DETERMINING THE LIBERATION SIZE OF MEKANESELAM IRON ORE SOUTHERN WOLLO ZONE, NORTHERN ETHIOPIA: IMPLICATION FOR BENEFICIATION.

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A Project work submitted to Center for Ethio-Mines Development in partial fulfillment of the requirements for the degree of Master of Engineering in Mineral processing.

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Declaration

Original project work, which was overseen by Dr. Dejene Hailemariam, General Director for Geological Institute of Ethiopia, and Mr. Belyneh Digafe, an exploration geologist at Geological Institute of Ethiopia, is about determining the liberation size of an iron ore deposit of Mekaneselam area with implications for beneficiation. I hereby state that this project work is original and is not being submitted in partial fulfillment of any degree requirements. All sources and papers consulted for this work are appropriately cited and fully acknowledged.

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Signature Date

Abstract

Iron is one of the most important types of ferrous metals that extracted from ore minerals of iron, like magnetite, hematite and others. Ethiopia has a lot of iron ore resources which are located in different parts of the country. Among this, Mekane Selam iron mineralization, which is located in south Wollo zone, Northern Ethiopia, is the target area of this project work. The main objective of this project work was to determine the liberation size of the target iron-bearing ore mineral through mineralogical identification, chemical composition analysis, and examination of the particle size distribution. Atomic absorption spectrometry (AAS), X-ray florescence (X-RF), X-ray diffraction (X-RD) analysis, and sieve analysis, were widely used methods for this project work. The chemical composition of Mekaneselam iron ore consists of 16.55–77.59 % Fe_2O_3, 7.31–59.02% SiO_2, and 1.44–17.38% Al_2O_3. With an average weight percentage of 48.34%,48.96% of Fe_2O_3, 34.7%,31.8 % of SiO_2, 8.2%,10.68% of Al_2O_3, and 0.018% , 0.19 % of P_2O_5 and other minor compositions that resulted from X-RF and AAS compositional analysis respectively. The mineralogical results generated from X-ray diffraction showed that Mekaneselam iron ore consists of major iron-bearing ore minerals of 40–60% hematite, 8–59% goethite, with an average value of 49.13% hematite and 27.85% goethite. The dominant associated gangue minerals are 1–21% quartz with an average value of 11.5% and 1–23.5% kaolinite with a mean value of 8.6%. The examination of the particle size distribution of sizing curves shows that 80 percent passing (P_{80}) of the grinded ore sample is 1100µm. The size-wise chemical compositional analysis of AAS revealed that a higher weight percentage of the target ore mineral was recorded under a sieve size range of (-250µm + 180 µm). This implies that the appropriate liberation size of the target iron-bearing ore mineral is found between (-250µm and +180µm) sieve size ranges. This liberation size range shows a cumulative passing of 38% total particles. The chemical and mineralogical results of Mekaneselam iron ore indicate that the ore is very low grade and can be upgraded to commercial values by using gravity concentration followed by a high-intensity magnetic separator. In addition, it can be upgraded by magnetic reduction roasting (MRR), followed by a low-intensity magnetic separator.

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Table of Contents

List of figures

List of tables

List of acronyms and abbreviations

AAS…………………………………………………………… Atomic absorption spectrometry

X-RD…………………………………………………………X-ray diffraction

X-RF…………………………………………………………X-ray florescence

RLM…………………………………………………………… Reflected light microscope

PSD………………………………………………………...Particle size distribution

TFe…………………………………………………........Total iron content

HIMS…………………………………………………………High intensity magnetic separator

MRRP………………………………………………………. Magnetic reduction roasting process

LIMS………………………………………………………… Low intensity magnetic separator

SG……………………………………………………………Specific gravity

MS……………………………………………………………Mekaneselam

CC……………………………………………………………Concentration criteria

GIE…………………………………………………………..Geological institute of Ethiopia

S.Wollo………………………………………………………South Wollo

Chapter one: Introduction

1.1 Background

Mineral resources are important raw materials for the manufacturing industry. They are pillars for the economic development of one's country. Among these, iron ore minerals like hematite (Fe_2O_3) and magnetite (Fe_3O_4) are important ore minerals for iron metal. Iron oxides and hydroxides form the main principal iron ore minerals due to their high iron content and occur in large quantities on surface deposits (Ferenczi, 2001**).** The iron and steel sectors are one of the most important parts of the infrastructural and technological development of any modern society. It is one of the most widely utilized metals in the various sectors of the world's economy.

The consumption of iron increased abruptly due to the rapid growth of the iron and steel industries. In order to supply the required amount of this resource to the iron and steel industry, the target metal should be extracted predominantly from the beneficiated ore minerals of hematite (Fe_2O_3), magnetite (Fe_3O_4), and to a lesser extent, goethite (FeO (OH)) and limonite (FeO (OH)).n (H_2O), siderite ($FeCO_3$), ilmenite ($FeTiO_3$), and others. Hematite (Fe_2O_3) is a widely distributed type of iron ore mineral found in various rocks and soils. However, it is not directly used in the steel and iron industries without preliminary beneficiation since it is low grade (Zhang and Yin, 2007).

The concentration of iron ore minerals can be conducted by gravity concentration (separation based on their difference in specific gravity between the target and gangue minerals), magnetic concentration (beneficiation based on their variation in magnetic properties), electrostatic separation (concentration of target minerals based based on the electrical conductivity of the materials), and flotation concentration (separation of target minerals from gangue minerals with their physico-chemical properties). Most commonly, it is concentrated using magnetic and gravity separation techniques (Holmes et al., 2022) and the flotation separation method is largely used for very low-grade iron ores. Gravity separation is the most commonly used type of concentration method for most minerals due to its cost effectiveness, ease of operation, and environmentally friendly nature as compared to other concentration methods. The selection of appropriate processing technologies and design a specific type of flow sheet for a typical iron ore mineral deposit that effectively separates the target mineral from its associated gangue mineral is selected based on the mineralogical properties of the ore deposit. This includes textural analysis, examination of the particle size distribution, mineral identification and quantification, chemical composition analysis, physical properties, and Physico-chemical property analysis of specific ore deposits.

Ethiopia has most of the resource materials required for steel production, including iron ore, coal, limestone, and others. Ethiopia has an estimated 350 million metric tons deposits of iron ore weighing across the country (Study of development of iron ore and metallurgy industry, 2015 –2025). One of these is iron ore deposits that are located in Abergele, Sekota, Mekaneselam, Mertolemaryam, and Wollega are the most prominent iron ore resources .Those resources can be beneficiated by a wise selection of suitable processing technologies. Even if Ethiopia has a lot deposits of iron ore, the government still spends a vast amount of hard currency for importing iron and steel products. To replace imports with locally manufactured of deposits of iron ore, the Ethiopian government has a long-term plan to reduce the amount of steel and iron imported. This is done over time by substituting locally manufactured iron products.

To make real this long-term plan, all the mineralogical properties including mineral identification, chemical composition analysis, and examination of the particle size distribution and determination of liberation sizes of an ore deposit should be investigated and an appropriate beneficiation method should be selected. Due to this, the main objective of the project work is focused on determining liberation size of target ore mineral in conjugation with mineral identification, compositional analysis and examination of the particle size distribution of an iron ore deposit for the beneficiation of target ore minerals of hematite (Fe_2O_3) from associated gangue (quartz (SiO_2) and kaolinite Al_2O_3 minerals of Mekaneselam area.

1.2 Statement of the problem

Various studies on potential iron resource areas have been conducted in Ethiopia. Based on this research, the most prominent areas that can be identified and taken as promising for iron resources are: Abergele (Shakura locality iron ore deposit), Sekota iron ore deposit, Wollega (Bikilal iron ore deposit), Mertolemaryam iron ore deposit, Mekane-selam iron ore deposit, and Melka Arab (Sidamo) and Shire (Tigray) iron ore deposits. Among these, the iron ore deposit of the Mekaneselam area is a prominent deposit that can be beneficiated with a detailed mineralogical characterization and the wise selection of appropriate processing technologies.

Iron is one of the most important metals used today in manufacturing industries in order to produce iron and steel, which are the primary raw materials for the construction industry. Ethiopia imports a vast amount of steel and iron products for the purpose of construction inputs and for other purposes by investing a huge amount of hard currency. In order to minimize as well as, over time, eliminate imports and make an import substitution with local products, the Ethiopian government has a long-term plan to manufacture iron and steel by using local iron ore resources. However, the bulk of the iron ore deposits that have been discovered by different researchers and are located in different parts of the country have not been well investigated in relation to their mineralogical characterization, compositional analysis, mineralogical identification, particle size distribution analysis, and determination of their liberation sizes. In addition to that, the beneficiation methods to separate the minerals of iron ore from their associated gangue minerals are the main gaps.

To make this long-term plan real and effective, all deposits of iron ore that are distinguished as prominent resources should be physically, chemically, and mineralogically well analysed, and the appropriate types of beneficiation and concentration methods should be selected and designed. Therefore, this project was intended to fill these scientific and technical gaps on the target ore deposit of the study area, including: (i) chemical composition analysis; (ii) mineralogical identification; (iii) particle size distribution (PSD) analysis; and (iv) determination of liberation sizes of the target iron ore mineral (Fe_2O_3).

1.3 Objectives

1.3.1 General objective.

The main objective of this project work is to determine the liberation size of the target iron ore mineral in conjunction with chemical and mineralogical analysis.

1.3.2 Specific objectives are:

- To evaluate the ore grade
- To select the appropriate beneficiation methods
- To determine D_{50} and P_{80} of particles
- To design conceptual communtion circuit flow sheet

1.4 Significance of the project

Ethiopia has numerous deposits of iron ore that have recently been discovered in various parts of the country and can be mined for economic profit. Even if the resources and reserves are known, current research on mineralogical identification, compositional analysis, examination of the particle size distribution, the determination of liberation size, and the method of beneficiation is lacking. Due to this reason, this project would have the intended purpose of conducting chemical composition analysis, mineralogical identification, examination of the particle size distribution, and the determination of liberation sizes of ore minerals for beneficiation. As a result, the finalised work of this project would have significant importance to the scientific community by filling informational gaps related to mineralogical assessments, including mineral identification, particle size distribution analysis, compositional analysis, and the determination of the liberation size of target ore minerals. And this is extremely beneficial to the research community, which wishes to conduct detailed work on iron ore characterization for beneficiation and processing from its ore deposit type of Mekaneselam iron mineralization.

Furthermore, the Ethiopian government has a long-term plan to manufacture iron and steel from the country's iron ore resources. The Mekane Selam iron ore deposit is included within this long term plan of import replacement by local products. This project would have a direct or indirect impact on the mining industry by serving as a preliminary feasibility study or promotional document. This is very important to attract foreign investing companies that want to invest in the country.

1.5 The project's scope

The project was intended to carry out only the chemical composition analysis, mineralogical identification, examination of the particle size distribution, and determination of the liberation size of the target ore mineral located in the Mekaneselam area. Further detailed flow sheet designs, textural analysis, and beneficiation tests were not included in this project due to limitations in locally available laboratory instruments, time constraints, and financial constraints. It was conducted with a time frame of April to June 2023, with a final outcome of a chemical composition analysis result, a mineralogical identification result, a particle size distribution (PSD) analysis result, and a determined liberation size of the target iron-bearing ore mineral.

1.6 Project frame work.

The project work of this study is constructed with five main chapters and some important sub chapters.

Chapter one: includes introduction (background, objectives, and statement of problem, significance of project and project's scope).

Chapter two: includes literature review (classification of iron ore deposit, ore minerals of iron, characterization of iron ore, size wise compositional analysis, iron ore processing, mineral beneficiation experience of Ethiopia, world reserve of iron ore, and iron resource potential of Ethiopia).

Chapter three: includes material and methods (material and equipment's, methods and procedures including (sample collection, sample preparation, chemical composition analysis, mineralogical analysis, communtion, sieve analysis, PSD, and size wise chemical composition analysis).

Chapter four: includes result and discussion (chemical composition analysis, mineralogical identification, PSD analysis, size wise compositional analysis, ore grade, liberation size, communtion circuit, and beneficiation methods).

Chapter five: includes conclusion and recommendation.

Chapter Two: Literature Review

2.1 Characterization of iron ore

Iron ore characterization relies substantially on the other stages of process flow sheet creation, including the quantitative classification of mineral deposits. Without an in-depth understanding of the mineral characteristics of the deposit, it might be impossible to build an effective process flow chart. For the target ore material to be successfully beneficiated, a thorough understanding of the ore's mineralogical and chemical makeup is crucial. (Venugopal et al., 2005) .Here are some of the studies that are covered under chemical and mineralogical characterization of iron ore**.**

Gidan Jaja iron ore in Zampara state, Nigeria, was chemically and mineralogically characterized by Asuke et al. (2019) using X-RF, X-RD, SEM, and an optical microscope. The material's typical makeup, according to the X-RF results, was 73.79% Fe_2O_3, 0.52% MnO, 17.50% TiO_2, 0.11% CaO, 0.50% Cr_2O_3, 3.84% SiO_2, 0.43% Al_2O_3, 0.034% CuO, 0.02% NiO, 0.46% PbO, and 2.76% LOI.. Furthermore, the X-RD results revealed that the ore contains 56% ilmenite, 34% magnetite, and 10% spinel. The petrographic analysis also shows the iron-bearing minerals are primarily magnetite and ilmenite, with some amounts of hematite, spinel, and quartz. Finally, the results obtained from SEM analysis showed the iron-hosting minerals are separated from other associated minerals by smooth grain boundaries.

Another study was conducted on the characterization and processing of iron ore slimes for the recovery of iron values with the help of X-RD, SEM, quantitative examination of the mineralogy using a field emission scanning electron microscope (FESEM) and scanning electron microscope (QEMSCAN) **(**Jena et al.,2015**)** using X-ray diffraction for mineralogical identification, X-ray fluorescence for chemical composition analysis, a pycnometer for specific gravity analysis, and quantitative mineralogy, studies on the mineralogical characterization of Matsitama banded iron ore in Botswana were conducted. Evaluation by scanning electron microscopy (QEMSCAN) for bulk mineralogy analysis and particle map analysis (PMA) was used. The deposit's composition was determined by X-RF analysis to be 55.9% Fe_2O_3 and 44.2% SiO_2, with trace levels of Al_2O_3, Cr_2O_3, P_2O_5, and TiO_2 components. According to quantitative mineralogical analysis using a scanning electron microscope (QEMSCAN), 25% of the hematite is connected with quartz and 75% of it is totally freed. **(**Ramakgala & Danha, 2019**).** Furthermore, research was done on the mineralogy, microstructure, and chemical composition of geothites in some iron ore deposits of Orissa, India, with the aid of an electroprobe micro analyzer (EPMA) for chemical compositional analysis, an X-ray diffractometer (X-RD) for mineralogical assessment, and a reflected light optical microscope for textural analysis in substitution for a scanning electron microscope (SEM) (Das et al., 2010).

The mineralogical characterization of the deposit of iron in Dilband in Balochistan, Pakistan, was carried out by (Abro et al., 2008) using X-RD for quantitative mineralogical analysis, X-RF for average chemical compositional analysis, AAS for size-wise elemental analysis, SEM with EDS for textural analysis, and a petrographic microscope for mineralogical analysis with thin sections. Deposit of iron in Dilband is composed primarily of 46.27 percent hematite, 17.41 percent quartz, 14.47 percent calcite, 9.24 percent chlinochlore, 10.5 percent kaolinite, and 1.75 percent fluorapatite minerals, according to mineralogical analysis.

Similarly, mineralogical and physical beneficiation studies for iron extraction from the Bardaskan titanomagnetite placer deposit were carried out using mineralogical characterizing instruments such as X-ray diffraction for mineralogical characterization, X-ray fluorescence for chemical composition analysis, EPMA for inclusion, exclusion, and other textural relationship analysis, and a confocal microscope and an optical microscope for the examination of textural characteristics in thin, polished sections. **(**Hosseinzadeh et al.,2017**).**

In addition, another study was conducted on the characterization and beneficiation of siliceous iron ore deposits, and the determination of liberation sizes was done by using size-wise chemical or elemental analysis with the aid of atomic absorption spectrometry (Dwari et al.,2013**).** Furthermore, investigations were conducted by using quantitative electron microscopy **(**QEM) for mineralogical characterization of applied iron ore tailings from the desliming stage, and the analysis revealed that the main mineralogical components are hematite and quartz with a lesser extent of goethite, kaolinite, and gibbsite. And the mode of mineralogical occurrence related to its degree of liberation showed that in hematite or magnetite, 88.13% of its particles are totally free, 0.53 % are associated with quartz, and 6.77 % are associated with goethite (Souza et al.,2021).

With the same vein, another investigation was done on the iron ore's characterization related to mineral associations, mineral liberation, and grain size distribution analysis using a scanning electron microscope and optical image analysis as a comparative study. The result showed that both OIA and SEM have their own advantages and draw backs. SEM can misidentify minerals with close chemical composition, like hematite as magnetite and virous hematite as goethite. However, for routine characterization OIA is a quicker, more affordable, and more accurate way to characterize iron ores with high iron concentration and a variety of iron oxides and oxyhydroxides. (Donskoi et al., 2013).

The characterization of iron ore by visible and infrared reflectance and Raman spectra was done by (Ramanaidou et al.,2015) with reflectance spectroscopy in the visible (380–750 nm) and infrared (750–14,000 nm), and this provides quantitative data on quartz, magnetite, maghematite, and kenomagnetite, compositional details on carbonates, hematite, and aluminous goethite. In addition, with the help of optical, X-ray diffraction (X-RD), and X-ray fluorescence (X-RF) techniques, the mineralogy of iron ore sinters was studied. The characterization of optically based point counting (OIA) was done based on the color, reflectivity, and morphology of each phase by using a reflected light microscope that was fitted with a stepping stage. Additionally, research was conducted on the mineralogy of iron ore sinters using a range of techniques, like analysis of optical images and point counting(PC), X-ray diffraction, and two different electron microscopy systems (quantitative evaluation of materials scan with an electron microscope (QEMSCAN) and TESCAN integrated mineral analyzer (TIMA (Honeyands et al.,2019).

2.2 Size wise compositional analysis

Using retained particles starting from sieve size ranges of 2300, 1700, 1180, 850, 600, 425, 300, 212, 150, 106, 75, and 63 m sieves, and investigation was conducted in Itapke, Nigeria to determine the economic liberation size of iron ore. All material collected at each sieve was analysed with AAS. The result indicates much amount of iron was recorded under the sieve size range of -425 to +300µm.This implies, the economic liberation size for Itapke iron deposit is found between size range of -425 and + 300µm (Ola-Omole & Nheta, 2020).

With the same vein, similar research was done in Nigeria for composition and liberation size analysis of Agbajja iron ore in Kogi sate. The sieve size ranges that was used for the investigation of particle size distribution was found between 2360 and -150µm.All the particles retained at each sieve size was collected and chemically analyzed for size wise compositional analysis and from this it was concluded that much amount of iron was recorded with sieve size ranges below 250 µm which is the target liberation size (Oluwaseyi & Funke, 2020).

Similar investigation was done on evaluating the possibility for determining liberation size in the manganese ore in Anka (Zamfara State, Nigeria). Fractional sieve analysis was conducted with size wise arranged sieve starting from sieve sizes 1000 down to 63µm. All the retained particles was at each sieve sizes was compositionally analyzed and high weight percentage of manganese was recorded in the sieve size range of f -180 + 125 µm that indicates the manganese ore can be economically liberated with this size range (Gbadamosi et al.,2021).

2.3 Iron ore processing

Three main products are created from the ore that is taken away from the mine site after it has been crushed using different types of crushers and then screened. Iron ore is beneficiated all over the world to create iron that conforms to the requirements required by the steel industry. However, due to its particular mineralogical characteristics, each source of iron ore has different beneficiation and metallurgical the prerequisites to obtain the best production out of it. The beneficiation technique to be utilized depends on the type of gangue present and how it interacts with the ore structure (Ghosh & Chatterjee, 2008).

2.3.1 Concentration methods

Gravity, magnetic, flotation, and as well as electrostatic separation are a few typical methods used to extract iron oxide from gangue materials. The separation of valuable minerals from gangue requires the effective exploitation of differences in the mineral properties of the ore.(Taylor, 1997).

2.3.1.1 Gravity separation

Based on the distinction between the gangue and precious minerals' specific gravities, gravity separation is a process of beneficiation. Common iron oxides can be distinguished from waste minerals by their differences in specific gravities since they are typically heavier than the latter.

Jigging is one of the earliest types of gravity concentration. Water pulses vertically through the feed to keep it moving. The more substantial granules descend to the bed's bottom and are eliminated. (Wehleekema, 2017).

Various studies on the process of enhancing iron ore have been conducted using gravity concentration methods. Among gravity concentration methods, the jig was tested for its effectiveness in the beneficiation of low-grade iron ore deposits in Orissa, India, and results showed that an optimum iron recovery of 78.6% was achieved with 63.7 % Fe in the concentrate when the jig was operated at an average stroke, average water velocity, and with a particle size of less than 5 mm (Rao et al., 2018). Another study was conducted on the beneficiation of reserves of low-grade iron ore in north-western Sudan using a two-stage concentration method (gravity and magnetic), with high-grade iron concentrates assaying 64% Fe and a 72% recovery (Das et al., 2008).

With the gravity concentration methods, another attempt was made to utilize subgrade iron ores in India, which have a modal composition of ROM with 40.8 % Fe and 40.9 % Sio2. After grinding into 100 microns, the ground ore is subjected to multi-gravity separators (MGS) to beneficiate the iron ore mineral hematite from quartz, and the result showed a concentrate of 55.8% Fe with a recovery of 84.4 (Seifelnassr et al., 2013**).** Further experiments were done to increase the grade of iron ore mineral concentrate with a multi-gravity separator on the same target iron ore deposit in India, and it was proved that a concentrate assaying 66.67% Fe_2o_3 and 3.12% SiO_2 with a recovery of 73.67% was obtained

A jigging operation of the gravity concentration method was performed in Nigeria for the beneficiation of the Itapke iron ore deposit with an appropriate sieve analysis of 4375 microns to -75 microns on 12 arranged sieves and with an operating variety of particle size, bed thickness, and dilution ratio. The final result showed that when the jig was operated at optimal levels of stroke and speed with feed slurry of average dilution and liberation size of 600 microns fed to the jig, 71% recovery of iron ore mineral was achieved (Olubambi & Potgieter ,2005).

2.3.1.2 Magnetic separation

In order to separate magnetic minerals (such as magnetite and, in some applications, hematite) from non-magnetic gangue materials like quartz, magnetic separators take advantage of the different magnetic characteristics of the ore minerals. Magnetic separators can be classified into low- and high-intensity machines, which may be further classified into dry-feed and wet-feed separators When the mineral is magnetite, low-intensity (500–1200G) separation is normally practiced because it is relatively cheap and effective.

If the size of the ore is intermediate, it is possible to use either method. High-intensity (1200–22000 G) materials with a small magnetic field can be separated using separators., such as hematite and hydrated hematite, from gangue materials for both wet and dry iron ores (Mular et al., 2002) .Some scholars have done research on the beneficiation of iron by using magnetic concentration methods.

With the same vein, another study was conducted on the beneficiation of low-grade hematite iron ores containing carbonates by applying magnetization followed by magnetic separation after roasting. Nearly all of the siderite and hematite was transformed into magnetite due to roasting with 8% coal for 8 minutes @ 800 oC roasting temperature. After roasting, magnetic separation was done, and a high-grade magnetic iron concentrate of 64 % Fe with 92.7 % recovery of iron ore minerals was achieved (Yu et al., 2017).

Similarly, another study was conducted on the recovery of iron ore minerals from phosphorous oolitic iron ores by using coal-based reduction followed by magnetic separation. The research was performed under the following operating conditions: reduction temperature, 1250 °C; reduction time, 50 min; C/O mole ratio, 2.0; and CaO content, 10 wt%. With these operational parameters, a magnetic concentrate containing 86.7 % Fe with a 96.21% iron recovery was obtained (Sun et al., 2013).In addition, research was also conducted on low-grade siliceous iron ore samples for the beneficiation of minerals of iron ore from siliceous iron deposits after grinding to 200 microns with the aid of the magnetic separation method, and it was possible to find a high-grade magnetic concentrate of 67 % Fe and 90 % recovery (Dwari et al., 2013).

2.3.1.3 Flotation Separation

A selective method known as foam flotation can be used to separate complicated ores in a specific way. This process utilizes the differences in physicochemical surface properties of particles of various minerals. A number of articles were published by different scholars on the basis of iron ore beneficiation with flotation separation methods. By using the flotation concentration method in conjunction with different dosages of depressants and collectors.

Similarly, research was also conducted focusing on improving the recovery of iron using columan flotation of iron ore slimes from two samples generated at hydrocyclone particle sizes of approximately 99% of 45µm, 25% of > 10 µm, 45% of 5 µm, and 15% of 1µm, or 3% of solids by weight and between 35% and 45% of Fe grade. Results showed that a final concentrate containing an assay of iron grade higher than 60 %, 4% SiO_2, and 3.1% Al_2O_3 had a recovery of up to 75 % in the rougher conventional flotation obtained from sample one of the first experiment with 45.2% Fe, 28.6% SiO_2, and 3.1% Al_2O_3, when a collector type amide-amine (Flotinor 5530) was used in substitution of a conventional aminollector (Matiolo et al., 2020).

As opposed to that, it was not possible to achieve a final focus containing an Fe grade higher than 55% from Sample2 with 39.6% Fe, 33.4% SiO_2, and 5.1% Al_2O_3, using both types of collector (amide-amine and amine), even when applying different types of column flotation circuits (rougher or rougher/cleaner). Based on the results obtained in the study, it can be observed that there is no standard solution for efficient slimes processing in the iron ore industry (Matiolo et al., 2020**).** In the same vein, recovered iron ore tailings were floated in Brazil to obtain a final concentrate of 66% Fe with silica (SiO_2) content less than 0.8% and phosphorus (P) content less than 0.03%, demonstrating that an affordable method to increase recovery from low-grade iron ores and tailings is ultrafine flotation. (Plinio Eduardo et al., 2013).

2.4 Mineral beneficiation experience of Ethiopia

To date, Ethiopian experience with mineral beneficiation is unsatisfactory. Medroc Gold Mine, Akobo gold mining, Kumuruk gold mining Company and other small-scale companies are currently beneficiating minerals such as gold, tantalum, and to a lessening degree coal jig concentration at a new plant that will begin operations soon. Tantalum of Kenticha was concentrated by using gravity (Jigg, spiral, and shaking table) concentration methods, with some restrictions on the recovery rates of 65–70 % (Woldeselsassie et al., 2019) .In addition, further investigations were done focusing on alternative beneficiation of tantalite and the removal of radioactive oxides from Ethiopian Kenticha pegmatite–spodumene ores with an X-RD analysis that showed the upper zone is mangano culombite and the inner zone is dominated by tantalite.

With an appropriate cleaning and beneficiation process, the upper zone can be beneficiated with a concentrated product of 57.34 wt% Ta_2O_5 and 5.41 wt% Nb_2O_5 (Gebreyohannes et al., 2017).

2.5 World reserve of iron ore

The world's iron ore reserves include considered by 2021 are presented in the table below.

Table 1: World reserve of iron ore recorded during 2021.

No	Country	Resereve (billon tones)	% Total
1	Australia	50	28.5
2	Brazil	29	19
3	Russia	25	13.9
4	China	20	11.2
5	Ukrain	6.5	3.6
6	Canada	6	3.3
7	India	5.5	3.1
8	USA	3	1.7
9	Iran	2.7	1.5
10	Peru	2.6	1.5
11	Othrer countries	22.930	12.8

Source**:**https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/iron-ore-facts/20517

2.6 Iron resource potential of Ethiopia

Ethiopia is thought to have an estimated potential iron ore reserve of up to 350 million tons. The most prominent areas that can contain economical ore deposits of iron are: Melka arba of Sidamo, Shire, Bikilal of Wollega, Sekota, Mertolemaryam, and Mekaneselam, which contain large amounts of iron ore resources.

Table 2: Location and distribution of iron ore resources and reserves of Ethiopia.

Locality	Estimated iron ore resource (million) ton	Ore minerals
Bikilal (Wollega)	57	Magnetite
Gamalucho (Kaffa)	12.5	Magnetite
Garao (Kaffa)	12.5	Hematite & limonite
Melka Arba (Sidamo)	111	Hematite ,magnetite & limonite
Shire(Tigray)	192	Goethite/limonite

Enthicho (Tigray)	14.23	Limonite
Metro lemareyam	32.2	Hematite, Goethite
Sekota(Waghemera zone)	57.01	Hematite, Goethite
Zikuala (Wagehemra zone)	31.4	Hematite, Goethite
Abergele (Waghemera zone)	15.73	Hematite, Goethite
Mekane Selam (S. Wello Zone)	184	Hematite, Goethite

Source: Study of the iron ore and metallurgy sectors' development: issues, opportunities, and potential course of action (2015–2025)

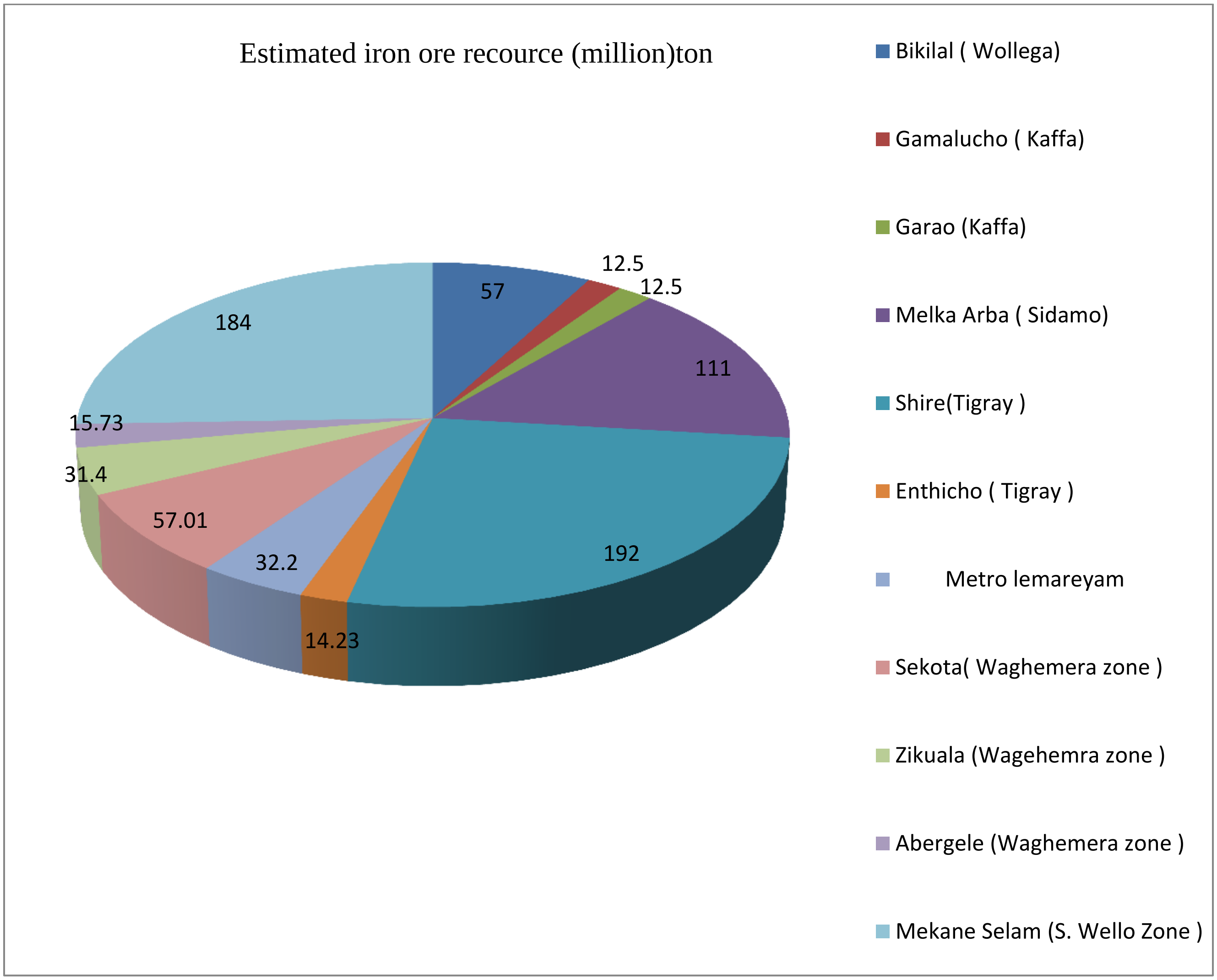

Figure 1: Location and distribution of major iron ore resource and reserves in Ethiopia

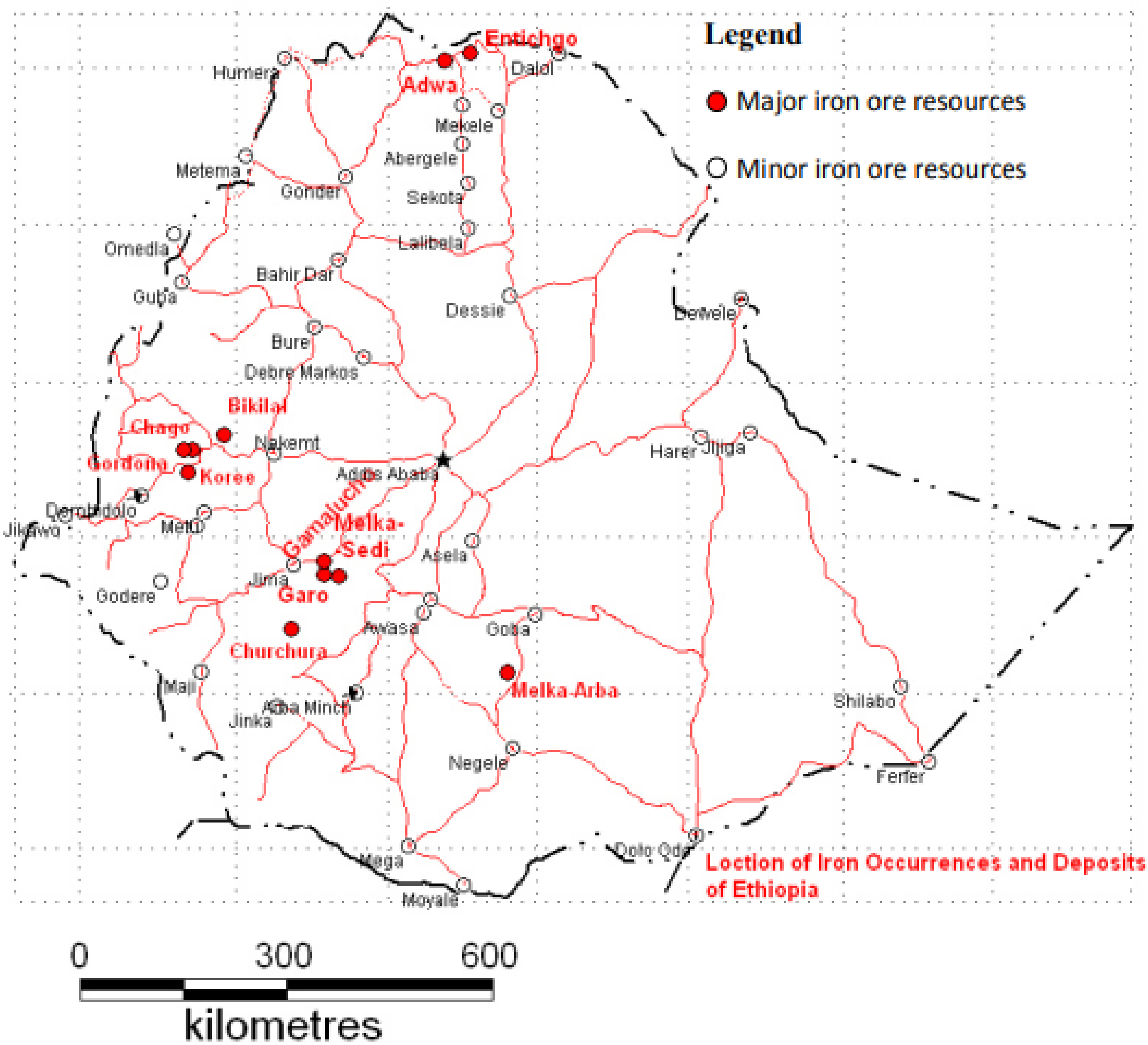

Figure 2: Location map of Ethiopia's iron resources and occurrences, sourced from the Geological Survey of Ethiopia in June 2010).

Chapter three: Materials and Methods

3.1 Materials and equipment's

The most useful materials and equipment's that were used for the accomplishment of this project work were;

- Iron ore sample
- Atomic absorption spectrometry (AAS): for elemental/ or chemical composition analysis
- X-ray florescence (X-RF) : for compositional analysis
- X-ray diffraction (X-RD) :for mineral identification in qualitative and quantitative form
- Primary crusher (Jaw crusher): for size reduction of the target ore.
- Grinding mill (ball mill): for further size reduction discharged from primary crusher.
- Size wise arranged sieve: for the distribution of particle sizes (PSD) analysis.

3.2 Methods and procedures

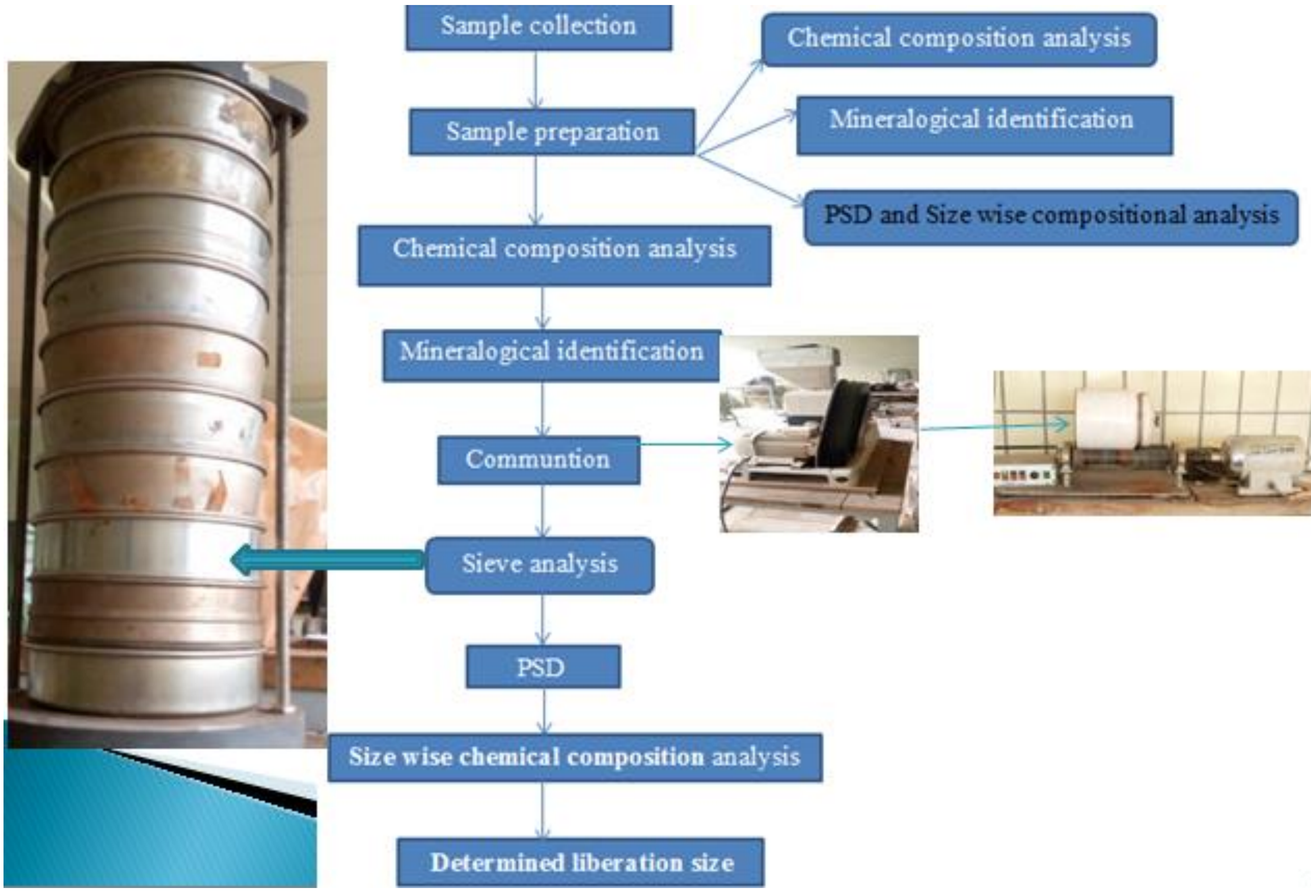

Figure 3: Diagrammatic representation for project work methods and procedures.

3.2.1 Sample collection

Representative samples of iron ore were collected from the Mekaneselam area of different localities (Dase, Millo, Lega worke, and Teba menu) with coordinate locations of 450832E, 118 5322N, 4504993E, 1183743N, 450755E, 1181678N, 453076E, and 1186550N, respectively, and the samples were labeled accordingly. About 25kg To ensure that the samples were as representative and recent as feasible, they were taken at a specific depth.

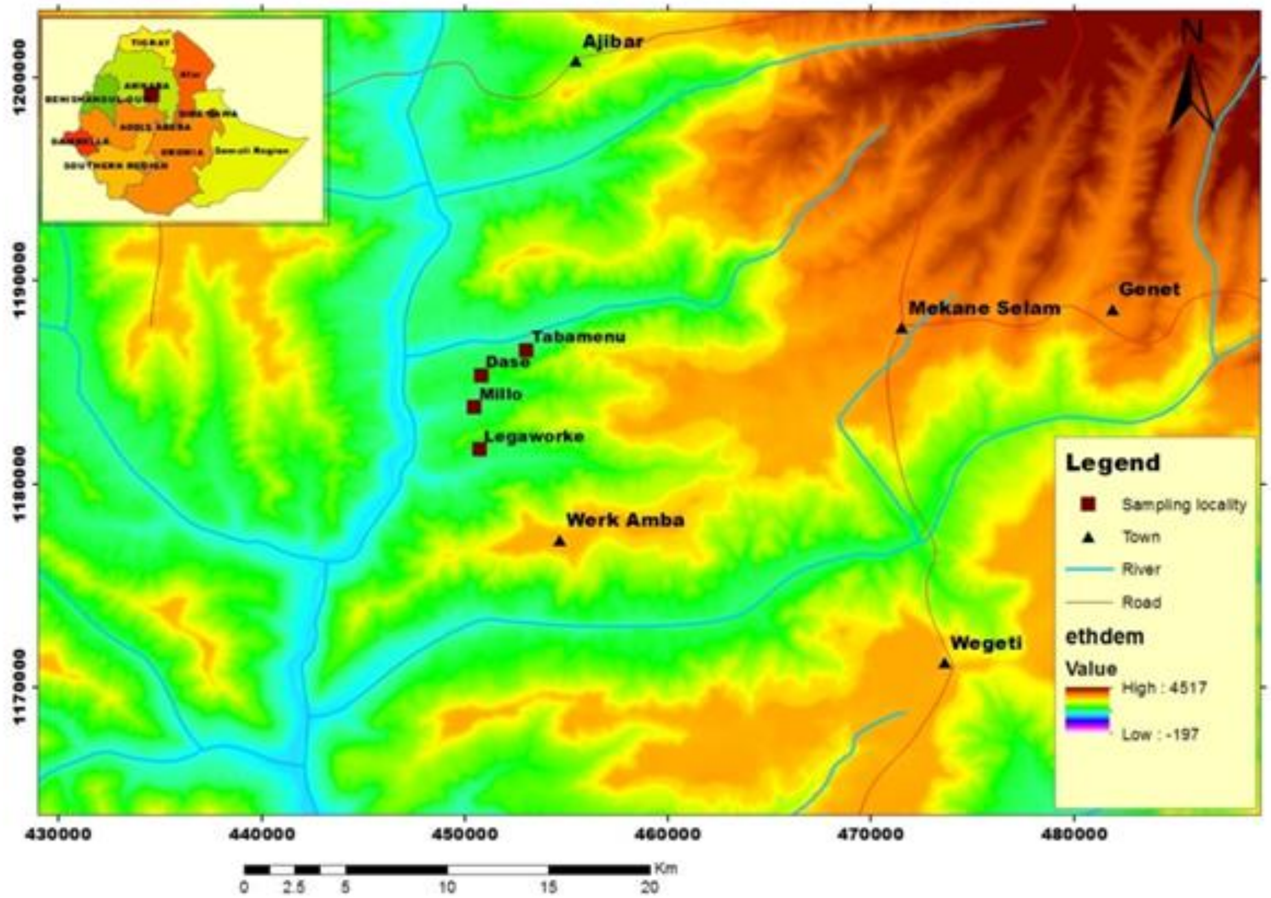

Figure 4: Specific sampling localities of the study area.

3.2.2 Sample preparation

The sample preparation varied from analysis to analysis, i.e., the sample preparation for chemical composition analysis is different from the sample preparation for mineral identification and particle size distribution analysis. For the distribution of particle size (PSD), bulk chemical composition, and size-wise chemical composition analysis, a cone and quartering method of sampling was used.

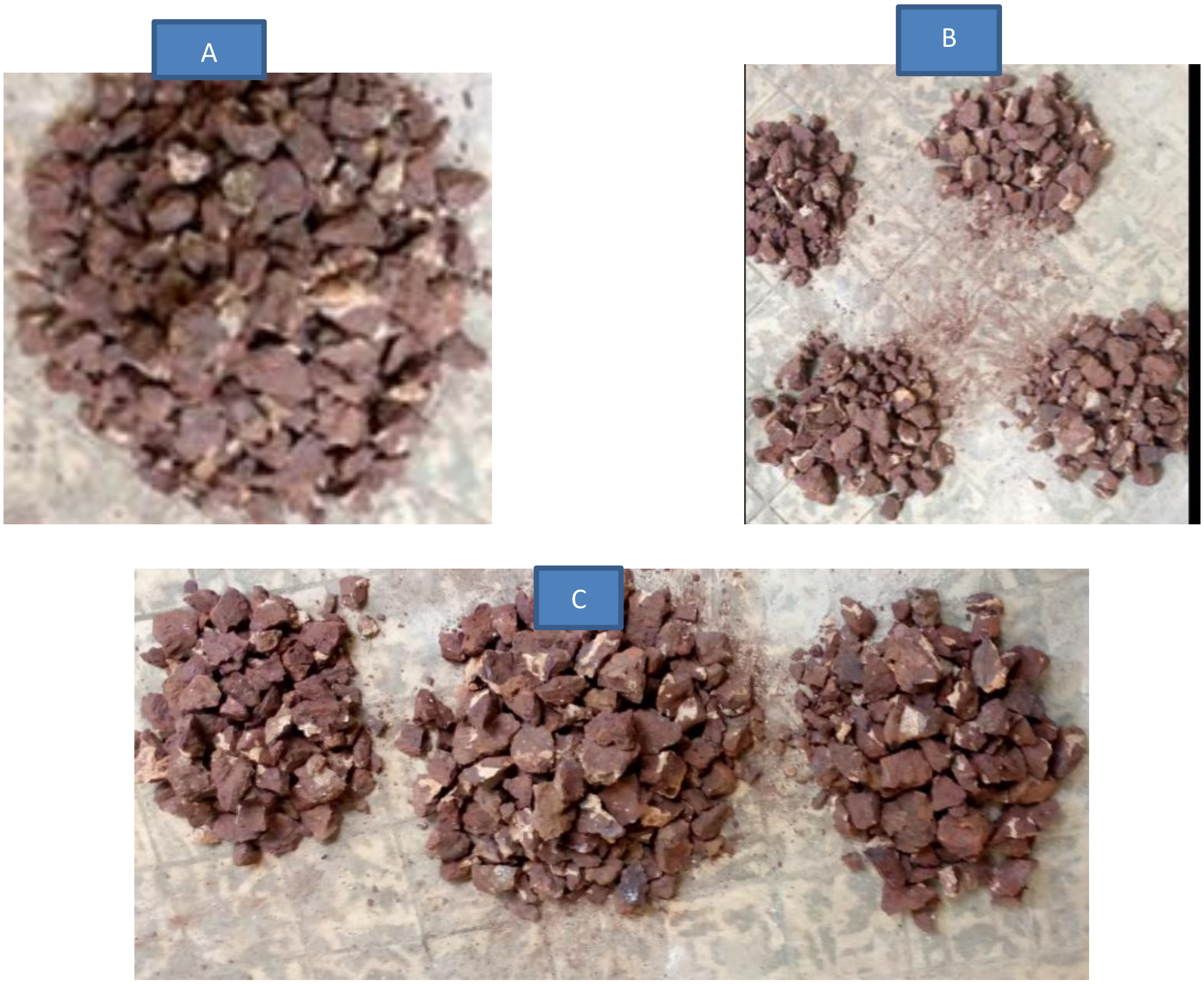

Figure 5: Cone and quartering method of sampling (A: cone shape, B: quartering: C: representative sample)

Sample preparation for chemical composition analysis: The sample preparation for compositional analysis was carried out at the Ethiopian Geological Survey Laboratory, including all processes of crushing, grinding, and pulverization, which are suited for X-RF analysis and for AAS analysis.

Sample preparation for mineral identification: Samples for X-RD analysis were prepared at the Ethiopian Geological Survey laboratory for the purpose of identifying minerals. The sample was crushed, milled up to 0.075mm/200 mesh size, and prepared for x-ray diffraction analysis.

Sample preparation for particle size distribution (PSD) and size wise compositional analysis: The sample preparation for both for the distribution of particle size and size-wise compositional analysis was done at the Addis Ababa Institute of Technology's minerals and construction input laboratory. The laboratory jaw crushers and ball mill were used for the sample preparation. The jaw crusher's maximum feed size is 5 mm, and samples that are above 5mm were crushed manually and fed to the jaw crusher with a 1mm jaw opening adjustment. After 10 minutes of crushing, jaw products were sieved with size-wise arranged sieves from 3.55mm down to 63µm. After sieve analysis, products retained from 1.4mm down to 63µm were fed to a ball mill and ground for 25 minutes at 350 revolutions per minute (RPM). After 25 minutes of grinding, products were sieved again with size-wise arranged sieves starting from 1.4mm down to 63µm, and products retained at 250µm, 180µm, 150µm, 90 µm, and 63µm were packed for size-wise chemical analysis.

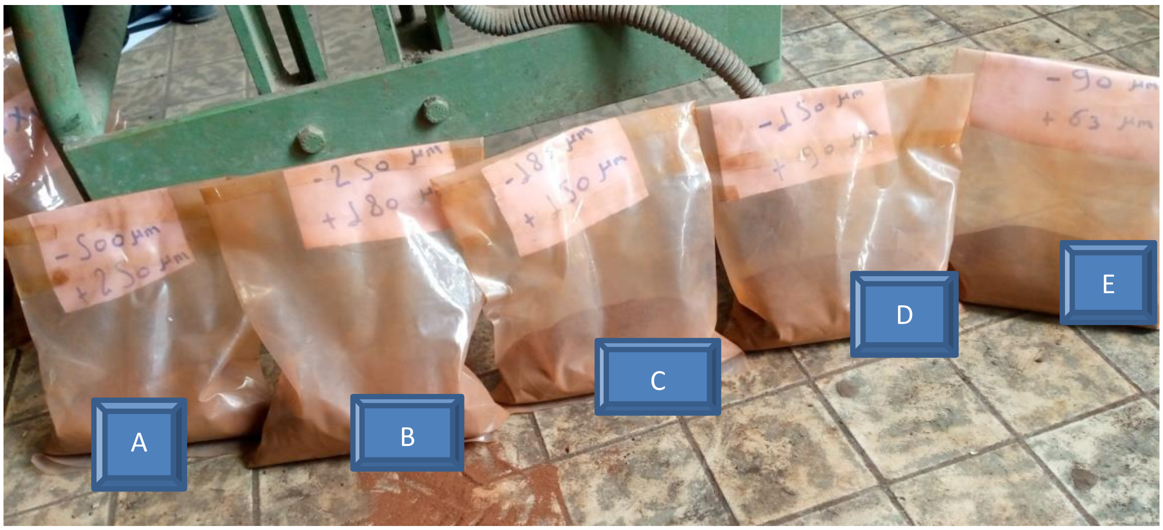

Figure 6 :Labeled samples for size wise compositional analysis (A: below 500 µm and above 250 µm, B: below 250 µm and above 180 µm, C: below 180 µm and above 150 µm, D: below 150 µm and above 90 µm, E: below 90 µm and above 63µm).

3.2.3 Chemical composition analysis

The chemical compositional analysis of the Mekaneselam iron ore deposit was conducted by wet chemical analysis of atomic absorption spectrometry (AAS) at the Ethiopian geological survey laboratory and X-RF analysis method conducted at the Czech Republic Geological Survey X-RD laboratory center. The results were taken from previous works at the study area.This analysis was done to determine the quantitative elemental composition of the ore and to understand which type of element is more dominant in the targeted ore deposit. Not only this, but it is also crucial in mineral processing to know the distribution of different types of deleterious elements that can have a severe impact on downstream processing activities.

3.2.4 Mineralogical analysis

Identification of both the target and gangue minerals of the Mekaneselam iron ore deposit was carried out using x-ray diffraction. For x-ray diffraction (X-RD), the powdered form of the sample was made at the Geological Survey laboratory, and the analysis was conducted at the Czech Republic Geological Survey X-RD laboratory center. The results were taken from previous works at the study area.The mineral identification was done to identify and understand both the qualitative and quantitative nature of the target, valuable, and gangue minerals of the target ore deposit.

3.3 Communtion

Size reduction or communication of Samples taken from Mekaneselam was conducted by using a laboratory jaw crusher at a 1mm jaw opening with a feed of 3.6 kg ore for 10 minutes of crushing, and the products obtained from the jaw crusher were fed to a laboratory ball mill after sieve analysis was done. The ball mill was fed 2.6 kg of crushed ore sample and operated for 25 minutes at 350 revolutions per minute (rpm), and The finished product went through a six-minute sieve.

Figure 7: Laboratory Jaw crusher for primary size reduction (A) and ball mill for final size reduction (B)

3.3.1 Sieve analysis.

After communication, sieve analysis was performed on the sample obtained from the field to determine the typical distribution of particle size. The dray method of sieving was used for a six-minute shaking time.

3.3.2 Particle size distribution analysis (PSD)

Analysis of the particle size distribution was performed using vertically arranged size-wise sieves at Addis Ababa Institute of Technology, minerals, and construction input materials laboratory. The sieves were properly cleaned with a sieve brush, and the sieves were arranged from 3350µm to 63µm, with the coarsest sieve on top and the finest at the bottom for jaw crusher products and 1400 µm to 63 µm for ball mill products. At the bottom of the last sieve, a tightly fitting pan was positioned to catch the remaining undersize. A sample that resulted from the jaw crusher was fed onto the coarsest sieve and covered with a lid to prevent the sample from escaping. Electric power was put on, and the sieve shaker was then operated, which continuously moved the material vertically up and down for six minutes.

During the shaking, the undersized material fell until it was caught on a sieve with holes that were just a little bit smaller than the diameter of the particles through a series of sieves. After a successful operation, each size fraction gathered on each sieve's retained material weighed, and recorded, and products retained from 1400 µm to 63µm were fed to a ball mill and ground for 25 minutes. After 25 minutes of grinding, products from the ball mill were fed to size-wise arranged sieves (1400 µm to 63 µm) and shaken for six minutes. After six minutes, all materials retained at each sieve aperture were recorded and packed for size-wise wet chemical analysis.

3.3.3 Size wise chemical composition analysis.

After examination of the particle size distribution, the retained sample collected from five consecutive sieve apertures (i.e., at -500µm + 250 µm, -250µm + 180 µm, -180 + 150 µm, -150µ + 90µm, and -90 µm+ 63µm) was used for size-wise compositional analysis. The composition analysis was carried out by atomic absorption spectrometry (AAS) using packed powdered iron ore samples that resulted from sieve analysis at different aperture sizes. The size-wise chemical analysis was conducted intentionally to determine the liberation size of the target iron ore mineral based on the weight percentage (W%) of iron at each sieve aperture size.

Chapter four: Result and Discussion

4.1 Results

4.1.1 Chemical Composition

The analysis of the chemical structure of a target ore deposit is crucial to understand the quantitative abundance of the target as well as the gangue mineral. The table shows major and minor oxide compositional analysis results for Mekaneselam iron ore.

Table 3: Chemical composition analysis result of major and minor oxides of Mekaneselam iron ore after cone and quartering method of sampling.

Composition	Weight percentage (Wt %)
SiO_2	31.8
Al_2O_3	10.68
Fe_2o_3	48.96
Fe	34.3
CaO	< 0.01
MgO	<0.01
k_2O	<0.01
Na_2O	1.92
H_2O	0.71
TiO_2	0.32
MnO	<0.01
P_2O5	0.19
LOI	5.8

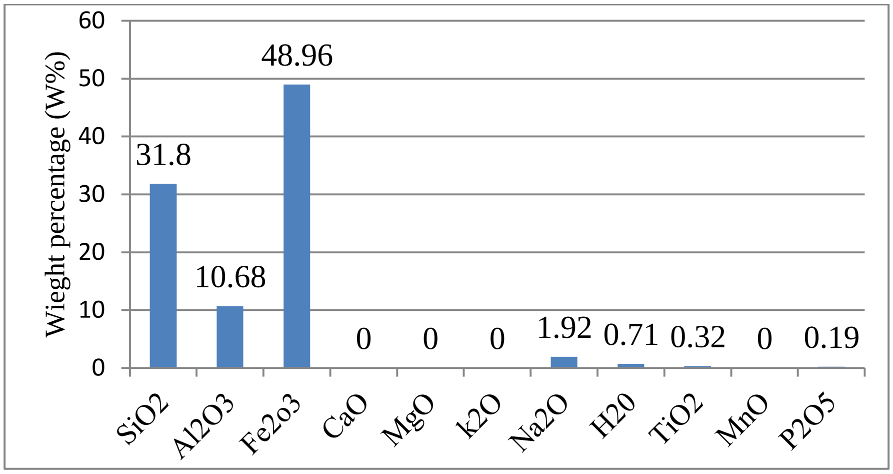

Figure 8: Average weight percentage value of major and minor oxides of Mekaneselam iron ore.

Based on the results obtained from the X-RF and AAS analysis, the Mekaneselam iron ore deposit consists of 16.55–77.93 Wt% of Fe_2O_3 with an average value of 48.34 Wt% and 48.96 respectively, 7.31–59.02 Wt% of SiO_2 with an average value of 34.7 and 31.8 respectively, and 1.44–17.38 Wt% of Al_2O_3 with an average value of 8.2% and 10.7 respectively (table 4, appendix I and fig.8).

4.1.2. Mineralogical identification.

The mineralogical identification of Mekaneselam iron ore deposit was Using x-ray diffraction (X-RD). The X-RD analytical results are presented in the figure.

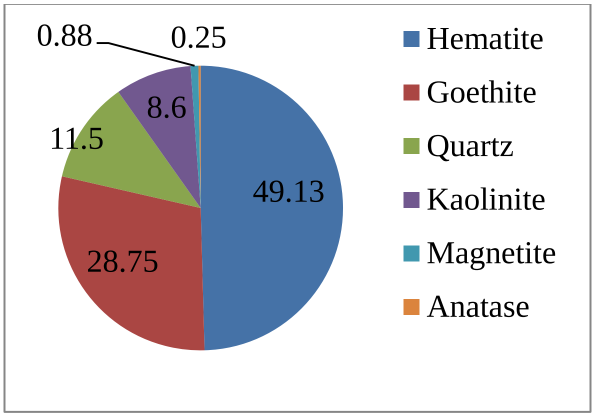

Figure 9: Average weight percentage value for mineralogical identification results of Mekaneselam iron ore

The mineralogical analysis resulted from X-ray diffraction (X-RD) revealed that the Mekaneselam iron ore deposit consists of 40–60% hematite with an average content of 49.13 %, 8–59% goethite with an average content of 28.75 %, 1–20% quartz with an average content of 11.5%, and 11-23.5% kaolinite with an average content of 8.65 % (table 5 and fig.10 **).**

4.2 Discussion

4.2.1 Ore Grade

Table 4: Generalized percentage classification of iron ores

T(Fe)			
	Low	Medium	High
Content mass %	<58	62-64	>65

(Source: Kiptarus et. al. 2015)

The analysis of the chemical structure of a target ore deposit is crucial to understand the quantitative abundance of the target as well as the gangue mineral and to determine the ore grade. The quantitative elemental analysis is necessary to know which targeted metal is beneficiated from the gangue mineral since it provides information about the abundance of a target metal of given ore deposit. During compositional analysis, any deleterious elements that might be hindering the beneficiation process as well as the final exam grade concentrate are going to be identified and detected.

The X-RF and AAS analysis (appendix I and table 3) respectively, and X-ray diffraction(Appendix VI **)** indicate that the major iron bearing ore minerals of the Mekaneselam iron ore deposit are hematite (Fe_2O_3))with an average compositional and mineralogical weight percentage of 48.96% and 49.13, respectively, and goethite (FeO(OH) with an average mineralogical weight percentage of 27.85% and the associated gangue minerals are quartz (SiO_2) with an average compositional and mineralogical weight percentage of 31.8% and 11.5% respectively, and kaolinite (Al_2O_3) with an average compositional and mineralogical weight percentage of 10.68 % and 8.63% respectively. The compositional and mineralogical analytical results imply that hematite (Fe_2O_3) followed by goethite (FeO (OH)) are the major target or valuable iron-bearing minerals, and quartz (SiO_2) followed by kaolinite (Al_2O_3) are the major gangue minerals of the Mekaneselam iron ore deposit.

As the compositional analysis result shows, the total iron (TFe) content of the Mekaneselam iron ore deposit is 34.3%, and according to Kiptarus, the Mekaneselam iron ore deposit is grouped under very low-grade iron ore deposits (table 6). This implies that the beneficiation or separation of the target iron-bearing ore mineral from associated gangue minerals (quartz and kaolinite) requires a wise analysis for the liberation size of target mineral and the selection of the appropriate concentration methods.

4.2.2. Particle size distribution (PSD)

The examination of the particle size distribution data provides detailed information about the distribution of target as well as gangue minerals at different sieve aperture sizes, and this will be very important for size-wise chemical analysis during the determination of liberation sizes. The PSD curve of the crushed ore sample at D_{40} shows 1400 µm (fig.10), and the PSD sizing curve of the grinded ore sample at D_{40} shows 200 µm (fig.11). This implies, the feed particle of 1400µm is reduced to 200 µm after grinding with a reduction ratio of 7:1. The 80 % passing (p_{80}) of a certain material was selected using a particle size distribution curve or sizing curve on the basis of dispersion of particle sizes data resulted from sieve analysis. From (fig.11), the 80 % passing (P_{80}) of ball mill product is 1100µm. This showed that 80% of the particles with in the target sample are finer than 1100 µm and 20 % are coarser than 1100 µm. Additionally, the median value (D50) indicates that 50% of the sieved particles are finer than 300 m and 50% are coarser than 300 m.

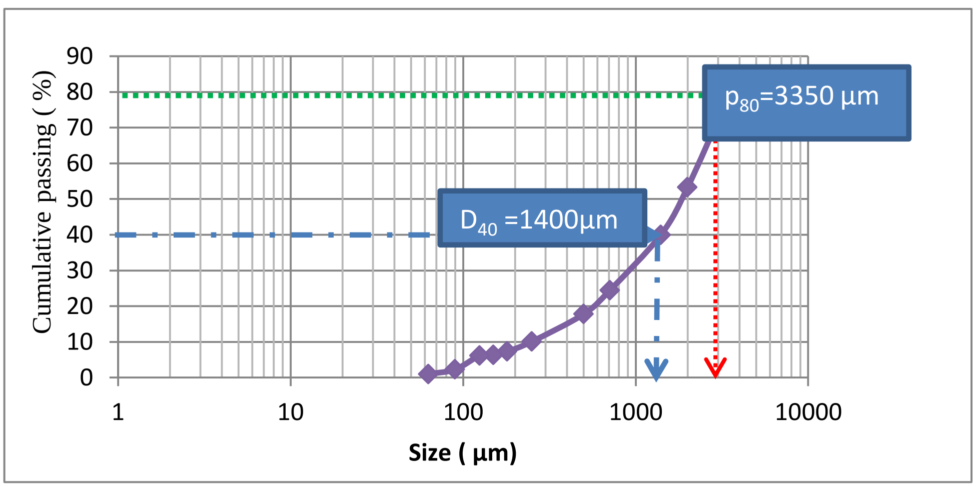

Figure 10: Sizing curve for crushed ore sample of Mekaneselam iron ore.

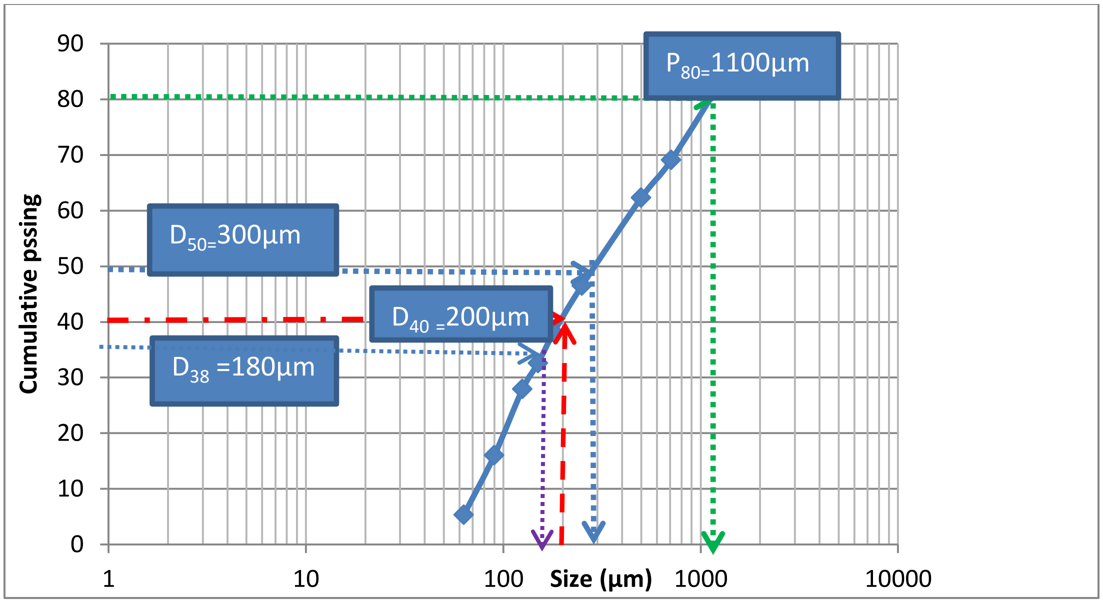

Figure 11: Sizing curve for grinded ore sample of Mekaneselam iron ore.

4.2.3 Liberation size

The purpose of size-wise compositional analysis was to understand at which sieve aperture size the higher weight percentage of target mineral or metal is achieved, and this will enable to analyse liberation size to be determine the valuable mineral that is going to be beneficiated or separated from any other gangue mineral. The size-wise compositional analysis resulted from atomic absorption spectrometry (AAS) showed that the weight percentage(W%) of Fe_2O_3 at -500µm to +250 µm, -250µm to +180 µm, -180µm to +150 µm, -150µm to +90µm, and -90µm to +63µm was 41.25%, 46.32 %, 45.2%, 43.92 %, and 44.32 %, respectively **(**appendix IV and fig. 12**).**The result indicates a higher percentage of Fe_2O_3 was recorded under a sieve size range of -250µm to +180 µm with a compositional weight percentage value of 46.32%. This implies that the appropriate liberation size of the Mekaneselam iron ore deposit is found in the particle size range of -250µm to +180µm. At this liberation size, the cumulative passing **(**fig.12) shows that 38% of the particles would pass through the sieve, meaning that 38% of the particles can be liberated at this liberation size and 62% of the particles that are not passed may not liberated. This indicates that to have at least 80% passing (P_{80}) (liberation) of the target mineral at this liberation size, 42% of particles should grind to below 250 µm and above 180 µm particle sizes.

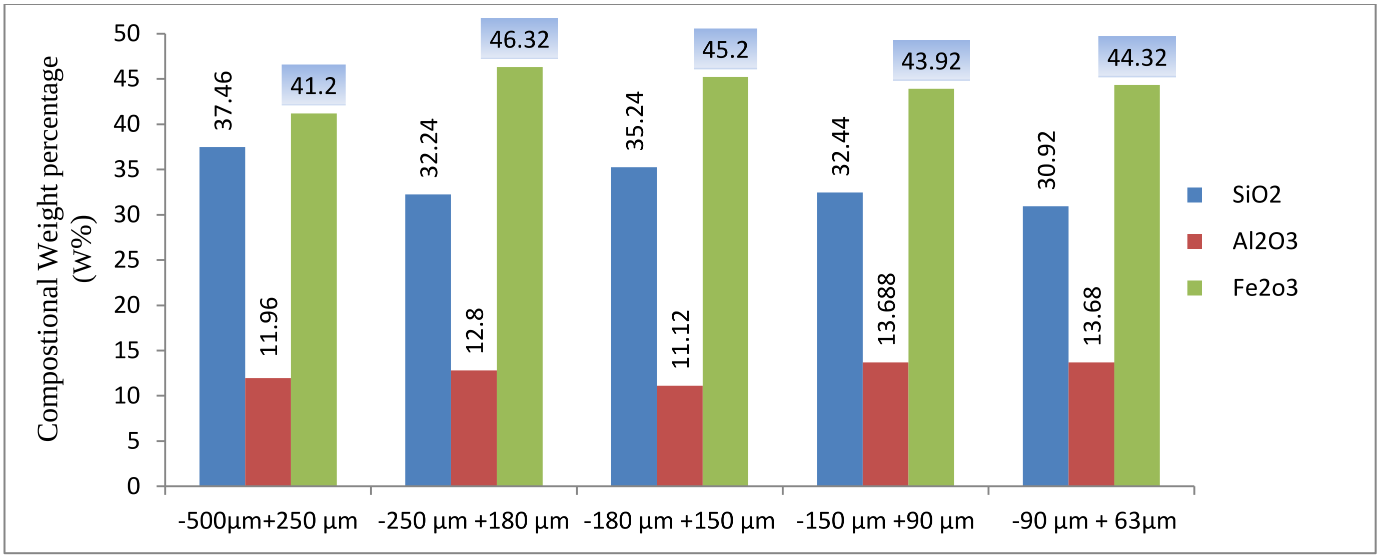

Figure 12: Size wise chemical composition analysis results for major oxides of Mekaneselam iron ore.

4.2.4 Comminution circuits

To achieve the target liberation size with an 80% passing rate (P_{80}), the communication circuits should be designed accurately and effectively based on the efficiency rate of communication machines. The common circuits included under this category are: screens, crushers, and grinders. As mentioned above, the liberation size of the target iron ore-bearing mineral is achieved between 250 µm and 180 µm under 350 rpm for a 25-minute grinding operation and alumina ball grinding media. Under this unit of operation, all the communication circuits should be designed based on the final output of the targeted liberation size. The comminution circuits presented below are designed on the basis of the maximum feed size of crushers and grinders and with the targeted liberation sizes. The ball mill's maximum feed size is 50 mm and below, while the secondary cone crusher's maximum feed size is 450–500 mm. (Wills & Finch, 2015).

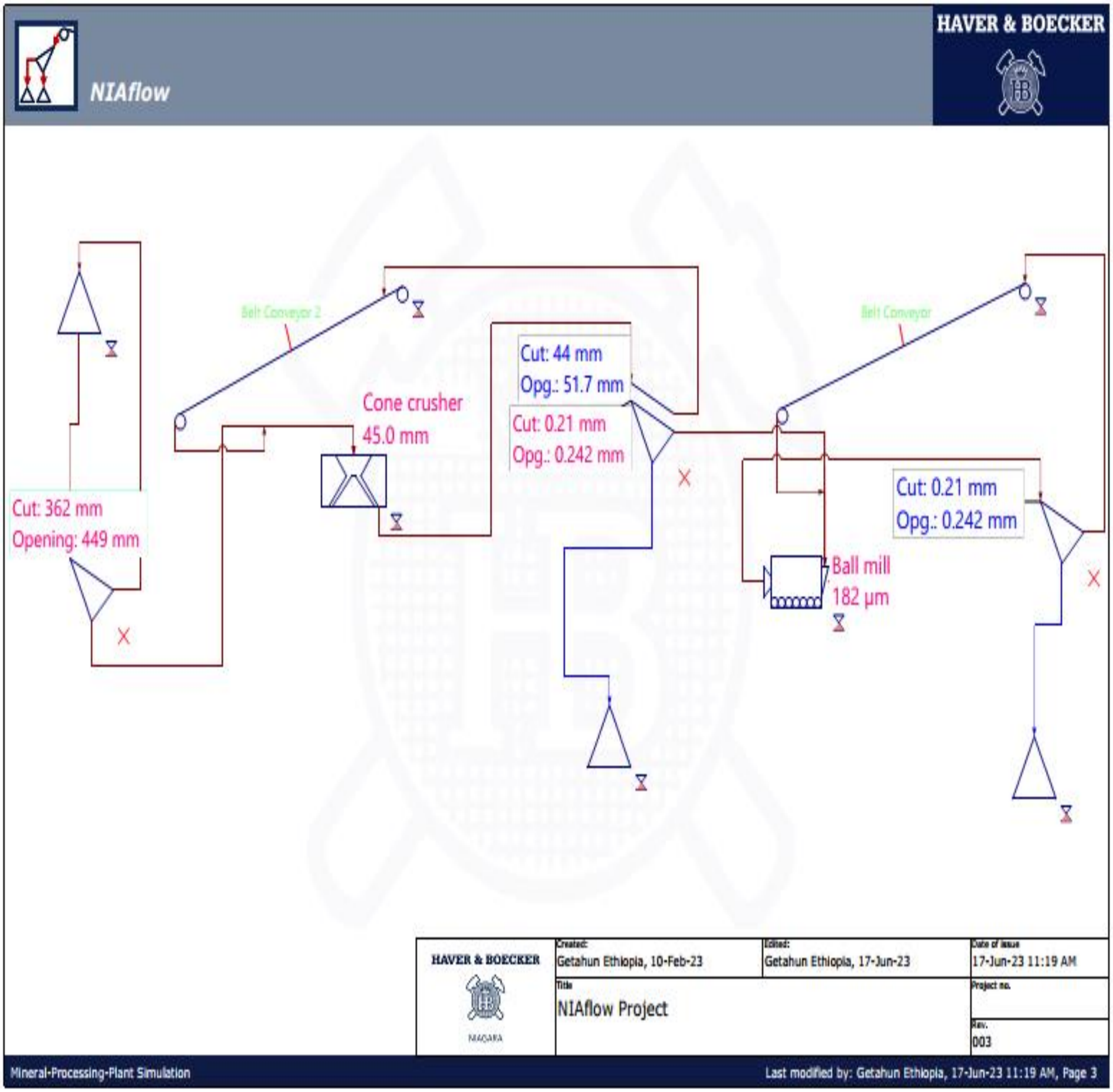

Figure 13: Conceptual communtion circuit design for the target liberation size.

4.2.5 Beneficiation methods

Table 5: Physical and Physico-chemical properties of major target and gangue minerals of Mekaneselam iron ore

Major valuable and gangue minerals	S.G	Magnetic property	Electrical-conductivity	Mohs hardness scale	Surface chemistry
Hematite	5.3	Para magnetic	Semi- conductive	5.5-6.5	Hydrophobic(θ=48)
Goethite	3.8	Para magnetic	Non –conductive	5-5.5	Hydrophilic(θ=0)
Quartz	2.6	Dia magnetic	Di- electric	7	Hydrophilic(θ=0)
Kaolinite	2.4	Dia magnetic	Di- electric	2-2.5	Hydrophobic(θ=150)

Source: Compiled from different literatures and online internet access.

Ores can be hard or soft based on their hardness scale, high dense or light dense based on their specific gravity, conductive, semi-conductive, and non-conductive based on their electrical conductivity response, dia-magnetic, paramagnetic, and ferromagnetic based on their nature of magnetic susceptibility, and hydrophobic or hydrophilic based on their physico-chemical properties.

Commonly, there are four types of mineral beneficiation or separation methods: gravity, magnetic, electrostatic, and flotation separation methods. The selection of an appropriate separation method is mostly dependent on the physical and physico-chemical properties of the ore mineral of the target ore deposit in addition to their study of the composition and texture. The gravity concentration method is the most common method of separation for most types of minerals due to its cost effectiveness, ease of operation, and environmentally friendly nature. But before deciding to use it, understanding the concentration criteria of a target mineral is recommended. It is used to determine the applicability of gravitational separation to a particular ore.

$$\text{Con.criteria (C.C)} = \frac{\text{(Specific gravity of heavy mineral)} - \text{(Specific gravity of fluid)}}{\text{(Specific gravity of light mineral)} - \text{(Specific gravity of fluid)}}$$

- C.C_1 of Hematite (Fe_2O_3) = $\frac{\rho \text{ of hematite} - \rho \text{ of water.}}{\rho \text{ of quartz} - \rho \text{ of water}}$

  = (5.3 – 1) ÷ (2.6 – 1)

  = 4.3 ÷ 1.6 = 2.7

- C.C_2 of Hematite (Fe_2O_3) = $\frac{\rho \text{ of hematite} - \rho \text{ of water.}}{\rho \text{ of kaolinite} - \rho \text{ of water}}$

  = (5.3 -1) ÷ (2.4 – 1)

  =4.3÷1.4 = 3.1

- C.C_1 of Goethite (Fe O (OH)) = $\frac{\rho \text{ of Goethite} - \rho \text{ of water.}}{\rho \text{ of quartz} - \rho \text{ of water}}$

  = (3.8-1) ÷ (2.6-1)

  =2.8 ÷1.6 =1.75

- C.C_2 of Goethite (Fe O (OH)) = $\frac{\rho \text{ of Goethite} - \rho \text{ of water.}}{\rho \text{ of kaolinite} - \rho \text{ of water}}$

  = (3.8 -1) ÷ (2.4-1)

  = 2.8 ÷1.4 = 2

The concentration criteria for the iron hematite (Fe_2O_3) target ore material are 2.7 and 3.1 for quartz and kaolinite, respectively, and 1.75 and 2 for goethite. This suggests that Mekaneselam iron ore deposit can be improved using gravitational concentration method with liberation sizes for hematite and goethite potentially reaching down to 75µm and 150µm respectively (Appendix VIII). It is appropriate to use gravity concentration followed by a high-intensity magnetic (HIM) separator to upgrade low-grade hematite and goethite to commercial grade due to the apparent difference in specific gravities and magnetic susceptibility between the target minerals, hematite and goethite, and the associated gangue minerals, quartz and kaolinite.

Additionally, the most efficient method of concentration for low grade paramagnetic ores, magnetized reduction roasting (MRRP), followed by low intensity magnetic (LIM), can be used. During reduction roasting, paramagnetic ore minerals hematite and goethite can change into artificial magnetite, which will give hematite and goethite a ferromagnetic nature that is easily severable from associated gangue minerals by using a low-intensity magnetic separator. The selected concentration methods are functional with in the targeted determined liberation size as shown in (appendix XI).

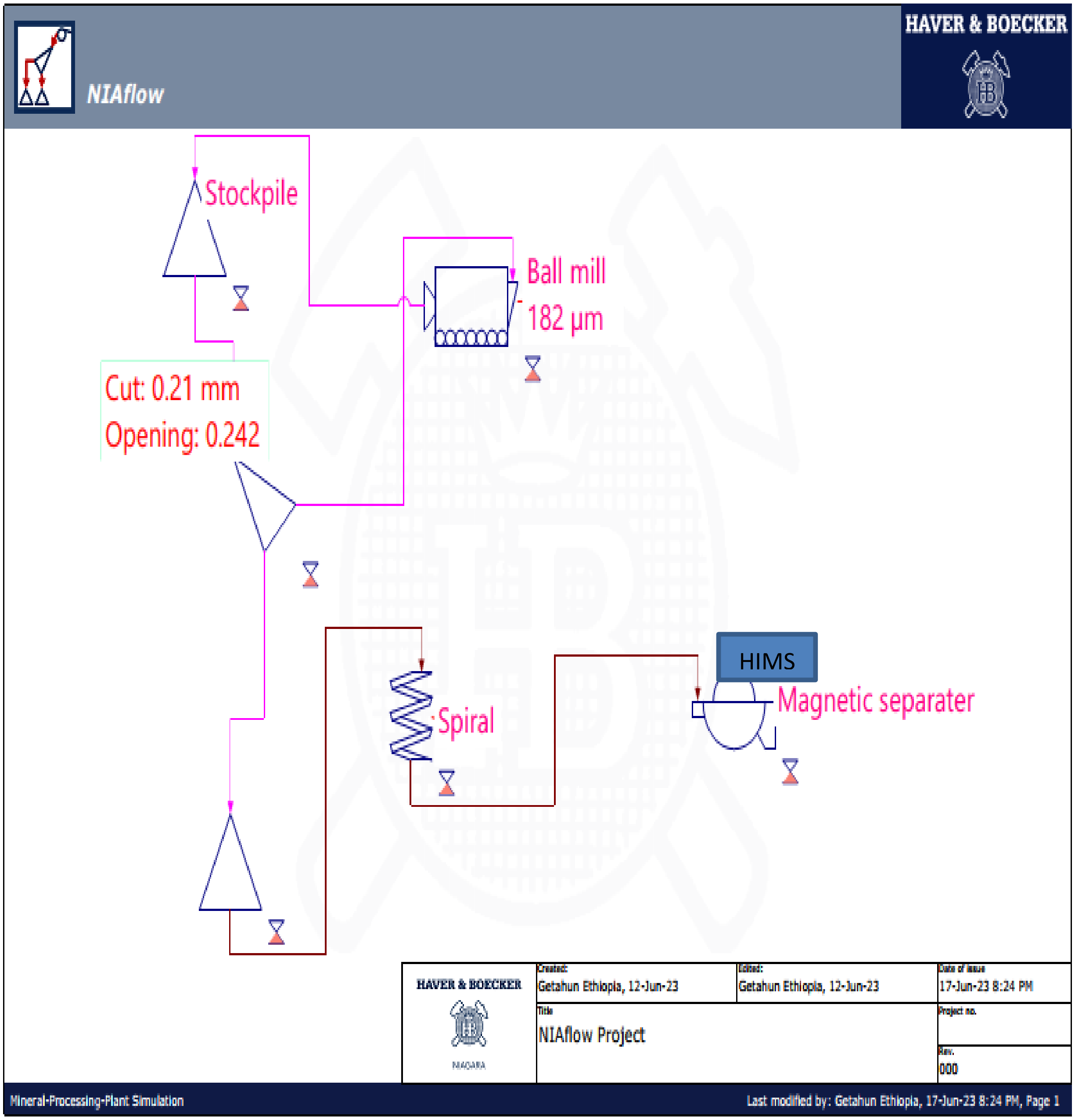

Figure 14: Conceptual concentrating flow sheet design for separation of valuable minera forms its associated gangue mineral.

Chapter five: Conclusion and Recommendation

5.1 Conclusion

From mineralogical, compositional, and particle distribution analysis, it can be concluded that : Mekaneselam iron ore is composed of the major minerals hematite, goethite, kaolinite, and quartz, and the trace constituents are calcium, magnesium, aluminum, manganese, and phosphorus oxides.

The major iron-bearing mineral is hematite, with a lesser extent of goethite and associated gangue minerals of quartz and kaolinite, which resulted from X-RD.

The ore's chemical analysis sample revealed that the iron ore contains an average weight percentage value of 48.96%, 48.34 % of Fe_2O_3 and associated gangue minerals of 31.8, 34.7% of SiO_2 and 10.68%, 8.2% of Al_2O_3 resulted from AAS by using cone and quartering method of sampling and X-RF analysis of each sample. From the result, it was concluded that, average total iron (TFe) is about 34.3% Fe, Which is very low grade.

The examination of the particle size distribution of the mill product shows 80 percent passing (P_{80}) of 1100 µm, and the size-wise compositional analysis revealed that higher weight percentage of the target ore mineral was recorded under a sieve size range of -250 µm to +180 µm. This implies that, an appropriate liberation size of the target ore mineral could be achieved within this sieve size range. At this liberation size, 38% of materials are passed through the screen, and the rest (42%) should be grinded to a minimal level of 80 percent passing (P_{80}).

The overall mineralogical and compositional analysis results show Mekaneselam iron ore is very low grade with a fine liberation size that can be highly energy intensive to achieve the 80 percent passing (P_{80}) for the target liberation size.

Even if it is very low grade, similar investigations under deposits of low-grade iron ore indicate that the Mekaneselam iron ore can be upgraded to commercial level by using gravity concentration followed by high-intensity magnetic separators. And also, Magnetic Reduction Roasting (MRR) followed by a low-intensity magnetic separator can be used.

5.2 Recommendation

For this project, laboratory alumina balls were used as grinding media. For ore minerals like hematite and other hard ore minerals, steel balls are a more recommended grinding medium to grind the ore effectively, and this is crucial for the investigation of particle size distribution and the determination of liberation size.

To achieve 80 percent passing (P_{80}) at the targeted liberation sizes, the maximal operating conditions should be determined by varying grinding durations , mill speeds with different revolutions and feed sizes.

The size-wise chemical analysis shows, a high percentage of hematite was recorded below 500 µm. This shows that further beneficiation tests at particle sizes below 500 µm are recommended to determine at which size more concentration of the target iron-bearing ore mineral is recovered.

To determine the economic feasibility of Mekaneselam iron ore, Detailed metallurgical test works and mineralogical investigations on the textural analysis with the aid of a scanning electron microscope (SEM), mineral liberation analyzer (MLA), particle map analyzer (MPA), electron probe micro analyzer (EPMA), and detailed Flow sheet development is mandatory.

The chemical compositional analysis results with X-RF and AAS show some variations related to the P_2O_5 value, which is 0.018 for X-RF analysis and 0.19 for AAS analysis. This indicates that further investigation of the chemical compositional analysis is very recommendable since the P_2O_5 value has a significant negative impact on the downstream process of beneficiation.

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Appendix

Appendix I: Major oxide compositional analysis result of Mekaneselam iron ore. (Source: Belayneh Digafe (Mineralogy, Geochemistry and Genesis of Mekaneselam iron ore occurrence, Northern Ethiopia, 2020).

Weight percentage (Wt %)								
Composition	MSB3	MSB4	MSB6	MSB7	MSB11	MSB12	MSB15	Average
SiO_2	59.02	28.2	24.04	34.23	38.13	52.23	7.31	34.7
Al_2O_3	1.61	17.38	3.83	4.29	9.66	19.23	1.44	8.2
Fe_2o_3	34.31	43.38	68.23	54.86	43.1	16.55	77.93	48.34
Fe	24.0	31.1	47.8	38.4	30.2	11.6	55.5	33.8
CaO	0.21	0.25	0.23	0.22	0.39	0.16	0.16	0.25
MgO	0	0.02	0.01	0	0.2	0.06	0	0.05
k_2O	0	0	0	0	0	0	0	0
NaO	0	0	0	0	0	0	0	0
Cr_2O_3	0.06	0.07	0.1	0.09	0.07	0.04	0.09	0.08
TiO_2	0.46	1.17	0.9	1.48	1.22	1.06	0.02	0.96
MnO	0.01	0	0	0	0	0	0	0
P_2O_5	0	0.01	0.02	0.02	0.05	0	0.03	**0.018**
LOI	3.84	9.37	3.8	4.53	6.65	9.22	7.31	6.38

Appendix II: Particle size distribution of crushed ore sample

Size(Microns)	Nominal size (Microns)	Weight Retained (g)	Weight Retained (%)	Cumulative Weight retained (%)	Cumulative Weight passing (%)
+3350	3350	704.4	19.2	19.2	80.8
-3350 +3150	3150	216.8	5.9	25.1	74.9
-3150 +2000	2000	796	21.6	46.7	53.3
-2000 +1400	1400	487.2	13.3	60	40
-1400 +710	710	569.1	15.5	75.5	24.5
-710 +500	500	247.6	6.7	82.2	17.8
-500 +250	250	282	7.7	89.9	10.1
-250 +180	180	102	2.8	92.7	7.3
-180 +150	150	33.8	0.9	93.6	6.4
-150 +125	125	6.4	0.2	93.8	6.2
-125 +90	90	143	3.9	97.7	2.3
-90 + 63	63	48.7	1.3	99	1
-63	----------	34.1	0.9	99.9	0.1

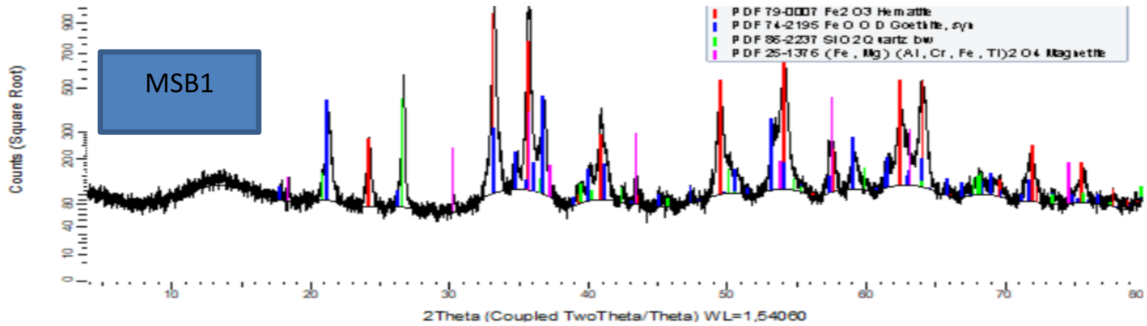
Appendix III: Particle size distribution of grinded ore sample

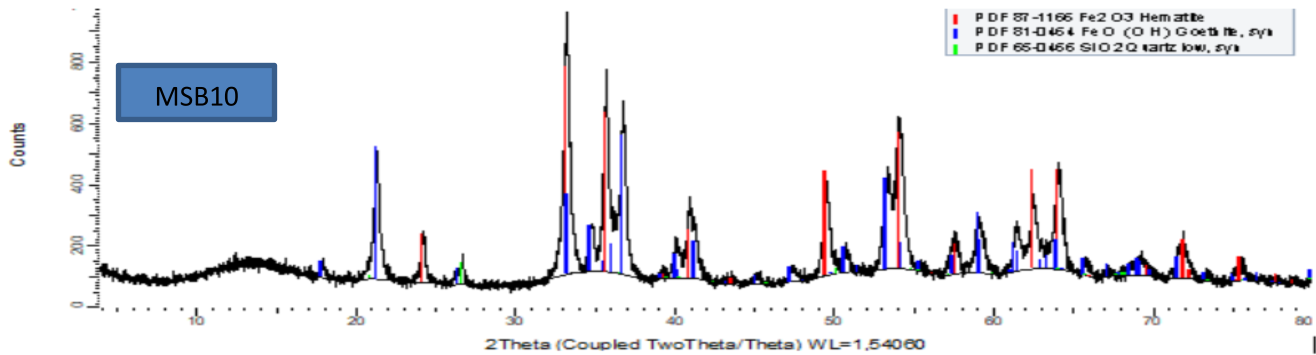
Size (µm)	Nominal size (µm)	Weight Retained (g)	Weight Retained (%)	Cumulative Weight retained (%)	Cumulative Weight passing (%)
+1400	1400	208.7	14.4	14.4	85.6
-1400 +710	710	242	16.6	30.9	69.1
-710 + 500	500	100.1	6.8	37.7	62.3
-500 + 250	250	229.8	15.8	53.5	46.5
-250 +180	180	122.2	8.4	61.9	38.1
-180 +150	150	79.7	5.5	67.4	32.6
-150 +125	125	69	4.7	72.1	27.9
-125 +90	90	172.9	11.9	84	16
-90 +63	63	155.1	10.7	94.7	5.3
-63		74	5.1	99.9	0

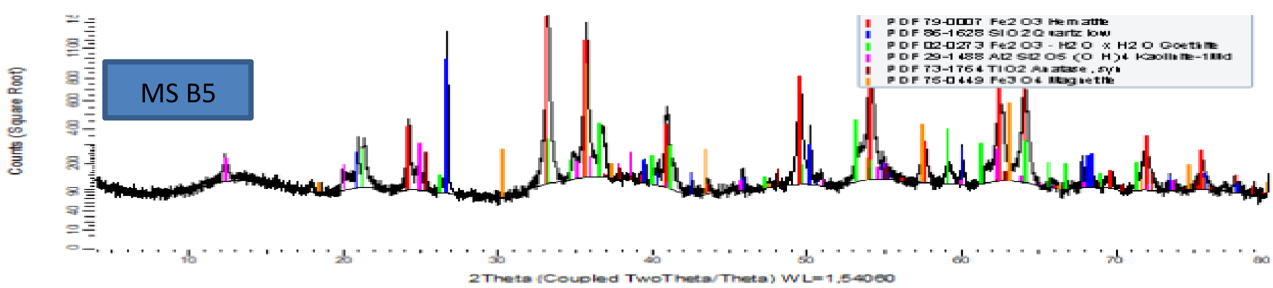
Appendix IV: Size wise major and minor oxide analytical results of Mekaneselam iron ore

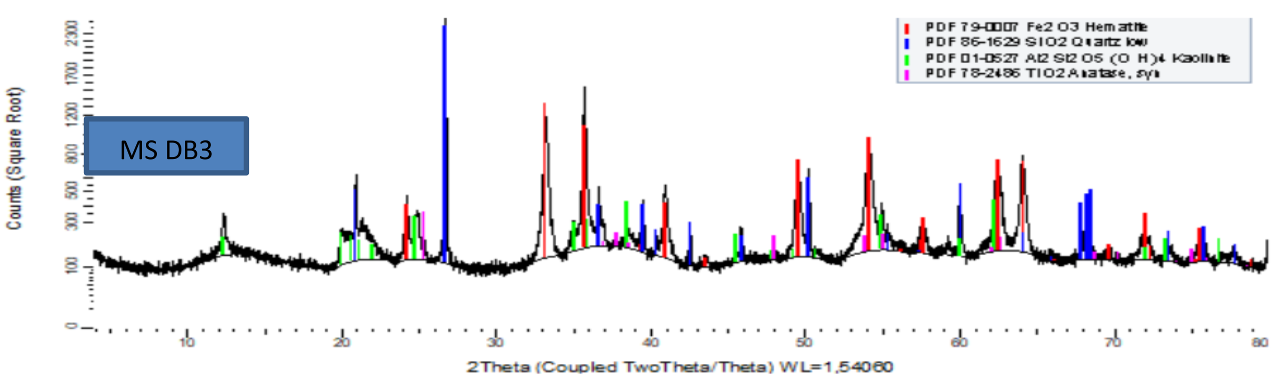
Size wise weight percentage (Wt %)					
Composition	-500µm+250 µm	-250µm +180 µm	-180µm +150 µm	-150µm +90 µm	-90 µm + 63µm
SiO_2	37.46	32.24	35.24	32.44	30.92
Al_2O_3	11.96	12.8	11.12	13.688	13.68
Fe_2o_3	41.20	46.32	45.2	43.92	44.32
Fe	28.8	32.4	31.9	30.7	31.0
CaO	<0.01	<0.01	<0.01	<0.01	<0.01
MgO	<0.01	<0.01	<0.01	<0.01	<0.01
k_2O	<0.01	<0.01	<0.01	<0.01	<0.01
Na2O	1.26	2.16	2.16	1.68	2.8
MnO	<0.01	<0.01	<0.01	<0.01	<0.01
P_2O_5	0.25	0.23	0.12	0.23	0.21
TiO_2	0.38	0.39	0.32	0.39	0.37
H_2O	0.86	0.75	0.93	1.13	1.19
LOI	5.86	6.12	6.25	6.16	6.49

Appendix V: X-ray diffraction(X-RD) value of iron ore sampels. Source: (Belayneh Digafe (Mineralogy, Geochemistry and Genesis of Mekaneselam iron ore occurrence, Northern Ethiopia, 2020)).





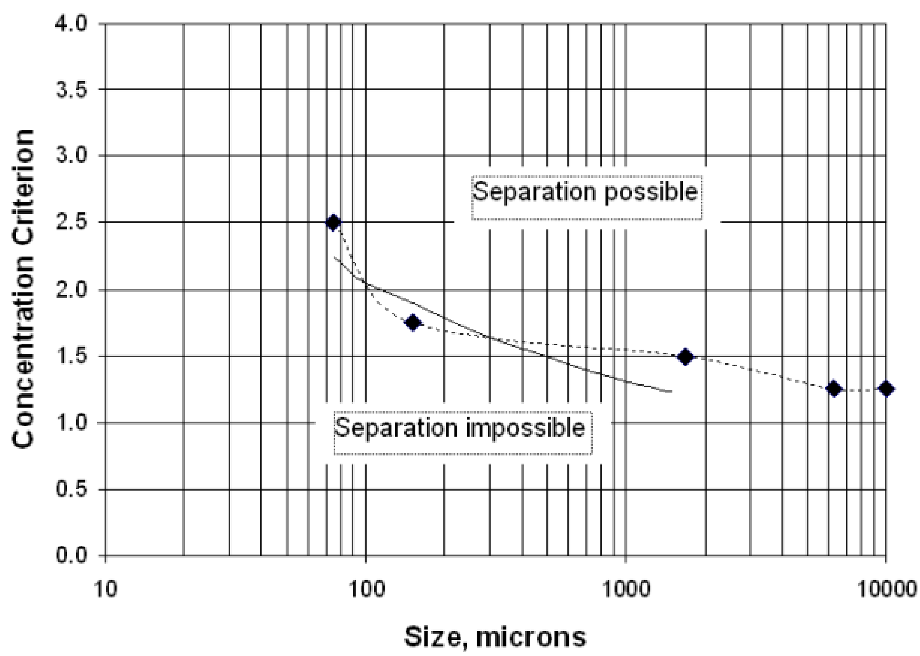




Appendix VI : Mineralogical identification results of Mekaneselam iron ore .Source: (Belayneh Digafe (Mineralogy, Geochemistry and Genesis of Mekaneselam iron ore occurrence, Northern Ethiopia, 2020)).

Weight percentage (Wt %)					
Minerals	MS B1	MS B10	MS B5	MS DB 3	Average
Hematite (Fe_2O_3)	40	46.5	50	60	49.13
Goethite(FeO(OH))	59	8	32	16	28.75
Quartz (SiO_2)	1	21	12	12	11.5
Kaolinite(Al_2O_3)	…….	23.5	……	11	8.6
Magnetite(Fe_3O_4)	……	……	3	0.5	0.88
Anatase(TiO_2)	1	….	……	1	0.25

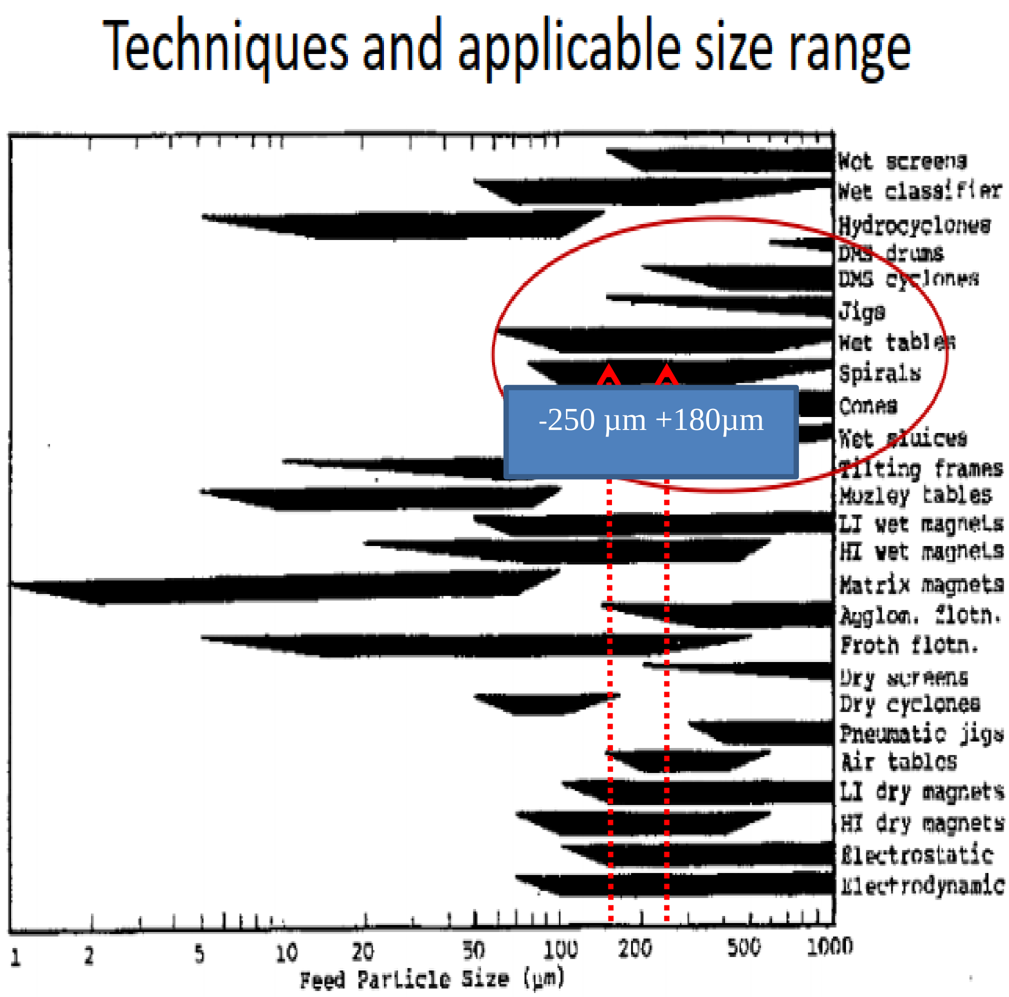
Appendix VII: Size limit for gravity concentration .Source :(Mineral Processing Design and Operation" – Gupta and Yan, 2016).



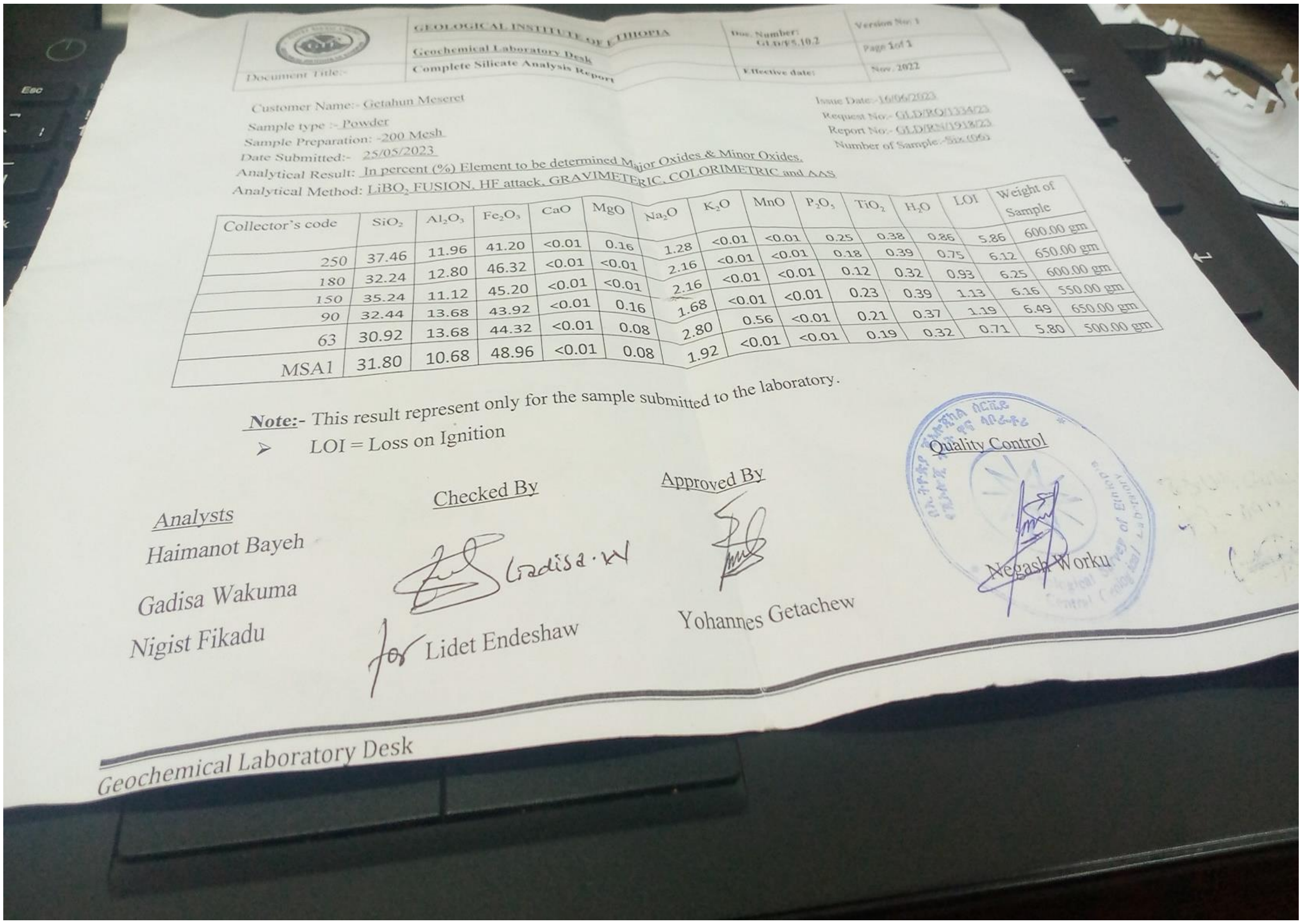
Appendix VIII: Concentration criteria guide for gravity separation method. Source: "(Mineral Processing Design and Operation" – Gupta and Yan, 2016).

Concentration criterion	Suitability to gravity concentration
CC >2.5	Easy down to 75 µm
1.75 <CC<2.5	Possible down to 150µm
1.5 <CC<1.75	Possible down to 1.7 mm
1.25 <CC<1.5	Possible down to 6.35
<1.25	Impossible at any size

Appendix XI: Figure 16: Concentration methods and optimal size ranges .Source: (Mineral Processing Design and Operation" – Gupta and Yan, 2016).



Appendix XII: Complete silicate analysis report from G.I.E



GEOLOGICAL INSTITUTE OF ETHIOPIA

Geochemical Laboratory Desk

Document Title:- Complete Silicate Analysis Report

Doc. Number: GLD/F5.10.2 | Version No: 1 | Page 1of 1

Effective date: Nov. 2022

Customer Name:- Getahun Meseret

Sample type :- Powder

Sample Preparation: -200 Mesh

Date Submitted:- 25/05/2023

Issue Date:- 16/06/2023

Request No:- GLD/RQ/1334/23

Report No:- GLD/RN/1918/23

Number of Sample:-Six (06)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector's code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI	Weight of Sample
250	37.46	11.96	41.20	<0.01	0.16	1.28	<0.01	<0.01	0.25	0.38	0.86	5.86	600.00 gm
180	32.24	12.80	46.32	<0.01	<0.01	2.16	<0.01	<0.01	0.18	0.39	0.75	6.12	650.00 gm
150	35.24	11.12	45.20	<0.01	<0.01	2.16	<0.01	<0.01	0.12	0.32	0.93	6.25	600.00 gm
90	32.44	13.68	43.92	<0.01	0.16	1.68	<0.01	<0.01	0.23	0.39	1.13	6.16	550.00 gm
63	30.92	13.68	44.32	<0.01	0.08	2.80	0.56	<0.01	0.21	0.37	1.19	6.49	650.00 gm
MSA1	31.80	10.68	48.96	<0.01	0.08	1.92	<0.01	<0.01	0.19	0.32	0.71	5.80	500.00 gm

Note:- This result represent only for the sample submitted to the laboratory.

- LOI = Loss on Ignition

Analysts
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Gadisa.W
for Lidet Endeshaw

Approved By
Yohannes Getachew

Quality Control
Negash Worku

Geochemical Laboratory Desk