ADDIS ABABA UNIVERSITY

COLLAGE OF TECHINILOGY AND BUILT ENVIRONMENT

CENTER FOR ETHIO MINES DEVELOPMENT

MASTERS IN MINERAL ENGINEERING

Flowsheet Design of Pilot Beneficiation Plant for Melka Arba Iron and Some Essential Minerals in Ethiopia Using METSIM

By: Asmamaw Mulugeta

A Graduate project Paper Work Submitted to Center for Ethio Mines Development, Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Masters of Engineering in Mineral Engineering.

June, 2025

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Advisor: Mulugeta Sisay (PhD)

Co-adviser: Ijara Tesfaye (MSC)

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Declaration of Originality

The flowsheet design of a typical pilot essential mineral beneficiation plant in Ethiopia using METSIM is the subject of this study. Under the guidance of Mr. Ijara Tesfaye and Dr. Mulugeta Sisay, I completed my initial master's degree. I would like to state that no university (or institution) has accepted this project work for credit toward a degree or diploma. We sincerely acknowledge the use of all pertinent source materials in our project.

Asmamaw Mulugeta ____________ ____________
Signature Date

As the university's advisers, we have given our approval for the candidate's project work statement to be submitted for assessment, and to the best of our knowledge, it is accurate.

Dr. Mulugeta Sisay (Advisor) _______________ _______________
Signature Date

Mr. Ijara Sisay (Co-advisor) _______________ _______________
Signature Date

Approval

Signed by the Examining Committee:

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School or Center chairperson

June, 2025
Addis Ababa, Ethiopia

Abstract

Despite having abundant natural resources, including coal, iron, lithium, niobium, chromium, gold, and tantalum, Ethiopia has a difficult time efficiently using these resources for economic development. The absence of dedicated simulating flowsheet of pilot mineral beneficiation facilities has hindered essential research and development activities, limiting the optimization of extraction and beneficiation techniques. This study proposes common simulating flowsheet design of a pilot beneficiation plant for essential minerals in Ethiopia, using METSIM simulation software, and testing the designed flowsheet by simulating the beneficiation of Melka Arba Iron using magnetic separation method. The study was conducted by assessing the literature to ascertain the equipment demands and using mineralogical analysis to select suitable Ethiopian minerals for beneficiation in order to acquire laboratory equipment in compliance with established specifications. Then, simulate the magnetic separation of Melka Arba iron ore for testing the designed flowsheet using METSIM software. The choice of equipment is crucial to the effectiveness of the procedure. In order to accommodate the distinct mineralogy of Ethiopian ores, the design carefully integrated industry-standard equipment, such as jaw and cone crushers, ball mills, and separation technologies, such as magnetic, gravity, and flotation techniques. Operations are streamlined and redundancy is reduced because to this integration. With a magnetite recovery of almost 95%, METSIM's simulation of the beneficiation of Melka Arba iron ore validated magnetic separation as a very successful concentration technique. The effective separation of magnetite from accessory and gangue minerals was confirmed by mass balance findings. These simulation results offered a strong basis for additional process modification, allowing for enhancements in recovery rates, operational effectiveness, and the overall viability of the Melka Arba iron ore beneficiation process from an economic standpoint. In conclusion, the novel pilot process design that has been introduced here provides a scalable model for modernizing Ethiopia's mineral processing industry, tackling present issues associated with the absence of standardized beneficiation methods.

Acknowledgment

I want to sincerely thank the Geological Institute of Ethiopia for giving us the chance to enroll in Addis Ababa University's Master of Mineral Engineering program. I would like to express my gratitude to Dr. Eng. Abubakar Yimam, the Director of the Mineral Engineering Department's Ethio-Mines Center, for his steadfast encouragement, support, and generous sharing of his knowledge during my entire academic career. I also want to express my gratitude to all of the Addis Ababa University teachers who shared their knowledge with us in our Mineral Engineering classes. My schooling has really benefited from your generosity.

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List of Acronyms and Abbreviations

AG	Auto Genius
ASPEN	Advanced System for Process Engineering
AI	Artificial Intelligence
AMD	Atomic Minerals Directorate
ChemCad	Chemistry Computer Aided Design
CRC	Cone Crusher
CRJ	Jaw Crusher
CSS	Closed Side Setting
CVB	Belt Conveyor
CYH	Hydrocyclone Separator
DDE	Dynamic Data Exchange
FLT	Flotation Separator
GRJ	Jigs Gravity Separator
Hysys	Hyprotech System
IPB	Inter Particle Breakage
METSIM	Metallurgy Simulator
MGW	Wet Magnetic Separator
MLB	Ball Mill
OSS	Open Size Setting
PMC	Centrifugal Pump
PSD	Particle Size Distribution
SABC	SAG mill, Ball mill and Cyclone
SAG	Semi Auto Genius
SCR	Screen
SEM	Scan Electron Microprobe Analysis
SMP	Sump Pump

Chapter One

Introduction

1.1 Background of the Study

Ethiopia has most of the essential elements required for mining success, including abundant mineral resources, a supportive legal framework, and strong government commitment to developing the sector. These abundant mineral resources including substantial amounts of tantalum and gold, as well as a wide range of untapped minerals. Gemstones and petroleum have also been found. A verified natural gas reserve that is ready for commercial exploitation has been found, along with deposits of platinum, tantalite, iron, copper, lead, zinc, nickel, and other base metals. Minerals used in construction and industry include quartz, feldspar, mica, kyanite, kaolinite, talc, chromates, graphite, magnetite, industrial olivine, marble, granite, potash, rock salt, soda ash, sulfur, silica sand, diatomite, and bentonite.(Yihdego et al., 2018). Notwithstanding its affluence, the nation has historically had difficulty efficiently utilizing these resources for economic growth. In order to optimize mineral extraction and processing methods, there are currently insufficient laboratory-scale (pilot) mineral processing facilities capable of carrying out critical research and development operations. The primary goals of utilizing a pilot plant to test a novel process or unit operation are to reduce inherent hazards and to enable continuous, closed-circuit operation as opposed to batch-wise operation, which is the norm in bench-scale testing.(Amini & Noble, 2017). Researchers and students from academic institutions, mining firms, and other organizations working in the fields of mining and mineral engineering use the mini-pilot plant as a research platform.

The functions of laboratory-scale (pilot) mineral processing facilities include completing feasibility studies, educating staff on contemporary technology, and advancing procedures from lab-scale to full-scale manufacturing. In addition to improving the nation's ability to evolve its mineral resources, the construction of a laboratory-scale mineral processing facility based on this suggested flowsheet design would support the growth of sustainable mining.

In the context of mineral processing, flowsheet design is the methodical depiction of the steps and procedures involved in the extraction and processing of minerals. This design functions as a guide that describes the steps, tools, and supplies needed to effectively turn row ore into useful products. It makes it easier to optimize the use of resources, improves operational effectiveness, and helps identify possible problems and solutions. Scaling up activities from the lab to full-scale production also requires a well-structured flowsheet to guarantee that the facility operates efficiently and meets economic and environmental requirements.

The flowsheet design of a pilot mineral processing plant is therefore crucial since it outlines the machinery and order of activities required to achieve the desired results. Additionally, by using METSIM software for this flowsheet design, we can simulate the processing steps, generate dynamic and detailed flow diagrams, and evaluate the effectiveness of various configurations. This software makes it easier to find bottlenecks and inefficiencies, which eventually results in a more efficient and profitable mineral processing plan. This project's primary goal is to use METSIM simulation software to create a standard, effective, and economical beneficiation flowsheet for a pilot facility for a few basic and necessary minerals in Ethiopia.

1.2 Problem of the Statement

Ethiopia's reliance on repetitive laboratory beneficiation analyses without simulation software integration, coupled with the global focus on pilot-scale flowsheet designs for specific or bilaterally hosted minerals, leads to resource-intensive, inefficient, and expensive processes. These restrictions make mineral testing and processing unaffordable and severely impair the scalability and optimization of mineral beneficiation. In order to fill this vital need, I used METSIM modeling software to build a common mineral beneficiation pilot plant for a few essential minerals in Ethiopia. Additionally, developing countries like Ethiopia need this multipurpose laboratory-scale or pilot plant beneficiation flowsheet for the primary critical minerals in order to reduce the cost of mineral beneficiation and laboratory testing.

Furthermore, Ethiopia possesses a wealth of mineral resources, but their efficient exploration and use have been severely hampered by the lack of a specialized pilot mineral processing facility. The absence of a research facility has hindered the development of crucial research and development activities, which in turn has limited the optimization of extraction and processing processes that are needed for improving the nation's mining sector. This key gap leads to a number of complex issues. Furthermore, the lack of such a facility has hindered the development of a trained workforce by preventing future professionals in the field from developing their research ability. As a result, Ethiopia's ability to compete in the international mineral market is still severely limited, which impedes both economic growth and the sustainable use of its abundant mineral resources.

1.3 Research Questions

1. What specific equipment is required to create a pilot beneficiation plant for Ethiopia's main minerals (coal, lithium, tantalum, and iron ore)?
2. Using METSIM modeling, which Ethiopian minerals may be modeled using this flowsheet of a pilot beneficiation plant?
3. What is the common and appropriate flowsheet design circuit of this pilot beneficiation plant?
4. What are the outcomes of utilizing the magnetic separation method to simulate the concentration of Melka Arba Iron ore?

1.4 Objective of the Study

1.4.1 General Objective

To build a versatile and efficient pilot mineral beneficiation plant flowsheet for Ethiopia's valuable minerals using METSIM software.

1.4.2 Specific Objectives

1. To ascertain the exact infrastructure, equipment, and specifications needed to establish a pilot mineral processing plant intended especially for Ethiopia's valuable minerals.
2. To examine some common and essential minerals in Ethiopia through studying their mineralogical and beneficiation characteristics.
3. To create versatile beneficiation pilot plant using METSIM.
4. To test the designed pilot plant flowsheet by simulating the beneficiation of Melka Arba Iron using magnetic separation method.

1.5 Scope of the Study

1. To evaluate and design adaptable mineral beneficiation strategies for Ethiopia's diverse deposits (including iron ore from Melka Arba, tantalum, and potash), focusing on simulation based optimization, resource efficiency, and integration with Ethiopia’s mining infrastructure and sustainability goals.
2. The investigation will be carried to offering the mineral resources of Ethiopia by designing the flowsheet of versatile beneficiation pilot plant.
3. Determine the precise equipment and operational requirements for a pilot mineral processing facility by conducting a needs assessment; Choose and acquire necessary equipment for crushing, grinding, screening, and magnetic separation; design and model a beneficiation flowsheet for Melka Arba iron ore, emphasizing magnetic separation to

improve iron recovery and lower impurities; and identify important Ethiopian minerals appropriate for laboratory-scale beneficiation and simulation using METSIM software.

4. Months 1-2: Needs analysis and mineral identification Months 3–4: Equipment selection and acquisition Months 5–8: METSIM setup, flowsheet design, and testing the designed flowsheet by simulating Melka Arba Iron Ore Month 9: Reporting, testing, and simulation were the nine months that the study was completed.

5. The study was conducted by using mineralogical analysis to select suitable Ethiopian minerals for beneficiation and by assessing the literature to ascertain the equipment requirements. acquiring equipment for laboratories in accordance with established needs; To simulate the magnetic separation of Melka Arba iron ore, a digital process model was created using METSIM software. Process parameters were iteratively optimized to obtain the desired recovery and concentrate quality. The simulation findings were validated by comparing them to benchmark data or small-scale testing.

1.6 Limitations of the Study

1. Lack of Local Literature and Best Practices: Published research and technical materials that particularly address laboratory-scale (pilot) mineral processing flowsheet design in Ethiopia are severely lacking. This gap may have an impact on the breadth and contextual relevance of the analysis since it restricts the ability to cite tried-and-true techniques and best practices from comparable local contexts.

2. Usability and Complexity METSIM's drawbacks include its lack of user-friendliness in comparison to other process simulators like Aspen, Hysys, and ChemCad. Due to its complicated interface and high learning curve, it may take longer to set up the simulation and make it more difficult to test several minerals or process scenarios effectively within the projects timeline.

1.7 Significance of the Study

Researchers, legislators, and the mining sector are among the many stakeholders who stand to gain much from the flowsheet design of a laboratory-scale (pilot) mineral processing facility. The research will offer:

1. Accurate Process Prediction: METSIM simulation saves time and money by confirming the findings of beneficiation tests prior to actual laboratory trials.

2. Scalable Solutions: For Ethiopia's important minerals, the study offers an economical and effective flowsheet that can be expanded from pilot to large-scale beneficiation facilities.

3. Cost Reduction and Recovery Optimization: The project avoids repetitious laboratory tests,

lowers research expenses, and maximizes mineral recovery rates by using simulation to optimize test settings.

4. Improved Research Capability: By setting up a specialized pilot plant, scientists can create processing methods that are specifically adapted to Ethiopia's distinct mineral resources.
5. Support for Economic Growth: More effective mineral processing in Ethiopia's mining sector leads to higher profitability, job generation, and overall economic growth.
6. Workforce Development: The initiative builds competent human capital to support the mining industry's future by providing professionals and students with a hands-on training platform.
7. Risk Mitigation: Unlike conventional batch-scale techniques, continuous, closed-circuit testing is made possible by pilot-scale process simulation and testing, which lowers operational risks.

Chapter Two

Literature Review

2.1 Ore Beneficiation

2.1.1 Introduction of Ore Beneficiation

A valuable metallic component can be profitably mined and extracted from ore, which is a group of economically relevant minerals. Most rock deposits contain minerals or metals; the material is called gangue or trash when the concentration of these materials is too low to justify mining. The primary cause of this is that gangue minerals surround rich minerals within an ore body; hence, mineral processing is necessary to remove and concentrate the precious minerals from the bulk mass using the proper mechanical treatment(Wills & Finch, 2015).

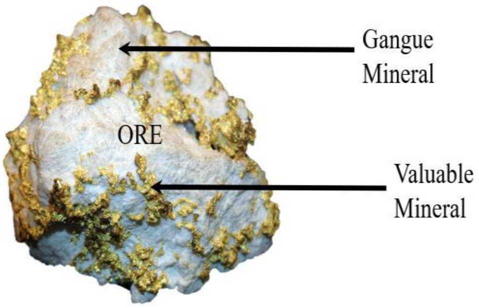


Figure 1- Valuable minerals found in ore structure (gold ore) are widely distributed and closely related to gangue minerals(Leon, 2023).

The process of mechanically separating the ore mineral grains from the gangue minerals to produce a concentrate (enriched component) that contains the majority of the ore minerals and a tailing (discard) that contains the majority of the gangue minerals is called beneficiation, sometimes referred to as ore dressing. Since most ore minerals are finely scattered and intimately connected to gangue minerals, they must be broken apart (freed) or "liberated" before the various minerals may be collected in separate products. Therefore, the initial step in any ore dressing process will be to crush and grind the ore until each mineral grain is almost free. Another name for this procedure is "Comminution"(Metso:Outotec, 2022).

The efficient liberation and concentration of precious vital minerals through a methodical approach that incorporates comminution and separation processes should be given priority in the flowsheet design of a mineral processing plant, according to the literature reviewed above. Therefore, the steps of the mineral dressing (ore beneficiation) process are as follows.

2.1.2 Comminution

2.1.2.1 Crushing

The precious minerals must be partially or completely exposed through crushing and grinding the rock in order to unlock or free them and separate them from gangue, or the waste minerals. Comminution is the term for this size-reduction procedure. One of the objectives of comminution is liberation at the coarsest particle size. Crushing and grinding are usually carried out in a sequence of operations that progressively reduce the lump size(Inoue, 2009). There are two grinding stages and three crushing stages:

Separating the precious minerals from the gangue is the main objective of crushing, the first mechanical stage in the comminution process. Crushing is a dry operation that is typically carried out in two or three stages (i.e., primary, secondary, tertiary crushing). Heavy-duty crushers compress run-of-mine ore lumps up to 1.5 macros to 10–20 cm during the primary crushing process(Metso:Outotec, 2022). The following are stages of crushing:

I. Primary crushing, also known as coarse crushing, is the process of smashing ore or run-of-mine ore up to 1 m in size down to about 10 cm using a jaw or gyratory crusher (Wills & Finch, 2015). Jaw crusher ratios typically range from 4:1 to 8:1, depending on the characteristics of the material and the circumstances of operation. (Eloranta & Chart, 2006).

II. Secondary Crushing (intermediate crushing): In this instance, jaw, cone, or roll crushers are used to crush the ore from a size of 10 cm to less than 1-2 cm. Compared to main crushers, these secondary crushers use more electricity. Operates in closed circuits with ratios ranging from 3.5:1 to 5:1(Sethi, 2024.).

III. Tertiary Crushing (fine crushing): Ore is crushed from 1-2 cm to less than 0.5 cm by tertiary crushers. Hammer mills, roll crushers, and short head cone crushers can all be utilized for this. Depending on the necessary product size distribution, crushing can also occur in an open-circuit or closed-circuit manner. Usually reaches 2.5:1 to 4:1 because of the more precise specifications for the product(Papolulis & Pillai, 2012).

2.1.2.2 Grinding

Often, grinding consumes the greatest energy, accounting for up to 50% of a concentrator's overall energy consumption. Since it is the procedure that extracts the valuables from the gangue, it is essential to the successful separation of the minerals. Grinding the ore to a fine size (100 μm) is sometimes necessary to get clean concentrates with little gangue mineral contamination. tiny grinding can result in very tiny, difficult-to-treat "slime" particles that could be lost into the tailings or even discarded before the concentration process, which increases energy costs. Thus, grinding becomes a trade-off between the loss of fine minerals, operational expenses, and the production of clean (high-grade) concentrates.

Grinding energy costs and fines losses can be significant if the ore is low grade and the minerals are scattered throughout the rock and have very tiny grain sizes(Wills & Finch, 2015). There are two types of grinding stages:

I. Course Grinding: Rod mills are typically used as equipment for coarse grinding. They can create a product as fine as 300 microns and process input as large as 50 mm.

II. Fine Grinding: The final stage of comminution, fine grinding, is accomplished in ball mills using steel balls as the grinding media. After 0.5 mm of material is introduced into the ball mill, it may generate a product smaller than 100 microns(Sethi, 2024).

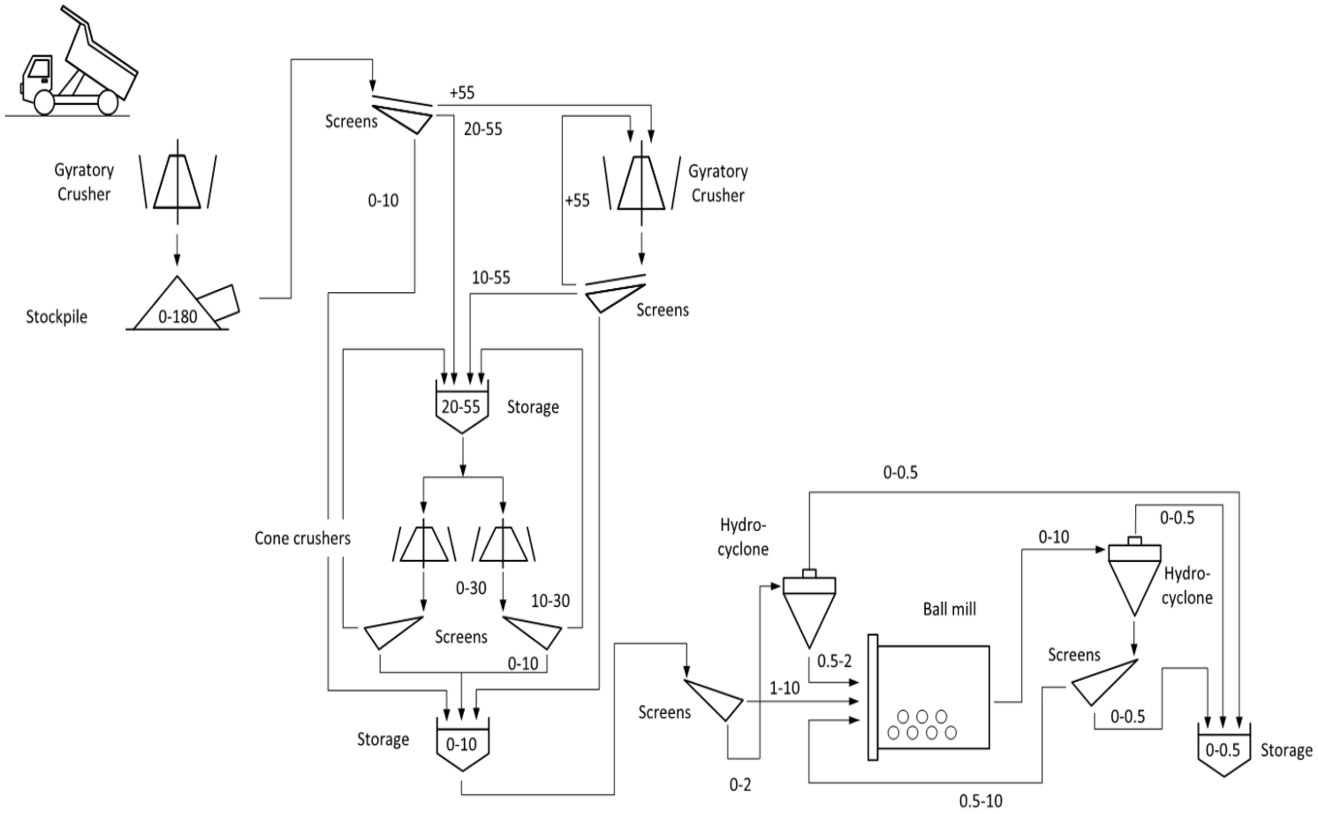


Figure 2-Size reduction circuit for mineral processing of an ore(Leon, 2023).

The ball mill closed with a hydrocyclone is an example of a closed circuit in the older style rod/ball mill design, while the rod mill is an example of an open circuit. Circuits are separated into two general categories: open and closed (the same words introduced for crushing circuits). Demonstrates a SAG/ball mill circuit in which both grinding mills are closed. To regulate the quantity of "critical size" material in the circuit, the SAG mill is closed with a crusher. The material is fed into the mill in an open circuit at a rate that is determined to yield the right product in a single pass(Inoue, 2009). In general, there are three fundamental kinds of comminution circuits:

1. Traditional closed-circuit crushing with three stages and grinding in a rod or ball mill.
2. Autogenous grinding and primary crushing.
3. Using an autogenous mill for primary crushing and a ball mill for fine grinding(Saramak et al., 2010.).

2.1.3 Screening

Industrial screening is commonly used for size separations between 300 mm and around 40 µm, however efficiency quickly decreases with fineness. While dry screening is frequently limited to materials larger than around 5 mm, wet screening is frequently used down to about 250 µm. Classification is most commonly used to size screens less than 250 µm, however some screen types can successfully differentiate sizes as tiny as 40 µm. The fact that classification may be less expensive than finer separations, which need greater areas of screening surface, for high-throughput applications influences the decision between screening and classification(Fernando Concha & Bascur, 2024).

2.1.4 Classification

Classification is a technique used to divide mineral combinations into two or more products based on how quickly the particles fall through a fluid media. Either a liquid or a gas can be used as the transporting fluid. In mineral processing, this fluid is usually water, and wet classification is usually applied to mineral particles that are believed to be too small (200 µm) for screens to separate them efficiently. A variety of classifiers, including cyclones, mechanical classifiers, and hydraulic classifiers, can be used for industrial classification. In essence, they are all based on the idea that particles are suspended in water that moves somewhat higher in relation to the particles. While coarser and heavier particles will settle, particles smaller than a specific size and density are carried away with the water flow(Wills & Finch, 2015).

The hydrocyclone, which is mostly employed as a classifier in mineral processing and has demonstrated exceptional efficacy at fine separation sizes, is one of the most important instruments in the mining industry. Although cyclones are employed in closed-circuit grinding, they are also employed in de-sliming, de-gritting, and thickening (dewatering). This is due to their great capacity relative to unit size, versatility, low cost of investment, and ease of use(Wills & Finch, 2015).

2.1.5 Concentration

The hydrocyclone is one of the most important instruments in the minerals industry. It is mostly employed as a classifier in mineral processing and has demonstrated exceptional efficacy at small separation sizes. Besides being utilized for closed-circuit grinding, cyclones are also used for de-sliming, de-gritting, and thickening (dewatering). Their great capacity relative to unit size, versatility, low cost of investment, and ease of use are the reasons behind this. Only the physical concentration method has been used in this experiment. Typical techniques for physical concentration include:

2.1.5.1 Magnetic Separation

Magnetic separators employ the variations in magnetic properties of minerals in a deposit to concentrate a desirable magnetic mineral (e.g., magnetite from quartz), remove magnetic contaminants, or separate mixtures of valuable magnetic and nonmagnetic minerals. Magnetic separators can be used to get rid of the latter. The tin-containing mineral cassiterite, which is commonly discovered alongside traces of the valuable minerals magnetite or wolframite, is one example of this. This category includes high-gradient and superconducting devices, however magnetic separators are usually classified as either low- or high-intensity machines. Low-intensity separators are used to handle ferromagnetic materials and some strongly paramagnetic minerals(Chakravorty, 2013).

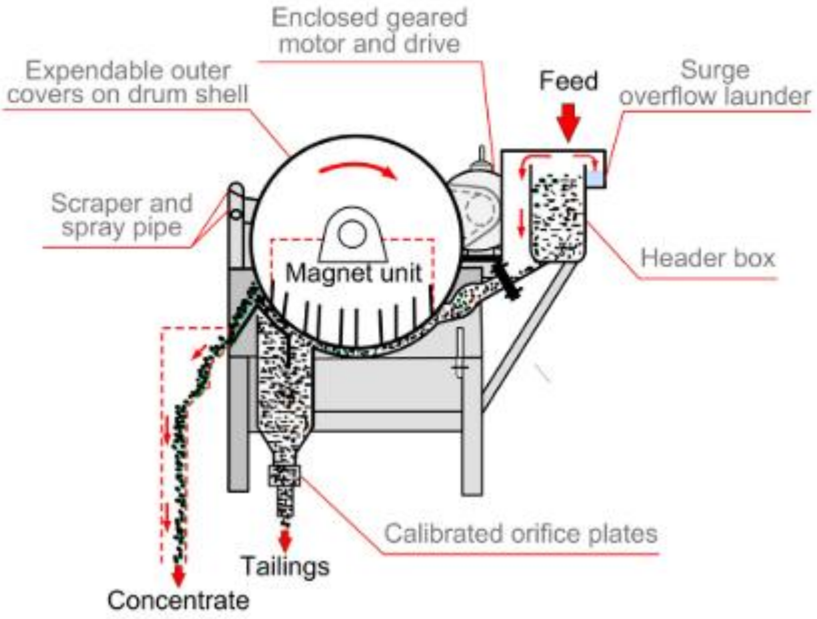


Figure 3- An illustration of a standard drum separator (Wills & Finch, 2015).

2.1.5.2 Gravity Separation

Gravity concentration is the process of sorting minerals based on differences in density. Techniques for concentrating gravity have been around for thousands of years. A method of retrieving gold that entailed submerging an animal hide, such a sheep's fleece, in a stream that contained alluvial gold is claimed to have served as the inspiration for Homer's Odyssey's tale of the Golden Fleece. After that, the thick gold particles would get ensnared in the fleece and be gathered. During the several gold rushes of the nineteenth century, many prospectors used gold panning, another outdated method of gravity concentration, to make their fortune.

Gravity concentration is the method of sorting minerals based on variations in their densities. For thousands of years, there have been methods for concentrating gravity. It is thought that the Golden Fleece myth in Homer's Odyssey was inspired by a method of collecting gold that included submerging an animal hide—like the fleece of a sheep—in a stream that held alluvial gold. It would then gather the thick gold particles after they got entangled in the fleece. In the many nineteenth-century gold rushes, many prospectors used gold panning, another outdated method of gravity concentration, to make their fortune.(Bornman, 2023).

Only recently have the basics of jigging, one of the first methods for gravity concentration, become clear. Xia et al. (2007) developed a computational fluid dynamics model of coal stratification in a jig; Jonkers et al. (2002) developed a mathematical model that predicts jig performance based on size by density; and Mishra and Mehrotra (1998) developed discrete element method models of particle motion in a jig. By separating materials with different specific gravities in a particle bed that is fluidized by a pulsating water stream, the jig produces stratification based on density. A specific mineral that has been introduced to and maintained in the jig may be the bed, also referred to as ragging. It is composed of a specific density and shape that permits the light particles to flow over the top while the dense particles pass through. In order for the heavier, smaller particles to move through the bed's interstices and the bigger, high-specific gravity particles to be in a state similar to hindered settling, the bed must be dilated and the dilation controlled(Chakravorty, 2013).

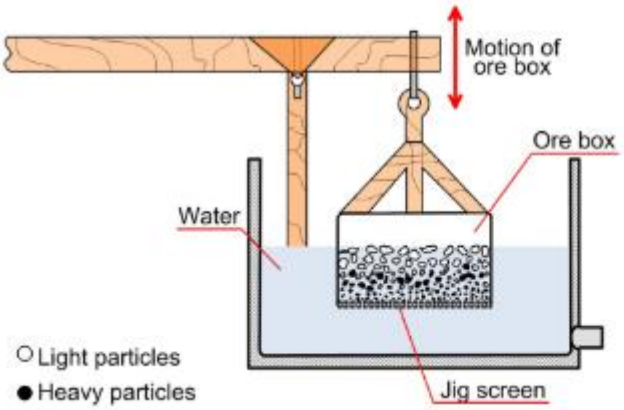


Figure 4: Jigging action: the particles separate according to density when the box is moved up and down. **(Wikedzi & Leißner, 2021).**

2.1.5.3 Flotation

Flotation is a separation technique that capitalizes on both man-made and natural differences in the surface properties of the minerals, such as whether they are hydrophilic the surface that easily absorbs water or hydrophobic the surface that repels water. If the mineral particle is hydrophobic, it can cling to air bubbles and float. The complex system is composed of three phases solids, water, and air as well as the interaction of physical and chemical factors. Controlling the transition from a hydrophilic to a hydrophobic state is the aim of the chemical variables. Physical variables include those that come from the ore's characteristics, including particle size and composition (liberation), as well as those that are produced by machines, like bubble size and air rate. The interaction was shown as a triangle by Klimpel (1984): machine, ore, and chemistry. Because of the combination of chemistry and physics, flotation is frequently referred to as a physicochemical process(Finkelstein & Lovell, 1972).

The technique of recovering material from pulp via flotation involves three mechanisms:

1. "True flotation or selective adhesion to air bubbles.
2. Water passing over the froth experiences entrainment.
3. The term "aggregation" is frequently used to describe the physical trapping of particles in the froth linked to air bubbles(Bu et al., 2017).

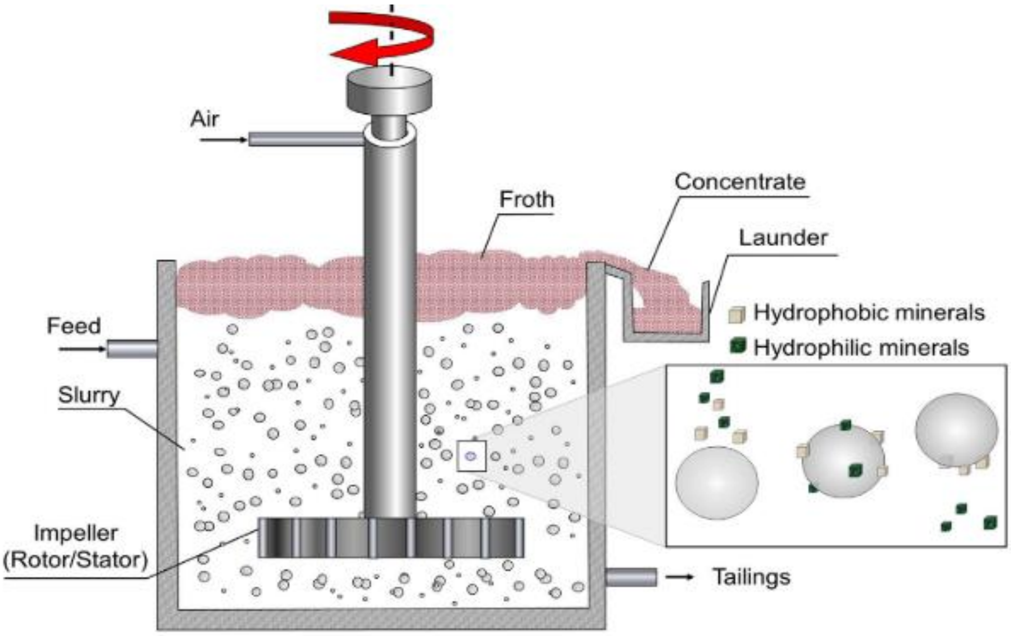


Figure 5: Principles of Flotation(Wills & Finch, 2015).

The mineral dressing process includes a number of crucial procedures to efficiently release, separate, and concentrate important minerals from the gangue materials, according to the thorough literature assessment that was supplied.

The design of an effective and economical flowsheet for the mineral processing plant may be accomplished by comprehending and putting into practice the suitable beneficiation techniques depending on the mineral attributes. By emphasizing the value of liberation, separation, and concentration procedures in optimizing the recovery of important metallic minerals, this literature review offers insightful information about the significance of each stage in the mineral dressing process.

In conclusion, the effective design and operation of a pilot mineral processing plant for key metallic minerals in Ethiopia depends on a comprehensive understanding of the mineral dressing process as well as the choice of appropriate beneficiation techniques. This information will make it possible to create a flowsheet that takes into account the operational and financial aspects that are essential to the project's success while optimizing mineral liberation, separation effectiveness, and overall processing performance.

2.2 Purpose of Laboratory-scale (Pilot) Mineral Beneficiation Plant

The purpose of the mini-pilot plant is to provide a research platform for scholars and researchers in the fields of mining and mineral engineering from academic institutions, mining firms, and other organizations.(Saramak et al.,(2010). The following are the primary justifications for testing a novel procedure or unit operation in a pilot plant.to reduce the inherent dangers and to function constantly and in a closed circuit as opposed to batch-wise, as is the case with the majority of bench-scale testing.(İzerdem & Özcan, 2019). In addition to lowering risk and offering the chance to run continuously in a closed circuit, the objectives of pilot-scale test work are as follows: (i) Testing construction materials; (ii) Calculating estimated maintenance needs; (iii) Evaluating potential risks, such as using chlorine as a gold solvent; (iv) Resolving waste disposal issues; (v) Educating operating personnel; (vi) Testing various control procedures; (vii) Gathering information for the full-scale plant design; (viii) Cost and feasibility studies; (ix) Convincing upper management that a concept is feasible; (x) The manufacturing of non-gold byproducts(Whincup, 2010).

Since these observations constitute the fundamental justifications for constructing a pilot plant, they are deemed worthy of being repeated. A full-scale plant's design and construction would require a significant time and financial commitment in a novel process, such as carbon-in-pulp in South Africa. Pioneering a new process path can have many benefits, but there is a risk that should be carefully evaluated. There is little doubt that operating a pilot plant lowers this risk (Bryson, 2004).

2.3 Purpose of Flowsheet Design using Simulation Software

The ultimate goal of process planning and flowsheet creation is to come up with a plan that will maximize project economics while staying within the physical limitations of the deposit characteristics. Some of the crucial technical, financial, and environmental factors that should be taken into account are the ore body's geology, mine life, the ore's cut-off grade, the location of the infrastructure or mining site, and investments(İzerdem & Özcan, 2019).

Simulation is widely used in design and optimization of mineral processing circuits to answer the use of various equipment and setups raises "what if" questions. If the long-term economic effects of various circuits are easily calculated during the design phase, taking into account both technical and financial limitations and criteria, the concerns could be properly addressed(Pietrobon et al., 2004).

The creation of operational and business cases heavily relies on the use of modeling and simulation in process plants. The interdependent technical data of the plant streams and the dynamic interactions between each stream are absent when depending only on engineering estimations or vendor information. Compared to the spreadsheet method, process simulation also enables tests with different process options in shorter amounts of time and with more accurate findings. The process flowsheet, particle size distributions, mass or energy balances,

plant discharge mediums in any step, and energy consumption are all provided less than one roof. By using simulation software, users can instantly alter any process parameter without modifying the links between upstream and downstream formulas. Furthermore, by employing suitable software and a modeling technique, one resource can produce outputs that can be readily used as input by other project departments, such as finance by supplying OPEX or CAPEX data, or the environmental department by releasing tonnage with toxins(Duru, 2022).
In order to successfully develop mineral beneficiation or concentration processes, possible flow sheets must be conceptualized based on the properties of the ore that are currently known. The most feasible processes must then be chosen and tested utilizing rigorous laboratory and pilot-plant scale test work. The application of mineral tracking to simulate the possible performance of various ores in specific circuit configurations is a perfect transition between the initial ore characterization work and the subsequent metallurgical test work program. By determining which ores or processes have the most economic potential and removing inappropriate possibilities, mineral tracking can be used as a decision-making tool to reduce the number of options. This will drastically cut down on the quantity of testing required for any subsequent metallurgical test work programs(Bryson, 2004).

By reducing the number of repetition testing sessions in mineral laboratories, flowsheet design using simulation software dramatically saves time and money, according to the studied literature. This is accomplished by enabling users to access and adjust the comminution and concentration equipment's parameters by simulating different values until the intended outcomes are obtained. By altering various equipment settings to attain the proper particle size distribution, for instance, we can model comminution circuits in the context of comminution techniques. Similar to this, we can model systems during the concentration stages by varying reagent kinds, quantities, and parameters until we get the desired results.

2.4 Beneficiation Methods of Some Essential Minerals in Ethiopia

An essential unit operation for improving low and medium grade ores is beneficiation. The impurities in the ores and the use of the resulting concentrates later on play a major role in the choice of a beneficiation process. Mineralogical and geo-metallurgical characteristics, including mineral liberation size, grain size, mineral association, density, and other surface characteristics of minerals, determine whether the ore beneficiation method is appropriate(Journal et al., 2019). Furthermore, the equipment that is chosen affects the beneficiation process. The apparatus under investigation makes use of various forces. The vibratory pulverizer uses compressive forces, the disc mill applies shear, and the hammer mill primarily uses impact forces. When applied forces are almost normal to the particle surface, impact and compression are two of the mechanisms that might cause grinding in ball mills. Furthermore, oblique forces may cause chipping, while forces running parallel to the particle surface may cause abrasion(Ofori-sarpong & Amankwah, 2011).

2.4.1 Beneficiation of Iron

The health and defense industries make extensive use of iron. The majority of iron ore mines currently use antiquated, irrational, asynchronous mining and mineral processing equipment. In many places, this problem results in waste, resource depletion, pollution, and environmental damage. The majority of the rich iron ore mines have been depleted due to the current rate of economic expansion. Finding the right technologies is therefore essential to processing and exploiting the increasingly difficult and impoverished iron ore resources. The two most common iron ores are magnetite and hematite. Flotation, magnetic separation, and gravity separation are the three most often used techniques for upgrading iron ore worldwide(Pham et al., 2024).

2.4.1.1 Iron Comminution Methods

In the first stage of crushing, primary gyratory crushers are employed. A gyratory crusher, as opposed to a cone type crusher, has a crushing chamber that can handle feed material that is comparatively large in respect to the mantle diameter. With its generously sized circular discharge opening (which offers a much larger area than that of the jaw crusher) and continuous operation principle (whereas the jaw crusher's reciprocating motion produces a batch crushing action), the primary gyratory crusher offers high capacity(Yarar, 1987).

The capacity of the gyratory crusher ranges from 1200 to more than 5000 t/h. The primary gyratory crusher needs to be significantly higher and heavier in order to have a feed aperture that matches that of a jaw crusher. As a result, major gyrators need a substantial foundation.

The cone crusher is a modified gyratory crusher. The primary distinction is that, unlike the gyratory, the cone crusher's shorter spindle is supported on a curved, universal bearing beneath the gyratory head or cone rather than hung. From the source, power is transferred to the countershaft via a direct drive or V-belt(Ummah, 2019).

The eccentric assembly's gear is driven by a bevel pinion that is pushed and keyed to the countershaft. The head and main shaft follow an eccentric route throughout each rotation cycle thanks to the eccentric assembly, which has a tapered, offset bore. Following initial crushing, cone crushers are employed for intermediate and fine crushing. The crushing chamber or cavity profile is the primary determinant of a cone type secondary crusher's performance. As a result, each crusher often has a variety of standard cavities that enable the selection of the best cavity for the given input material(Jankovic, 2015).

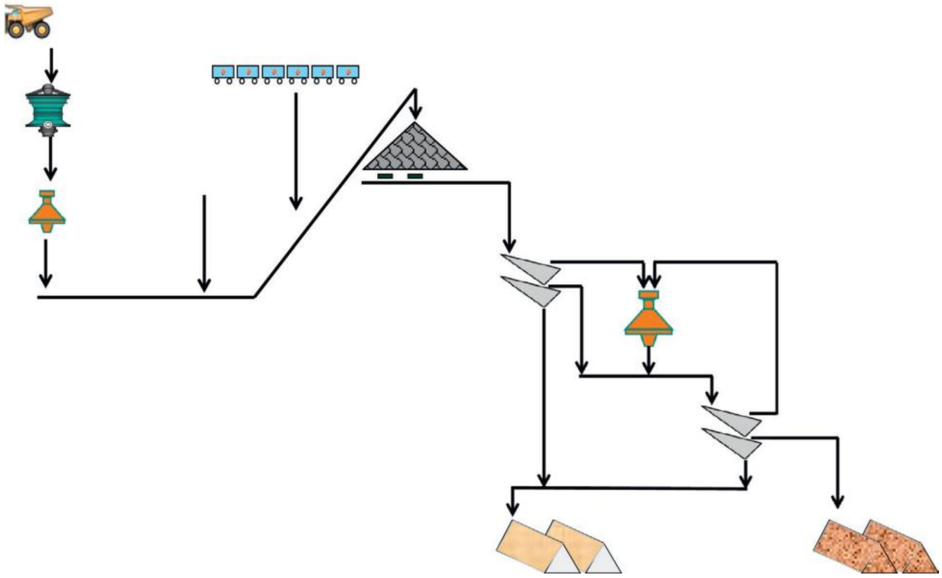


Figure 6: General Flowsheet of the Newman Hub in Western Australia(Jankovic, 2015).

2.4.1.2 Iron Separation using Magnetic Separation Method

The best technique for treating iron ore is magnetic separation. Magnetic separation, which is based on variations in magnetic susceptibility, is generally defined as the process of separating materials using a magnetic field with the appropriate intensity, gradient, and other criteria. Strong magnetic minerals are typically recovered by magnetic separation; in this case, the magnetite mineral has a magnetic susceptibility of 625x10-6÷1156x10-6 m3/kg, which is 100 times greater than that of the second-ranked martite mineral (6x10-6÷13.5x10-6 m3/kg). The cost of production is minimal for certain kinds of equipment. With extremely low operating costs (0.3 x 0.5 kWh of electricity and 2 m3 of recyclable water per ton of concentrate ore), the capacity can reach 500 tons per hour(Pham et al., 2024).

2.4.1.3 Iron Separation using Gravity Separation Method

Hematite/goethite iron ore is the primary application for this technique. Before being transported, they typically need to undergo additional processing at their source, which is mine. The goal is to provide the market with iron of a higher grade (reducing unwanted elements like Si and Al) and at an acceptable particle size (6.3÷31.5 mm). Miller (2013) summed up the four generations of non-magnetic ore treatment technology, which included jigs, dense medium separation, washing and dis-liming, and additional scrubbing(Pham et al., 2024). Several reputable firms that are used in Australia and South Africa for dense medium separation. The most effective technique for gravity separation is this one. Ferrosilicon serves as this solution's medium. The earliest method of mineral separation, jigging, is still often employed in iron ore. This machine is specifically used for low-grade iron ore whose Fe content is close to that of a marketable product. It is possible to view the case study in South Africa. The (50-60)% Fe) ROM ore can then be improved to 64% Fe, which is what the customer has requested. Engaging in these tasks helps to improve the mine's source(Yarar, 1987).

2.4.1.4 Iron Separation using Flotation Method

An efficient technique for eliminating contaminants from iron ore is flotation. Flotation is used to process iron ore in order to separate silica from precious minerals and to remove phosphorus, sulfur, and aluminum. Depending on the type of iron ore, there are three flotation techniques for silica removal. These include reverse cationic flotation, reverse anionic flotation, and direct flotation. In the iron ore sector in America, Canada, Brazil, India, Sweden, and Australia, reverse cationic flotation is typically used, although direct flotation is rarely used in practice. China, on the other hand, is a nation that favors using reverse anionic flotation. Furthermore, the application of reverse cation flotation technology is expanding globally. However, prior to treatment, this technology needs to be de-slimed. This is the primary reason for the loss of fine-grained iron. Quartz is extracted from iron ore by reverse flotation with an anion collector(Kumar et al., 2005).

This flotation approach has the advantage of having a significantly smaller dose range for the collector and having less of an impact on slime. After that, reagents come in a variety of forms, including depressants (starches), frothers (MIBC, pine oil), activators, dispersants, flocculants, and collectors (mono and diamines, oleic acid, tall oil, fatty acid soaps, or a mix of the anion and cation collectors). Several noteworthy instances at Tilden Mine (USA) demonstrate the use of flotation in silica removal. Iron ores are widely distributed and closely related to gangue in the United States. Therefore, to separate valuable minerals from non-valued minerals, extremely fine grinding is necessary(Pham et al., 2024).

According to the reviewed literature, iron ore can be separated using froth flotation, magnetic separation, and gravity separation techniques, depending on the mineralogical characteristics of the ore.

2.4.2 Beneficiation of Gold

2.4.2.1 Gold Comminution Methods

The most common flowsheets for contemporary large gold plants are HPGR-ball-mill circuits, autogenous/semi-autogenous (AG/SAG) ball-mill circuits, and crushing circuits (for heap leaching). The top 20 producers of gold are dominated by such flowsheets. However, a closer look at the flowsheets within each category also shows that there are numerous ways to correctly construct the unit operations in these circuits(Mosher, 2016).

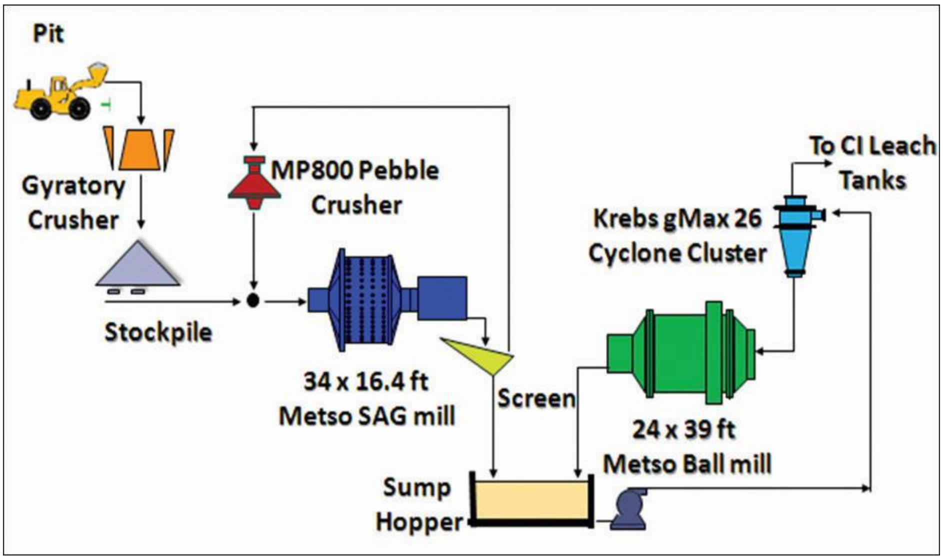


Figure 7 : Example of SABC Circuit **(Wills, B. A., & Finch, J. A. (2015)**.

The best common circuits for global gold communication in contemporary large gold plants, as depicted in the above picture, are SAG mill, ball mill, and cyclone; nevertheless, these circuits are not preferred for this common pilot plant or laboratory-scale mineral communication plant. Because the characteristics of the comminuted minerals may be impacted if various minerals are contaminated with SAG ball components. For this conventional mineral pilot plant, the cone crusher has been utilized in place of the SAG mill.

2.4.2.2 Gold Concentration using Gravity Separation

Gravity concentrators are the most economical and ecologically friendly way to recover gold. The specific density difference in gravity concentration is used to categorize particles. A typical ore typically has a specific gravity of around 2.6 (e.g., quartz is 2.7, Pyrite 5.0, Magnetite 5.3, and Feldspar 2.6), while gold has a specific gravity of 15.0 to 19.3. In order for gravity concentration to be effective, the gold must be completely released and have a somewhat coarse particle size. Comminution is the method used to liberate consolidated ores during processing. When used in mineral extraction, comminution should ideally cause the mineral grains in the ore to be released at the interfacial boundaries(Bath et al., 1973).

2.4.2.3 Gold Concentration using Flotation

This comprises manufacturing a mineral concentrate with the use of chemical conditioning agents followed by high agitation and aeration of the agitated ore slurry to produce a mineral rich foam concentrate. A hydrophobic organic layer or iron oxide coating is frequently applied to the surface of gold grains, and some are leached free of impurities (like silver) to reveal a rim of pure gold. All of these processes make the surface hydrophobic. It may be possible to recover fine gold via froth flotation. In order to remove material finer than 10 to 20 µm, de-sliming is typically necessary. There have been recoveries of 78% to 93%(Mosher, 2016). Procedure On the flotation tanks' surface, the mineralized slurry causes air bubbles to rise through it. The valuable minerals selectively adhere to the air bubbles by the interaction of chemical reagents with the mineral particles, which makes the minerals hydrophobic(Mosher, 2016).

In addition, gravity concentrators are the most economical and ecologically beneficial technique for recovering gold. Additionally, the flotation process can be used to concentrate gold.

2.4.3 Beneficiation of Tantalum

The most frequent primary ores of tin and tantalum minerals found in Rwanda are cassiterite (SnO_2) and coltan ($(Nb, Ta)_2 O_5$), which are typically linked to granitic intrusion in the northeastern Kibaran belts. These ores can accumulate in primary or secondary forms. While the secondary formation of tin and tantalum is weathered rock, either in situ (pegmatite veins primarily hosting both tin and tantalum) or transported from the source rock by stream or river to form eluvial and alluvial deposits, the primary formation of tin and tantalum is hard rock without weathering from the source rock (quartz veins primarily hosting tin). More than half of the economically important minerals in the tailings are lost as a result of the artisanal processing techniques used to mine these deposits, which are mostly vein mining, underground mining, and semi-mechanized processing techniques including panning and ground sluicing(Uwizeyimana et al., 2022).

2.4.3.1 Tantalum Comminution Methods

A jaw crusher crushes the columbite-tantalite material, which is then wet processed in a ball mill to a size of -100 meshes. The Atomic Minerals Directorate (AMD), where the mineral upgrading stage is completed, is where we are obtaining the -100 mesh CT mineral in this instance(Pham et al., 2024).

2.4.3.2 Tantalum Separation using Magnetic Method

In addition to iron ores, Colombo tantalite ores may also be processed well using magnetic separation. The process is based on the magnetic susceptibilities of the different minerals that need to be separated. Coltan usually contains gangue minerals such as magnetite, hematite, muscovite, and quartz, as well as other desirable minerals such as wolframite, cassiterite, ilmenite, and rutile. Wolframite and coltan are paramagnetic, while quartz, muscovite, and cassiterite are not. A modest magnetic field (<0.5 T) can be used to isolate magnetite from the remaining non-magnetic material because it has the highest magnetic susceptibility of any mineral. Coltan and other minerals including quartz, muscovite, and cassiterite can subsequently be separated using high intensity magnetic separation (>0.5 T) on this resultant fraction(Shikika et al., 2020).

2.4.3.3 Tantalum Separation using Gravity Separation

About 25-70% Nb2O5 and 6-40% Ta2O5 are found in the columbite tantalite mineral, which is found in pegmatite gravels in India. Pilot facilities are run by the Atomic Minerals Directorate (AMD) to recover Columbite tantalite from pegmatitic gravel. Gravity separation is used to separate columbite-tantalite from other pegmatitic minerals like quartz and feldspar, which are light (sp. gravity 2.8), because the former is heavy (sp. gravity 5.3-7.8). These pegmatites include beryl, which is often collected and sorted by hand according to its color, luster, and hexagonal crystalline structure(Mirji & Saibaba, 2016).

2.4.3.4 Tantalum Separation using Flotation Method

Flotation-based recovery of Ta and Nb from ores containing coltan is still in its infancy. The flotation of Nb2O5 from pyrochlore, which is already done on an industrial scale, is the lone exception to this rule (Burt, 2016). Using oxalic acid as a surfactant and a cationic collector based on amines, the flotation occurs at an acidic pH of 2.5 to 3.5. Typically, dispersants such hydrochloric, oxalic, and fluorosilicic acids are used to keep the pulp's pH at 3. The majority of the gangue minerals in the pyrochlore are leached out and eliminated during the procedure. This method's final concentrates are typically rated between 55 and 65 percent in Nb_2O_5.

Some industrial processes, like those used in the Catalao (Brazil) and Niobec (Canada) mines, involve flotation of the gangue minerals in reverse first, then flotation of the Nb oxides directly. Similar to the flotation of phosphates, spodumene, and rare earth minerals, the reverse flotation process uses fatty acids as collectors. Oleic acid, causticized sodium oleate, synthetic fatty acids, tall oil, and certain oxidized petroleum derivatives are the most widely utilized fatty acids(Shikika et al., 2020).

According to the studied literature, tantalum ore can be separated utilizing froth flotation, magnetic separation, and gravity separation techniques, depending on their mineralogical characteristics.

2.5 METSIM Simulation Software

The powerful software METSIM might be used to model and simulate any known inorganic and metallurgical chemical processes. METSIM is used by companies worldwide to plan, simulate, and oversee a wide range of operations, from tailing to mining and all in between. The simplest type of process flow diagram can be made with WILD. Mass and energy balance for static or dynamic mining, storage, mass extraction, material handling, milling, beneficiation, hydrometallurgy, pyro-metallurgy, gas and steam processing, and waste management procedures are among the functions of METSIM modules and embedded units.

Mineralogy, particle size analysis, size class specific or multi-component size analysis, washability data, mechanical, physical, and thermodynamic properties are only a few examples of the information supplied on the material to be processed. The software program was used to create METSIM. Because it is simpler and less complicated, the application enables users to program everything they can think of without requiring a degree in computer science. Through METSIM's integration with Excel and other programs that use Dynamic Data Exchange (DDE), data may be imputed and displayed for viewing, analysis, and monitoring. METSIM can provide answers to both straightforward and intricate metallurgical and process-related queries, saving the user and engineer time by eliminating the need for laborious spreadsheets(Isbn, 2014).

Chapter Three

Methodology

3.1 Research Design

Numerous vital mineral resources, such as iron, gold, coal, tantalum, and copper, are abundant in Ethiopia and offer substantial prospects for long-term economic growth. Using METSIM simulation software to create a flexible pilot-scale mineral beneficiation plant provides a calculated method to standardize and maximize processing for these various minerals. The objective of this research is to improve resource utilization while taking into account the distinct mineralogical features of Ethiopian deposits by combining a flexible crushing and grinding circuit with mineral-specific concentration techniques, such as magnetic separation for iron ores, as demonstrated by Melka Arba.

In addition to efficiently recovering and upgrading various ore types, the pilot plant flowsheet offers a scalable framework that can be tailored to Ethiopia's diverse mineral industries, promoting value addition and industrial growth. According to recent studies on pilot plant testing and mineral processing techniques in the area, this strategy is in line with continuous efforts to grow Ethiopia's mineral sector through sophisticated beneficiation technologies and thorough process simulation.

3.2 Material

Four essential components were needed for this study: appropriate computer hardware, scientific and technical literature, and primary data for Melka Arba iron ore, and METSIM modeling software. With the ability to simulate all significant unit processes, carry out mass and energy balances, optimize parameters, and integrate with Excel for data management, METSIM functioned as the central tool for developing, simulating, and assessing mineral processing flowsheets. Comprehensive primary data for Melka Arba iron ore, such as the mineral composition, particle size distribution, grade-by-size analysis, physical and magnetic characteristics, and any accessible beneficiation test results, are necessary for accurate simulation. Essential references for flowsheet generation and benchmarking were found in scientific and technical literature, including studies on Ethiopian iron ores, standard processing textbooks, and pertinent case studies. To ensure effective operation, all simulations and data processing were carried out on a contemporary Windows-based computer with at least 4GB of RAM and sufficient storage.

3.3 Methods

3.3.1 Design a Versatile Pilot Beneficiation Flowsheet

It was necessary to balance variations in ore hardness, liberation properties, and beneficiation responses in order to design a common flowsheet. For example, the gravity concentration requirements of tantalum are in stark contrast to the magnetic characteristics of iron ore. Adjustable separation phases and intentional sacrifices made during comminution design are the answer. This strategy is in line with worldwide movements toward intelligent, scalable mineral processing technologies that consume less energy and produce less waste.

As a proof-of-concept, the Melka Arba iron ore case study replicated the performance of magnetic separation under the unified flowsheet. Through shared infrastructure, the methodology's successful validation here created a framework for applying to Ethiopia's other vital minerals, potentially lowering processing plant costs by (20–30) %.

3.3.1.1 Selection of Equipment

The choice of equipment is a crucial element that has a direct impact on the flowsheets overall performance, cost, and efficiency. Profitability is increased by selecting equipment that is suited to the unique properties of the ore and processing objectives. This maximizes throughput, lowers energy consumption, and improves product quality. On the other hand, poor choice may result in inefficiencies, more upkeep, and more expenses. Equipment that strikes a balance between capability, cost-effectiveness, and operational efficiency is given priority in this design, guaranteeing the beneficiation plant's best performance and highest recovery.

3.3.1.1.1 Feeding Equipment

Starting with the first feed material through feeding equipment, mineral processing will begin. The belt conveyor is the most often used type of feeding material, while there are many other kinds of feeding equipment as well(Wills & Napier-munn, 2006). As a result, a belt conveyor has been chosen to provide the comminution circuit with feedstock. This decision maximizes the circuit's overall performance by guaranteeing dependable, effective, and continuous material movement. The stockpile temporarily stores the ore before feeding it into the screen on the belt conveyor(Wills & Napier-munn, 2006).

3.3.1.1.2 Screening

The feed material is screened through a screen as the initial step in the comminution process(Wills & Napier-munn, 2006). A two-deck inclined vibrating screen was selected in order to maximize efficiency and reduce the demand for equipment. By effectively separating incoming material into coarse and fine fractions, this sophisticated screen system expedites the separation process and boosts overall production.

3.3.1.1.3 Comminution Circuit

A crucial stage in mineral processing, comminution involves crushing and grinding ore to release precious minerals. Large ore chunks are broken up into smaller pieces by crushing, and the particle size is further refined to the ideal fineness for downstream beneficiation by grinding. By increasing the mineral's surface area, this size reduction improves total recovery and extraction efficiency in later processing steps. Therefore, optimizing plant efficiency and resource usage requires an effective comminution circuit design. The typical flow charts for the comminution stage are depicted in the accompanying figure.

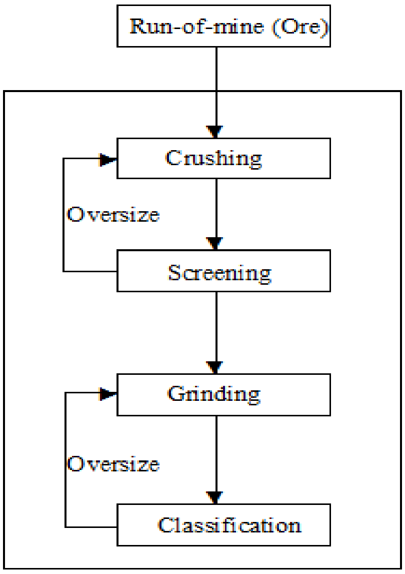


Figure 8-Comminution stage Flow Chart

3.3.1.1.3.1 Primary Crushing (Jaw Crusher)

According to the crushing capacity flow charts, gyratory and jaw crushers will be utilized as primary crushers in the mineral processing industries(Michaud, 2016). A jaw crusher works well as the main crusher for the laboratory-scale pilot plant. The jaw crusher breaks down large particles into an intermediate size that can be ground further using the coarse material that is kept on the vibrating screen's top deck. Control over the particle size distribution and throughput capacity is possible thanks to the jaw crusher's adjustable gape. Recirculating crushed material for re-crushing also reduces the number of crushing stages, which maximizes equipment use and efficiency.

3.3.1.1.3.2 Secondary Crushing (Cone Crusher)

A cone crusher is the most widely used piece of equipment for intermediate and tertiary crushing stages. Compressive breakage is the basis for cone crusher operation. Particles in this machine experience both single particle breakage (SPB) and inter particle breakage (IPB) at various points throughout the reduction process. The outer cone (concave) stays fixed while the inner cone (mantle) moves to compress the particles(Leon, 2023). Both the recycled material from the main jaw crusher and the particles that were retained from the final screen are processed by the cone crusher. It does not require a tertiary crusher because it works in a closed circuit with the screen. Consistent size reduction is ensured by continuously recycling and re-crushing oversized particles. With this configuration, the cone crusher maximizes particle size distribution and circuit efficiency by producing around 80% of the material below 10 mm.

3.3.1.1.3.3 Ball Mill

The wet or dry size reduction step known as grinding is when individual mineral liberation sizes can be achieved. Crushing reduces size; however the finished goods have a size limit. We must apply grinding procedures if we need even further reduction, say below 5–20 mm. Grinding serves two primary functions: first, it releases individual minerals that are locked in rock crystals (ores), making room for further enrichment in the form of separation; second, it increases the specific surface area of mineral fractions to generate fines (or filler)(Balasubramanian, 2017).

In the crushing circuit, around 80% of the particles are shrunk to 10 mm or less. These particles are sent to the ball mill after going through the third deck of the grizzly screen, where they are pulverized into a size that may be separated by flotation, gravity, or magnetic means. The material is separated into two streams by a hydrocyclone that receives the ball mill's output. The undersized particles move on to the separation stage, while the larger particles are recycled back to the ball mill for further crushing. The jaw and cone crushers' closed circuits, along with the ball mill and hydrocyclones closed-loop arrangement, guarantee the appropriate particle size distribution for effective separation. This maximizes process simplicity and cost-effectiveness by eliminating the need for extra fine grinding steps.

3.3.1.1.3.4 Hydrocyclone

Because of its demonstrated effectiveness as a continuous classification device that uses centrifugal force to speed up particle settling and enable exact separation of tiny particles essential for downstream processing, the hydrocyclone was chosen for this prototype beneficiation plant. By recycling oversize material back to the mill and isolating undersized particles for additional beneficiation, it can handle the whole ball mill output, ensuring the best possible particle size distribution and maximizing plant efficiency.

Furthermore, studies on the processing of iron ore fines have shown that hydrocyclones perform well in iron ore beneficiation at typical slurry concentrations of 30–35% solids by weight. They are also well known in the mineral processing industry for their versatility in classification, de-sliming, and thickening(Hore & Das, 2011). The hydrocyclone is an essential part of the pilot plant flowsheet because of its operating efficacy, flexibility, and scalability.

3.3.1.1.4 Mineral Separation Methods

3.3.1.1.4.1 Magnetic Separation

Because wet drum magnetic separation has been shown to be successful in processing Ethiopian iron ores, especially magnetite and hematite deposits like those at Melka Arba, it was chosen for this experimental beneficiation facility. By taking advantage of these iron minerals' strong to moderate magnetic susceptibility, this technique effectively separates them from non-magnetic gangue. By adjusting variables like feed size and magnetic field intensity, magnetic separation can dramatically enhance low-grade ores, leading to iron recoveries above 80% and better concentrate grades, according to studies on Ethiopian iron ores, including the Bikilal deposit. Wet drum separators are ideal for pilot-scale operations because of their affordability, ease of use, and low maintenance requirements. Near-pure iron concentrates can be obtained without changing the mineral composition thanks to their adjustable magnetic flux density, which enables the selective recovery of minerals with different magnetic characteristics. The selection of wet drum magnetic separation as a key technique in this adaptable pilot plant is justified by these benefits, together with its wide industrial application and enhanced concentrate grades, which exceed 80%(Gupta, A.; Yan et al., 2006).

3.3.1.1.4.2 Gravity Separation

By stratifying particles using forces like water resistance, gravity separation takes use of variations in mineral density to separate precious dense minerals from lighter gangue. This stratification is accomplished by pulsating water currents in jigs, a popular gravity separation method that successfully separates coarse and dense minerals like gold, iron, and tantalum with recoveries as small as 75 μm. They are ideal for pilot-scale mineral beneficiation plants due to their cost-effectiveness, operational durability, and capacity to handle a broad particle size range (usually 3–10 mm). Furthermore, by avoiding the use of chemicals, jigs promote environmentally friendly production. Their extensive industrial use in the processing of coal, iron ore, and gold, as well as their shown effectiveness in separating minerals with notable density differences, such as fluorite from quartz, further support their selection. Jigs are the best option for this adaptable pilot plant because of their simplicity, scalability, and environmentally benign operation(Gupta, A.; Yan et al., 2006).

3.3.1.1.4.3 Flotation

For this experimental beneficiation plant, flotation was chosen because of its special capacity to separate minerals according to variations in surface chemistry, particularly hydrophobicity. Hydrophilic gangue stays in the slurry while finely processed ore is floated in water and treated with reagents that make the target minerals hydrophobic. This allows the minerals to adhere to air bubbles and rise as froth for collection. Because of its adaptability, flotation works very well for complicated and finely dispersed ores that are difficult to process using gravity or magnetic techniques. Additionally, it improves recovery and focuses purity by eliminating impurities like ash in coal or silica in iron ores. Flotation is a crucial supplementary technique in this adaptable plant that can handle a variety of Ethiopian minerals with different surface characteristics because of its versatility through reagent control, demonstrated industrial efficiency across metals like copper, gold, and lead, and availability in pilot-scale equipment for process optimization(Keshav, 2013).

3.3.1.1.5 Key METSIM Parameters for Modeling Crushing Circuit

I used the following useful approach, which is based on industry norms and customized to pilot plant limitations, to develop a reliable closed-circuit crushing plant at the pilot scale. In order to minimize expenses and simplify operations, the circuit purposefully omits the tertiary crusher, using a jaw crusher as the primary crusher and a cone crusher as the secondary stage. A vibrating screen is used to transfer feed material to the crushers, guaranteeing effective size classification and constant feed quality. This simplified setup is ideal for pilot-scale testing and process modification since it preserves product size control, optimizes throughput, and improves overall plant reliability.

1. Equipment Sizing and Feed Rate

Jaw Crusher

The typical size of a pilot plant is a jaw crusher that is 10" x 16" to 12" x 20"(Eloranta & Chart, 2006).

Feed Size: For pilot plants, up to about 200 mm (8").

Product Dimensions: 30-50 mm (1.2-2"), ideal for feeding cone crushers.

Capacity: Depending on the hardness of the ore and the required product size, a pilot plant's feasible feed rate ranges from 5 to 20 tons per hour (tph)(Eloranta & Chart, 2006).

Cone Crusher

Feed Size: 50 mm or more.

Product size ranges from 6mm to 20 mm.

Capacity: For a pilot configuration, (10–40) tph is appropriate since it should equal the output of the jaw crusher and support the circulating load, which is usually two to three times fresh input(Erwin et al., 2022).

Screen

Type of Screen: tilted or vibrating screen.

Double decks

Aperture: Measured to produce the intended end result (10 mm for fine aggregate or grinding feed, for example).

Capacity: 30–60 tph is required to manage the entire throughput (fresh feed + recirculation) (Vienna, 1990).

2. Design Considerations for Closed Circuits

The tertiary crusher can be removed on a pilot scale if the target product size is not ultra-fine (typically >6 mm). A closed circuit with a screen ensures a consistent product size by controlling the re-grinding and circulation load.

Design for a 100–300% circulating load; controlling this requires careful consideration of the crusher's settings and screen performance. Because of the revolving (re-grinding) load, the total throughput (what the crushers and screen must handle) in a closed-circuit crushing plant is greater than the original (fresh) feed rate. The amount of raw ore that enters the circuit is known as the initial feed rate, whereas the circulating load is made up of oversize material that is recycled for additional crushing. The following procedures are used to determine the circulation load(Gupta, A.; Yan et al., 2006).

3. Design Steps

A. Establish the jaw crusher's maximum feed size, which is normally (80–200) mm for pilot scale.

B. Configure the jaw crusher CSS such that it generates a product that is appropriate for cone crusher input (30–50) mm.

C. To manage jaw crusher output and reduce to the desired size (6–15) mm, choose a cone crusher.

D. Send the oversized screen back to the Cone crusher.

E. Keep an eye on the circulating load and modify parameters to strike a balance between throughput and product quality.

3.3.1.1.6 Key METSIM Parameters for Modeling Grinding Circuit

The main objective of the grinding circuit for this versatile pilot plant is to optimize the particle size distribution (PSD) of the crushed material for downstream magnetic, gravity, and flotation separation using a single ball mill in closed circuit with a hydrocyclone. To accomplish this, the researcher would have used the following secondary data from previous studies and industry standards.

1. Feed Size Optimization:

To maximize grinding efficiency, crushed material (less than 10 to 15 mm) is supplied into the ball mill in accordance with industry norms. Ball mill capacity and throughput are increased by finer feed sizes because they use less energy per ton of material processed(Erwin et al., 2022).

2. Ball Mill Function:

Through the use of mechanical forces (impact, extrusion, and friction) from grinding balls, the ball mill reduces particle size. For downstream separation, ideal feed sizes (e.g., less than 15 mm) guarantee target P80 (100–200 µm) and improve grinding speeds(Erwin et al., 2022).

3. Hydrocyclone Operation:

The hydrocyclone classifies mill discharge into:

Overflow: Finer particles (target P80) proceed to magnetic/gravity/flotation separation.

Underflow: Course particles recirculate to the mill, maintaining closed-circuit efficiency.

Stable cyclone operation (feed density, pressure control) is critical to balance circulating load (typically 100–300%) and prevent over-grinding(MLANDVO BRIAN THEMBINKOSI DLAMINI, 2019).

4. Efficiency of Hydrocyclone:

The capacity of a hydrocyclone to separate "heavies" (denser or coarser particles) from the feed stream is known as its efficiency. The percentage decrease in heavy materials in the overflow relative to their concentration in the feed is a frequent way to express it. Higher values indicate better separation performance, and this efficiency number shows how successfully the hydrocyclone extracts the target particles from the feed. The following formula can be used to determine the hydrocyclones efficiency(Yuan & Wu, 2013).

$$\text{Efficiency (\%)} = \frac{(\text{Solids in Feed}) - (\text{Solids in Overflow})}{\text{Solids in Feed}} \text{ x } 100\%$$

Circulating Load:
Design for the ideal circulating load, which for closed ball mill–cyclone circuits is usually about 250%. This guarantees effective classification and grinding.

3.3.1.1.7 Key METSIM Parameters for Modeling Magnetic Separation

1. Feed Composition

Magnetite, accessory minerals, and gangue proportions have been added to METSIM based on the Melka Arba Iron mineralogy. Additionally, a comminution circuit has been prepared the necessary magnetite particle size distribution, which was then transferred to a magnetic separator. Then, METSIM independently determined and set by itself the aforementioned magnetic separator parameters based on the mineralogical data that was supplied.

2. Configuration of the Magnetic Separator

Wet low-intensity magnetic separators (LIMS) were chosen by the researcher in light of the literature review and the mineralogical properties of Melka Arba Iron. The drum's rotational speed and magnetic field strength have then been adjusted using METSIM.

3. Process Flow Parameters

Here are the main process flow parameters that I adjusted the METSIM to simulate the separation of magnetite from gangue and accessory minerals, based on the data that was supplied and literature reviewed:

A. Concentration of Solids in the Feed Slurry

Value Suggestion: (30–40) % solids by weight.

Depending on the allowable concentration of the feed slurry, magnetic separation circuits are employed with feed slurries that contain 30–40% solids by weight. This range maintains enough density for high throughput and excellent magnetic capture while guaranteeing adequate fluidity for efficient separation. This range for the best separation efficiency is supported by the literature and industry practice (Metso, 2015).

B. The recommended value for the number of stages or passes through the separator is: Rougher + Cleaner or Rougher + Cleaner + Scavenger are the two to three steps. Two-stage magnetic separators (Rougher + Cleaner) have been chosen as a pilot plant. Because it usually takes several steps to separate magnetite from gangue minerals effectively. The majority of the gangue is removed in the first stage, which is harsher. The magnetite concentration is further purified in the second stage (cleaner) (Sheahand, 1958).

4. Workflow within METSIM

A. Define Feed Stream: Provide the feed's size and mineralogical information.

B. Configure the magnetic separator unit by selecting the proper separator module and entering machine-specific parameters (drum speed, field strength, etc.).

C. Conditions of the Input Process: Indicate the operational parameters, flow rate, and slurry density.

D. Set Up Streams of Output: Set up split fractions according to the anticipated separation efficiency and assign concentrate and tailings streams.

E. Execute Simulation and Modify: Analyze data and iteratively change settings to match desired magnetite recovery and gangue rejection.

You may model and optimize the separation of magnetite from gangue and accessory minerals in your process flowsheet by carefully entering these parameters and utilizing METSIM's configurable modules.

3.3.2 Separation of Melka Arba Iron Ore using Magnetic Separator in METSIM

The researcher has simulated the Melka Arba Iron Ore using magnetic separator to testing the designed versatile beneficiation pilot plant flowsheet. As a proof-of-concept, the Melka Arba iron ore case study simulates magnetic separation performance under the unified flowsheet.

3.3.2.1 Location of Melka Arba Iron

The Melka Arba iron potential is situated in Dolo Mena Woreda, Bale Zone, and Oromia Regional State. It is roughly 650 kilometers southeast of Addis Ababa. About 110 kilometers separate Goba and the closest town, Dolo Mena. From Dolo Mena, a dry weather road travels southwest via Angetu to Melka Arba. The prospect is located in the Angetu sub-sheet (0639Dl) of the Dodola maps sheet and is limited by latitudes 6°15'38"N - 6°20'32"N and longitudes 39°35' 14'E - 39°37'59"E(Masresha, 2002).

3.3.2.2 Mineralization of Melka Arba Iron

Massive and widely distributed, the Melka Araba iron ore is a titaniferous magnetite-type deposit. The majority of the contacts with the country rocks are gradational to the later and sharp to massive ore. Massive ore is primarily composed of 30–35% Ilmenite and 45–52% Magnetite, including Maritized form. Chalcopyrite, Pyrite, and Pyrrhotite are examples of accessories. The gangue minerals, which make up 15–25% of the total, include amphibole, plagioclase, pyroxene, and chlorite. Because ilmenite intergrowths typically form as plates along the magnetite grain boundaries, the magnetite grains are rarely homogeneous(Masresha, 2002).

There are less large exosolution lamellae than in the Bikilal iron deposit. Spinel and magnetite form a fine network in the majority of ore sections. The sizes of magnetite and ilmenite vary from 0.2 to 0.5 mm. Hematite microlitic exosolutions in ilmenite are also frequent. In general, ilmenite corrodes and is finer than magnetite. Large plagioclase crystals formed initially, followed by fine to medium plagioclase, apatite, pyroxene, hornblende, and garnet, and then the ore minerals, according to the typical genetic sequence. A number of dispersed ore-bearing pyroxenite lenses with widths varying from stringers to several meters have been identified by the Melka Arba Phosphate Exploration Project.

Along the northwest to northeast trend, they are consistent with the gabbroic structure. When there are large iron ore lenses nearby, they occur more frequently. In some locations, the pyroxenite host rock's contact relationship between large and dispersed ore seems gradational(Masresha, 2002).

3.3.2.3 Laboratory Analysis of Melka Arba Iron

There was negligible variation in the chemical composition of huge ore at various trench sites. (48–52) % total Fe, (16–19) % Ti02, (0.03–0.09) % P205, and 0.05% P205 with low sulfur (0.1–0.4) % are the significant oxides that are evaluated. In actuality, sulfur concentrations may rise with depth and are correlated with oxidized environments. Conversely, the Besharo locality's dispersed ore in pyroxenite has an Apatite concentration between 3.92 and 3.36. Using a hand magnet, the magnetic separation technique was used to 44 ore samples to see whether the metal iron could be extracted during ore processing(Masresha, 2002).

The ore may have been concentrated to 66% Fe, and if a magnetic dressing machine had been available, greater concentration up to 69% Fe has been empirically predicted. The magnetic concentration is also believed to include 2.4% titanium oxide. Grain size study of dispersed ore using Scan Electron Microprobe study (SEM) with Image Analysis Software showed that 60% of apatite and 88% of ilmenite had grain sizes larger than 250 µm, with weighted mean diameters of 180 µm and 230 µm, respectively(Exploration, 2002).

3.3.2.4 Comminution of Melka Arba Iron using METSIM Simulation Software

Before separation can begin, the majority of minerals must first be "unlocked" or "liberated" since they are deeply entangled with the gangue and widely distributed. Comminution is used to do this, progressively reducing the ore's particle size until the pure mineral particles can be separated using the methods now in use(Pereira et al., 2023).

Melka Arba Iron uses every comminution circuit that has been planned. A considerable percentage of ilmenite (88%) and apatite (60%) have grain sizes larger than 250 µm, with mean diameters of 230 µm and 180 µm, respectively, according to the grain size analysis of Arba Iron Melka. This suggests that in order to separate valuable minerals from gangue, the ore may need to be efficiently crushed and ground to a size that can be achieved. The existence of several mineral species, including gangue minerals like apatite and iron-bearing minerals like ilmenite, suggests that the comminution process should be adjusted to reduce size while reducing the production of fines that could make further separation procedures more difficult(Pereira et al., 2023).

As a result, the kind of concentration or separation technique used for Melka Arba Iron ore determines the comminution process. Therefore, choosing the right separation technique should be necessary prior to starting the comminution process.

3.3.2.5 Selection of Separation Method for Melka Araba Iron

Because Melka Araba ore has a high percentage of strongly magnetic magnetite (45–52) %, magnetic separation is the most efficient way to concentrate iron from this Ore. 44 samples underwent laboratory testing, yielding iron percentages of up to 66% Fe, with the possibility of reaching 69% Fe with the use of sophisticated magnetic dressing procedures. Although less magnetic, ilmenite (30–35) % is also partially concentrated, which improves economic viability by enabling titanium recovery as a lucrative by-product. Iron quality is favored by the ore's low phosphorus and sulfur levels (0.1–0.4) %, however mining management must be monitored because sulfur varies with depth.

Because gangue minerals have similar densities and tiny grain sizes (0.2–0.5) mm, gravity separation is less effective than other methods. Flotation is also less effective for magnetite concentration, even if it works well for sulfides and ilmenite. To recover ilmenite and increase product purity, magnetic separation should be the main technique, possibly followed by flotation. Iron recovery and by-product extraction from Melka Araba ore are optimized by this integrated method.

3.3.2.6 Grain Size Analysis of Melka Araba Iron

Grain size measurement of Melka Arba iron ore during magnetic separation provides important information for magnetite recovery process optimization. This is an organized analysis:

A. Grain Size Characteristics of Feed Material

88% of the grains in ilmenite are larger than 250 µm, with a weighted mean diameter of 230 µm. 60% of the grains in apatite are larger than 250 µm, with a weighted mean diameter of 180 µm. Grain sizes in magnetite range from 0.2 to 0.5 mm (200 to 500 µm), and they frequently intergrown with ilmenite.

B. Impact of Particle Size Distribution

Several size fractions, including -250 µm +180 µm, -180 µm +150 µm, and -150 µm +90 µm, underwent liberation and chemical composition investigations based on the literature given, especially the study on the Mekane Selam iron ore (which is compositionally and texturally comparable to Melka Arba) (Meseret, Getahun; Kebede, Bisrat; and Digafe, Belayneh, 2025). Finding the size fraction at which iron (magnetite) is most efficiently released from gangue minerals was the aim of these analyses. It is frequently noted in this research that:

- The presence of locked magnetite, which is still intergrown with gangue, is common in larger particles (>250 µm).
- Finer particles (less than 150 µm) may be completely released, but because of their small size and propensity to form slimes, they may cause higher losses during magnetic separation.
- The 150–250 µm size range is commonly found to be a workable compromise where a sizable amount of magnetite is released while maintaining good separation efficiency.

Empirical results of size-wise liberation investigations, which show that the -250 µm +150 µm fraction maximizes iron concentration and liberation degree, are the source of the 150 µm lower limit.

- Excessive fines (less than 150 µm) should be avoided since they can cause entrainment and poor magnetic response, which can lower recovery during magnetic separation.
- In conclusion, liberation investigations on similar iron ores support the 150 µm minimum, demonstrating that below this barrier, additional grinding results in decreasing recovery returns and increases processing difficulties.

Thus, a concise and comprehensive examination of the ideal particle size distribution and liberation behavior for magnetic separation can be summed up as follows, based on the literature that has been supplied and the grain size properties of the Melka Arba iron ore:

1. Features of Grain Size

The 0.2 to 0.5 mm (200–500) µm magnetite grains found in Melka Arba ore are frequently intergrown with gangue minerals such amphibole, pyroxene, and chlorite as well as ilmenite. Apatite also exhibits a sizable fraction above 250 µm, while ilmenite grains are typically finer, with many exceeding this size.

Particles greater than 250 µm typically contain locked mineral intergrowths, which limit successful separation, according to liberation experiments on similar iron ores. Particles smaller than 150 µm, on the other hand, are often better liberated but present difficulties including increased slime production and ineffective magnetic separation because of fine particle entrainment.

2. Optimum Particle Size Range for Liberation and Separation

The -250 µm to +150 µm size fraction provides a workable equilibrium between liberation and recovery efficiency, according to literature on iron ore comminution and liberation (such as Malmberget and other magnetite ores). A considerable amount of magnetite liberation is attained at this size range, reducing trapped particles and preventing excessive fines that impair magnetic separation performance. On low-grade manganese and magnetite ores, for instance, liberation studies reveal roughly 60–80% liberation at the 150–250 µm fraction, with diminishing results below 150 µm because of slime and entrainment problems(Ismail et al., 2016).

3. Grinding and Liberation Efficiency

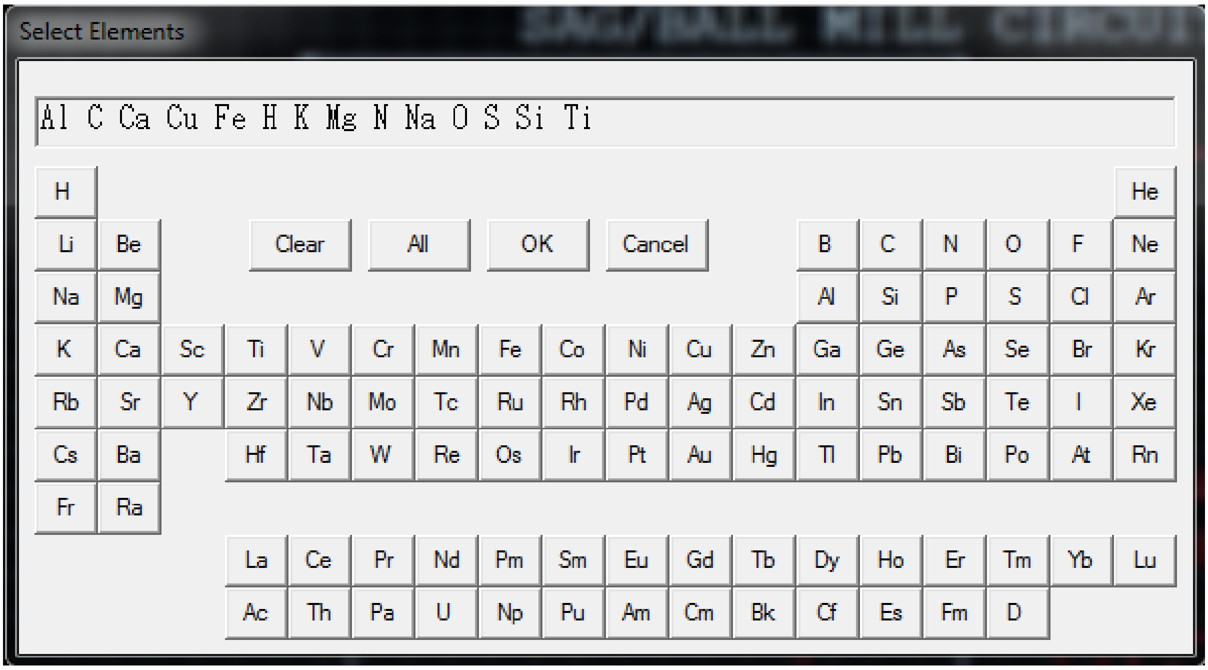
Grinding larger than 250 µm can improve liberation, but doing so comes with fines that make magnetic separation more difficult and decrease recovery. Since gangue minerals typically grind more efficiently than magnetite, overgrinding may break gangue more selectively, resulting in slime development and iron mineral loss(Ismail et al., 2016). In order to maximize liberation while keeping the particle size manageable for magnetic separation, it is best to aim for a P80 of 150 µm –250 µm.

4. Magnetic Separation Implications

Due to its strong magnetic properties, magnetite may be efficiently separated using low-intensity magnetic separators in the 150 µm –250 µm ranges. After initial magnetite recovery, high-intensity magnetic separation can be used to extract ilmenite, a weakly magnetic mineral. The total separation efficiency is increased and gangue entrainment in concentrates is decreased by avoiding excessive fines (<75 µm). Therefore, the ideal range of particle sizes for the Melka Arba iron ore to enhance magnetite liberation from gangue and accessory minerals is (150–250) µm. While minimizing fines that lower the effectiveness of magnetic separation, grinding to this size range guarantees enough liberation. Magnetite can then be efficiently recovered by further magnetic separation; ilmenite and magnetite concentrates are separated using high-intensity magnetic separation.

3.3.2.7 Data Setup and Process Design in METSIM

The METSIM process begins with project registration and the establishment of critical parameters such as the size of the filter and the size distribution of the feed particles. Users then input all of the identified minerals from the test samples into the mineral dialog box, which provides an accurate depiction of the ore's composition for precise process simulation.



Al C Ca Cu Fe H K Mg N Na O S Si Ti

Figure 9: List of Inserted Elements on METSIM Select Elements Dialog box

METSIM automatically creates all potential compounds in the sample once minerals are added, enabling users to choose the pertinent compounds for additional process modeling.

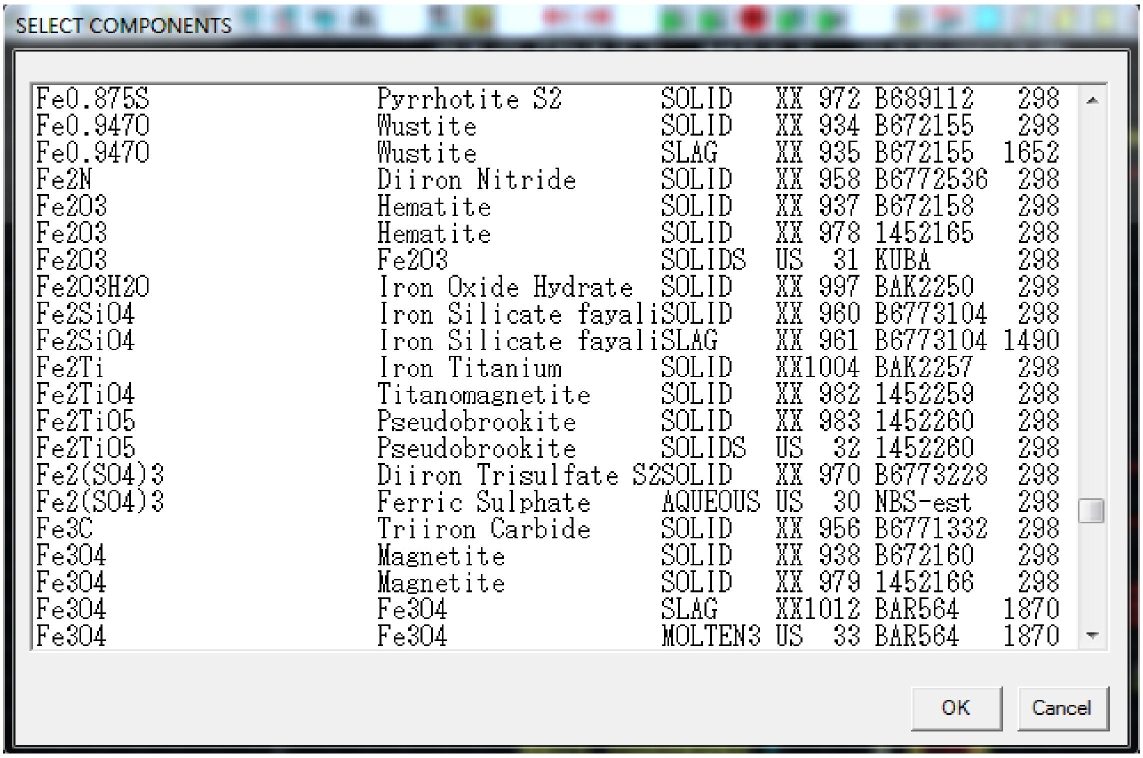
In order to support accurate mass and energy balance calculations for process design and optimization, METSIM's compound generation and selection functions guarantee that all significant phases, valuable, accessory, and gangue minerals are accurately represented in the simulation.

Table 1: Chemical composition of Melka Arba Iron Ore

Principal Compounds	**Chemical Formula**	**Concentration (%)**
Titanomagnetite	Fe_2TiO_4	48-52
Ilmenite	(Fe, Mg, Mn, Ti) O_3	16-19
Phosphorous pentoxide	P_2O_5	0.03 - 0.09
Sulphur	S	0.1-0.4
Accessory Minerals		
Pyrrhotite	FeS	3.92-4.36

Pyrite	FeS_2	
Chalcopyrite	$CuFeS_2$	
Gangue Minerals		
Chlorite	$(Fe, Mg, Al)_6$ $(Si\ Al)_4$ O10 $(OH)_5$	15-20
Pyroxene (Magnesium Metasilicate)	(Fe, Mg) $(Si, Al)_2O_6$	
Plagioclases	(Na, Ca) $(Si, Al)_4$ O_8	
Amphibole	Si O_4	

As seen in Figure 12, METSIM produced a large number of compounds from the input minerals. The essential molecules are shown in Figure 13, and all compounds that fit into the three categories were chosen for simulation. This choice guarantees that the simulation model accurately captures the mineralogical complexity of the ore.

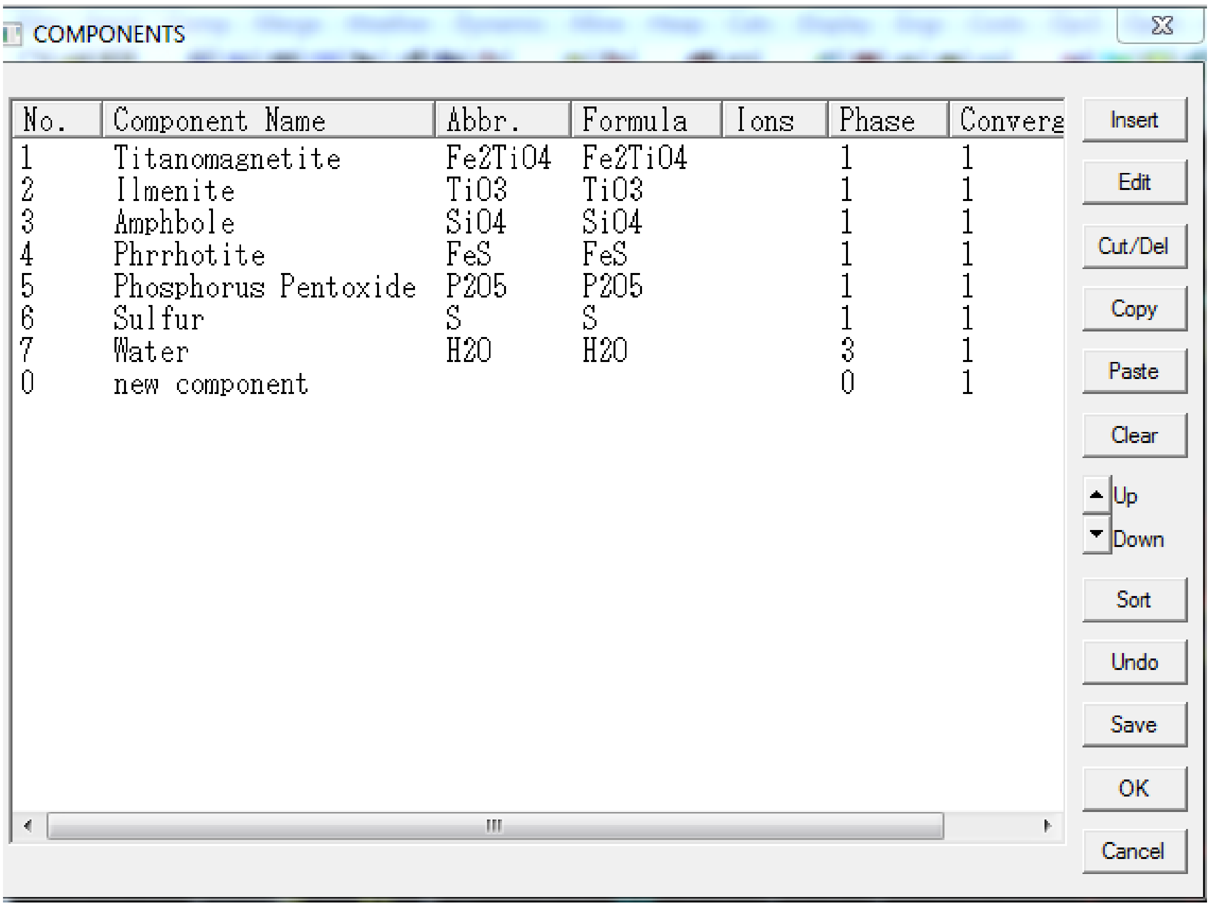


```
Fe0.875S            Pyrrhotite S2      SOLID   XX 972 B689112   298
Fe0.9470            Wustite            SOLID   XX 934 B672155   298
Fe0.9470            Wustite            SLAG    XX 935 B672155  1652
Fe2N                Diiron Nitride     SOLID   XX 958 B6772536  298
Fe2O3               Hematite           SOLID   XX 937 B672158   298
Fe2O3               Hematite           SOLID   XX 978 1452165   298
Fe2O3               Fe2O3              SOLIDS  US  31 KUBA      298
Fe2O3H2O            Iron Oxide Hydrate SOLID   XX 997 BAK2250   298
Fe2SiO4             Iron Silicate fayaliSOLID  XX 960 B6773104  298
Fe2SiO4             Iron Silicate fayaliSLAG   XX 961 B6773104 1490
Fe2Ti               Iron Titanium      SOLID   XX1004 BAK2257   298
Fe2TiO4             Titanomagnetite    SOLID   XX 982 1452259   298
Fe2TiO5             Pseudobrookite     SOLID   XX 983 1452260   298
Fe2TiO5             Pseudobrookite     SOLIDS  US  32 1452260   298
Fe2(SO4)3           Diiron Trisulfate S2SOLID  XX 970 B6773228  298
Fe2(SO4)3           Ferric Sulphate    AQUEOUS US  30 NBS-est   298
Fe3C                Triiron Carbide    SOLID   XX 956 B6771332  298
Fe3O4               Magnetite          SOLID   XX 938 B672160   298
Fe3O4               Magnetite          SOLID   XX 979 1452166   298
Fe3O4               Fe3O4              SLAG    XX1012 BAR564   1870
Fe3O4               Fe3O4              MOLTEN3 US  33 BAR564   1870
```

Figure 10: List of generated components by METSIM

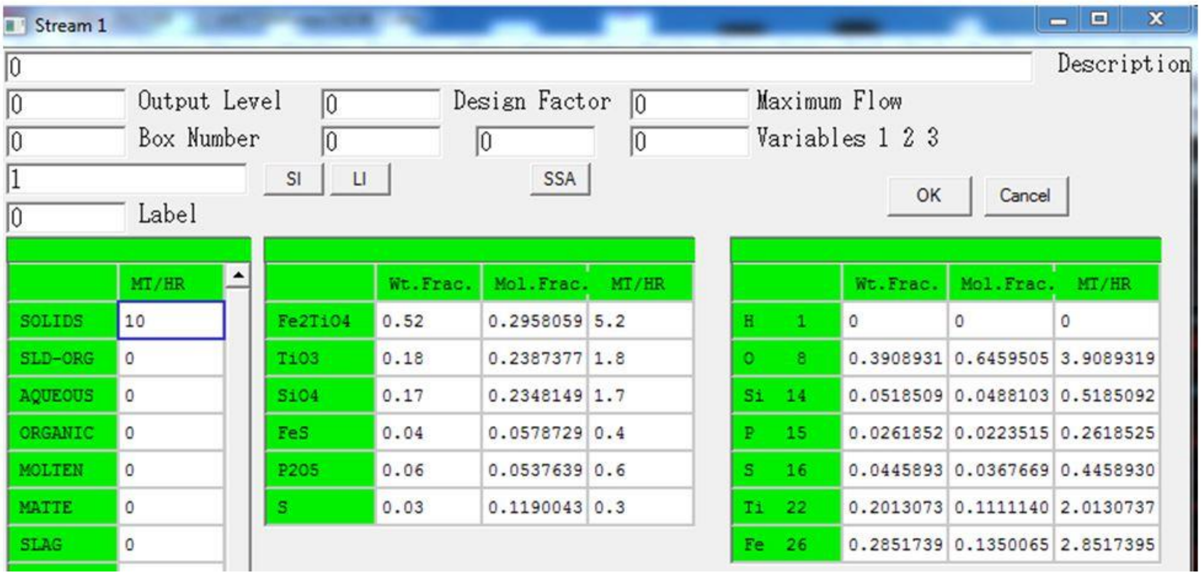
By integrating the sample data into the software, this stage makes it possible to start an accurate and successful simulation.

METSIM offers a number of helpful buttons, as can be seen in the dialog box for the components above. The Cut/Del buttons can be used to eliminate any superfluous compounds that are listed in the dialogue box above. Additionally, the component name may occasionally exclude the essential compounds. Edit or copy/paste buttons can be used to resolve such issues. Additionally, there are up/down buttons for rearranging the components.



No.	Component Name	Abbr.	Formula	Ions	Phase	Converg
1	Titanomagnetite	Fe2TiO4	Fe2TiO4		1	1
2	Ilmenite	TiO3	TiO3		1	1
3	Amphbole	SiO4	SiO4		1	1
4	Phrrhotite	FeS	FeS		1	1
5	Phosphorus Pentoxide	P2O5	P2O5		1	1
6	Sulfur	S	S		1	1
7	Water	H2O	H2O		3	1
0	new component				0	1

Figure 11: List of the required components to METSIM simulation for beneficiation of Melka Arba Iron



0 Description
0 Output Level 0 Design Factor 0 Maximum Flow
0 Box Number 0 0 0 Variables 1 2 3
1
0 Label

	MT/HR
SOLIDS	10
SLD-ORG	0
AQUEOUS	0
ORGANIC	0
MOLTEN	0
MATTE	0
SLAG	0

	Wt.Frac.	Mol.Frac.	MT/HR
Fe2TiO4	0.52	0.2958059	5.2
TiO3	0.18	0.2387377	1.8
SiO4	0.17	0.2348149	1.7
FeS	0.04	0.0578729	0.4
P2O5	0.06	0.0537639	0.6
S	0.03	0.1190043	0.3

	Wt.Frac.	Mol.Frac.	MT/HR
H 1	0	0	0
O 8	0.3908931	0.6459505	3.9089319
Si 14	0.0518509	0.0488103	0.5185092
P 15	0.0261852	0.0223515	0.2618525
S 16	0.0445893	0.0367669	0.4458930
Ti 22	0.2013073	0.1111140	2.0130737
Fe 26	0.2851739	0.1350065	2.8517395

Figure 12: Weight Fraction of Compounds and Elements of Melka Arba Iron Ore from METSIM Description Dialog Box

Chapter Four

Result and Discussion

4.1 Comminution Circuit Optimization

A jaw crusher and a cone crusher are positioned as primary and secondary crushers, respectively, in the crushing circuit.

There is no need for a tertiary crusher because the jaw and cone crushers operate in a closed circuit with a two-deck inclined screen.

One ball mill is used in the grinding circuit. By combining the ball mill and hydrocyclone in a closed circuit, fine grinding is accomplished, and large particles are recycled for further grinding.

The screening process is streamlined by a two-deck inclined screen that services the jaw crusher, cone crusher, and ball mill.

One belt conveyor recycles the output from the jaw and cone crushers back to the screen for re-grinding, while another belt conveyor feeds the output from the crushing circuit to the grinding circuit.

4.2 Flexible Separation Flowsheet

Different separation techniques and control mechanisms can be used to treat disaggregated minerals in parallel or series configurations.

By opening or closing specific streamlines, a stream splitter that processes the hydrocyclone overflow through a magnetic separator in parallel circuit enables the direct separation of magnetic and non-magnetic minerals. The same stream splitter arrangement can be used to perform alternative separation techniques like flotation or gravity separation.

The hydrocyclone overflow in a series circuit is separated by magnetic separation, which separates all magnetic materials, and then by gravity separation, which separates minerals according to particular density differences. Products from the gravity separator may be reground in a ball mill and floated if more concentration is needed. A hydrocyclone is used to separate the output after a stream splitter sends the flow to a ball mill for regrinding. Minerals are sorted according to their surface characteristics in a flotation mixer tank after the overflow has been combined with chemical reagents. Another streamlining of the stream splitter can be used to divert the flow from the magnetic separator to the flotation cell if gravity separation proves unsatisfactory.

In general, this flowsheet combines effective comminution with flexible separation phases, enabling process optimization through streamlined configurations and thoughtful equipment selection, as well as adaptation to different Ethiopian minerals.

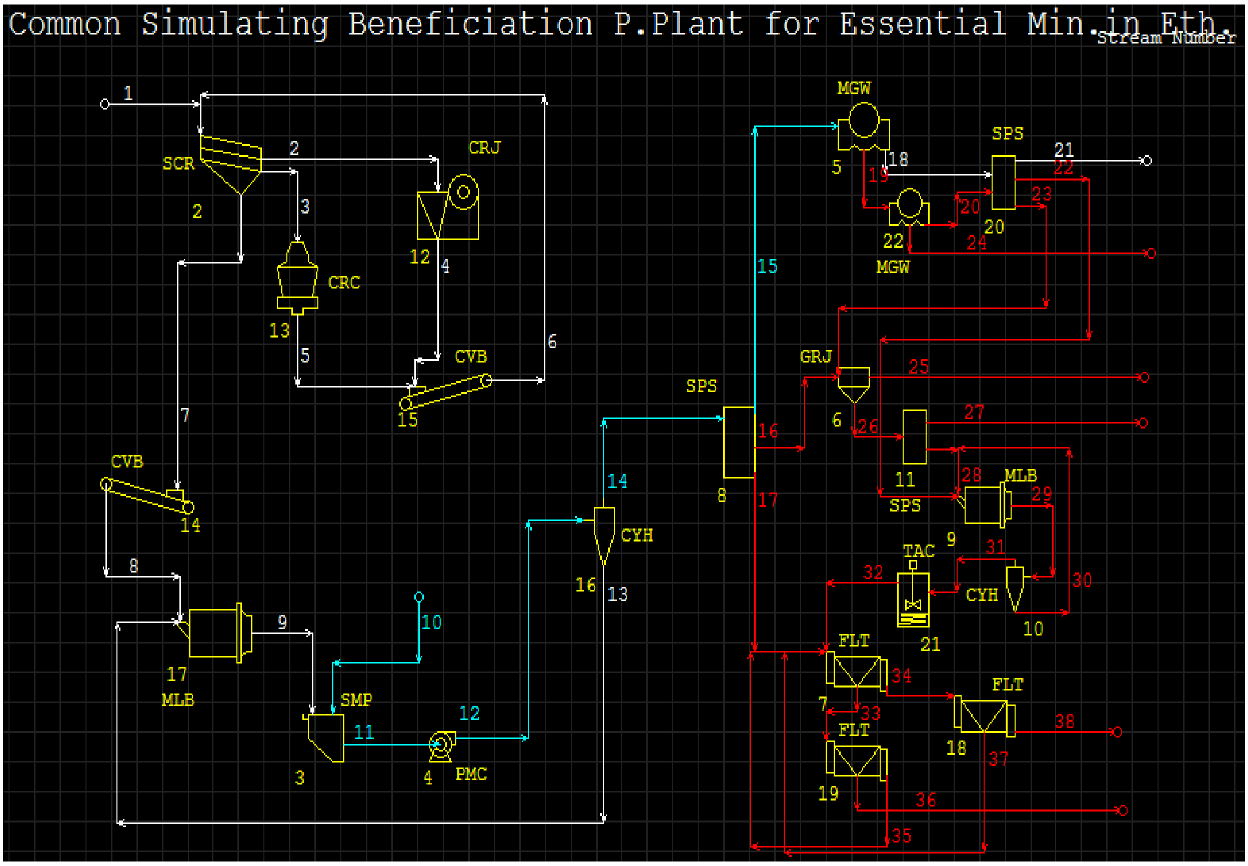


Figure 13: Versatile Beneficiation Pilot Plant Flowsheet created by METSIM

4.3 Mass Balancing

Because it enables a methodical approach to comprehending the flow of materials through the processing circuit, mass balancing is a crucial step in the mineral comminution process. We can increase recovery rates, reduce waste, and maximize comminution process efficiency by precisely accounting for inputs and outputs. This will ultimately result in more profitable and sustainable operations in the mineral processing sector(Wills & Finch, 2015).

The integrity of the mass balance throughout the crushing and grinding circuit was validated by METSIM simulation. There is no material loss when 10 tons of iron ore are fed into the screen per hour since the output of undersized material from the inner screen equals the input at that rate. Likewise, at 10 tons per hour, the hydrocyclone overflow and the ball mill's feed are equal. In the simulation environment, this shows a steady and balanced process flow, guaranteeing precise modeling and effective circuit design.

Furthermore, by entering all required parameters for the vibrating screen, jaw crusher, and cone crusher in accordance with conventional design standards, the METSIM flowsheet showed that the ideal circulating load for the jaw-cone crushing closed circuit was reached. The resulting circulating load satisfied the necessary optimum range for such circuits, which is normally between 100 and 200 percent, as evidenced by the circuit's starting input of 10 t/h and output of 18.508t/h. This demonstrated that the circuit functioned in accordance with the intended design specifications. Additionally, the circulating load between the ball mill and hydrocyclone met the ideal design requirements for a closed-circuit system, which are often around 250%, according to the METSIM simulation flowsheet. In this instance, there was a circulating load of almost 260% as the circuit feed was 10t/h and the output was 26.45t/h. The circuit's operation within the optimal design parameters was validated by this outcome.

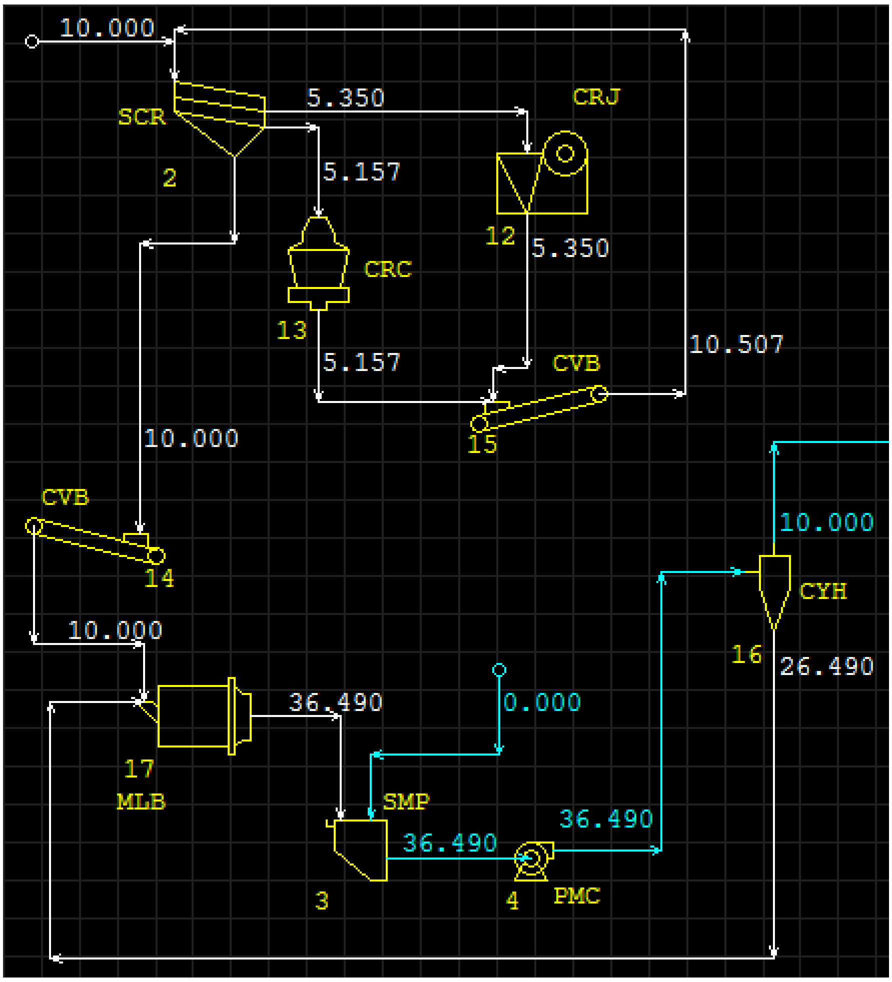


Figure 14: Mass Balance of Comminution Circuit of Melka Arba Iron

4.4 Particle Size Distribution Analysis of Comminution Method

Because it has a direct impact on process efficiency, mineral liberation, and the effectiveness of downstream separation techniques, particle size distribution (PSD) analysis is crucial in comminution circuits. Operators can minimize energy consumption, avoid over-grinding, and cut expenses by optimizing equipment settings based on their understanding of PSD. Additionally, precise PSD analysis aids in determining the ideal circumstances for mineral liberation, guaranteeing that valuable minerals are successfully extracted from gangue(Terzi, 2018).

PSD data is eventually crucial for organizing and improving downstream procedures including magnetic, gravity, and flotation separation since particle size significantly affects recovery and product quality.

4.4.1 Jaw Crusher

The Jaw Crusher efficiently processes iron ore overflow (80% passing 181 mm) from the two-deck inclined screen, achieving a significant size reduction from an F80 of 161,211 µm to a P80 of 33,863 µm passing through 45mm screen.

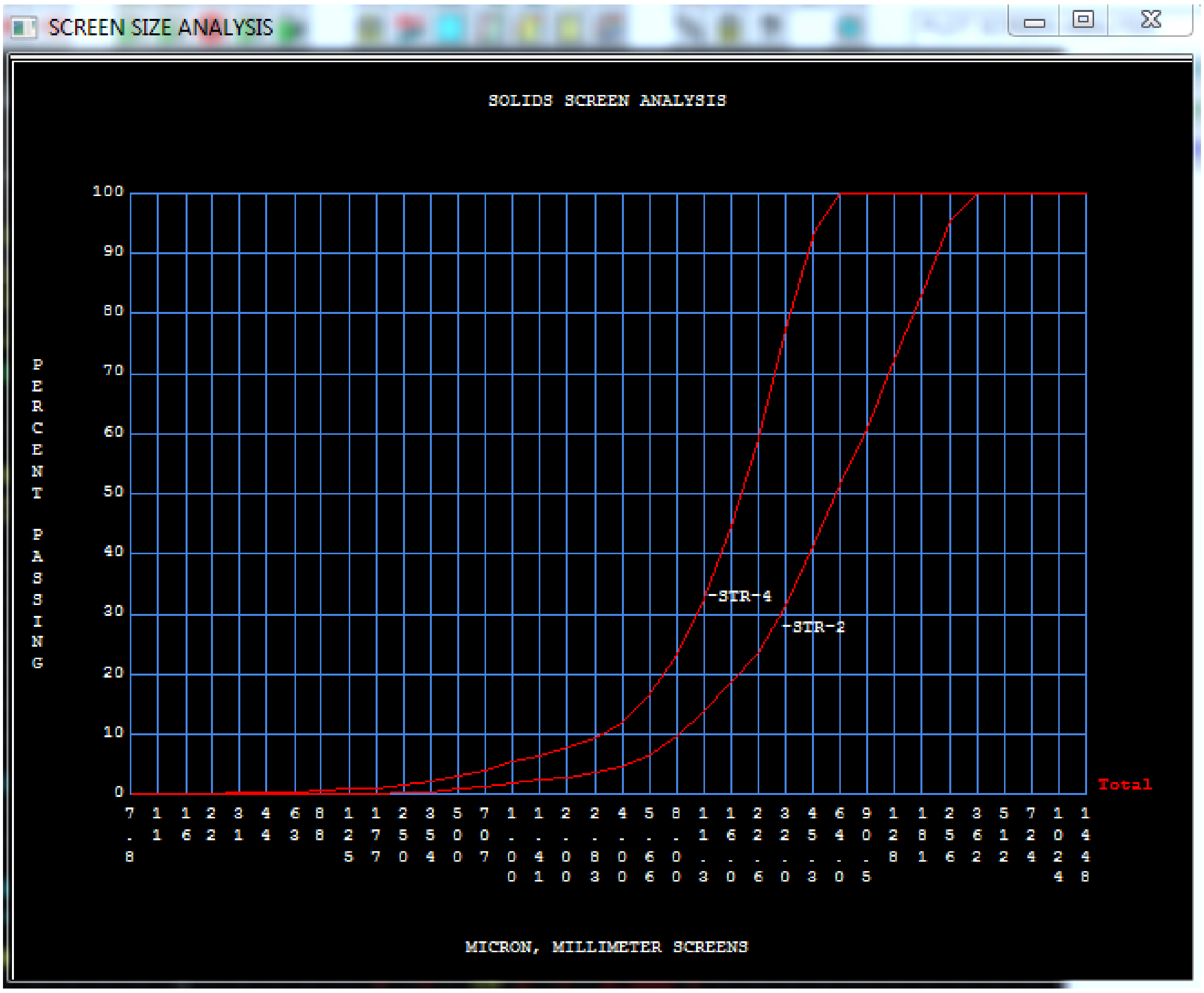


Figure 15 Jaw Crushing PSD input (STR-2) and output (STR-4)

Jaw crushers in a closed circuit with cone crushers and screens typically operate with a reduction ratio ranging from 4:1 to 8:1(Ummah, 2019)

$$\text{Reduction Ratio (RR)} = \frac{\text{80\% passing size of Feed}}{\text{80\% passing size of the Product}}$$

$$RR = \frac{F80}{P80}$$

$$RR = \frac{160{,}887\ \mu m}{33863\ \mu m}$$

RR = 4.75

One important measure of jaw crusher efficiency is the reduction ratio (RR), which shows how well the crusher reduces feed size to the required product size.

4.4.2 Cone Crusher

The desired PSD was attained by modifying the cone crusher's open and closed side settings iteratively using METSIM simulations. In particular, 80% of the feed from the cone crusher travels through a 45 mm screen with a F80 of 37,990 µm and a P80 of 10,014 µm passing through 11mm screen, which corresponds to the ideal feed parameters for efficient ball mill operation.

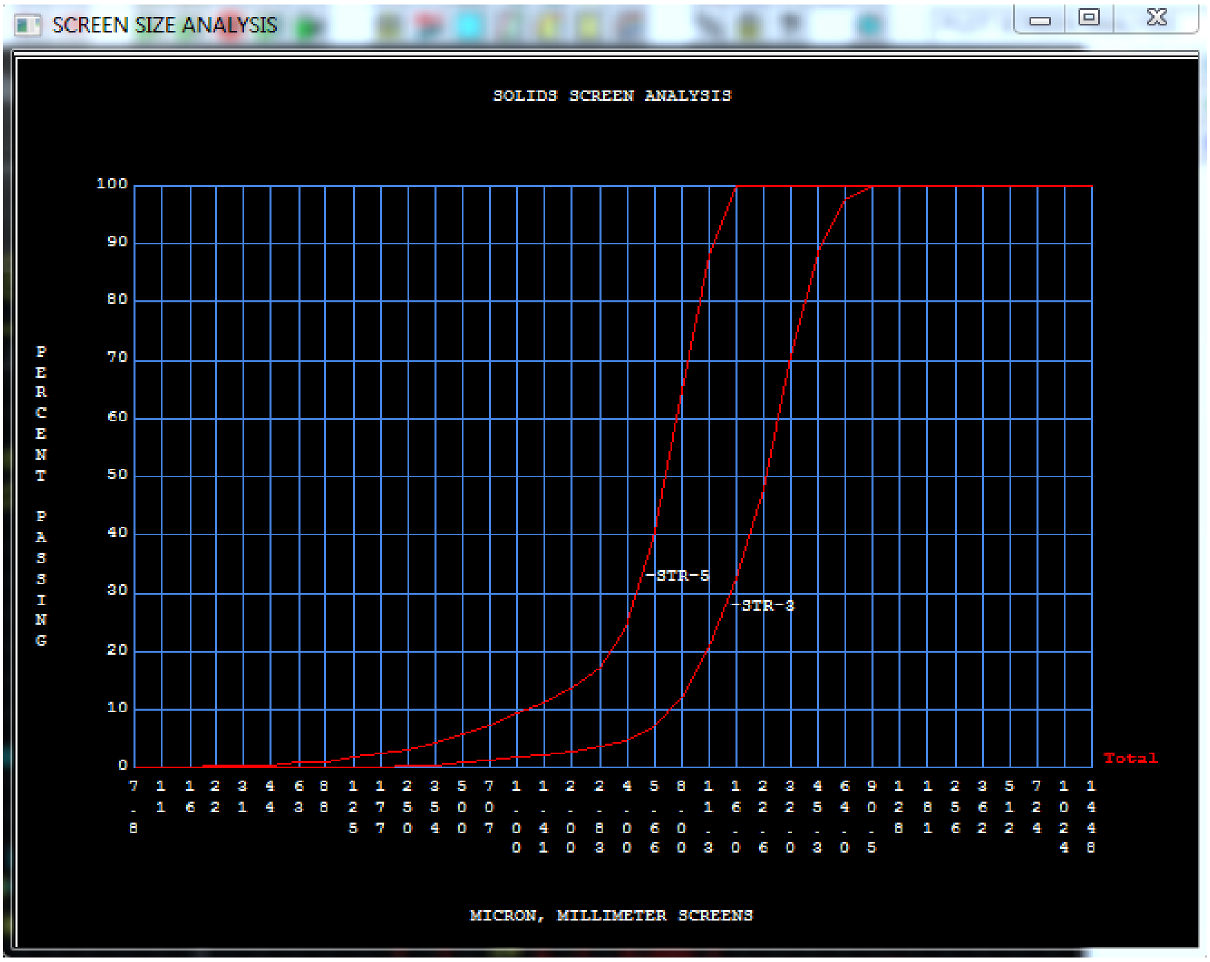


Figure 16-Cone Crushing PSD input (STR-3) and output (STR-5)

The cone crusher's proper reduction ratio should be between 3:1 and 5:1, or higher(Michaud, 2016).

$$\text{Reduction Ratio (RR)} = \frac{\text{80\% passing size of Feed}}{\text{80\% passing size of the Product}}$$

$$\text{RR} = \frac{\text{F80}}{\text{P80}}$$

$$\text{RR} = \frac{37{,}967\ \mu\text{m}}{10013\ \mu\text{m}}$$

RR = 3.79

The cone crusher's great comminution efficiency is confirmed by the reduction ratio (RR). By using METSIM to simulate important factors like open and closed side settings, this performance may be maintained and improved, guaranteeing reliable and efficient size reduction.

By entering all required parameters for the vibrating screen, jaw crusher, and cone crusher in accordance with conventional design standards, the METSIM flowsheet (figure 19) showed that the jaw-cone crushing closed circuit's ideal circulating load was reached. Given that the circuit's initial input was 10t/h and its output was 10.508t/h, the circulating load that resulted satisfied the necessary optimum range for these circuits, which is normally between 100 and 200 percent. This demonstrated that the circuit functioned in accordance with the intended design specifications.

4.4.3 Ball Mill

According to the solids screen analysis, an 11 mm screen with a F80 of 9,054 µm was used to filter 80% of the ball mill feed. The ball mill product obtained a P80 of 967.6µm after being ground and classified using a hydrocyclone, indicating that 80% of the powdered material passed a 1 mm screen. This outcome produces a fine particle distribution appropriate for further processing and shows efficient size reduction.

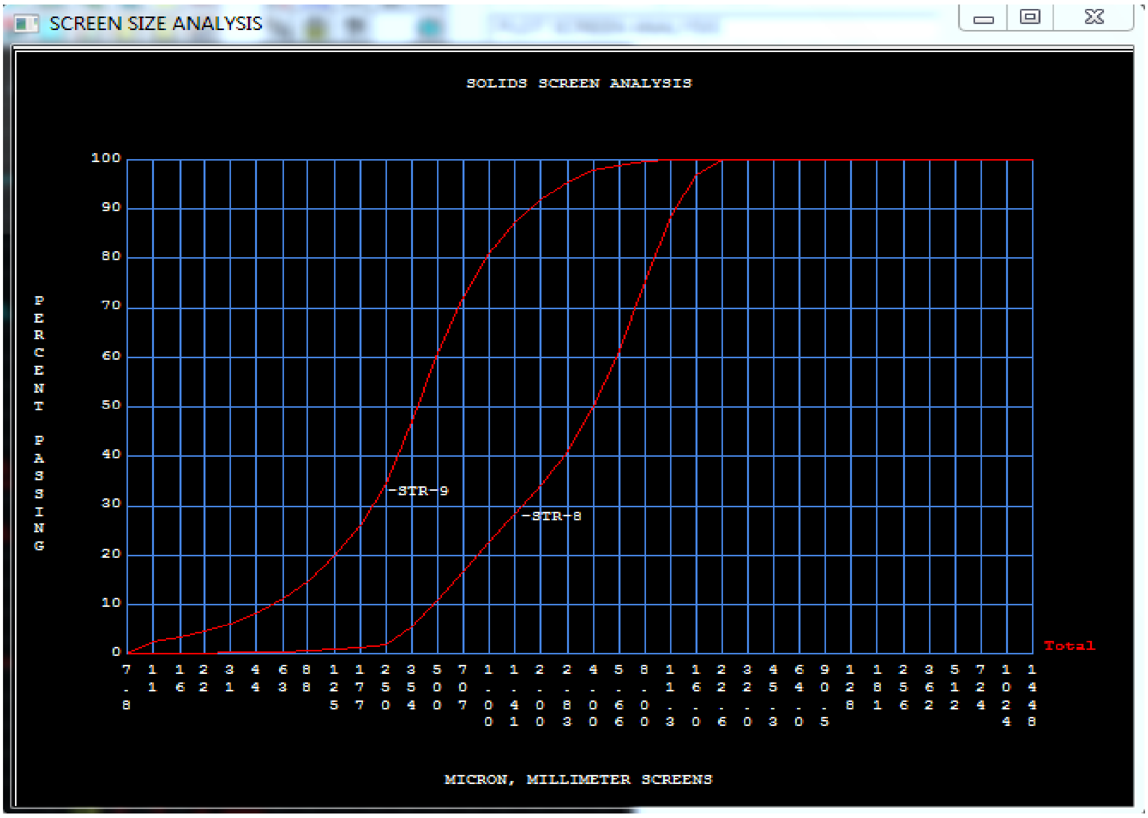


Figure 17-Ball Mill Crushing PSD input (STR-10) and output (STR-11)

For open-circuit grinding, standard ball mill reduction ratios typically fall between 5:1 and 20:1, but for closed-circuit grinding, they are frequently less than 10:1(MLANDVO BRIAN THEMBINKOSI DLAMINI 2019). For efficient mineral liberation and ideal downstream processing, achieving such a reduction ratio is essential.

$$\text{Reduction Ratio (RR)} = \frac{80\%\ \text{passing size of Feed}}{80\%\ \text{passing size of the Product}}$$

$$\text{RR} = \frac{\text{F80}}{\text{P80}}$$

$$\text{RR} = \frac{9054\ \mu\text{m}}{967.6\ \mu\text{m}}$$

RR = 9.357

The ball mill's high comminution efficiency is confirmed by the reduction ratio (RR), which can be maintained by utilizing METSIM to precisely regulate and optimize key parameters like feed size, ball charge, and mill speed.

4.4.4 Hydrocyclone

The hydrocyclone overflow reached a P80 of 199.9 µm, according to the METSIM simulation flowsheet, exactly matching the particle size distribution needed for the separation of iron ore from Melka Arba. This outcome demonstrated that the hydrocyclone successfully categorized the ground ore in accordance with process requirements. To ensure constant size reduction and ideal mineral liberation, the underflow was recirculated to the ball mill for additional grinding. By striking a balance between effective grinding and efficient classification, our closed-circuit setup optimized recovery and preserved constant product quality.

The circulating load between the ball mill and hydrocyclone met the ideal design requirements for a closed-circuit system, which are normally around 250%, according to the METSIM simulation flowsheet. In this instance, there was a circulating load of almost 260% since the output reached 26.45t/h while the circuit feed was 10t/h. The circuit's operation within the optimal design parameters was validated by this outcome.

And also, the efficiency of the hydrocyclone can be calculated by the following formula: As shown in figure 19, the solid in feed is 32.47% and the solid in overflow is 13.06.

$$\text{Efficiency (\%)} = \frac{(\text{Solids in Feed}) - (\text{Solids in Overflow})}{\text{Solids in Feed}} \text{x } 100\%$$

$$= \frac{32.47 - 13.06}{32.47} \text{x } 100\%$$

$$= \mathbf{59.78\%}$$

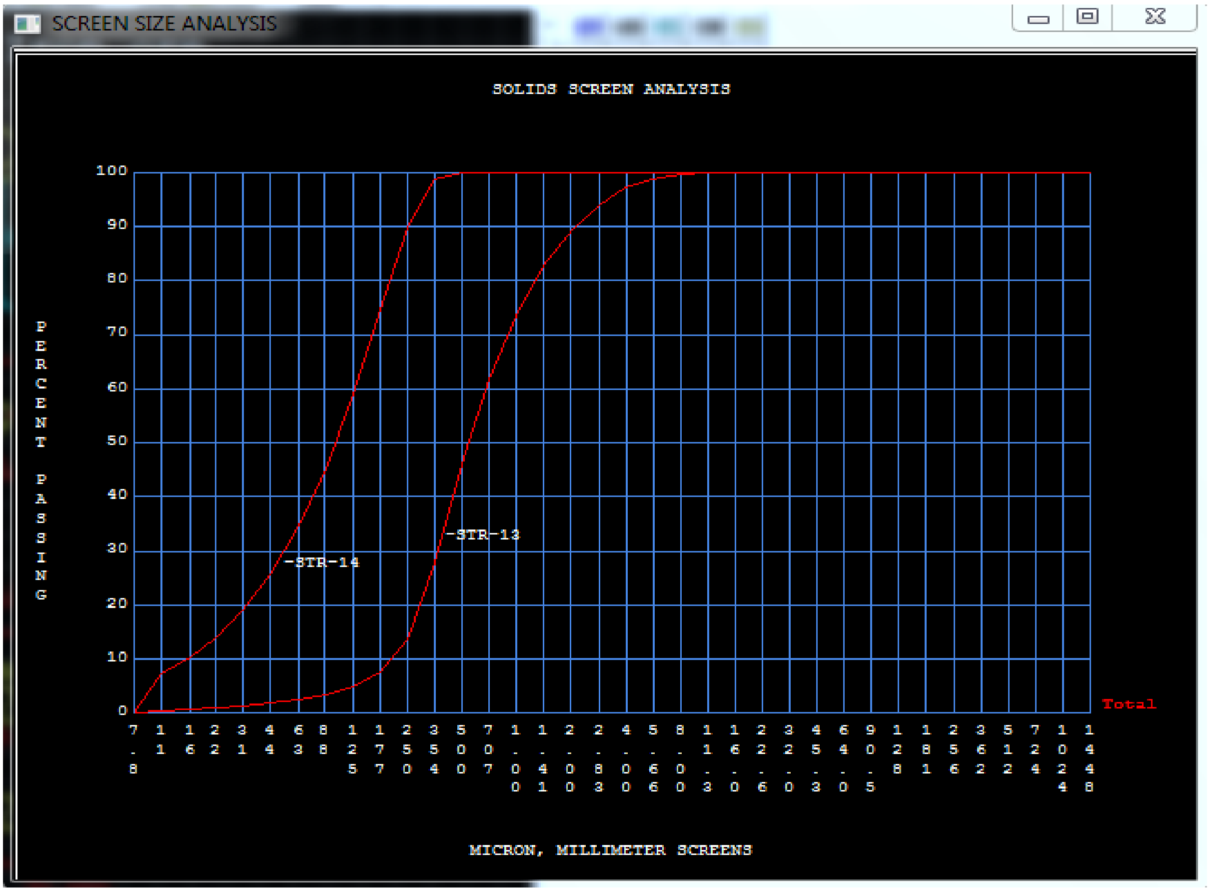


Figure 18- Overflow and Underflow of P80 graph of Hydrocyclone

4.5 Magnetic Separation of Melka Araba Iron

One essential method for the beneficiation of iron ores, such as the Melka Araba deposit in Ethiopia, is magnetic separation. This method effectively separates iron minerals from non-magnetic gangue materials by utilizing their magnetic qualities, such as those of magnetite and hematite, which have stronger fields(Xiong et al., 2015).

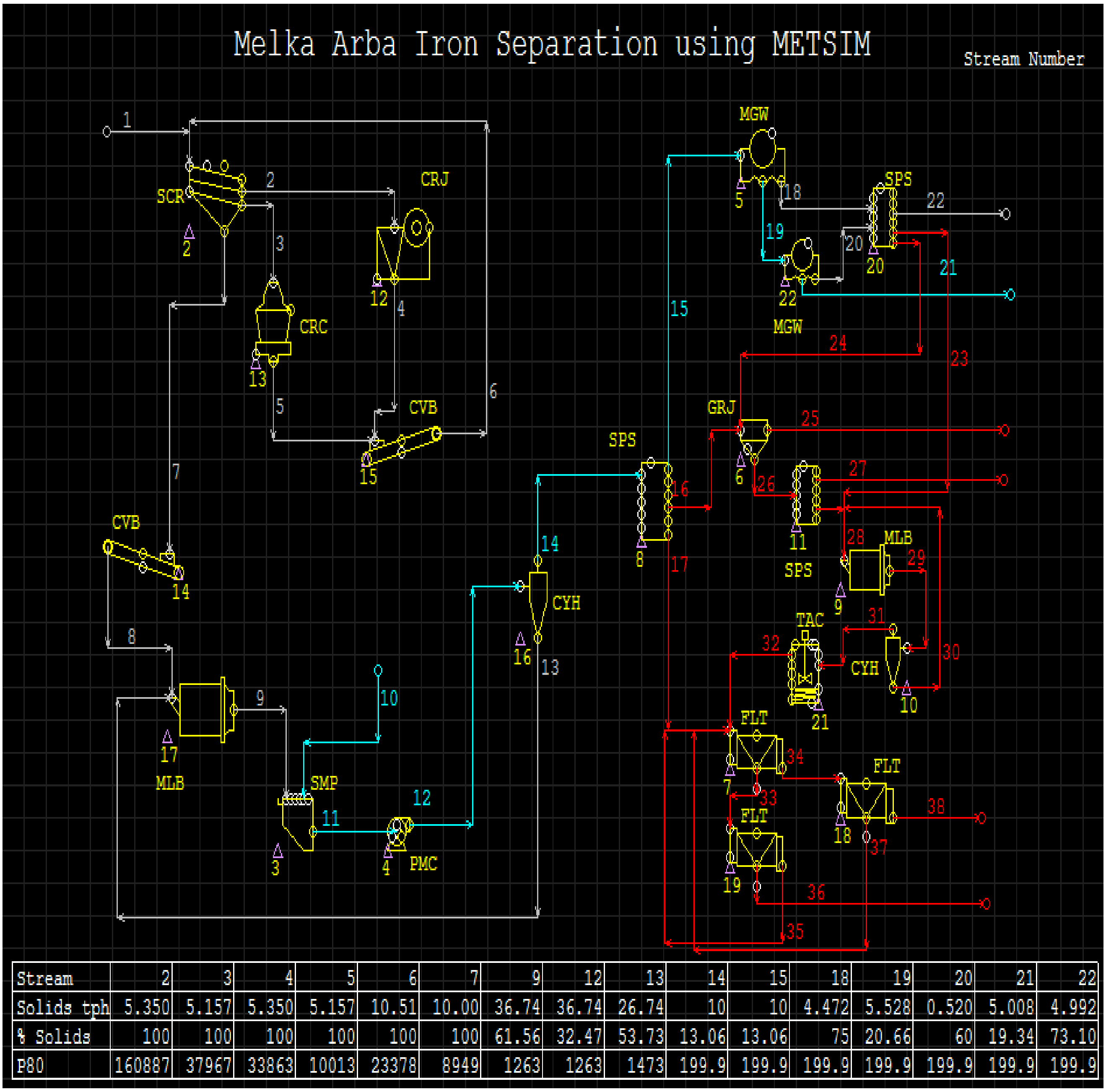
Iron-bearing minerals are separated from the surrounding gangue by comminution crushing and grinding of iron ore prior to magnetic separation. This release is essential because the degree to which magnetic particles are released from non-magnetic material determines how well magnetic separation works(Xiong et al., 2015). A higher-quality concentrate and better total recovery are the results of well-liberated particles, which guarantee that the magnetic separator can effectively attract and separate iron minerals.

Melka Araba operations can increase the effectiveness of iron recovery and generate a cleaner, more valuable iron ore product fit for direct use or additional processing by streamlining the comminution process before magnetic separation(Xiong et al., 2015).

Finding the exact P80 value that maximizes recovery is crucial for process optimization, even though the particle size distribution range of 150 µm to 250 µm has been found to be ideal for magnetite liberation and recovery. This was accomplished by running simulations with the METSIM software, a potent tool for simulating circuits involved in mineral processing, using a variety of P80 values.

These simulations evaluated the impact of changing the P80, the size at which 80% of the material passes, on the overall recovery and concentrate quality. As seen in the accompanying figures, the results provide significant new information regarding the relationship between particle size distribution and magnetic separation efficiency.

By evaluating these results, the right P80 may be found, allowing for targeted grinding and separation processes that optimize magnetite recovery while lowering processing expenses and energy usage. In order to replicate the results of the ore's separation using a certain particle size distribution, the accompanying figure shows the spreadsheet table and general flow line streams of maximum recovery of Melka Arba Iron ore using P80 of 200µm.



Stream	2	3	4	5	6	7	9	12	13	14	15	18	19	20	21	22
Solids tph	5.350	5.157	5.350	5.157	10.51	10.00	36.74	36.74	26.74	10	10	4.472	5.528	0.520	5.008	4.992
% Solids	100	100	100	100	100	100	61.56	32.47	53.73	13.06	13.06	75	20.66	60	19.34	73.10
P80	160887	37967	33863	10013	23378	8949	1263	1263	1473	199.9	199.9	199.9	199.9	199.9	199.9	199.9

Figure 19- Magnetic Separation Results of Melka Arba Iron Using PSD of 200µm

4.5.1 Effect of Particle Size Distribution (PSD) in Separation Method

The precise P80 value that usually results in maximum recovery is frequently located close to the middle of the 150µm–250µm optimal particle size distribution (PSD) range for magnetite recovery. The METSIM flowsheet provides evidence for this. Figure 21 illustrates that the highest magnetite recovery occurs when the P80 of the material reaches 200 microns.

The particle size gets excessively coarse when the P80 surpasses 250 microns. Usually, this leads to less magnetite being released from the nearby gangue minerals. When there is poor release, a high amount of magnetite is trapped inside bigger particles, which decreases its recovery during magnetic separation. The METSIM flowsheet illustrates that employing P80 values greater than 250 microns results in a decrease in magnetite recovery.

Particles become extremely fine when the P80 is lowered below 150 microns. Slimes are produced as a result, even if this promotes emancipation. Because very tiny particles may not react effectively to magnetic fields or may be lost in tailings due to entrainment, slimes can reduce the effectiveness of magnetic separation. Therefore, utilizing P80 values below 150 microns resulted in a decrease in magnetite recovery, as seen in the figure below.

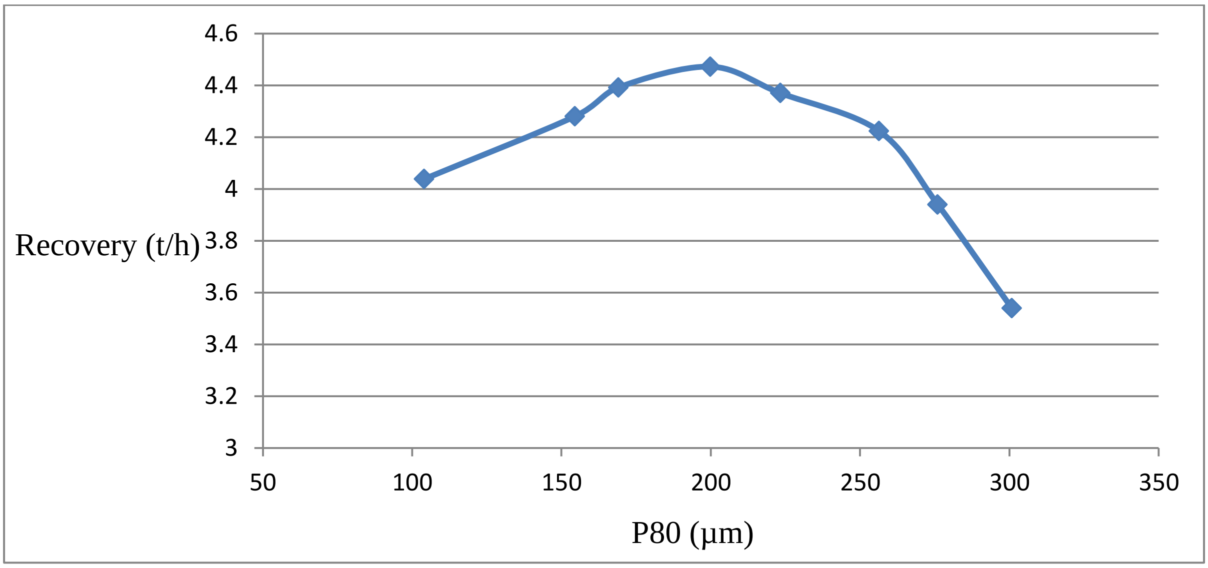


Figure 20: P80 VS Recovery Graph

4.5.2 Recovery

Important information about the effectiveness of magnetic separation for separating magnetite from accessory and gangue minerals may be found in the METSIM simulation of Melka Arba magnetite ore. The results are summed up by the critical parameters listed below:

A. Initial Feed Conditions and Composition

The composition of feed ore is as follows: 52% of the ore is magnetite, while 48% is made up of gangue and accessory minerals.

Feed Rate: A feed rate of 10t/h was used for the simulation.

B. Results of Simulations

Recovery of Magnetite: 4.472t/h of magnetite was recovered from a 10t/h feed.

Recovery of Ilmenite: 0.52t/h of ilmenite was recovered from 10t/h feed

Accessory and Gangue Minerals: The non-magnetic material that was extracted from the ore is represented by the 5.008t/h residual.

C. Verification of Mass Balance

Mass balance consistency is confirmed when the total feed (10t/h) equals the sum of recovered magnetite and ilmenite (4.992t/h) and gangues and accessory minerals (5.008t/h).

D. Efficiency of Recovery

Percentage of Magnetite Recovery:

The recovery percentage of magnetite from the initial feed can be computed to further assess the process's efficiency:

It is possible to compute the starting mass of magnetite in the feed as follows:

= 10t/h x 0.52

= 5.2t/h

0 Description
0 Output Level
0 Box Number
0 Design Factor
0 0 Maximum Flow
0 0 Variables 1 2 3
22
0 Label

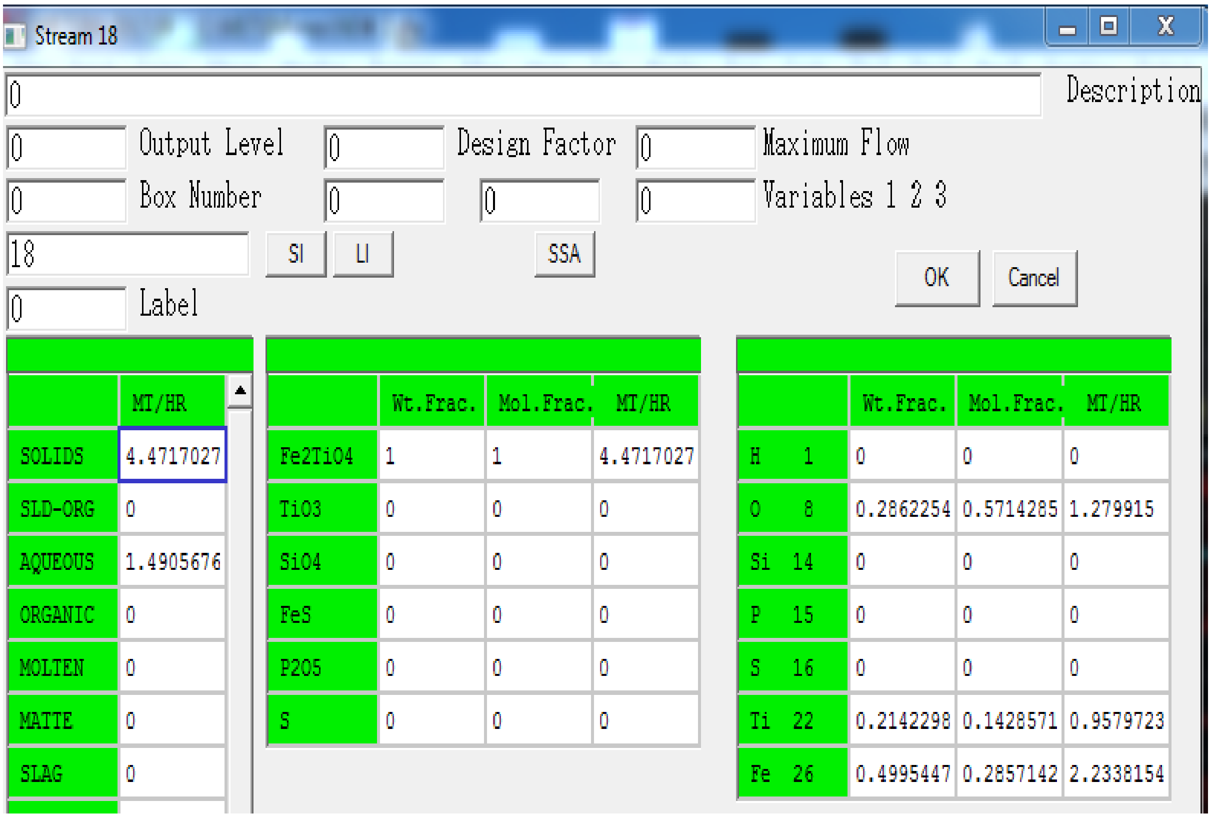
	MT/HR
SOLIDS	4.9922
SLD-ORG	0
AQUEOUS	10.382154
ORGANIC	0
MOLTEN	0
MATTE	0
SLAG	0

	Wt.Frac.	Mol.Frac.	MT/HR
Fe2TiO4	0.8957974	0.7866490	4.472
TiO3	0.1042025	0.2133509	0.5202
SiO4	0	0	0
FeS	0	0	0
P2O5	0	0	0
S	0	0	0

	Wt.Frac.	Mol.Frac.	MT/HR
H 1	0	0	0
O 8	0.3085546	0.5953900	1.5403664
Si 14	0	0	0
P 15	0	0	0
S 16	0	0	0
Ti 22	0.2439545	0.1572340	1.2178696
Fe 26	0.4474908	0.2473759	2.2339639

Figure 21- Results of Magnetite and its Elements Concentration from METSIM Description Dialog Box

The amount of iron concentrated in titaniferous magnetite is 2.234t/h, while the value of titaniferous magnetite is 4.472t/h, as indicated on the concentration stream METSIM description dialog box (figure 21). Additionally, the magnetite iron contains 1.1t/h of tin. The amount of tin that is readily available is far greater than what is needed to enhance the characteristics of iron. Therefore, we must use METSIM to identify utilizing flotation or another metallurgy approach.



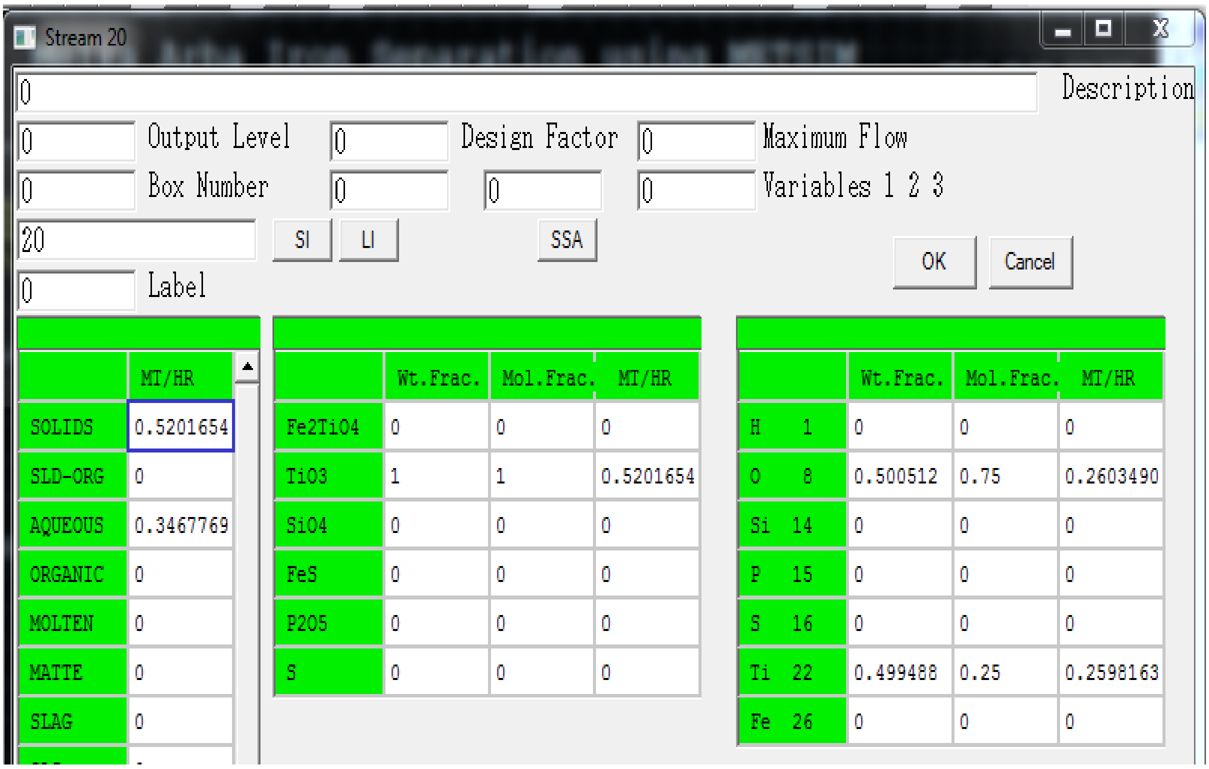
Description: 0
Output Level: 0
Design Factor: 0
Maximum Flow: 0
Box Number: 0
Variables 1 2 3: 0 0 0
18
Label: 0

	MT/HR
SOLIDS	4.4717027
SLD-ORG	0
AQUEOUS	1.4905676
ORGANIC	0
MOLTEN	0
MATTE	0
SLAG	0

	Wt.Frac.	Mol.Frac.	MT/HR
Fe2TiO4	1	1	4.4717027
TiO3	0	0	0
SiO4	0	0	0
FeS	0	0	0
P2O5	0	0	0
S	0	0	0

	Wt.Frac.	Mol.Frac.	MT/HR
H 1	0	0	0
O 8	0.2862254	0.5714285	1.279915
Si 14	0	0	0
P 15	0	0	0
S 16	0	0	0
Ti 22	0.2142298	0.1428571	0.9579723
Fe 26	0.4995447	0.2857142	2.2338154

Figure 22 Concentrated Results of Stream 18 Description Dialog Box



Description: 0
Output Level: 0
Design Factor: 0
Maximum Flow: 0
Box Number: 0
Variables 1 2 3: 0 0 0
20
Label: 0

	MT/HR
SOLIDS	0.5201654
SLD-ORG	0
AQUEOUS	0.3467769
ORGANIC	0
MOLTEN	0
MATTE	0
SLAG	0

	Wt.Frac.	Mol.Frac.	MT/HR
Fe2TiO4	0	0	0
TiO3	1	1	0.5201654
SiO4	0	0	0
FeS	0	0	0
P2O5	0	0	0
S	0	0	0

	Wt.Frac.	Mol.Frac.	MT/HR
H 1	0	0	0
O 8	0.500512	0.75	0.2603490
Si 14	0	0	0
P 15	0	0	0
S 16	0	0	0
Ti 22	0.499488	0.25	0.2598163
Fe 26	0	0	0

Figure 23 Concentrated Results of Stream 20 Description Dialog Box

4.5.2.1 Magnetite Recovery in Concentrate

$$R_{\text{Magnetite}} = \frac{\text{Mass of Magnetite Recovered}}{\text{Initial Mass of Magnetite in Feed}} \times 100\%$$

$$= \frac{4.472 \text{ t/h}}{5.2 \text{ t/h}} \times 100\%$$

$$= \mathbf{86\ \%}$$

This indicates that approximately 86% of magnetite in the feed was successfully recovered. This demonstrates that magnetic separation can recover iron by more than 86%.

Important information about the efficiency of the magnetic separation method for separating magnetite from its accessory and gangue minerals has been obtained from the beneficiation simulation of Melka Arba iron ore using METSIM software. The following criteria should be taken into account as a crucial topic for discussion:

Conclusions:

Magnetic Separation's Effectiveness: The high recovery rate of almost 86% suggests that magnetic separation is a successful technique for removing magnetite from iron ore from Melka Arba. This shows that the separation process is efficient, with minimal loss of important magnetite.

Effectiveness of Selected Particle Size Distribution: PSD was successfully chosen for magnetic separation using a 199.9 µm particle size distribution based on the laboratory results of Melka Arba Iron Ore mineralogical composition and particle size distribution analysis.

Material Distribution: The findings demonstrate that the concentration contains 4.472t/h magnetite recovered from the first magnetic (figure 22) separator and 0.52t/h ilmenite (figure 23) recovered from the second magnetic separator and totally 4.992t/h as a recovery obtained from the final concentration stream. In the meantime, the rest of the accessory minerals and gangues (5.008t/h) obtained as tailing. This result suggesting that the separation process did not successfully separates the ore into its valuable and non-value components due the mixing of the magnetite recovery and ilmenite recovery from the second magnetic separator.

Processing Implications: The outcomes of the simulation offer a solid basis for the beneficiation process's future expansion. The significant magnetite recovery indicates that additional optimization and the operation's possible economic feasibility should be investigated.

Additional Research: Because accessory and gangue minerals are so prevalent, more research might concentrate on the characteristics of these minerals, their possible economic worth, and how they affect the final magnetite concentrate's overall quality.

In conclusion, by omitting the second magnetic separator, we can obtain the highly successful magnetite recovery from the magnetic separation beneficiation simulation of Melka Arba iron ore and we suggests the possibility of processing this iron ore in a way that is profitable. To improve recovery rates and concentrate quality, further study may entail more process parameter optimization.

4.5.2.2 Iron Recovery in Concentrate

The original iron mass is 2.852t/h (Figure 12), and the recovered iron is 2.234t/h (Figure 21). This results in:

$$R_{Fe} = \frac{\text{Mass of Iron Recovered}}{\text{Initial Mass of Iron in the ore}} \text{ x } 100\%$$

$$= \frac{2.234 \text{ t/h}}{2.852 \text{ t/h}} \text{ x } 100\%$$

$$\mathbf{= 78.33\ \%}$$

4.5.3 Grade

4.5.3.1 Magnetite Grade in Concentrate

The percentage of recovered magnetite in relation to the total input mass determines the magnetite grade:

$$\text{Magnetite Grade} = \frac{\text{Recovered Magnetite}}{\text{Feed Rate}} \text{ x } 100\%$$

$$= \frac{4.472 \text{ t/h}}{10 \text{ t/h}} \text{ x } 100\%$$

$$\mathbf{= 44.72\ \%}$$

4.5.3.2 Iron Grade in Concentrate

The iron grade in the concentrate is as follows, based on the METSIM modeling conclusion that the ore contains 49.96% iron:

$$\text{Fe \% in Magnetite} = \frac{\text{Recovered Iron}}{\text{Recoverd Magnetite}} \text{ x } 100\%$$

$$= \frac{2.234 \text{ t/h}}{4.992 \text{ t/h}} \text{ x } 100\%$$

$$\mathbf{= 49.95\%}$$

Iron Grade=Magnetite Grade × Fe % in Magnetite

=44.72 % × 49.955 %

= 22.34%

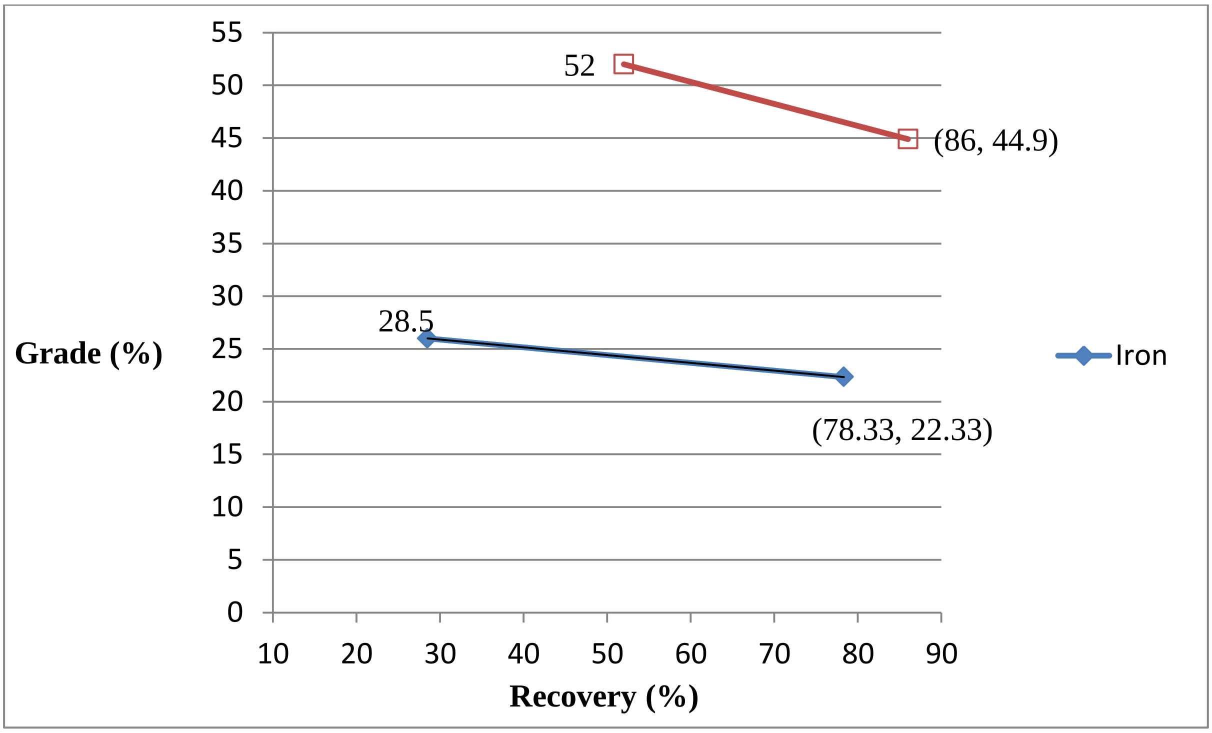


Figure 24-Recovery verses Grade graph

Just over half of the feed mass is successfully recovered as magnetite in the concentrate stream, according to the calculated magnetite grade in the concentrate of 44.72%. Since a sizable amount of the feed is transformed into magnetite concentrate, this indicates a modest efficiency in the separation or concentration process. Based on the assumption that magnetite contains 44.75% iron, the concentrate's iron grade, when taken into account, is 22.23%. This iron grade represents the concentrate's actual iron concentration found only in magnetite, which is a crucial factor in determining the product's quality and financial worth.

Although there is a significant amount of magnetite in the concentrate, the comparatively moderate iron grade suggests that more upgrading or beneficiation may be necessary to meet processing or market requirements for the total iron content.

In conclusion, the findings show a respectable magnetite recovery, but they also point to the necessity of possible beneficiation process adjustment to improve the iron grade. The value and effectiveness of the concentrate in downstream processes, such steel making, would rise with an improvement in iron grade. Higher grades and improved performance could be attained with more research into separation methods and process factors.

Chapter Five

Conclusion and Recommendation

5.1 Conclusions

Given Ethiopia's wealth of mineral resources, a specialized laboratory-scale mineral processing facility is desperately needed. To advance research and optimize extraction methods for important minerals including iron, gold, coal, and tantalum, a pilot beneficiation plant must be established. An organized, data-driven method for effective mineral liberation and concentration is provided by the suggested METSIM-based flowsheet.

The choice of equipment is crucial to the effectiveness of the procedure. In order to accommodate the distinct mineralogy of Ethiopian ores, the design carefully integrates industry-standard equipment, such as jaw and cone crushers, ball mills, and separation technologies, such as magnetic, gravity, and flotation techniques. Operations are streamlined and redundancy is reduced because to this integration.

With a magnetite recovery of almost 95%, METSIM's simulation of the beneficiation of Melka Arba iron ore validates magnetic separation as a very successful concentration technique. The effective separation of magnetite from accessory and gangue minerals is confirmed by mass balance findings.

These simulation results offer a strong basis for additional process modification, allowing for enhancements in recovery rates, operational effectiveness, and the overall viability of the Melka Arba iron ore beneficiation process from an economic standpoint.

In conclusion, the novel pilot process design that has been introduced here provides a scalable model for modernizing Ethiopia's mineral processing industry, tackling present issues associated with the absence of standardized beneficiation methods.

5.2 Recommendations

The creation of a simulated mineral beneficiation plant flowsheet is a very efficient way to cut down on the expenses and time involved with superfluous laboratory testing. Utilizing cutting-edge technologies such as artificial intelligence (AI) and simulation software enables quick scenario analysis, maximizes resource utilization, and permits well-informed decision-making without the need for lengthy, repeating tests.

Based on the suggested flowsheet, Ethiopia ought to make an investment in the construction of a specialized pilot mineral beneficiation facility. Modern technology should be installed in this facility to facilitate training, research, and the expansion of mineral processing for the nation's important minerals.

In order to improve recovery rates and concentrate quality, ongoing research must concentrate on streamlining beneficiation processes for economically significant minerals by investigating cutting-edge separation techniques and refining current approaches. Additionally, the pilot plant ought to serve as a professional and student training facility, developing a trained labor force to assist Ethiopia's expanding mining industry. For the pilot plant and simulation flowsheet to meet industry demands and advance sustainable mining practices, close cooperation between academic institutions, mining firms, and governmental organizations is crucial.

Future research should incorporate environmental evaluations to guarantee adherence to rules and reduce ecological effects, incorporating sustainability into the layout and functioning of the pilot plant.

Given that Melka Arba iron ore contains accessory minerals such titanium dioxide and ilmenite, additional separation by flotation or gravity should be simulated within the flowsheet in order to collect these valuable by-products.

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