water above the sludge bed overflows into a collection launder which discharges through a single outlet and pipe to the thickener overflow tank.

Flocculant

A substance called a flocculant is used to speed up particle settling in a thickener. Small individual particles are brought together by a flocculant to form an agglomeration that settles more quickly.

Table 4.4 Type of Flocculent used in legadembi process plant

Product Name	Chemical family	Physical form	Type of Polyacrylamide
Magnafloc R 351	Polyacrylamide	White powder	Non-ionic PAM
Magnafloc R 156	Polyacrylamide	White powder	Anionic PAM

Flocculation

Flocculant are used to agglomerate particles if the P^H value of the suspension is greater than 4, the electrical charge of particles becomes negative. Therefore positively charged flocculants should be used to have agglomerates[47].

Sodium cyanide mixing and dosage

The circuit is designed to prepare solutions of sodium cyanide for gold dissolution in the preparation tank .2 ton of NaCN box daily transported from store by loader and placed nearby cyanide preparation tank. Wooden intermediate bulk container of sodiumcyanide immediately lifted by overhead crane and poured into preparation tank[48]. The preparation tank has a volume of $17m^3$ and single stage impeller powered by 7.5kw electric motor. The preparation tank used to prepare 11.76% sodium cyanide solution weight by volume[49].

4.3 Leaching and Adsorption

Legadembi process plant implements a chemical process for dissolution or extraction of gold and silver from its ore. Ore mined from Open pit,Legadembi and Sakaro underground are non-refractory or free milling, so they are amenable to direct cyanidation.The separation process basically uses diluted sodium cyanide chemical; process name called cyanidation.Cyandation is the most common method by which gold is recovered from its ore.GoldCyanidation process takes place in six interconnected mechanically agitated leach tank for 48hr in 50% of solid slurry with compressed air that sparged at the bottom of the tank.

4.3.1 Leaching

Leaching is a common extractive metallurgy procedure that turns metals into impurities that are insoluble in aqueous media and soluble salts. Leaching is commonly defined as the process of removing a solvent-soluble component from a solid, either naturally or through an industrial process. The method is hydrometallurgical, and the solid to be separated contains both soluble and insoluble components. To selectively dissolve the solid, the liquid or solvent is added. To put it another way, the constituent of interest is separated from the other constituent parts and dissolved[50].

4.3.2 Adsorption

The metal ions that are to be recovered from the leach liquor or pregnant solutions (PS) are often concentrated, and occasionally it is necessary to remove unwelcome metal ions. Prior to metal recovery or precipitation, aqueous solution metals can be purified or concentrated through the post-leaching process of adsorption. Another way to put it is that surface forces cause a substance's concentration to rise at the boundary between a condensed layer and a liquid or gaseous layer [50].

Adsorptive (gas or liquid) molecules bond to a solid surface in the idea of adsorption. Adsorption is often done in a column filled with porous sorbents, either in batch or continuously. Three steps make up the entire adsorption process: surface reaction, which is the attachment of the adsorptive to the internal surface of the sorbent, film diffusion (external diffusion), which is the transport of the adsorptive from the bulk phase to the external surface of the adsorbent, and pore diffusion (intra-particle diffusion, or IPD), which is the transport of the adsorptive from the external surface into the pores [50].

Adsorption could be accomplished by bio-sorption, sorption on ion exchange resins, extraction with organic solvents, and adsorption on activated charcoal. The processes often involve loading, washing, unloading, or stripping/elution.

4.3.3 Activated Carbon

The term "activated carbon" refers to a group of extremely porous carbonaceous materials that cannot be identified by a chemical or structural formula but are known for their capacity to adsorb due to their incredibly large internal surface area. Almost any source of carbonaceous material, including peat, lignite, coconut shells, coal, fruit pits, wood, bones, and many others, can be used to make activated carbon. Properties including the number and size distribution of the pores, bulk density, hardness, abrasion resistance, and particle size distribution can be used to differentiate between the various forms of activated carbon. The most widely used charcoals in the gold business are made of extruded coal and coconut shell [51].

4.3.4 Adsorption techniques

The three methods by which the carbon adsorption procedure can be used are as follows:

1. Carbon-in-pulp (CIP): The pulp from the leached gold ore is combined directly with activated carbon.

2. Carbon-in-leach (CIL): As cyanidation occurs, activated carbon is added to the ore pulp in the mixing tanks.

3. Carbon in columns: Gold solutions that have been cleared or partially clarified pass through columns that are stuffed with activated granular carbon.

1. Carbon- in –column (CIC)

Large cylindrical tanks of various sizes are grouped in ascending order of height. Granules of activated charcoal are distributed on a multinozzle plate at the bottom of each tank. Leach liquid is let to enter the first tank, which is positioned at the highest elevation from the bottom, pass through the bed at the desired pace, decant, and then flow by gravity through each subsequent carbon column. High-grade metal solutions interact with the carbon that is nearly fully loaded in the countercurrent system. Eluted carbon from the first column is returned to the last column after being freed from metal ions.

2. Carbon-in-pulp (CIP) Process

After milled ore is leached by cyanide solution in aerated alkaline slurries, metal recovery or concentration by adsorption onto activated carbon by the carbon-in-pulp (CIP) method has become a viable gold extraction technology. It consists of two basic steps, the first of which is the leaching process and the second of which is the carbon adsorption. Continuously, the CIP adsorption process takes place in a series of sizable agitated tanks, typically six vessels with an average retention time of roughly an hour each. The vessel's conventional parts include the mechanical agitator's shaft and blades. Additionally, the tank has an unusual sparger next to the bottom of the tank that is used to sparge oxygen into the tank to improve the effectiveness of the activated carbon's adsorption.

3. Carbon-in-leach (CIL) Process

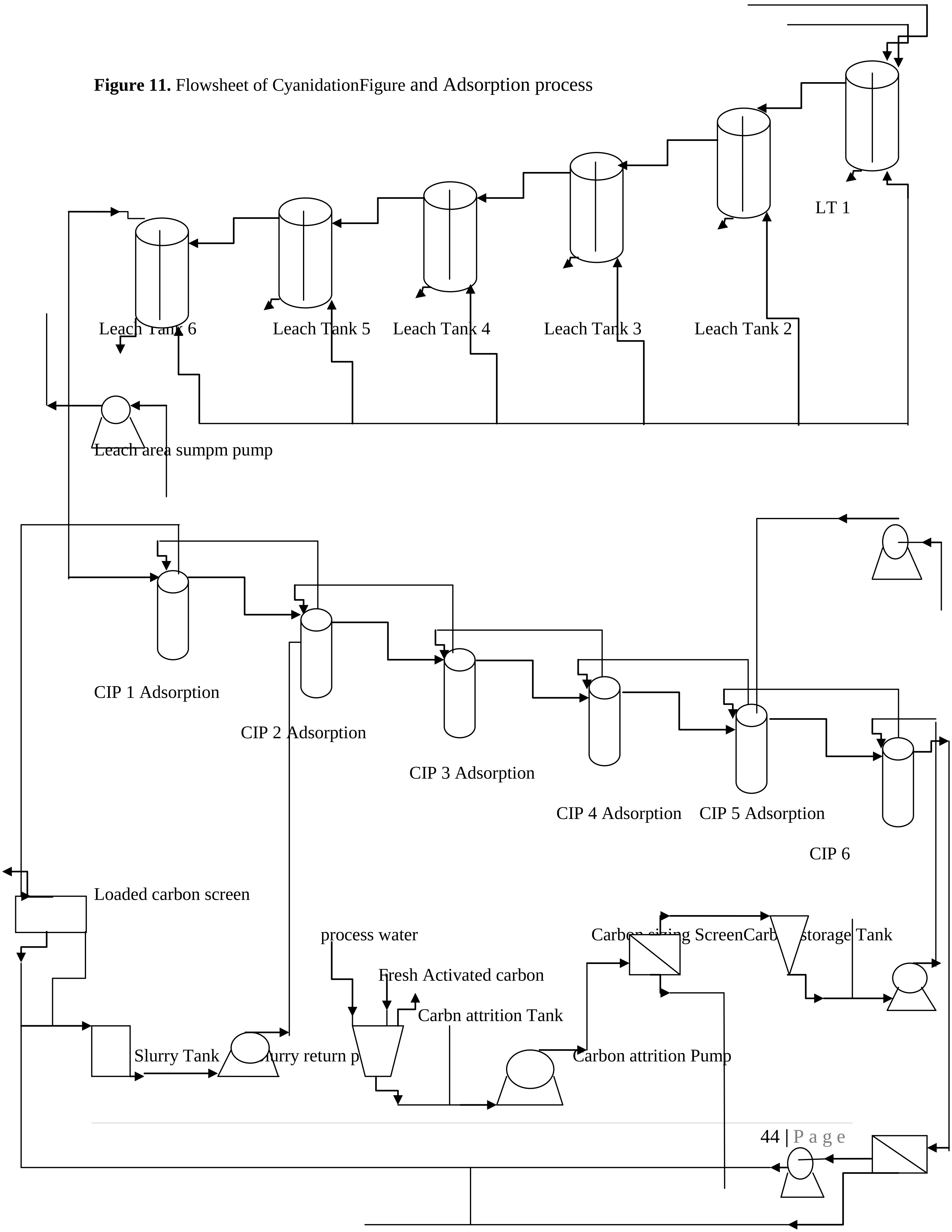
The process has the advantage of lower capital investment cost than separate leaching and carbon adsorption systems and it also improves gold extraction by the presence of carbon. The CIL process is a good alternative, but there are also some disadvantages. For example, it requires a larger carbon inventory resulting in a larger in process tie-up of gold. Carbon and gold losses due to carbon attrition are higher and carbon loading will be lower than in CIP process, meaning that more carbon has to be stripped.

4.3.5 Adsorption circuit process System

The carbon in pulp (CIP) technology is used at the Legadembi processing facility to extract gold from leached slurry. The final leach tank's leached ore slurry gravitates through a Dura pipe to the CIP circuit for the process of adsorbing gold and silver.

The circuit is made to deposit gold and silver on activated carbon after they have been dissolved in cyanide in the leaching circuit. Continuous pulp flow through the adsorption tank is accompanied by intermittent counter-current carbon movement. Before being supplied to the first of six adsorption tanks in succession, the pulp from the leach circuit's discharge is sampled by an automatic sampler for solution gold analysis. Each CIP tank has mechanical agitation, is built identically, and has a cylindrical wedge-type screen installed at the pulp discharge launders.

Figure 11. Flowsheet of CyanidationFigure and Adsorption process



4.4 Elution

Gold elution process performed in Legadembi elution plant, when 2.7 ton of loaded carbon passed a process of acid wash, acid flush, loaded carbon transfer and column flush. The Loaded carbon recovered from Adsorption circuit to harvesting screen gravitate to acid wash tank.The process manually controlled by visual inspection to fill the Acid wash tank .Acid wash process removes inorganic foulant precipitated or absorbed on the surface of load carbon.

4.4.1. Acid wash process

At the desorption step in a gold production method, the deposition of inorganic foulants on the carbon surface is undesired since it causes a reduction in the desorption kinetics leading to higher. Most processing locations have leftover gold on the lifeless carbon. Inorganic foulants may also desorb and effect the eluate composition adversely.

4.5 Electrowinning and Gold Smelting

4.5.1 Electrowinning

Electrowinning is the procedure used to extract gold from pregnant (gold-bearing) solutions. When a current of electricity is run through the solution, solid gold begins to plate out on steel wool cathodes. By running an electrical current through the solution, electrowinning cells are employed to process the high-grade eluate. A voltage is delivered across a pair of electrodes dipped in the solution, exceeding the reaction's reversible electrode potential.

4.5.2 Gold Smelting

The last step in the creation of gold is smelting. Smelting is done to turn metallic and other impurities into slag and create gold-silver bullion, which normally contains more than 95% precious metals.

The process of smelting involves heating the calcined cathodes in the presence of fluxes that produce slag to temperatures over the melting points of the calcined and the charge's constituent parts. To achieve complete impurity separation into the slag, the smelt temperature is maintained for a period of time. Since the alloy made by the molten gold and silver is heavier than the slag, it sinks to the bottom of the smelting crucible. The molten charge is then poured out, forming the gold-silver alloy into bars.

4.6 Tailing Management

The tailing dam management system at the Legadembi is aimed to hold cyanide carrying slurry which is discharged from the CIP tank # 6. Sample is taken from CIP tank # 6 tail discharge launder in every two hours to check the amount of gold in the tails.

The tail discharged from the CIP tank # 6 contains approximately 120ppm cyanide concentration which may kill people and animals if they drink it. For this reason the tails is treated before it is released to the environment. The tailing management system is divided into three parts.

- The first dam (starter dam)
- The second dam(reclaim dam)
- The detoxification plant

The first dam:-the starter dam is the biggest of all the dams where the first high cyanide concentrated slurry is collected. The dam has 9 raises of waste rockfill each. In this dam the solid part of the slurry settles and the water containing cyanide is flowing to the northern end part of the dam. Some portion of water is recycled to be used by the plant operation particularly in grinding unit.

The Second Dam: -which is called the reclaim dam is situated south of the first dam and north of the detoxification plant. The main function is to hold and feed the cyanide containing water to the detoxification plant. It is approximately 80m long and 8m in height. Water is flowing by gravity through steel pipes and controlled by valves.

The Third Dam:- the dam is approximately 40m long and 5m height. Before the water is released to the environment sample is taken.

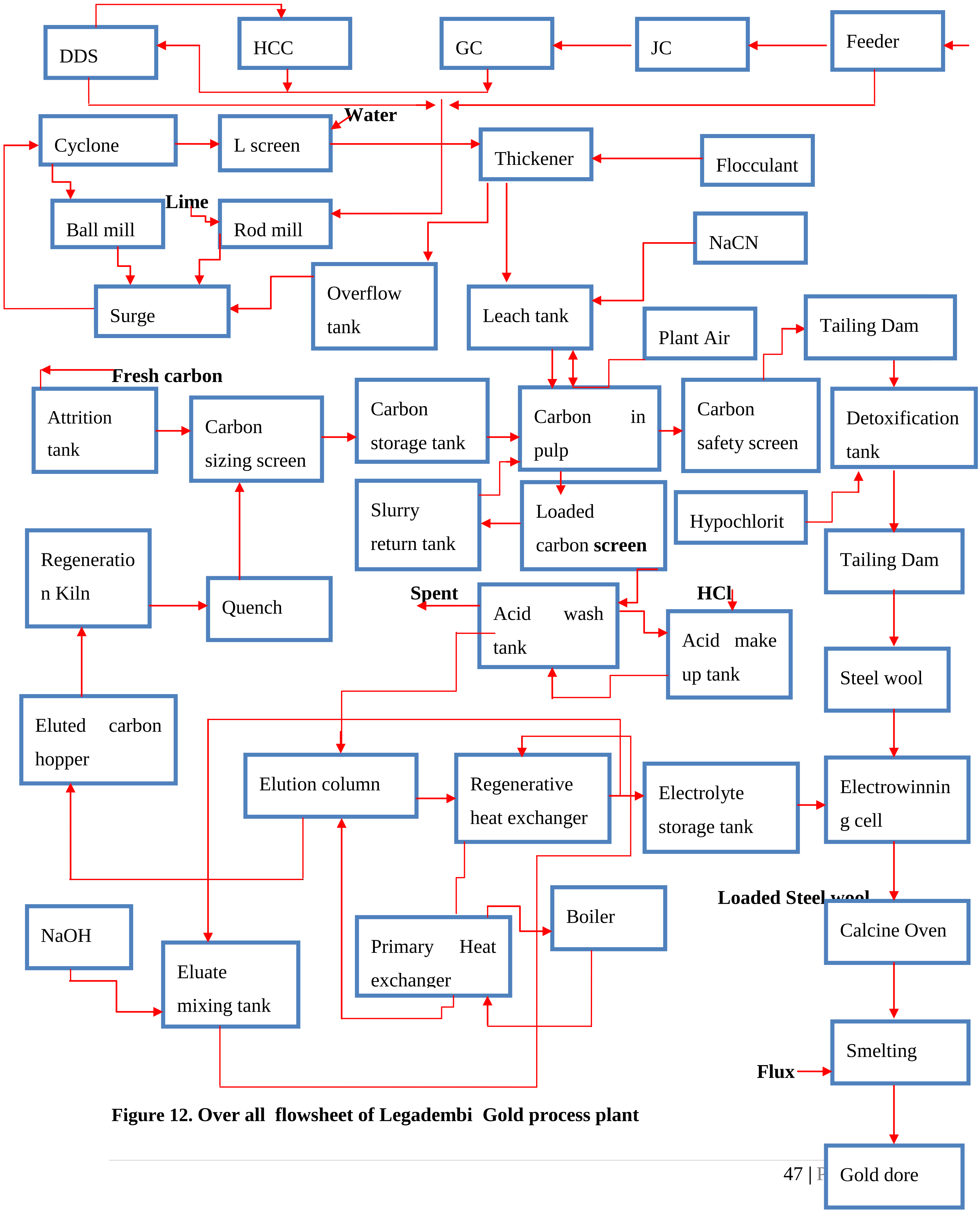


Figure 12. Over all flowsheet of Legadembi Gold process plant

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Treatment of gold ore is the most predominant step, targeting to upgrade gold recovery. The flowsheet development for the processing of gold ores may seem to have been superseded. On the other hand, it is used to provide a framework for plant control and monitoring. However, the main drawback lies in efficiently recovery gold. To get a high yield of gold using economically viable beneficiation technologies is the main challenge facing scientists. A crucial step in mineral processing is the beneficiation of gold ore since the efficacy of the entire flowsheet development depends on the beneficiation methods.

This project focuses on Legadambi gold process plant to develop an effective flowsheet development and environmental friend beneficiation methods that efficiently separates the gold. In this work, there is different beneficiation methods, i.e. Comminution (crushing and grinding) , Thickening and reagent; Leaching (Extraction), Adsorption and Desorption (stripping), Electrowinninng and Gold Smelting,Tailing dam and Detoxification plant was applied. Consequently, the work address different parameters that affect the beneficiation methods of gold ore.

Finally, flowsheet development of different beneficiation methods of gold ore was carried out in each unit operation and unit process.

Therefore, with all these work, it can be concluded that flowsheet development techniques were the most effective techniques to optimize gold recovery from its ore body.

5.2 Recommendation

The flowsheet development of Legadembi gold process plant was carried out for effective, enhanced gold recovery and for optimized project economy has been studied. The beneficiation of gold has a Free-milling ore character that easily liberated using physical methods (crushing, grinding, and direct cyanidation) to separate from other minerals and increases the efficiency of gold recovery. The following points are taken into consideration in further efforts based on the current project work:

- This project work indicates there is still a lack of quality controlling system and software based applications of various beneficiation techniques for improved gold recovery. Consequently, it is necessary to assess the effectiveness of various beneficiation processes for different gold ore and the relationship between the beneficiation of gold ore and the suitable flowsheet according to their different beneficiation methods.

- Additionally, it is strongly advised for further development of existing beneficiation method that must be being improved because it considered as effective way to increase gold recovery and to reduce environmental compliance.

- The creation of a novel, highly efficient pretreatment method that is also environmentally favorable chemical systems that convert tailing water to fesh water instead of hazaredeous acid is recommended.

- Last but not least, in this project work flowsheet development are optimized for effective gold recovery. However, in the future project work should conduct additional research to maximize beneficiation methods and flowsheet process to obtain obtain an improved yield of gold recovery.

References

[1]. Mironov, A.G., Zhodik, S.M., Maksimova, E.A., 1981. An experimental investigation of thesorption of gold by pyrites with different thermoelectric properties. Geochem. Int. 18(2),153–160.

[2]. Vaughan, J. 2004. The process mineralogy of gold: The classification of ore types. JOM, vol. 56. pp. 46.

[3]. Aylmore M G , (2005). Alternative lixiviants to cyanide for leaching of gold ores, Developments in Mineral Processing, Ed. Mike D. Adams, Vol. 21, in Advances in Gold Ore Processing, 501-539.

[4]. Sutton-Pratt, A Gold mining in Africa-the final frontier? Trans Inst Mining Metall Sect B: (1996), 3-12.

[5]. Lane, G., Lunt, D., 1997. SAG mill circuit selection, scale-up and sizing. In: Optimizing Crushing and Grinding in the Mining Industry. IRR, Perth

[6]. Chryssoulis, S.L., Cabri, L.J., 1990. Significance of gold mineralogical balances in mineral processing. Trans. Inst. Min. Metall., Sect. C 99, C1eC9.

[7]. Bulatovic, S.M., 1997. Flotation behaviour of gold during processing of porphyry copper-gold ores and refractory gold bearing sulfides. Miner. Eng. 10 (9), 895e908.

[8]. Taggart, A.F., 1927. Flotation of gold and silver. In: Handbook of Mineral Dressing, Section 12. Wiley, New York, pp. 866e868.

[9]. Major, K., 2002. Types and characteristics of crushing equipment and circuit flowsheets. In: Mular, A.L., et al., (Eds.), Mineral Processing Plant Design, Practice, and Control, vol. 1. SME, Littleton, CO, USA, pp. 566-583.

[10]. Lewis, F.M., et al., 1976. Comminution: a guide to size-reduction system design. Mining Eng. 28 (9), 29-34.

[11]. Blake, E.W., 1858. Machine for Crushing Stone. US Patent No. US20542.

[12]. Erikson, M.T., 2014. Innovations in comminution equipment: crushers, high pressure grinding rolls, semi-autogenous grinding, ball mills and regrind mills. In: Anderson, C.G., et al., (Eds.), Mineral Processing and Extractive Metallurgy: 100 Years of Innovation. SME, Englewood, CO, USA, pp. 65-76.

[13]. Wills, B.A., Atkinson, K., 1993. Some observations on the fracture and liberation of mineral assemblies. Miner. Eng. 6 (7), 697-706.

[14]. Jones, D.A., et al., 2006. Understanding microwave assisted breakage. Miner. Eng. 18 (7), 659-669.

[15]. Van der Wielen, K., et al., 2014. High voltage breakage: a review of theory and applications, Proc. 27th International Mineral Processing Congr., (IMPC), Santiago, Chile, pp. 78-86 (Chapter 9).

[16]. Leung, K., et al., 1992. Decision of Mount Isa Mines Limited to change to autogenous grinding. In: Kowatra, S.K. (Ed.), Comminution - Theory and Practice. SME, Littleton, CO, USA, pp. 331-338.

[17]. Wei, D., Craig, I.K., 2009. Grinding mill circuits: a survey of control and economic concerns. Int. J. Miner. Process. 90 (1-4), 56-66.

[18]. Lewis, F.M., et al., 1976. Comminution: a guide to size reduction system

design. Mining Eng. 28 (Sept.), 29-35.

[18]. Stehr, N., 1988. Recent developments in stirred ball milling. Int. J. Miner. Process. 22 (1-4), 431-444.

[20]. Underle, U., et al., 1997. Stirred mill technology for regrinding McArthur River and Mount Isa zinc/lead ores, Proc. 20th International Mineral Processing Congr., Aachen, Germany, pp.

71-78.

[21]. Radziszewski, P., Allen, J., 2014. Towards a better understanding of stirred milling technologies - estimating power consumption and energy use, Proc. 46th Annual Meeting of The Canadian Mineral Processors Conf., Ottawa, ON, Canada, pp. 55-66.

[22]. Nesset, J.E., et al., 2006. Assessing the performance and efficiency of fine grinding technologies. Proc. 38th Annual Meeting of The Canadian Mineral Processors Conf.. CIM, Ottawa, ON, Canada, pp. 283-309.

[23]. D.J. Lunt, A. Thompson, I.C. Ritchie, 1996, “The Design and Operation of the Kanowna Belle.

[24]. Will, B.A., 1988. Mineral Processing Technology. Pergamon Press, Oxford, p. 785.

[25]. Knipe, S.W., Chryssoulis, S.L., July 2004. Flaky gold: problems with recovery and mineralogical quantification. JOM 58e62.

[26]. Nicol, M.J., Fleming, C.A. & Cromberge, G., The adsorption of gold cyanide onto activated carbon .II. Application of the kinetic modelto multistage circuits.J. Africa Inst.Min. Metall. 84(3), 70(1984).

[27]. Johnson, W., Abstraction of gold and silver from their solution in potassium cyanide. U.S. Patent 522 260(1894).

[28]. Woodcock, J.T.,1982. Carbon-in-Pulp technology in gold extraction. Carbon-in-Pulp Technology for the Extraction of Gold, Aus.I.M.M., Melbourne.

[29]. Zhou, Joe, Bruce Jago, 2004 and Chris Martin. "Establishing the process mineralogy of gold ores." Technical bulletin.

[30]. 6 http://en.wikipedia.org/wiki/Gold_cyanidation

[31]. U.S. Environmental Protection Agency. Telephone Checklist: Newmont Gold Company, Rain Mine,1991 (August).. Completed with David Baker, Vice President for Environmental Affairs and Steve Hoffman, EPA Office of Solid Waste, August 16, 1991,.

[32]. Chryssoulis, S.L., 2003a.Venter, D., Dimov, S.S., On the floatability of gold grains. In: Wilson, J. (Ed.), 35th CMP Proceedings 2003, Ottawa, vol. 28. CIM, Montreal, pp. 455e472.

[33]. Fishman, M.A., 1967 and Zelenov, B.I., Practice in Treatment of Sulphides and Precious Metal Ores, Izdatelstro Nedra (Russian), Moscow, Vol. 5, pp. 22–101.

[34]. Sristinov, N.B., The Effect of the Use of Stage Grinding in Processing of Refractory Clay-Containing Gold Ore, Kolima, No. 1, pp. 34–40

[35]. Bulatovic, S.M., 1996. An Investigation of Gold Flotation from Base Metal Lead-Zinc and Copper-Zinc Ores, Interim Report LR049.

[36]. La Brooy, S.R., Linge, H.G., Walker, G.S., 1994. Review of gold extraction from ores.

Minerals Engineering 7(10), 1213–1242.

[37]. Youlton, K. L., J. A, 2021. Kinnaird, and B. J. Youlton. "Depositional environment-The original control on gold processing." Journal of the Southern African Institute of Mining and Metallurgy 121.6 : 267-276.

[38]. H.M. Nicholson, S. Oti Atakorah, D.J. Lunt, I.C. Ritchie, 1993, "Selection of a Refractory Gold Treatment Process for the Sansu Project", Biomine 93, pp. 20.1 - 20.11 AMF, Adelaide.

[39]. Nicholson, H.K., Oti Atakorah, S., Lunt, D.J., Ritchie, I.C., 1993. Selection of a refractory gold treatment process for the Sansu Project. In: Biomine 1993. Australian Mineral Foundation, Glenside, South Australia.

[40]. Foo, K.A., Bath, M.D., 1989. Trends in the treatment of refractory gold ores. In: Randol 1989 Conference. Randol, Colorado.

[41]. Hilson G & Monhemius A J, 2006. "Alternatives to cyanide in the gold mining industry: what prospects for the future?" Journal of Cleaner Production, Vol. 14, 1158-1167.

[42]. Rajan kumar Mishra, Anshuman Mishra, KottalaVinay, 2019. Industrial screening.

[43]. Enrique Ortega-Rivas, 2012. Unit Operations of Particulate Solids. Taylor & Francis Group.

[44]. A.Gupta and D.S. Van, 2006. Introduction to mineral processing design and operation.Elsevier First edition.

[45]. Ashleigh-Rachel Collins, 2016 .Classification of Multi-Component Feeds in a Hydrocyclone. Julius Kruttschnitt Mineral Research Centre, University of Queensland.

[46]. Barry A.Wills and Tim Napier-Munn, October 2006 .Mineral Processing Technology, An Introduction to the Practical Aspects of Ore Treatment and Mineral. Publisher, Elsevier Science & Technology Books.

[47]. L. Spencer, 1984. Selective flocculation of coal and shale. University of Nottingham.

[48]. Young, C. A., & Jordan, T. S, 1995. Cyanide Remediation: Current AndPastTechnologies. Conference On Hazardous Waste Research. Manhattan, Kansas: Department Of Metallurgical Engineering, Montana Tech, Butte,MT 59701.

[49]. Lorösch, J. (2001): Process and Environmental Chemistry of Cyanidation. Frankfurt.

[50]. AfolabiFataiAyeni, 2020.The development of sustainable hydrometallurgical processes for the recovery of precious metal. Department of Chemical and Biological Engineering University of Saskatchewan Saskatoon,Canada.

[51]. Kelly Snyder.,2019. Mill design report.Calico resources USA corp. Grassy mountain gold project, Malheur County, Oregon, USA.